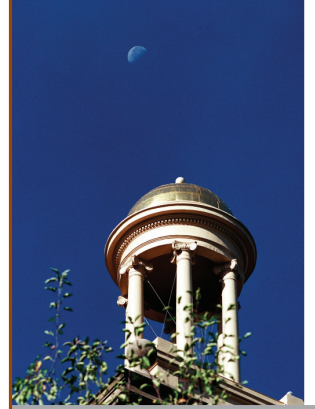


2007-08

Colorado School of Mines

Graduate Bulletin

# Colorado School of Mines



Graduate Bulletin

2007-08



*Colorado  
School of Mines*

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*2007–2008  
Graduate Bulletin*

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To CSM Graduate Students:

This Bulletin is for your use as a source of continuing reference. Please save it.

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# Table of Contents

<b>Academic Calendar</b> . . . . .	<b>4</b>	Auditing Courses . . . . .	24
<b>University Administration / Useful Contacts</b> . . . . .	<b>5</b>	Off Campus Study . . . . .	25
Office of Graduate Studies . . . . .	5	<b>General Regulations</b> . . . . .	<b>26</b>
Student Housing . . . . .	5	Graduate School Bulletin . . . . .	26
Financial Aid . . . . .	5	Curriculum Changes . . . . .	26
International Student Services . . . . .	5	General Policies of Student Conduct . . . . .	26
Registrar's Office . . . . .	5	Student Honor Code . . . . .	26
Graduate Student Association . . . . .	5	Academic Integrity . . . . .	27
Academic Departments & Divisions . . . . .	5	Resolution of Conflicting Bulletin Provisions . . . . .	28
<b>General Information</b> . . . . .	<b>6</b>	Unsatisfactory Academic Performance . . . . .	28
Mission and Goals . . . . .	6	Exceptions and Appeals . . . . .	29
Institutional Values and Principles . . . . .	6	Public Access to the Graduate Thesis . . . . .	29
History of CSM . . . . .	9	Making up Undergraduate Deficiencies . . . . .	29
Location . . . . .	9	Graduate Students in Undergraduate Courses . . . . .	30
Administration . . . . .	9	Independent Study . . . . .	30
<b>The Graduate School</b> . . . . .	<b>10</b>	Course and Research Grades . . . . .	30
Unique Programs . . . . .	10	Grade Appeal Process . . . . .	30
Graduate Degrees Offered . . . . .	10	Graduation . . . . .	31
Accreditation . . . . .	10	Withdrawing from School . . . . .	31
<b>Admission to the Graduate School</b> . . . . .	<b>11</b>	Nondegree Students . . . . .	32
Admission Requirements . . . . .	11	Veterans' Benefits . . . . .	32
Categories of Admission . . . . .	11	Grading System . . . . .	32
Admission Procedure . . . . .	11	Access to Student Records . . . . .	33
Financial Assistance . . . . .	12	<b>Tuition, Fees, Financial Assistance</b> . . . . .	<b>35</b>
Application Review Process . . . . .	12	Tuition . . . . .	35
Health Record and Additional Steps . . . . .	12	Fees . . . . .	35
International Students . . . . .	12	Payments and Refunds . . . . .	35
<b>Student Life at CSM</b> . . . . .	<b>13</b>	<b>Graduate Degrees and Requirements</b> . . . . .	<b>37</b>
Housing . . . . .	13	I. Professional Programs . . . . .	37
Student Services . . . . .	13	II. Master of Science and Engineering Programs . . . . .	38
Military Science . . . . .	15	III. Doctor of Philosophy . . . . .	40
Student Activities . . . . .	15	IV. Individualized, Interdisciplinary Graduate Degrees . . . . .	42
<b>Facilities and Academic Support</b> . . . . .	<b>18</b>	V. Combined Undergraduate/Graduate Programs . . . . .	43
Arthur Lakes Library . . . . .	18	<b>Graduate Degree Programs and Description of Courses</b> . . . . .	<b>45</b>
Academic Computing and Networking . . . . .	18	Chemical Engineering . . . . .	45
Copy Center . . . . .	18	Chemistry and Geochemistry . . . . .	51
CSM Alumni Association . . . . .	19	Economics and Business . . . . .	58
Environmental Health and Safety . . . . .	19	Engineering . . . . .	67
Green Center . . . . .	19	Environmental Science and Engineering . . . . .	84
INTERLINK Language Center (ESL) . . . . .	19	Geochemistry . . . . .	91
LAIS Writing Center . . . . .	19	Geology and Geological Engineering . . . . .	97
Off Campus Study . . . . .	19	Geophysics . . . . .	114
Office of International Programs . . . . .	20	Hydrologic Sciences and Engineering . . . . .	124
Office of Technology Transfer . . . . .	20	Liberal Arts and International Studies . . . . .	127
Public Relations . . . . .	20	Materials Science . . . . .	135
Registrar . . . . .	20	Mathematical and Computer Sciences . . . . .	142
Research Administration . . . . .	21	Metallurgical and Materials Engineering . . . . .	149
Special Programs and Continuing Education (SPAC) . . . . .	21	Mining Engineering . . . . .	159
Telecommunications Center . . . . .	21	Nuclear Engineering . . . . .	167
Women in Science, Engineering and Mathematics (WISEM) . . . . .	21	Petroleum Engineering . . . . .	169
<b>Registration and Tuition Classification</b> . . . . .	<b>22</b>	Physics . . . . .	176
General Registration Requirements . . . . .	22	Systems . . . . .	180
Research Registration . . . . .	22	<b>Research Centers and Institutes</b> . . . . .	<b>181</b>
Eligibility for Thesis Registration . . . . .	22	<b>Directory of the School</b> . . . . .	<b>187</b>
Graduation Requirements . . . . .	22	<b>Policies and Procedures</b> . . . . .	<b>201</b>
Full-time Status - Required Course Load . . . . .	22	Affirmative Action . . . . .	201
Late Registration Fee . . . . .	23	Unlawful Discrimination Policy & Complaint Procedure . . . . .	201
Leave of Absence . . . . .	23	Sexual Harassment Policy & Complaint Procedure . . . . .	204
Reciprocal Registration . . . . .	23	Personal Relationships Policy . . . . .	207
In-State Tuition Classification Status . . . . .	23	<b>Index</b> . . . . .	<b>208</b>
Dropping and Adding Courses . . . . .	24		



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# Academic Calendar

## Fall Semester 2007

Confirmation deadline	Aug. 20, Monday
Faculty Conference	Aug. 20, Monday
Classes start (1)	Aug. 21, Tuesday
Graduate Students—last day to register without late fee	Aug. 26, Sunday
Labor Day (Classes held)	Sept. 3, Monday
Last day to register, add or drop courses without a “W” (Census Day)	Sept. 5, Wednesday
Fall Break	Oct. 15 & 16, Monday & Tuesday
Midterm grades due	Oct. 15, Monday
Last day to withdraw from a course—Continuing students	Oct. 30, Tuesday
Priority Registration Spring Semester	Nov. 12-16, Monday–Friday
Non-class day prior to Thanksgiving Break	Nov. 21, Wednesday
Thanksgiving Break	Nov. 22–Nov. 25, Thursday–Sunday
Last day to withdraw from a course—New students	Nov. 30, Friday
Last day to completely withdraw from CSM	Dec. 6, Thursday
Classes end	Dec. 6, Thursday
Dead Day	Dec. 7, Friday
Graduating students’ lowest possible grades due	Dec. 11, Tuesday
Final exams	Dec. 8, 10-13, Saturday, Monday–Thursday
Semester ends	Dec. 14, Friday
Midyear Degree Convocation	Dec. 14, Friday
Final grades due	Dec. 17, Monday
Winter Recess	Dec. 15–Jan. 8, Saturday–Tuesday

## Spring Semester 2008

Confirmation deadline	Jan. 8, Tuesday
Classes start (1)	Jan. 9, Wednesday
Grad Students—last day to register without late fee	Jan. 13, Sunday
Last day to register, add or drop courses without a “W” (Census Day)	Jan. 24, Thursday
Non-class day - Presidents’ Day	Feb. 18, Monday
Midterms grades due	March 3, Monday
Spring Break	March 8-16, Saturday–Sunday
Last day to withdraw from a course—Continuing students	March 25, Tuesday
E-Days	April 3-5, Thursday–Saturday
Priority Registration, Field, Summer and Fall Term	April 7-11, Monday–Friday
Last day to withdraw from a course—New students	April 25, Friday
Last day to completely withdraw from CSM	May 1, Thursday
Classes end	May 1, Thursday
Dead Day	May 2, Friday
Graduating students’ lower possible grades due	May 6, Tuesday
Final exams	May 3, May 5-8 Saturday, Monday–Thursday
Semester ends	May 9, Friday
Commencement	May 9, Friday
Final grades due	May 12, Monday

## Field/Summer Sessions 2008

First Field Term First Day of Class and Summer Research, Registration (1)	May 12, Monday
Last day to register, add or drop courses without a “W”—Field Term and Summer Research (Census Day)	May 16, Friday
Memorial Day (Holiday—No classes held)	May 26, Monday
Last day to withdraw from First Field Term	June 6, Friday
First Field Term ends	June 20, Friday
Field Term grades due	June 23, Monday
Summer School First Day of Class, Registration (1)	June 16, Monday
Last day to register, add or drop courses without a “W”—Summer School	June 24, Tuesday
Independence Day (Holiday—No classes held)	July 4, Friday
Second Field Term begins	July 7, Monday
Last day to register, add or drop courses without a “W”—Second Field Term	July 11, Friday
Last day to withdraw from Summer School	July 11, Friday
Last day to withdraw from Second Field Term	August 1, Friday
Summer School ends	Aug. 8, Friday
Summer School grades due	Aug. 11, Monday
Second Field Term ends	Aug. 15, Friday
Second Field Term grades due	Aug. 18, Monday

(1) Petition for changes in tuition classification due in the Registrar’s office for this term.

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# University Administration / Useful Contacts

## Office of Graduate Studies

### Mailing address

1500 Illinois Street  
Golden, CO 80401-1887

### Telephone

303 273-3247

John M. Poate

Vice President for Research  
and Technology Transfer

Lisa Kinzel

Executive Assistant to the Vice  
President for Research and  
Technology Transfer

Thomas M. Boyd

Dean of Graduate Studies

Jahi Simbai

Director of Graduate Recruiting  
and Admissions  
jsimbai@mines.edu

Linda L. Powell

Graduate Admissions Officer  
lpowell@mines.edu

Brenda Neely

Student Services  
bneely@mines.edu

Kay Leaman

Admissions Coordinator

## Student Housing

Kathy Rice

Apartment Housing Coordinator

## Financial Aid

Roger Koester

Director of Financial Aid

Christina Jensen

Graduate Student Financial Aid Advisor

## International Student Services

Leslie Olsen

International Student Advisor

## Registrar's Office

Registrar

## Graduate Student Association

Rob Applegate

President

303 273-2101

## Academic Departments & Divisions

The address for all CSM academic departments  
and divisions is

1500 Illinois Street

Golden, Colorado 80401-1887

World Wide Web address: <http://www.mines.edu/>

Academic department and division telephone numbers are

### *Chemical Engineering*

..... 303 273-3720

### *Chemistry and Geochemistry*

..... 303 273-3610

### *Economics and Business*

..... 303 273-3482

### *Engineering*

..... 303 273-3650

### *Environmental Science and Engineering*

..... 303 273-3427

### *Geology and Geological Engineering*

..... 303 273-3800

### *Geophysics*

..... 303 273-3450

### *Liberal Arts and International Studies*

..... 303 273-3750

### *Materials Science*

..... 303 273-3660

### *Mathematical and Computer Sciences*

..... 303 273-3860

### *Metallurgical and Materials Engineering*

..... 303 273-3770

### *Mining Engineering*

..... 303 273-3701

### *Nuclear Engineering*

..... 303-273-3618

### *Petroleum Engineering*

..... 303 273-3740

### *Physics*

..... 303 273-3830

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# General Information

## Mission and Goals

Colorado School of Mines is a public research university devoted to engineering and applied science related to resources. It is one of the leading institutions in the nation and the world in these areas. It has the highest admission standards of any university in Colorado and among the highest of any public university in the U.S. CSM has dedicated itself to responsible stewardship of the earth and its resources. It is one of a very few institutions in the world having broad expertise in resource exploration, extraction, production and utilization which can be brought to bear on the world's pressing resource-related environmental problems. As such, it occupies a unique position among the world's institutions of higher education.

The school's role and mission has remained constant and is written in the Colorado statutes as: *The Colorado School of Mines shall be a specialized baccalaureate and graduate research institution with high admission standards. The Colorado School of Mines shall have a unique mission in energy, mineral, and materials science and engineering and associated engineering and science fields. The school shall be the primary institution of higher education offering energy, mineral and materials science and mineral engineering degrees at both the graduate and undergraduate levels. (Colorado revised Statutes, Section 23-41-105)*

Throughout the school's 127 year history, the translation of its mission into educational programs has been influenced by the needs of society. Those needs are now focused more clearly than ever before. We believe that the world faces a crisis in balancing resource availability with environmental protection and that CSM and its programs are central to the solution to that crisis. Therefore the school's mission is elaborated upon as follows:

*Colorado School of Mines is dedicated to educating students and professionals in the applied sciences, engineering, and associated fields related to*

- ◆ *the discovery and recovery of the Earth's resources,*
- ◆ *their conversion to materials and energy,*
- ◆ *their utilization in advanced processes and products, and*
- ◆ *the economic and social systems necessary to ensure their prudent and provident use in a sustainable global society.*

*This mission will be achieved by the creation, integration, and exchange of knowledge in engineering, the natural sciences, the social sciences, the humanities, business and their union to create processes and products to enhance the quality of life of the world's inhabitants.*

*The Colorado School of Mines is consequently committed to serving the people of Colorado, the nation, and the global community by promoting stewardship of the Earth upon which all life and development depend. (Colorado School of Mines Board of Trustees, 2000)*

## Institutional Values and Principles Graduate Education

The Colorado School of Mines (CSM) is dedicated to serving the people of Colorado, the nation and the global community by providing high quality educational and research experiences to students in science, engineering and related areas that support the institutional mission. Recognizing the importance of responsible earth stewardship, CSM places particular emphasis on those fields related to the discovery, production and utilization of resources needed to improve the quality of life of the world's inhabitants and to sustain the earth system upon which all life and development depend. To this end, CSM is devoted to creating a learning community which provides students with perspectives informed by the humanities and social sciences, perspectives which also enhance students' understanding of themselves and their role in contemporary society. CSM therefore seeks to instill in all graduate students a broad class of developmental and educational attributes:

- ◆ An in-depth knowledge in an area of specialization, enhanced by hands-on experiential learning, and breadth in allied fields, including:
  1. the background and skills to be able to recognize, define and solve problems by applying sound scientific and engineering principles, and
  2. for thesis-based students, experience in conducting original scientific research and engineering design at the forefront of their particular area of specialization.
- ◆ The ability to function effectively in an information-based economy and society, including:
  1. written, oral and graphical communications skills that enable effective transmission of concepts and ideas as well as technical information, and
  2. expertise in finding, retrieving, evaluating, storing and disseminating information in ways that enhance their leadership role in society and their profession.
- ◆ Preparation for leadership in a team-based milieu, including:
  1. the flexibility to adjust to an ever-changing professional environment and to appreciate diverse approaches to understanding and solving professional and societal problems,
  2. the creativity, resourcefulness, receptivity and breadth of interests to think critically about a wide range of cross-disciplinary issues,

3. a strong work ethic that inspires commitment and loyalty on the part of colleagues,
  4. interpersonal skills and attitudes which promote cooperation and enable leadership, and
  5. acceptance of responsibility for their own growth through life-long learning.
- ◆ The capability of adapting to, appreciating and working effectively in an international environment, including:
    1. being able to succeed in an increasingly interdependent world where borders between cultures and economies are becoming less distinct, and
    2. appreciating the traditions and languages of other cultures, as well as valuing and supporting diversity in their own society.
  - ◆ High standards of integrity expressed through ethical behavior and acceptance of the obligation to enhance their profession and society through service and leadership.

### *Professional Education*

A central purpose of a university is the widespread and open distribution of the special knowledge created by, and reposing in, the expertise of the faculty. At CSM, that special knowledge falls into several broad categories:

- ◆ A mature body of knowledge, in areas of historic leadership, which is of great value to professionals in those fields throughout the world.
- ◆ Creative advances in emerging fields of science and engineering, developed in Mines' leading-edge research laboratories, which can contribute to the economic and physical well-being of people in Colorado and the nation.
- ◆ Expertise in problem-solving methodologies, including engineering design and structured decision-making, which is of growing importance in all technical-social-political realms as our global society becomes increasingly complex and interdependent.
- ◆ Leadership in the development of innovative educational tools and techniques which can help people—young and old—to be better prepared to succeed in advanced education, productive careers, and satisfying personal lives.

Additional outreach responsibilities are imposed by the special role and nature of Mines:

- ◆ CSM is committed to inculcating in its traditional residential undergraduate and graduate students an appreciation for and commitment to life-long learning and inquiry. This imposes on Mines a responsibility to create and support Professional Outreach programs that will expose students to self-directed learning experiences while still in residence, and provide opportunities for continued intellectual growth after they graduate.

- ◆ The State requires all public colleges and universities in Colorado, in concert, to provide appropriate educational opportunities in rural areas which are under-served by traditional residential institutions.

In addition to these philosophical goals, Professional Outreach can make an important pragmatic contribution to the university by:

- ◆ Developing and sustaining programs which address the lifelong education needs of individuals in professions associated with science, mathematics, engineering, and technology.
- ◆ Recruiting high-quality students for the traditional residential programs
- ◆ Spreading and enhancing the reputation of Mines throughout the world
- ◆ Generating revenues that help support the residential and research missions of the university

### *Research*

The creation and dissemination of new knowledge are primary responsibilities of all members of the university community. Public institutions have an additional responsibility to use that knowledge to contribute to the economic growth and public welfare of the society from which they receive their charter and support. As a public institution of higher education, a fundamental responsibility of CSM is to provide an environment which enables contribution to the public good by encouraging creative research and ensuring the free exchange of ideas, information, and results. To that end, the institution acknowledges the following responsibilities:

- ◆ To insure that these activities are conducted in an environment of minimum influence and bias, it is essential that CSM protect the academic freedom of all members of its community.
- ◆ To provide the mechanisms for creation and dissemination of knowledge, the institution recognizes that access to information and information technology (e.g. library, computing and internet resources) are part of the basic infrastructure support to which every member of the community is entitled.
- ◆ To promote the utilization and application of knowledge, it is incumbent upon CSM to define and protect the intellectual-property rights and responsibilities of faculty members, students, as well as the institution.

The following principles derive from these values and responsibilities:

- ◆ The institution exists to bring faculty and students together to form a community of scholars.
- ◆ Faculty members have unique relationship with the institution because of their special responsibility to create and disseminate knowledge independent of oversight or direction from the institution.

- ◆ Students have a dual role as creators and recipients of knowledge.
- ◆ The institution and the faculty share responsibility for facilitating the advancement of students in their chosen discipline.
- ◆ The institution and the faculty are mutually dependent upon each other, and share the responsibility for the reputation of both the university and the individual.
- ◆ Although research objectives should be informed by the institution's responsibility (as a public institution) to contribute to economic growth and societal well-being, research priorities must be driven by academic needs relating to the creation, development and dissemination of knowledge.
- ◆ Research policies and practices must conform to the state non-competition law which requires that all research projects have an educational component through the involvement of students and/or post-doctoral fellows.
- ◆ Both the creator and the institution have interest in, and a responsibility to promote, the dissemination and utilization of new knowledge for public good through publication and commercialization.
- ◆ Although commercialization is not a primary responsibility of the university community, it is a common result of technology transfer. The creator and the institution may each have an interest in the commercialization of intellectual property and should share in the potential benefits and risks based on their contributions.

### *Intellectual Property*

The creation and dissemination of knowledge are primary responsibilities of all members of the university community. As an institution of higher education, a fundamental mission of CSM is to provide an environment that motivates the faculty and promotes the creation, dissemination, and application of knowledge through the timely and free exchange of ideas, information, and research results for the public good. To insure that these activities are conducted in an environment of minimum influence and bias, so as to benefit society and the people of Colorado, it is essential that CSM protect the academic freedom of all members of its community. It is incumbent upon CSM to help promote the utilization and application of knowledge by defining and protecting the rights and responsibilities of faculty members, students and the institution, with respect to intellectual property which may be created while an individual is employed as a faculty member or enrolled as a student. The following principles, derived from these responsibilities and values, govern the development and implementation of CSM's Intellectual Property Policies.

- ◆ The institution exists to bring faculty and students together to form a community of scholars.
- ◆ Faculty members have a unique relationship with the institution because faculty create and disseminate knowledge independent of oversight or direction from the institution.
- ◆ Faculty activities must be driven by academic needs relating to the creation and dissemination of knowledge rather than commercial opportunities.
- ◆ The institution and the faculty share responsibility for facilitating the advancement of students in their chosen discipline. Students are the independent creators of the expression of ideas in their theses, but may have a dual role as both an independent creator of an expression of ideas and as directed employees.
- ◆ The institution and the faculty are mutually dependent upon each other, and share the responsibility for the reputation of both the university and the individual.
- ◆ Both the creator and the institution have an interest in, and a responsibility to promote, the dissemination and utilization of knowledge for the public good.
- ◆ Although commercialization is not a primary responsibility of the university community, it is sometimes the result of technology transfer.
- ◆ The creator and the institution should share in the potential benefits and risks in proportion to their contributions and/or agreed assumption of benefits and risks.
- ◆ All members of the CSM community will demonstrate the highest level of integrity in their activities associated with intellectual property.

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## History of CSM

In 1865, only six years after gold and silver were discovered in the Colorado Territory, the fledgling mining industry was in trouble. The nuggets had been picked out of streams and the rich veins had been worked, and new methods of exploration, mining, and recovery were needed.

Early pioneers like W.A.H. Loveland, E.L. Berthoud, Arthur Lakes, George West and Episcopal Bishop George M. Randall proposed a school of mines. In 1874 the Territorial Legislature appropriated \$5,000 and commissioned Loveland and a Board of Trustees to found the Territorial School of Mines in or near Golden. Governor Routt signed the Bill on February 9, 1874, and when Colorado became a state in 1876, the Colorado School of Mines was constitutionally established. The first diploma was awarded in 1883.

As CSM grew, its mission expanded from the rather narrow initial focus on nonfuel minerals to programs in petroleum production and refining as well. Recently it has added programs in materials science and engineering, energy and environmental engineering, and a broad range of other engineering and applied science disciplines. CSM sees its mission as education and research in engineering and applied science with a special focus on the earth science disciplines in the context of responsible stewardship of the earth and its resources.

CSM long has had an international reputation. Students have come from nearly every nation, and alumni can be found in every corner of the globe.

## Location

Golden, Colorado, has always been the home of CSM. Located in the foothills of the Rocky Mountains 20 minutes west of Denver, this community of 15,000 also serves as home to the Coors Brewing Company, the National Renewable Energy Laboratory, and a major U.S. Geological Survey facility that also contains the National Earthquake Center. The seat of government for Jefferson County, Golden once served as the territorial capital of Colorado. Skiing is an hour away to the west.

## Administration

By State statute, the school is managed by a seven-member board of trustees appointed by the governor, and the student body elects a nonvoting student board member each year. The school is supported financially by student tuition and fees and by the State through annual appropriations. These funds are augmented by government and privately sponsored research, and private gift support from alumni, corporations, foundations and other friends.



# The Graduate School

## Unique Programs

Because of its special focus, Colorado School of Mines has unique programs in many fields. For example, CSM is the only institution in the world that offers doctoral programs in all five of the major earth science disciplines: Geology and Geological Engineering, Geophysics, Geochemistry, Mining Engineering, and Petroleum Engineering. It also has one of the few Metallurgical and Materials Engineering programs in the country that still focuses on the complete materials cycle from mineral processing to finished advanced materials.

In addition to the traditional programs defining the institutional focus, CSM is pioneering both undergraduate and graduate interdisciplinary programs. The School understands that solutions to the complex problems involving global processes and quality of life issues require cooperation among scientists, engineers, economists, and the humanities.

CSM offers interdisciplinary programs in areas such as materials science, environmental science and engineering, management and public policy, engineering systems, hydrology, and geochemistry. These programs make interdisciplinary connections between traditional fields of engineering, physical science and social science, emphasizing a broad exposure to fundamental principles while cross-linking information from traditional disciplines to create the insight needed for breakthroughs in the solution of modern problems.

To provide flexibility in meeting new challenges, CSM also provides students the opportunity to develop individualized, interdisciplinary graduate research programs at both the Master and PhD level. This program allows students to earn degrees which have one of the following titles:

Doctor of Philosophy (Interdisciplinary)

Master of Science (Interdisciplinary)

Master of Engineering (Interdisciplinary)

When the need arises, CSM also offers interdisciplinary, non-thesis Professional Master degrees to meet the career needs of working professionals in CSM's focus areas.

Coordinated by the several departments involved, these interdisciplinary programs contribute to CSM's leadership role in addressing the problems and developing solutions that will enhance the quality of life for all of earth's inhabitants in the next century.

## Graduate Degrees Offered

CSM offers professional masters, master of science (M.S.), master of engineering (M.E.) and doctor of philosophy (Ph.D.) degrees in the disciplines listed in the chart at right.

In addition to masters and Ph.D. degrees, departments and divisions can also offer graduate certificates. Graduate certificates are designed to have selective focus, short time to completion and consist of course work only.

## Accreditation

Colorado School of Mines is accredited through the level of the doctoral degree by the Higher Learning Commission of the North Central Association, 30 North LaSalle Street, Suite 2400, Chicago, Illinois 60602-2504 - telephone (312) 263-0456.

The Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology, 111 Market Place, Suite 1050, Baltimore, MD 21202-4012 - telephone (410) 347-7700, accredits undergraduate degree programs in chemical engineering, engineering, engineering physics, geological engineering, geophysical engineering, metallurgical and materials engineering, mining engineering and petroleum engineering. The American Chemical Society has approved the degree program in the Department of Chemistry and Geochemistry.

Degree Programs	Prof.	M.S.	M.E.	Ph.D.
Applied Physics		■		■
Chemical Engineering		■		■
Chemistry		■		
Applied Chemistry				■
Engineering		■		■
Engineering & Technology Management		■		
Environmental Geochemistry	■			
Environmental Science & Engineering		■		■
Geochemistry		■		■
Geological Engineering		■	■	■
Geology		■		■
Geophysical Engineering		■		■
Geophysics		■		■
Hydrology		■		■
International Political Economy & Resources		□		
Materials Science		■		■
Mathematical & Computer Science		■		■
Metallurgical & Materials Engineering		■	■	■
Mineral Economics		■		■
Mineral Exploration & Mining Geosciences	■			
Mining & Earth Systems Engineering		■	■	■
Nuclear Engineering		■		■
Petroleum Engineering		■	■	■
Petroleum Reservoir Systems	■			

□ Master of International Political Economy of Resources

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# Admission to the Graduate School

## Admission Requirements

The Graduate School of Colorado School of Mines is open to graduates from four-year programs at recognized colleges or universities. Admission to all graduate programs is competitive, based on an evaluation of prior academic performance, test scores and references. The academic background of each applicant is evaluated according to the requirements of each department outlined later in this section of the Bulletin.

To be a candidate for a graduate degree, students must have completed an appropriate undergraduate degree program. Undergraduate students in the Combined Degree Program may, however, work toward completion of graduate degree requirements prior to completing undergraduate degree requirements. See the Combined Undergraduate/Graduate Degree section of the Graduate Bulletin for details of this program.

## Categories of Admission

There are three categories of admission to graduate studies at Colorado School of Mines: regular, provisional, and special graduate nondegree.

### *Regular Degree Students*

Applicants who meet all the necessary qualifications as determined by the program to which they have applied are admitted as regular graduate students.

### *Provisional Degree Students*

Applicants who are not qualified to enter the regular degree program directly may be admitted as provisional degree students for a trial period not longer than 12 months. During this period students must demonstrate their ability to work for an advanced degree as specified by the admitting degree program. After the first semester, the student may request that the department review his or her progress and make a decision concerning full degree status. With department approval, the credits earned under the provisional status can be applied towards the advanced degree.

### *International Special Graduate Students*

Applicants who wish to study as non-degree students for one or two semesters may apply for Special Graduate status. Special Graduate student status is available to a limited number of applicants from abroad. All such students who attend class or audit courses at Colorado School of Mines must register and pay the appropriate nonresident tuition and fees for the credits taken.

### *Nondegree Students*

Practicing professionals may wish to update their professional knowledge or broaden their areas of competence without committing themselves to a degree program. They may enroll for regular courses as nondegree students. Inquiries and applications should be made to the Registrar's Office, CSM, Golden, CO 80401-0028. Phone: 303-273-3200; FAX 303-384-2253. A person admitted as a nondegree student

who subsequently decides to pursue a regular degree program must apply and gain admission to the Graduate School. All credits earned as a nondegree student may be transferred into the regular degree program if the student's graduate committee and department head approve.

### *Combined Undergraduate/Graduate Programs*

Several degree programs offer CSM undergraduate students the opportunity to begin work on a Graduate Certificate, Professional Degree, or Master Degree while completing the requirements for their Bachelor Degree. These programs can give students a head start on graduate education. An overview of these combined programs and description of the admission process and requirements are found in the Graduate Degrees and Requirements section of this Bulletin.

## Admission Procedure

### *Applying for Admission*

Apply electronically for admission on the World Wide Web. Our Web address is

<http://www.mines.edu/Admiss/grad>

Follow the procedure outlined below.

1. Application: Go to the online application form at [www.mines.edu/Admiss/grad/graduate\\_admissions.html](http://www.mines.edu/Admiss/grad/graduate_admissions.html). You may download a paper copy of the application from our website or contact 303-273-3247 or [grad-school@Mines.edu](mailto:grad-school@Mines.edu) to have one sent my mail. Students wishing to apply for graduate school should submit completed applications by the following dates:

for Fall admission

January 15 - Priority consideration for financial support\*

April 1 - International student deadline

July 1 - Domestic student deadline\*\*

for Spring Admission

September 1 - International student deadline

November 1 - Domestic student deadline

\*March 1 for Chemistry and Applied Chemistry applicants

\*\*March 15 for Geology and Geological Engineering applicants

Students wishing to submit applications beyond the final deadline should make a request to the individual academic department.

2. Transcripts: Send to the Graduate School two official transcripts from each school previously attended. The transcripts may accompany the application or may be sent directly by the institution attended. International students' transcripts must be in English or have an official English translation attached.



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3. Letters of Recommendation: Three (3) letters of recommendation are required. Individuals who know your personal qualities and scholastic or professional abilities can use the online application system to submit letters of recommendation on your behalf. Letters can also be mailed directly to the Graduate School. At least two letters should be from individuals acquainted with your scholastic abilities.

4. Graduate Record Examination: Most departments require the General test of the Graduate Record Examination for applicants seeking admission to their programs. Refer to the section Graduate Degree Programs and Courses by Department or the Graduate School application packet to find out if you must take the GRE examination. For information about the test, write to Graduate Record Examinations, Educational Testing Service, PO Box 6000, Princeton, NJ 08541-6000 (Telephone 609-771-7670), or visit online at [www.gre.org](http://www.gre.org).

5. English Language Requirement: Applicants whose native language is not English must complete the TOEFL examination (Test of English as a Foreign Language), and have the results sent to the Graduate School as part of the admission process. The institution has minimum TOEFL examination requirements. These may be found at [http://www.mines.edu/admiss/grad/intl\\_stu\\_admission\\_app.html](http://www.mines.edu/admiss/grad/intl_stu_admission_app.html). Contact local American embassies or write to TOEFL Services, Educational Testing Service, P.O. Box 6151, Princeton, NJ 08541-6151, USA, (Telephone 609-771-7100) for information about the TOEFL examination. You may also visit online at [www.toefl.org](http://www.toefl.org). If a TOEFL exam score indicates that the applicant will be handicapped academically, as a condition for admission the applicant may be required to enroll in the INTERLINK Language program at CSM until the required proficiency is achieved.

The INTERLINK Language program offers intensive English language instruction and skills development for academic success. See the detailed description of INTERLINK on page 15 of this catalog.

6. Additional instructions for admission to graduate school specific to individual departments are contained in the application for admission.

## **Financial Assistance**

To apply for CSM financial assistance, check the box in the Financial Information section of the online graduate application or complete the Financial Assistance section on the paper application.

## **Application Review Process**

When application materials are received by the Graduate School, they are processed and sent to the desired degree program for review. The review is conducted according to the process developed and approved by the faculty of that degree program. The degree program transmits its decision to the Dean of the Graduate School, who then notifies the applicant. The decision of the degree program is final and may not be appealed.

## **Health Record and Additional Steps**

When students first enroll at CSM, they must complete the student health record form which is sent to them when they are accepted for enrollment. Students must submit the student health record, including health history, medical examination, and record of immunization, in order to complete registration.

Questions can be addressed to the Coulter Student Health Center, 1225 17th Street, Golden, CO 80401-1869. The Health Center telephone numbers are 303-273-3381 and 303-279-3155.

## **International Students**

Qualifying international students (see Admission Requirements above) apply for graduate study by following steps one through six listed in this section.

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# Student Life at CSM

## Housing

### *Mines Park*

The Mines Park apartment complex is located west of the 6th Avenue and 19th Street intersection on 55 acres owned by CSM. The complex houses some freshmen, upper class students, graduate students, and families. Residents must be full-time students.

Units are complete with refrigerators, stoves, dishwashers, cable television, campus phone lines and T-1 connections to the campus network system. There are two community centers which contain the laundry facilities, recreational/study space, and a convenience store.

2007-08 Rates are as follows:

#### Family Housing

1 bedroom	\$650/mo
2 bedroom	\$750/mo

#### Apartment Housing

1 bedroom	\$650/mo
2 bedroom	\$878/mo
3 bedroom	\$1,170/mo

For an application to any of the campus housing options, please contact the housing office at (303) 273-3350 or visit the Student Life office in the Ben Parker Student Center, Room 218.

### *Campus Residence Halls*

Four of the residence halls located on campus have the traditional double rooms and common bathrooms, and our fifth Residence Hall, Weaver Towers, has suites for seven to eight people with two private bathrooms and a common living room.

Residence hall rooms are contracted for the entire academic year; costs range from \$3,880 for a traditional double room to \$4,810 for a single in Weaver Towers. All students in residence halls must also choose a dining hall meal plan. Meal plans are \$3,455 per year, and students can choose from options available for residence hall students.

## Student Services

### *Ben H. Parker Student Center*

The Ben H. Parker Student Center has recently undergone a four million dollar renovation and addition. The building contains the offices for the Vice President of Student Life and Dean of Students, the Director of Student Life, Housing, Conferences Reservation Office, Student Activities and Greek Advisor, ASCSM Offices, and Student Groups. The Student Center also contains the student dining hall, the I-Club, a food court, game room, bookstore, and student lounges and TV room. There are also a number of meeting rooms and banquet facilities in the Student Center. Another addition was completed during the summer of 2001 which contains meeting rooms and banquet facilities as well as the offices of Admissions/Financial Aid, Cashier, Student Development and Academic Services/Services for Students with Disabilities, International Student Services, Career Services and Registrar.

### *Student Recreation Center*

Completed in May, 2007, the 108,000 square foot Student Recreation Center, located at the corner of 16th and Maple Streets in the heart of campus, provides a wide array of facilities and programs designed to meet student's recreational and leisure needs while providing for a healthy lifestyle. The Center contains a state-of-the-art climbing wall, an eight-lane, 25 meter swimming and diving pool, a cardiovascular and weight room, two multi-purpose rooms designed and equipped for aerobics, dance, martial arts programs and other similar activities, a competition gymnasium containing three full-size basketball courts as well as seating for 2500 people, a separate recreation gymnasium designed specifically for a wide variety of recreational programs, extensive locker room and shower facilities, and a large lounge and juice bar facility intended for relaxing, playing games or watching television. In addition to housing the Outdoor Recreation Program as well as the Intramurals and Club Sports Programs, the Center serves as the competition venue for the Intercollegiate Men and Women's Basketball Programs, the Intercollegiate Volleyball Program and the Men and Women's Intercollegiate Swimming and Diving Program.

### *Office for Student Development and Academic Services*

The Student Development and Academic Services Office (SDAS), located in the Student Center, serves as the personal, academic and career counseling center. Through its various services, the center acts as a comprehensive resource for the personal growth and life skills development of our students. SDAS houses a library of over 300 books and other materials for checkout, and is home to CSM's Engineers Choosing Health Options (ECHO) program, promoting wise and healthy decision making regarding students' use of alcohol and other drugs.

**Counseling:** Experienced, professional counselors offer assistance in a variety of areas. Personal counseling for stress management, relationship issues, wellness education and/or improved self image are a few of the areas often requested. Assertiveness, stress management, time management, gender issues, personal security, and compatibility with roommates are also popular interactive presentations. SDAS works closely with other student life departments to address other issues.

**Academic Services:** The staff often conducts workshops in areas of interest to college students, such as time management, learning skills, test taking, preparing for finals and college adjustment. Advising on individual learning skills is also available. Additional learning resources are provided on the department website.

**Tutoring and Academic Excellence Workshops:** Graduate students are welcome to avail themselves of free walk-in tutoring and/or weekly workshops in introductory calculus, chemistry, and physics.

**Office of Services for Students with Disabilities (OSSD):** This office serves students with documented disabilities who are seeking academic accommodations or ad-

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justments. OSSD coordinates CSM's efforts to comply with the broad mandates of Section 504 of the Rehabilitation Act of 1973 and the Americans with Disabilities Act of 1990.

### ***International Student Services***

The International Student Office advises international students, coordinates the Host Family Program, and holds orientation programs for new foreign students at the beginning of each semester. The international student advisor processes student visas and work permits.

For more information, call the International Student Services office at 303-273-3210 or FAX 303-273-3099.

### ***Identification Cards (BLASTER CARD)***

Blaster cards are made in the Student Life Office in the Parker Student Center, and all new students must have a card made as soon as possible after they enroll. Each semester the Student Activities Office issues validation stickers for student ID's, and students can replace lost, stolen, or damaged Blaster Cards for a small fee.

The Blaster Card can be used as a debit card to make purchases from all campus vending machines, at all campus food service facilities, at the campus bookstore, to use any campus laundry facility as well as any campus copying machine, to check material out of the CSM Library and to make purchases at participating golden area businesses. It will also serve as an access card to the campus residence halls and may be required to attend various CSM campus activities.

Please visit the website at <http://www.is.mines.edu/BlasterCard> for more information.

### ***Student Health Center***

The Student Health Center, located at 17th and Elm, provides primary health care to CSM students and their spouses. Students pay a \$46.50 fee each semester which entitles them to unlimited visits with a physician or nurse as well as limited prescription and over-the-counter medications. Spouses of enrolled students may also pay the fee and receive the same services. The health center also provides dental services, wellness education, immunizations, allergy shots, flu shots, nutrition counseling and information regarding a wide range of health concerns. Staff members are also available to provide health-promotion events for students groups and residence hall program.

The Student Health Center is open Monday through Friday 8-12 and 1-4:45 P.M. It is staffed by RN's throughout the day. Physician's coverage is provided by family practice physicians who are on site for two hours daily and on-call at all times. Dental services are also provided on a scheduled basis. To be eligible for care, students must be enrolled currently; have paid the Health Center fee if they are part time and have a completed Health History Form on file at the Health Center.

Supervised by Vice President and Dean of Student Life.  
Phone: (303) 273-3381; FAX: (303) 279-3155.

### ***Mandatory Health Insurance***

Colorado School of Mines requires health insurance as a

condition of enrollment for all CSM students, regardless of full-time or part-time status. For students without health insurance coverage, the School offers an insurance plan. Additional coverage for spouses and children is also available.

All international students are, however, required to enroll in the CSM Plan, regardless of the existence of their own personal health coverage. There are two exceptions to this requirement: (1) the international student has an insurance policy approved by the CSM International Student Office; or (2) the international student is receiving benefits for a health insurance claim that would otherwise be pre-existing under the CSM Plan. Additional coverage for spouses and children is also available.

NOTE: The Coulter Student Health Center fee and required health insurance are two separate programs.

### ***Motor Vehicles, Parking***

All motor vehicles on campus must be registered with the campus Department of Public Safety, 1812 Illinois Street, and must display the CSM permit. Vehicles must be registered at the beginning of each semester or within 10 days of bringing the vehicle onto campus, and updated whenever you change your address.

### ***Career Center***

The CSM Career Center mission is to assist students in developing, evaluating, and/or implementing career, education, and employment decisions and plans. Career development is integral to the success of CSM graduates and to the mission of CSM. All Colorado School of Mines graduates will be able to acquire the necessary skills to enable them to successfully take personal responsibility for the management of their own careers.

In order to accomplish our mission, we provide a comprehensive array of career services:

#### ***Career Advice and Counseling***

- ◆ Resources to help choose a major
- ◆ Individual resume and cover letter critiques
- ◆ Individual job search advice
- ◆ Practice video-taped interviews

#### ***Career Planning Services***

- ◆ Online resources for exploring careers and employers
- ◆ "Career Digger" online - short bios describe what recent grads are doing on their jobs
- ◆ "Career Manual" online - resume writing, resume and cover letter examples, and job search tips
- ◆ Job Search Workshops - successful company research, interviewing, networking skills
- ◆ Salary and "placement" information
- ◆ Company contact information
- ◆ Grad school information
- ◆ Career resource library

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### *Job Resources*

- ◆ Career Day (Fall and Spring)
- ◆ Online summer, part-time, and full-time entry-level job postings at [www.diggernet.net](http://www.diggernet.net)
- ◆ On-campus interviewing - industry and government representatives visit the campus to interview students and explain employment opportunities
- ◆ Resume referrals
- ◆ Employer searching resource
- ◆ Continued services up to 18 months after graduation

### *Oredigger Student Newspaper*

The Oredigger student newspaper, published on a regular basis during the school year, contains news, features, sports, letters, and editorials of interest to students, faculty, and the Golden community.

### *Veterans' Benefits*

The Registrar's Office offers veterans counseling services for students attending the School and using educational benefits from the Veterans Administration.

### **Military Science Army ROTC (AROTC)**

The Military Science Program at the Colorado School of Mines (CSM) is offered in conjunction with the University of Colorado at Boulder (CU-B). The Department of Military Science offers programs leading to an officer's commission in the active Army, Army Reserve, or National Guard in conjunction with an undergraduate or graduate degree. Military science courses are designed to supplement a regular degree program by offering practical leadership and management experience. Students attend classes at the Colorado School of Mines in Golden.

### *Two-Year Program*

The two-year program consists of the advanced course, preceded by attending the Leaders Training course (a four-week summer ROTC basic course at Ft. Knox, Kentucky). Veterans or Active Army Reserve/Army National Guard Soldiers, are eligible to enroll in the advanced course without attending the Leaders Training Course. Inquiries on advanced placement should be directed to the Department of Military Science. Advanced course students must obtain permission from the Professor of Military Science (PMS) at 303-492-6495.

### *Registration and AROTC Course Credit*

Army ROTC serves as elective credit in most departments. Elective course credit toward your degree for AROTC classes will be determined by your individual academic advisor. AROTC classes begin with the MSGN prefix.

For more information, contact the CU-Boulder Army ROTC Enrollment and Scholarship Officer at 303-492-3549 or 303-492-6495. You can also go to <http://www.colorado.edu/AROTC>. For information about CSM, call 303-273-3398 or 303-273-3380.

### **Student Activities**

Student government committees, professional societies, living group organizations, special events, honor societies, and interest group organizations add a balance to the CSM community and offer participants the chance to develop leadership and management skills. The Student Activities office can give you an up-to-date list of recognized campus organizations and more information about them.

### *Student Government*

The Graduate Student Association was formed in 1991 and is recognized by CSM and the National Association of Graduate-Professional Students (NSGPS). GSA's primary goal is to improve the quality of a graduate education, offer academic support for graduate students, and provide social interaction.

GSA takes an active role in university affairs and promotes the rights and responsibilities of graduate students. GSA also serves to develop university responsibility to non-academic concerns of graduate students. GSA is funded through and works with Associated Students of the Colorado School of Mines and is presently represented on the Faculty Senate Graduate Council and Associated Students of CSM. Phone: 303-273-3094.

The Associated Students of the Colorado School of Mines works to advance the interest and promote the welfare of CSM and of all students, and to foster and maintain harmony among those connected with or interested in the school, including students, alumni, faculty, trustees, and friends.

Through funds collected as student fees, ASCSM strives to ensure a full social and academic life for all students with its organizations, publications, and social events.

The Mines Activity Council (MAC) serves the ASCSM as the campus special events board. Most student events on campus are planned by the MAC committees. Committees are the Friday Afternoon Club (FAC) committee, which brings comedians and other performers to campus on most Fridays in the academic year; the Special Events committee, which coordinates events like the annual Back-to-School Bash, Discount Sport Nights at professional sporting events, and one-time specialty entertainment; the E-Days committee; and the Homecoming committee.

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### Special Events

**Research Fair:** GSA presently co-sponsors a graduate paper competition with Sigma XI during CSM's spring semester Engineering Days (E-Days). The fair is designed to give graduate students the opportunity to make a presentation in a professional conference setting about research they have been working on. At the conclusion of the event, cash prizes are awarded to graduate students whose papers exhibit outstanding contributions to their areas of study.

**International Day** is planned and conducted by the International Student Organization. It includes exhibits and programs designed to further the cause of understanding among the countries of the world. The international dinner, including entertainment and samples of foods from countries all over the world, is one of the top campus social events of the year.

**Winter Carnival**, sponsored by Blue Key, is an all-school ski day held each year at one of the nearby ski slopes.

**Homecoming** weekend is one of the high points of the entire year's activities. Events include a football rally and game, campus decorations, election of Homecoming queen and beast, parade, burro race, and other contests.

**Engineer Days** are held each spring. The three-day affair is organized entirely by students. Contests are held in drilling, hand-spiking, mucking, oil-field olympics, and soft-ball, to name a few. Additional events include a fireworks display, an E-Day concert, and the traditional orecart push.

**GSA Fall and Spring Blowout:** GSA sponsors parties twice a year for graduate students. Held in the late spring and early fall at local parks, they let graduate students take a break from studying.

### Honor Societies

Honor societies recognize the outstanding achievements of their members in scholarship, leadership, and service. Each of the CSM honor societies recognizes different achievements by our students. The Colorado School of Mines honor societies, and their representative areas, are as follows:

Alpha Phi Omega	Service
Alpha Sigma Mu	Metals
Blue Key	Service, Scholarship, Activities
Kappa Kappa Psi	Band
Kappa Mu Epsilon	Mathematics
National Society of Pershing Rifles	Military Science
Order of Omega	Greek Scholarship
Pi Epsilon Tau	Petroleum Engineering
Sigma Pi Sigma	Physics
Tau Beta Pi	Engineering

### Interest Organizations

Interest organizations meet the special and unique needs of the CSM student body by providing specific co-curricular activities. These organizations are:

- Association of Geoscience Students (AGS)
- Band
- Bioengineering Club
- Campus Crusade for Christ
- College Republicans
- Chorus
- CSM Ambassadors
- Earthworks
- Fellowship of Christian Athletes
- Hawaii Club
- Math Club
- Mines Little Theatre
- Non-Traditional Students
- Students for Creative Anachronism
- Young Democrats

### International & Minority Organizations

International and minority organizations provide the opportunity to experience different cultures while at Mines and help the students from those cultures adjust to Mines campus life. These organizations include

- Afro-Caribbean Students Union
- Chinese Student Association
- International Student Organization (ISO)
- Japanese Student Association (JSA)
- Muslim Student Association (MSA)
- Taiwanese Student Association
- American Indians in Science & Engineering (AISES)
- Asian Student Association (ASA)
- National Society of Black Engineers (NSBE)
- Hispanic Professional Engineers & Scientists (SHPEs)

### Professional Societies

Professional societies are generally student chapters of the national professional societies. As student chapters, the professional societies offer a chance for additional professional development outside the classroom through guest speakers, trips, and interactive discussions about the current activities in the profession. Many of the organizations also offer internships, fellowships, and scholarships. The Colorado School of Mines chapters are as follows:

- American Association of Drilling Engineers (AADE)
- American Association of Petroleum Geologists (AAPG)
- American Institute of Professional Geologists (AIPG)
- American Institute of Chemical Engineers (AIChE)
- American Institute of Mining, Metallurgical & Petroleum

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Engineers (AIME)  
American Ceramic Society (Am. Cer. Soc.)  
American Chemical Society (ACS)  
American Society of Civil Engineers (ASCE)  
American Society of Metals (ASM International)  
American Society of Mechanical Engineers (ASME)  
American Welding Society  
Association of Engineering Geologists (AEG)  
Association of General Contractors (AGC)  
Institute of Electrical & Electronic Engineers (IEEE)  
International Society for Measurement and Control (ISA)  
Society of American Military Engineers (SAME)  
Society of Automotive Engineers (SAE)  
Society of Economic Geologists (SEG)  
Society of Mining Engineers (SME)  
Society of Petroleum Engineers (SPE)  
Society of Physics Students (SPS)  
Society of Graduate Geophysics Students (SGGS)  
Society of Women Engineers (SWE)  
The Minerals, Metals & Materials Society of AIME

### ***Recreational Organizations***

Recreational organizations give students with similar recreational interests the chance to participate as a group in the activities. Most of the recreational organizations compete on both the local and regional levels at tournaments during the school year. These clubs are:

Billiards Club  
Caving Club  
Cheerleading  
Kayak Club  
Racquetball Club  
Rugby Club  
Shooting Club  
Ski Club/Team  
Men's Volleyball  
Women's Soccer  
BMOC (Big Men on Campus)

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# Facilities and Academic Support

## Arthur Lakes Library

JOANNE V. LERUD-HECK, Librarian and Library Director

LISA G. DUNN, Librarian

LAURA A. GUY, Librarian

ROBERT K. SORGENFREI, Librarian

LISA S. NICKUM, Associate Librarian

CHRISTOPHER THIRY, Associate Librarian

PATRICIA E. ANDERSEN, Assistant Librarian

CHRISTINE BAKER, Assistant Librarian

PAMELA M. BLOME, Assistant Librarian

MEGAN TOMEO, Assistant Librarian

HEATHER L. WHITEHEAD, Assistant Librarian

Arthur Lakes Library is a regional information center for engineering, energy, minerals, materials, and associated engineering and science fields. The Library supports education and research programs at CSM and is committed to meeting the information needs of the CSM community and all library users.

The Library has over 140,000 visitors a year and is a campus center for learning, study and research. Facilities include meeting space, a campus computer lab, and individual and group study space. We host many cultural events during the year, including concerts and art shows.

The librarians provide personalized help and instruction, and assist with research. The Library's collections include more than 500,000 books; thousands of print and electronic journals; hundreds of databases; one of the largest map collections in the West; an archive on CSM and western mining history; and several special collections. The Library is a selective U.S. and Colorado state depository with over 600,000 government publications.

Catalyst, the Library's Web-based catalog, provides access to Library collections and your user account. Our databases allow users to find publications for general use, classroom assignments or research. Students and faculty can use most of the Library's electronic databases and publications from any computer on the campus network, including those in networked CSM residential facilities. Dial-up and Internet access are available out of network.

Arthur Lakes Library is a member of the Colorado Alliance. Students and faculty can use their library cards at other Alliance libraries, or can order materials directly using Prospector, a regional Web-based catalog. Materials can also be requested from anywhere in the world through interlibrary loan.

## Academic Computing and Networking

DEREK WILSON, Director & CIO

PHIL ROMIG, III, Associate Director

Academic Computing and Networking (AC&N) provides computing and networking services to meet the instructional, research, and networking infrastructure needs of the campus. AC&N manages and operates the campus network along with central academic computing systems and laboratories

located in the Computer Commons, CTLM, Writing Center, and Library. In addition, AC&N's academic department support services group provides support services for many departmental servers, laboratories, and desktops.

Central computing accounts and services are available to registered students and current faculty and staff members. Information about hours, services, and the activation of new accounts is available on the web site at <http://www.mines.edu/academic/computer/>, directly from the Help Desk in the Computer Commons or by calling (303) 273-3431.

Workrooms in several locations on campus contain networked PCs and workstations. Printers, scanners, digitizers, and other specialized resources are available for use in some of the locations.

In addition to central server and facilities operations, services provided to the campus community include e-mail, wired and wireless network operation and support, modem pools, access to the commodity Internet, Internet 2, and National Lambda Rail, network security, volume and site licensing of software, on-line training modules, videoconferencing, and campus web site and central systems administration and support. In addition, support and administration is provided for some academic department servers, laboratories, and desktops. AC&N manages and supports the central course management system (Blackboard), calendaring services, printing, short-term equipment loan, and room scheduling for some general computer teaching classrooms.

All major campus buildings are connected to the computing network operated by AC&N and most areas of the campus are covered by the wireless network. All residence halls and the Mines Park housing complex are wired for network access and some fraternity and sorority houses are also directly connected to the network.

All users of Colorado School of Mines computing and networking resources are expected to comply with all policies related to the use of these resources. Policies are posted at <http://www.mines.edu/academic/computer/policies/>.

For more information about AC&N, see the web pages at <http://www.mines.edu/academic/computer/>

## Copy Center

Located on the first floor of Guggenheim Hall, the Copy Center offers on-line binding, printed tabs, and halftones. Printing can be done on all paper sizes from odd-sized originals. Some of the other services offered are GBC and Velo Binding, folding, sorting and collating, reduction and enlargement, two sided copying, and color copying. We have a variety of paper colors, special resume paper and CSM watermark for thesis copying. These services are available to students, faculty, and staff. The Copy Center campus extension is 3202.

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## CSM Alumni Association

(CSMAA) The Colorado School of Mines Alumni Association, established in 1895, serves the Colorado School of Mines and its alumni. Services and benefits of membership include:

Mines, a quarterly publication covering campus and alumni news; an online directory of all Mines alumni for networking purposes; on-line job listings; section activities that provide social and networking connections to the campus and other Mines alumni around the world; invitations to local and annual alumni meetings, reunions, golf tournaments and other special events on and off campus; awards, including the opportunity to nominate outstanding fellow alumni and be nominated yourself; CSM library privileges for Colorado residents; access to career service aids, including High Impact Job Search; and discounts with partner vendors.

Benefits for current Colorado School of Mines students are legacy grants for children or grandchildren of alumni; the Student Financial Assistance Program; recognition banquets for graduating seniors/graduate students; the CSMAA Mentorship program, pairing students with alumni for professional development; assistance and support of School events such as Homecoming; alumni volunteer assistance in student recruiting; Order of the Engineer ceremonies; and various other programs that enrich students' lives via alumni involvement.

For further information, call 303-273-3295, FAX 303-273-3583, e-mail [csmaa@mines.edu](mailto:csmaa@mines.edu), or write Mines Alumni Association, 1600 Arapahoe Street, P.O. Box 1410, Golden, CO 80402-1410.

## Environmental Health and Safety

The Environmental Health and Safety (EHS) Department is located in Chauvenet Hall room 194. The Department provides a variety of services to students, staff and faculty members. Functions of the Department include: hazardous waste collection and disposal; chemical procurement and distribution; chemical spill response; assessment of air and water quality; fire safety; laboratory safety; industrial hygiene; radiation safety; biosafety; and recycling. Staff is available to consult on issues such as chemical exposure control, hazard identification, safety systems design, personal protective equipment, or regulatory compliance. Stop by our office or call 303 273-3316. The EHS telephone is monitored nights and weekends to respond to spills and environmental emergencies.

## Green Center

Completed in 1971, the Cecil H. and Ida Green Graduate and Professional Center is named in honor of Dr. and Mrs. Green, major contributors to the funding of the building.

Bunker Memorial Auditorium, which seats 1,386, has a large stage that may be used for lectures, concerts, drama productions, or for any occasion when a large attendance is expected.

Friedhoff Hall contains a dance floor and an informal stage. Approximately 600 persons can be accommodated at tables for banquets or dinners. Auditorium seating can be arranged for up to 450 people.

Petroleum Hall and Metals Hall are lecture rooms seating 123 and 310, respectively. Each room has audio visual equipment. In addition, the Green Center houses the modern Computing Center and the Department of Geophysics.

## INTERLINK Language Center (ESL)

The INTERLINK Language program combines intensive English language instruction (ESL) with academic training and cultural orientation to prepare students for their studies at CSM. Designed for international students in engineering and the sciences, the program prepares students for a successful transition to their new academic and cultural environment. The curriculum focuses on individual student needs, utilizing experiential learning projects, media technology (video, film, computers, TV, radio, the Internet) and various sources and resources in the surrounding community. Successful completion of the program may entitle academically qualified students to begin their academic studies without a TOEFL score.

The program is open to adults who have completed secondary school in good standing (grade point average of C+ or above) and are able to meet their educational and living expenses. For further information contact INTERLINK Language Center (ESL) at:

INTERLINK Language Center (ESL)  
Colorado School of Mines, Golden, CO 80401  
<http://www.eslus.com>  
<http://www.mines.edu/Outreach/interlink>  
Email: [interlinkcsm@mines.edu](mailto:interlinkcsm@mines.edu)  
Tele: 303-279-9389  
Fax: 303-278-4055

## LAIS Writing Center

Located in room 311 Stratton Hall (phone: 303-273-3085), the LAIS Writing Center is a teaching facility providing all CSM students, faculty, and staff with an opportunity to enhance their writing abilities. The LAIS Writing Center faculty are experienced technical and professional writing instructors who are prepared to assist writers with everything from course assignments to scholarship and job applications. This service is free to CSM students, faculty, and staff and entails one-to-one tutoring and online resources (at <http://www.mines.edu/academic/lais/wc/>).

## Off-Campus Study

A student must enroll in an official CSM course for any period of off-campus, course-related study, whether U.S. or foreign, including faculty-led short courses, study abroad, or any off-campus trip sponsored by CSM or led by a CSM faculty member. The registration must occur in the same term that the off-campus study takes place. In addition, the student must complete the necessary release, waiver, and emer-



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gency contact forms, transfer credit pre-approvals, and FERPA release, and provide adequate proof of current health insurance prior to departure. For additional information concerning study abroad requirements, contact the Office of International Programs at (303) 384-2121; for other information, contact the Registrar's Office.

## Office of International Programs

The Office of International Programs (OIP) fosters and facilitates international education, research and outreach at CSM. OIP is administered by the Office of Academic Affairs.

OIP is located in 109 Stratton Hall. For more specific information about study abroad and other international programs, contact OIP at 384-2121 or visit the OIP web page (<http://www.mines.edu/Academic/lais/OIP/>).

The office works with the departments and divisions of the School to: (1) help develop and facilitate study abroad opportunities for CSM undergraduate and graduate students and serve as an informational and advising resource for them; (2) assist in attracting new international students to CSM; (3) serve as an information resource for faculty and scholars of the CSM community, promoting faculty exchanges and the pursuit of collaborative international research activities; (4) foster international outreach and technology transfer programs; (5) facilitate arrangements for official international visitors to CSM; and (6) in general, help promote the internationalization of CSM's curricular programs and activities.

Graduate students may apply for participation in dual degree programs offered by CSM and its partners. Generally these programs require the preparation and defense of one jointly supervised thesis project and the completion of degree requirements at each participating university.

## Office of Technology Transfer

The purpose of the Office of Technology Transfer (OTT) is to reward innovation and entrepreneurial activity by students, faculty and staff, recognize the value and preserve ownership of CSM's intellectual property, and contribute to local and national the economic growth. OTT reports directly to the Vice President of Research and Technology Transfer and works closely with the school's office of Legal Services to coordinate activities. Through its internal technical review team and external Advisory Board, OTT strives to:

- (1) Initiate and stimulate entrepreneurship and development of mechanisms for effective investment of CSM's intellectual capital;
- (2) Secure CSM's intellectual properties generated by faculty, students, and staff;
- (3) Contribute to the economic growth of the community, state, and nation through facilitating technology transfer to the commercial sector;
- (4) Retain and motivate faculty by rewarding entrepreneurship;

- (5) Utilize OTT opportunities to advance high-quality faculty and students;
- (6) Generate a new source of revenue for CSM to expand the school's research and education.

## Public Relations

The communications staff in the President's Office is responsible for public relations and marketing initiatives at Mines. For information about the School's publications guidelines, including the use of Mines logos and for media-related requests, contact Marsha Williams, Director of Integrated Marketing Communications, at 303-273-3326 or [marswill@mines.edu](mailto:marswill@mines.edu); or Karen Gilbert, Public Relations Specialist, at 303-273-3541 or [Karen.Gilbert@is.mines.edu](mailto:Karen.Gilbert@is.mines.edu).

## Registrar

LARA MEDLEY, Registrar  
TRICIA DOUTHIT-PAULSON, Associate Registrar  
DAHL GRAYCKOWSKI, Assistant Registrar  
JUDY WESTLEY, Records Specialist  
ADRIENEE BRITO, Registration Specialist

The Office of the Registrar supports the academic mission of the Colorado School of Mines by providing service to our current and former students, faculty, staff, and administration. These services include maintaining and protecting the integrity and security of the official academic record, registration, degree verification, scheduling and reporting. Our office routinely reviews policy, makes recommendations for change, and coordinates the implementation of approved policy revisions.

The Office of the Registrar seeks to fulfill this mission through a commitment to high quality service provided in a professional, efficient and courteous manner. Our specific services include but are not limited to:

- Enrollment and degree verifications
- Transcripts
- Degree auditing and diplomas (undergraduate)
- Transfer credit entry and verification
- Veteran's Administration Certifying Official services
- Registration setup and execution
- Course and room scheduling
- Academic and enrollment reporting
- Residency for current students
- Grade collection, reporting and changes

Management of the Registrar's Office adheres to the guidelines on professional practices and ethical standards developed by the American Association of Collegiate Registrars and Admissions Officers (AACRAO). Our office also complies with the Family Educational Rights and Privacy Act of 1974 (FERPA), Colorado Department of Higher Education rules and policies, and the Colorado School of Mines policies on confidentiality and directory information.

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The Registrar's Office is located in the Student Center, Room 31. Hours of operation are Monday through Friday, 8am - 5pm. The office phone number is (303) 273-3200. The fax number is (303) 384-2253. Lara Medley represents Colorado School of Mines as the Registrar. She is normally available on a walk-in basis (when not in meetings) if a student or other client has an issue that needs special attention. Appointments are also welcomed.

### **Research Administration**

The Office of Research Administration (ORA), under the Associate Vice President for Finance and Operations and Controller, provides administrative support in proposal preparation and contract and grant administration, which includes negotiation, account set-up, and close out of expired agreements. Information on any of these areas of research and specific forms can be accessed on our web site at [www.is.mines.edu/ors](http://www.is.mines.edu/ors).

### **Special Programs and Continuing Education (SPACE)**

The SPACE Office offers short courses, special programs, and professional outreach programs to practicing engineers and other working professionals. Short courses, offered both on the CSM campus and throughout the US, provide concentrated instruction in specialized areas and are taught by faculty members, adjuncts, and other experienced professionals. The Office offers a broad array of programming for K-12 teachers and students through its Teacher Enhancement Program, and the *Denver Earth Science Project*. The Office also coordinates educational programs for international corporations and governments through the *International Institute for Professional Advancement* and hosts the Mine Safety and Health Training Program. A separate bulletin lists the educational programs offered by the SPACE Office, CSM, 1600 Arapahoe St., Golden, CO 80401. Phone: 303 273-3321; FAX 303 273-3314; email [space@mines.edu](mailto:space@mines.edu); website [www.mines.edu/Outreach/Cont\\_Ed](http://www.mines.edu/Outreach/Cont_Ed).

### **Telecommunications**

The Telecommunications Office is located in the CTLM building 2nd floor east end room 256 and provides telephone services to the campus. Local telephone service is provided, as part of the housing rates (optional for Mines Park residence). The Telecommunications Office provides maintenance for telephone lines and services. Students will need to bring or purchase their own calling line ID device if they choose to take advantage of this feature.

Telecommunications Office provides long distance services for the Residence Halls, Sigma Nu house, Fiji house, PI PHI House, ALPHA PHI House, SIGMA KAPPA House and Mines Park housing areas through individual account codes. Long distance rates for domestic calling are 0.05 cents per minute, 24 hours a day, seven days a week. International rates are available at the Telecommunications Office or through the Web at <http://www.is.mines.edu/telecomm/Students/StudRate.asp>. Accounts are issued by request at any time. Monthly long distance charges are assessed to the student accounts by the 5th of each month for calls made the prior month, and invoices are mailed directly to students at their campus address. Questions regarding the above services should be directed to the Telecommunications Office by calling (303) 273-3000 or 1-800-446-9488 and saying Telecommunications, or via the Web at <http://www.is.mines.edu/telecomm/>.

### **Women in Science, Engineering and Mathematics (WISEM) Program**

The mission of WISEM is to enhance opportunities for women in science and engineering careers, to increase retention of women at CSM, and to promote equity and diversity in higher education. The office sponsors programs and services for the CSM community regarding gender and equity issues. For further information, contact: Debra K. Lasich, Executive Director of Women in Science, Engineering and Mathematics, Colorado School of Mines, 1133 17th Street, Golden, CO 80401-1869, or call (303) 273-3097; [dlasich@mines.edu](mailto:dlasich@mines.edu) or [www.mines.edu/Academic/affairs/wisem](http://www.mines.edu/Academic/affairs/wisem)

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# Registration and Tuition Classification

## General Registration Requirements

The normal full load for graduate students is 9 credit hours per term. Special cases outlined below include first-year international students who must receive special instruction to improve their language skills, and students who have completed of their credit-hour requirements and are working full time on their thesis.

Full-time graduate students may register for an overload of up to 6 credit hours (up to 15 credit hours total) per term at no increase in tuition. Subject to written approval by their advisor and department head or division director, students may register for more than 15 credit hours per term by paying additional tuition at the regular part-time rate for all hours over 15. The maximum number of credits for which a student can register during the summer is 12.

Students may register at less than the required full-time registration, except for students meeting any of the following conditions.

- ◆ International students subject to immigration requirements. This applies to international students holding J-1 and F-1 visas.
- ◆ Students receiving financial assistance in the form of graduate teaching assistantships, research assistantships, fellowships or hourly contracts.
- ◆ Students enrolled in academic programs that require full-time registration. Refer to the degree program sections of this bulletin to see if this applies to a particular program.

Students for whom any one of these conditions apply must register at the appropriate full-time credit hour requirement.

If not required to register full-time, to remain in good standing, students must register continuously each fall and spring semester. Summer registration is not required for students to remain in good standing.

Students who continue to work on degree programs and utilize CSM facilities during the summer, however, must register. Students registered during the summer pay full summer fees.

## Research Registration

In addition to completing prescribed course work and defending a thesis, students in thesis-based degree programs must complete a research or engineering design experience under the direct supervision of their faculty advisor. Master students must complete a minimum of 6 hours of research credit, and doctoral students must complete a minimum of 24 hours of research credit at CSM. While completing this experience, students will register for research credit under course numbers 704 (M.E.), 705 (M.S.) or 706 (Ph.D.) as appropriate. Faculty will assign grades indicating satisfactory or unsatisfactory progress based on their evaluation of the student's work. Students registered for research during the

summer semester and working on campus must pay thesis research fees for summer semester.

## Eligibility for Reduced Registration

Students enrolled in thesis-based degree programs who have completed the minimum course and research requirements for their degree are eligible to pursue their graduate program full time at a reduced registration level. In order to be considered for this reduced, full-time registration category, students must satisfy the following requirements:

1. For M.S./M.E. students, completion of 36 hours of course and research credits combined
2. For Ph.D. students, completion of 72 hours of course and research credits combined
3. For all students, an approved Admission to Candidacy form must be on file in the Graduate Office within the first week of the semester you are applying for reduced thesis registration.
4. Candidates for thesis-based degrees may not use more than 12 credit hours per semester in determining eligibility for reduced, full-time registration.

Transfer credits that have been accepted toward the degree count toward the 36 or 72 hour requirement. Students who are eligible for reduced, full-time registration will be considered full time if they are registered for 4 credit hours of research under course numbers 704 (M.E.), 705 (M.S.) or 706 (Ph.D.) as appropriate. Faculty will assign research grades indicating satisfactory or unsatisfactory progress based on their evaluation of the student's work.

## Graduation Requirements

To graduate, students must be registered during the term in which they complete their program. In enforcing this registration requirement, the Graduate School allows students to complete their checkout requirements past the end of the semester. Late checkout is accepted by the Graduate School through the last day of registration in the semester immediately following the semester in which a student has completed his or her academic degree requirements; the Spring for Fall completion, the Summer for Spring completion, and Fall for Summer completion. Students not meeting this checkout deadline are required to register for an additional semester before the Graduate School will process their checkout request. Refer to page 32 for additional information or [www.mines.edu/admiss/grad/graduation.htm](http://www.mines.edu/admiss/grad/graduation.htm)

## Full-time Status - Required Course Load

To be deemed full-time during the fall and spring semesters, students must register for at least 9 credit hours. However, international students need only register for 6 credit hours per semester during their first year, if they are required to take special language instruction or are accepted in Provisional Status. In the event a thesis-based student has com-

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pleted his or her required course work and research credits and is eligible for reduced, full-time registration, the student will be deemed full-time if he or she is registered for at least 4 credit hours of research credit.

To be deemed full-time during the summer semester, students must register for a minimum of 3 credit hours.

### **Late Registration Fee**

Students must complete their registration by the date specified in the Academic Calendar. Students who fail to complete their registration during this time will be assessed a \$100 late registration fee and will not receive any tuition fellowships for which they might otherwise be eligible.

### **Leave of Absence**

Leaves of absence will be granted only when unanticipated circumstances make it temporarily impossible for students to continue to work toward a degree. Leave of absence requests for the current semester must be received by the Dean of Graduate Studies prior to the last day of classes. Leave of absence requests for prior semesters will not be considered.

Any request for a leave of absence must have the prior approval of the student's faculty advisor, the department head or division or program director and the Dean of Graduate Studies. The request for a leave of absence must be in writing and must include (1) the reasons why the student must interrupt his or her studies and (2) a plan (including a timeline and deadlines) for resuming and completing the work toward the degree in a timely fashion.

Students on leaves of absence will remain in good standing even though they are not registered for any course or research credits.

Thesis-based students will not have access to CSM resources while on a leave of absence. This includes, but is not limited to, office space, computational facilities, library and faculty.

Students who fail to register and who are not on approved leaves of absence have their degree programs terminated. Students who wish to return to graduate school after an unauthorized leave of absence must apply for readmission and pay a \$200 readmission fee.

The financial impact of requesting a leave of absence for the current semester is covered in the section on "Payments and Refunds" on page 35.

### **Reciprocal Registration**

Under the Exchange Agreement Between the State Supported Institutions in Northern Colorado, CSM graduate students who are paying full-time tuition may take courses at Colorado State University, University of Northern Colorado, and University of Colorado (Boulder, Denver, Colorado Springs, and the Health Sciences Center) at no charge by completing the request form and meeting the required conditions on registration and tuition, course load, and course

and space availability. Request forms are available from the Registrar's office.

### **In-State Tuition Classification Status** *General Information*

The State of Colorado partially subsidizes the cost of tuition for all students whose domicile, or permanent legal residence, is in Colorado. Each CSM student is classified as either an "in-state resident" or a "non-resident" at the time of matriculation. These classifications, which are governed by Colorado law, are based upon information furnished by each student on his or her application for admission to CSM. A student who willfully furnishes incorrect information to CSM to evade payment of non-resident tuition shall be subject to serious disciplinary action.

It is in the interest of each graduate student who is a U.S. citizen and who is supported on an assistantship or fellowship to become a legal resident of Colorado at the earliest opportunity. Typically, tuition at the non-resident rate will be paid by CSM for these students during their first year of study only. After the first year of study, these students may be responsible for paying the difference between resident and non-resident tuition.

### *Requirements for Establishing In-State Residency*

The specific requirements for establishing residency for tuition classification purposes are prescribed by state law (Colorado Revised Statutes, Title 23, Article 7). Because Colorado residency status is governed solely by Colorado law, the fact that a student might not qualify for in-state status in any other state does not guarantee in-state status in Colorado. The tuition classification statute places the burden of proof on the student to provide clear and convincing evidence of eligibility.

In-state or resident status generally requires domicile in Colorado for the year immediately preceding the beginning of the semester in which in-state status is sought. "Domicile" is "a person's true, fixed and permanent home and place of habitation." An unemancipated minor is eligible for in-state status if at least one parent (or his or her court-appointed guardian) has been domiciled in Colorado for at least one year. If neither of the student's parents are domiciliaries of Colorado, the student must be a qualified person to begin the one-year domiciliary period. A "qualified person" is someone who is at least twenty-two years old, married, or emancipated. A student may prove emancipation if: (1) the student's parents have entirely surrendered the right to the student's custody and earnings; (2) the student's parents are no longer under any duty to financially support the student; and (3) the student's parents have made no provision for the continuing support of the student.

To begin the one-year domiciliary period, a qualified person must be living in Colorado with the present intention to reside permanently in Colorado. Although none of the following indicia are determinative, voter registration, driver's



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license, vehicle registration, state income tax filings, real property interests, and permanent employment (or acceptance of future employment) in Colorado will be considered in determining whether a student has the requisite intention to permanently reside in Colorado. Once a student's legal residence has been permanently established in Colorado, he or she may continue to be classified as a resident student so long as such residence is maintained, even though circumstances may require extended temporary absences from Colorado.

For more information about the requirements for establishing in-state residency, please contact the Registrar's Office.

### ***Petitioning for In-State Tuition Classification***

A continuing, non-resident student who believes that he or she has become eligible for in-state resident tuition due to events that have occurred subsequent to his or her initial enrollment may file a *Petition for In-State Tuition Classification* with the Registrar's Office. This petition is due in the Registrar's Office no later than the first day of the semester for which the student is requesting in-state resident status. Upon receipt of the petition, the Registrar will initially decide whether the student should be granted in-state residency status. The Registrar's decision may be appealed by petition to the Tuition Classification Review Committee. For more information about this process, please contact the Registrar's Office.

### ***In-State Tuition Classification for WICHE Program Participants***

WICHE, the Western Interstate Commission for Higher Education, promotes the sharing of higher education resources among the participating western states. Under this program, residents of Alaska, Arizona, Hawaii, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming who are enrolled in qualifying graduate programs may be eligible for in-state tuition classification. Current qualifying programs include:

- Applied Chemistry (Ph.D.)
- Chemistry (M.S.)
- Engineering Systems (M.S. and Ph.D.)
- Environmental Science & Engineering (M.S. and Ph.D.)
- Geochemistry (M.S. and Ph.D.)
- Geological Engineering (M.S., M.E., and Ph.D.)
- Hydrology (M.S. and Ph.D.)
- Mineral Economics (M.S. and Ph.D.)
- Mining and Earth Systems Engineering (M.S. and Ph.D.)
- Petroleum Engineering (M.S. and Ph.D.)

Contact the Office of Graduate Studies for more information about WICHE.

## **Dropping and Adding Courses**

Students may drop or add courses through web registration without paying a fee during the first 11 school days of a regular semester, the first four school days of a six-week

field course, or the first six school days of an eight-week summer term.

After the 11th day of classes through the 10th week, continuing students may drop any course for any reason with a grade of "W". Graduate students in their first semester at CSM have through the 14th week of that semester to drop a course. A student must process a form and pay a \$4.00 fee for any change in class schedule after the first 11 days of class, except in cases beyond the student's control or withdrawal from school. Forms are available in the Registrar's Office.

After the 10th (or 14th) week, no drops are permitted except in case of withdrawal from school or for extenuating circumstances. To request consideration of extenuating circumstances, a student must submit a written request to the Graduate Dean, which includes the following:

1. A list of the courses from which they wish to withdraw. This must include all courses for which they are registered.
2. Documentation of the problem which is the basis for the request.
3. If the problem involves a medical condition, the documentation must be signed by a licensed medical doctor or a representative of the CSM Counseling Office.
4. Signatures indicating approval by the student's advisor and department head or division director.

A student who is allowed to withdraw from courses under this policy will receive a grade of "W" for each course and will be placed on automatic leave of absence. In order to resume their graduate program, they must submit a written application that includes documentation that the problems which caused the withdrawal have been corrected. The student will be reinstated to active status upon approval of their application by their advisor and their department head or division director.

The financial impact of a withdrawal is covered in the section on "Payments and Refunds."

## **Auditing Courses**

As part of the maximum of 15 semester hours of graduate work, students may enroll for no credit (NC) in a course with the permission of the instructor. Tuition charges are the same for no credit as for credit enrollment.

Students must enroll for no credit before the last day of registration. The form to enroll for a course for no credit is available in the Registrar's Office. NC designation is awarded only if all conditions stipulated by course instructors are met.

Mines requires that all U.S. students who are being supported by the institution register full time, and federal financial aid regulations prohibit us from counting NC registration in determining financial aid eligibility. In addition, the INS requires that international students register full time, and recent anti-terrorism proposals discourage us from counting

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NC registration toward that requirement. Furthermore, there are no consistent standards for expectations of students who register for NC in a course. Therefore, in order to treat all CSM students consistently, NC registration will not count toward the minimum number of hours for which students are required to register. This includes the minimum continuous registration requirement of part-time students and the 3-, or 9-hour requirement for students who must register full time.

The reduced registration policy is based on the principle that the minimum degree requirement (36 or 72 hours) would include only the credits applied toward that degree. Deficiency and extra courses are above and beyond that minimum. NC courses fall into the latter category and may not be applied toward the degree. Therefore, NC registration will not count toward the number of hours required to be eligible for reduced thesis registration.

NC registration may involve additional effort on the part of faculty to give and/or grade assignments or exams, so it is the institution's policy to charge tuition for NC courses. Therefore, NC registration will count toward the maximum number of credits for which a graduate student may be allowed to register. This includes a tuition surcharge for credits taken over 15.

### **Off-Campus Study**

A student must enroll in an official CSM course for any period of off-campus, course-related study, whether U.S. or foreign, including faculty-led short courses, study abroad, or any off-campus trip sponsored by CSM or led by a CSM faculty member. The registration must occur in the same term that the off-campus study takes place. In addition, the student must complete the necessary release, waiver, and emergency contact forms, transfer credit pre-approvals, and FERPA release, and provide adequate proof of current health insurance prior to departure. For additional information concerning study abroad requirements, contact the Office of International Programs at (303) 384-2121; for other information, contact the Registrar's Office.

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# General Regulations

## Graduate School Bulletin

It is the responsibility of the graduate student to become informed and to observe all regulations and procedures required by the program the student is pursuing. Ignorance of a rule does not constitute a basis for waiving that rule. The Graduate Bulletin current when a graduate student first enrolls gives the academic requirements the student must meet to graduate. However, with department consent, a student can change to the requirements in a later catalog published while the student is enrolled in the graduate school. Changes to administrative policies and procedures become effective for all students as soon as the campus community is notified of the changes.

The Graduate Bulletin is available to students in both print and electronic forms. Print bulletins are updated annually. Electronic versions of the Graduate Bulletin may be updated more frequently to reflect changes approved by the campus community. As such, students are encouraged to refer to the most recently available electronic version of the Graduate Bulletin. This version is available at the CSM website. The electronic version of the Graduate Bulletin is considered the official version of this document. In case of disagreement between the electronic and print versions, the electronic version takes precedence.

## Curriculum Changes

The CSM Board of Trustees reserves the right to change any course of study or any part of the curriculum to respond to educational and scientific developments. No statement in this Bulletin or in the registration of any student shall be considered as a contract between Colorado School of Mines and the student.

## General Policies of Student Conduct

In addition to the student conduct policies described in detail in this section of the Graduate Bulletin, the Colorado School of Mines has a number of policies which govern student behavior on campus. Following is a list of those important policies with a brief definition or description of each. Copies of the complete text describing each policy are available from the Office of the Vice President for Student Affairs.

### *Campus Security*

This policy is intended to improve security and reduce crime on campus. It includes the publishing of campus crime statistics and procedures for reporting crimes.

### *Alcohol Use*

This policy conforms to state and local laws on alcohol use, distribution, and consumption. The text restates the legal drinking age, designates campus locations for consuming alcoholic beverages, explains procedures for planning student events at which alcohol is served, and gives the penalties for violating the policy.

### *Drug Use*

Recognizing the threat to health and welfare from the use of illegal drugs, this policy requires CSM students to obey all Colorado and Federal laws concerning the manufacture, possession, sale, and use of drugs.

### *Drug Free Schools & Communities Act*

This policy informs CSM students of community standards and potential consequences (the legal sanctions) for using alcohol or drugs illegally.

### *Firearms, Explosives, and Other Weapons*

Covered in this policy are the general ban on campus of firearms, explosives, and other weapons, exceptions to the ban, and the firearm storage procedures.

### *Distribution of Literature*

Given in this policy are the restrictions on distributing (including the selling of) literature, newspapers, and magazines on school property; the limit on distributing advertising or commercial material (for example, handbills); the requirements for soliciting and vending on school property; and the right to picket or demonstrate on campus.

## Student Honor Code

The Associated Students of the Colorado School of Mines (ASCMS) passed the new CSM Student Honor Code in a vote held in March 2003.

### *Preamble*

The students of Colorado School of Mines have adopted the following Student Honor Code in order to establish a high standard of student behavior at CSM. The Honor Code may only be amended through a student referendum supported by a majority vote of the Mines student body.

### *Code*

Mines students believe it is our responsibility to promote and maintain high ethical standards in order to ensure our safety, welfare, and enjoyment of a successful learning environment. Each of us, under this Code, shall assume responsibility for our behavior in the area of academic integrity. As a Mines student, I am expected to adhere to the highest standards of academic excellence and personal integrity regarding my schoolwork, exams, academic projects, and research endeavors. I will act honestly, responsibly, and above all, with honor and integrity in all aspects of my academic endeavors at Mines. I will not misrepresent the work of others as my own, nor will I give or receive unauthorized assistance in the performance of academic coursework. I will conduct myself in an ethical manner in my use of the library, computing center, and all other school facilities and resources. By practicing these principles, I will strive to uphold the principles of integrity and academic excellence at Mines. I will not participate in or tolerate any form of discrimination or mistreatment of another individual.

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## Academic Integrity

### *Policy on Violation of Academic Integrity*

In an academic setting, student misconduct is broadly defined as behavior that erodes the basis of mutual trust on which scholarly exchanges rest, undermines the Institution's ability to fairly and effectively evaluate a student's academic achievements, and restricts the Institution's ability to accomplish its scholarly objectives and educational mission. Because of the serious institutional ramifications, student misconduct of the type and nature described below is not tolerated at CSM. If a student is found to have engaged in these activities sanctions ranging from a disciplinary change of grade, to loss of institutional privileges or, in extreme cases, to academic suspension or dismissal may be imposed by the Institution.

Some of the more common forms of misconduct are listed below as a guide. This list is not intended to be exhaustive, but rather illustrative of the practices the CSM community has deemed inappropriate.

1. *Dishonest Conduct* – general conduct unbecoming of a scholar. Examples include issuing misleading statements; withholding pertinent information; not fulfilling, in a timely fashion, previously agreed to projects or activities; and verifying as true things that are known to the student not to be true or verifiable.
2. *Plagiarism* – presenting the work of another as one's own. This is usually accomplished through omission of acknowledgment. Examples include submitting as one's own work the work of another student, a ghost writer, or a commercial writing service; quoting, either directly or paraphrased, a source without appropriate acknowledgment; and using figures, charts, graphs or facts without appropriate acknowledgment. Inadvertent or unintentional misuse or appropriation of another's work is still considered plagiarism.
3. *Falsification/Fabrication* – inventing or altering information. Examples include inventing or manipulating data or research procedures to report, suggest, or imply that particular results were achieved from procedures when such procedures were not actually undertaken or when such results were not actually supported by the pertinent data; false citation of source materials; reporting false information about practical, laboratory, or clinical experiences; submitting false excuses for absence, tardiness, or missed deadlines; and altering previously submitted examinations.
4. *Tampering* – interfering with, altering or attempting to alter university records, grades, assignments, or other documents without authorization. Examples include using a computer or a false-written document to change a recorded grade; altering, deleting, or manufacturing any academic record; gaining unauthorized access to a university record by any means.

5. *Cheating* – giving, using, or attempting to give or use, unauthorized materials or aid with the intent of demonstrating academic performance through fraudulent means. Examples include copying from another student's paper or receiving unauthorized assistance on a quiz, test or examination; using books, notes or other devices such as calculators, unless explicitly authorized; acquiring without authorization copies of examinations before the scheduled examination; and copying reports, laboratory work or computer files from other students. Authorized materials are those generally regarded as being appropriate in an academic setting, unless specific exceptions have been articulated by the instructor.
6. *Impeding* – negatively impacting the ability of other students to successfully complete course or degree requirements. Examples include removing materials from the library that are placed on reserve for general use; failing to provide team members necessary materials or assistance; and knowingly disseminating false information about the nature of a test or examination.

### *Procedures for Addressing Academic Misconduct*

If a member of the CSM community has reasonable grounds for suspecting that a student or students have engaged in academically dishonest conduct, they have an obligation to act on this suspicion in an appropriate fashion. Faculty who suspect student(s) should inform the student(s) of the allegations, and attempt to resolve the issue directly. Students who suspect other students of academically dishonest conduct should inform the course instructor, research advisor or division/department head, whichever is most appropriate for the particular case and let them followup on the allegation. In cases where allegations are associated with the research activities vital to a student's thesis or dissertation, the student's thesis committee must be made aware of the allegations, and the thesis committee is charged with attempting to resolve the issue.

Faculty members and thesis committees have the responsibility to address and resolve misconduct matters in a manner that is commensurate with the infraction and consistent with the values of the Institution, and have the responsibility to follow due process in cases where students appeal an accusation of misconduct. This includes imposition of appropriate academic sanctions for students involved in academically dishonest behavior. While faculty members will make reasonable efforts to maintain the confidentiality of the parties involved, if academic sanctions are to be imposed a written summary of the suspected infraction and the sanction to be imposed must be provided the accused student, the student's Department Head/Division Director and the Graduate Dean within 10 business days of disclosure of the accusation.

Students who disagree with the accusation or penalty imposed may, or in case where faculty believe that a non-academic response (e.g., suspension, dismissal, or revocation of



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specific campus privileges) is appropriate must appeal to the Graduate Dean. Appeals to the Graduate Dean must be in writing and must be delivered within 20 business days of the initial disclosure of the accusation.

The Graduate Dean will review the accusation and determine the appropriate appeal process. In most instances, appeals of accusations that are related to research misconduct associated with a student's thesis or dissertation will be processed according to the Institution's Research Integrity Policy. The Research Integrity Policy is available as section 10.11 of the Faculty Handbook. Appeals of accusations related to misconduct in most other areas of a student's academic program will be processed through the Student Judicial Panel. A description of this process is available in the Colorado School of Mines Student Handbook.

(<http://www.mines.edu/stu/life/activities/rules.shtml>)

## **Resolution of Conflicting Bulletin Provisions**

If a conflict or inconsistency is found to exist between these policies and any other provision of the CSM Graduate Bulletin, the provisions of these policies shall govern the resolution of such conflict or inconsistency.

## **Unsatisfactory Academic Performance** *Unsatisfactory Academic Progress Resulting in Probation or Discretionary Dismissal*

A student's progress toward successful completion of a graduate degree shall be deemed unsatisfactory if any of the following conditions occur:

- ◆ Failure to maintain a cumulative grade point average of 3.0 or greater (see Grading System section);
- ◆ Receipt of an "In-Progress-Unsatisfactory" grade for research; or
- ◆ Receipt of an "Unsatisfactory Progress" recommendation from: (1) the head or director of the student's home department or division, (2) the student's thesis committee, or (3) a departmental committee charged with the responsibility of monitoring the student's progress.

Unsatisfactory academic progress on the part of a graduate student shall be reported to the Dean of Graduate Studies in a timely manner. Students making unsatisfactory progress by any of the measures listed above shall be placed on academic probation upon the first occurrence of such indication. Upon the second occurrence of an unsatisfactory progress indication, the Dean shall notify the student that he or she is subject to discretionary dismissal according to the procedure outlined below.

In addition, students in thesis-based degree programs who are not admitted to candidacy within the time limits specified in this Bulletin may be subject to immediate mandatory dismissal according to the procedure outlined below. Failure to fulfill this requirement must be reported to the Dean of Grad-

uate Studies in a timely manner by the department head or division/program director.

## **Probation and Discretionary Dismissal Procedures**

If a student is subject to academic probation as a result of an initial indication of unsatisfactory academic progress, the Dean of Graduate Studies shall notify the student of his or her probationary status in a timely manner.

If a student is subject to discretionary dismissal by one of the mechanisms defined above, the Dean shall notify the student and invite him or her to submit a written remedial plan, including performance milestones and deadlines, to correct the deficiencies that caused or contributed to the student's unsatisfactory academic progress. The remedial plan, which must be approved by the student's faculty advisor and the department head, division or program director, shall be submitted to the Dean no later than 15 business days from the date of official notification. If the Dean concludes that the remedial plan is likely to lead to successful completion of all degree requirements within an acceptable time frame, the Dean may halt the discretionary dismissal process and allow the student to continue working toward his or her degree. If the Dean concludes that the remedial plan is inadequate, or that it is unlikely to lead to successful completion of all degree requirements within an acceptable time frame, the Dean shall notify the student of his or her discretionary dismissal and inform the student of his or her right to appeal the dismissal as outlined below.

## **Unsatisfactory Academic Performance Resulting in Mandatory Dismissal**

Unsatisfactory performance as gauged by any of the following measures shall result in immediate, mandatory dismissal of a graduate student: (1) failure to successfully defend the thesis after two attempts; (2) failure to be admitted to candidacy; or (3) failure by a student subject to discretionary dismissal to achieve a performance milestone or meet a deadline contained in his or her remedial plan. The Dean of Graduate Studies shall be notified promptly of any situation that may subject a student to mandatory dismissal. In this event, the Dean shall notify the student of his or her dismissal and inform the student of his or her right to appeal the dismissal as outlined below.

Students who have been notified of mandatory dismissal will be placed in non-degree status. They may request re-admission to either the same or a different degree program by submitting a full application for admission to the Graduate Office. The application will be reviewed through the normal admission process.

If a student who has been reinstated or readmitted to their former degree program subsequently is found to be making unsatisfactory progress, they immediately will be subject to mandatory dismissal.

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## *Appeal Procedures*

Both mandatory and discretionary dismissals may be appealed by a graduate student pursuant to this procedure. To trigger review hereunder, an appeal must: (1) be in writing; (2) contain a succinct description of the matter being appealed; and (3) be filed with the Office of the Dean of Graduate Studies no later than 20 business days from the date upon which the student received official notification from the Dean regarding his or her dismissal.

Upon receipt of a timely appeal of a discretionary or mandatory dismissal, the Dean shall appoint a review committee composed of three tenured faculty members who are not members of the student's home or minor department or division. The review committee shall review the student's appeal and issue a written recommendation thereon to the Dean within 20 business days. During the course of performing this function, the committee may: (1) interview the student, the student's advisor, and, if appropriate, the student's thesis committee; (2) review all documentation related to the appeal under consideration; (3) secure the assistance of outside expertise, if needed; and (4) obtain any other information necessary to properly consider the appeal.

The authority to render a final decision regarding all graduate student appeals filed hereunder shall rest with the Dean of Graduate Studies.

## **Exceptions and Appeals**

### *Academic Policies and Requirements*

Academic policies and requirements are included in the Bulletin on the authority of the CSM Board of Trustees as delegated to the Faculty Senate. These include matters such as degree requirements, grading systems, thesis and dissertation standards, admission standards and new and modified degree programs, certificates, minors and courses. No CSM administrator, faculty or staff member may change, waive or grant exceptions to such academic policies and requirements without approval of the Graduate Council, the Senate and/or the Board of Trustees as appropriate.

### *Administrative Policies and Procedures*

Administrative Policies and Procedures are included in this Bulletin on the authority of the CSM Board of Trustees as delegated to the appropriate administrative office. These include (but are not limited to) matters such as student record keeping, thesis and dissertation formats and deadlines, registration requirements and procedures, assessment of tuition and fees, and allocation of financial aid. The Dean of Graduate Studies may waive or grant exceptions to such administrative policies and procedures as warranted by the circumstances of individual cases.

Any graduate student may request a waiver or exception by the following process:

1. Contact the Graduate Office to determine whether a standard form exists. If so, complete the form. If a standard form does not exist, prepare a memo with a statement of the request and a discussion of the reasons why a waiver or exception would be justified.
2. Have the memo or the form approved by the student's advisor and department head or division director, then submit it to the Dean of Graduate Studies.
3. If the request involves academic policies or requirements, the Dean of Graduate Studies will request Graduate Council approval at their next regularly scheduled meeting.
4. The Dean of Graduate Studies will notify the student of the decision. The student may file a written appeal with the Executive Vice-President for Academic Affairs within 10 business days of being notified of the decision. The EVPAA will investigate as appropriate to the issue under consideration and render a decision. The decision of the EVPAA is final.
5. At the next graduate Council meeting, the Dean will notify the Graduate Council of the request, the decision and the reasons for the decision. If the Graduate Council endorses the decision, then any other student in the same situation having the same justification can expect the same decision.

## **Public Access to the Graduate Thesis**

The award of a thesis-based graduate degree is conditioned on the student's deposit of his or her completed thesis in the CSM library to ensure its availability to the public. Although the student retains the copyright in the thesis, by depositing the thesis with the library, the student assigns a perpetual, non-exclusive, royalty-free license to CSM to permit CSM to copy the thesis and allow the public reasonable access to it.

Under special circumstances, CSM may agree to include proprietary research in a graduate student's thesis. The nature and extent of the proprietary research reported in the thesis must be agreed upon in writing by the principal investigator, student and Dean of Graduate Studies. In some cases, the proprietary nature of the underlying research may require the school to delay public access to the completed thesis for a limited period of time. In no case will public access to the thesis be denied for more than 12 months from the date the Statement of Work Completion form is submitted to the Graduate School.

## **Making up Undergraduate Deficiencies**

If the department or division decides that new students do not have the necessary background to complete an advanced degree, they will be required to enroll in courses for which they will receive no credit toward their graduate degree, or complete supervised readings, or both. Students are notified of their apparent deficiency areas in their acceptance letter

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from the Graduate School or in their first interview with their department advisor.

Graduate students must attain a B average in deficiency courses, and any student receiving a grade of D in a deficiency course will be required to repeat the course. Grades for these deficiency courses are recorded on the student's transcript, become part of the student's permanent record, and are calculated into the overall GPA. Students whose undergraduate records are deficient should remove all deficiencies as soon as possible after they enroll for graduate studies.

## Graduate Students in Undergraduate Courses

Students may receive graduate credit for a maximum of nine semester hours of department-approved 400-level course work not taken to remove deficiencies upon the recommendation of the graduate committee and the approval of the Graduate Dean.

Students may receive graduate credit for 300-level courses only in those programs which have been recommended by the department and have been approved by the Graduate Council before the students enroll in the course. In that case a maximum of nine total hours of 300- and 400-level courses will be accepted for graduate credit.

## Independent Study

For each semester credit hour awarded for independent study a student is expected to invest approximately 45 hours of effort in educational activity. To register for independent study or for a "special topics" course, a student should get from the Registrar's Office the form provided for that purpose, have it completed by the instructor involved and appropriate department/division head, and return it to the Registrar's Office.

## Course and Research Grades

All candidates for graduate degrees must maintain a cumulative grade point average of at least 3.0 in all courses taken after acceptance into a degree program. This includes both graduate and undergraduate courses. Any grade lower than "C-" is unsatisfactory and is not acceptable for credit toward graduate degree requirements or graduate deficiencies.

For research credits, students receive either an "In Progress-Satisfactory" or an "In Progress-Unsatisfactory" grade based on their faculty advisor's evaluation of their work. Research grades do not enter into the calculation of the student's grade point average.

Students who fail to maintain a grade point average of at least 3.0, or who receive an In Progress-Unsatisfactory research grade are placed on academic probation by the Graduate Dean and may be subject to discretionary dismissal as defined by the Unsatisfactory Academic Performance section of this Bulletin (see page 28).

## Grade Appeal Process

CSM faculty have the responsibility, and sole authority for, assigning grades. As instructors, this responsibility includes clearly stating the instructional objectives of a course, defining how grades will be assigned in a way that is consistent with these objectives, and then assigning grades. It is the student's responsibility to understand the grading criteria and then maintain the standards of academic performance established for each course in which he or she is enrolled.

If a student believes he or she has been unfairly graded, the student may appeal the grade to the Faculty Affairs Committee of the Faculty Senate. The Faculty Affairs Committee is the faculty body authorized to review and modify course grades, in appropriate circumstances. Any decision made by the Faculty Affairs Committee is final. In evaluating a grade appeal, the Faculty Affairs Committee will place the burden of proof on the student. For a grade to be revised by the Faculty Affairs Committee, the student must demonstrate that the grading decision was unfair by documenting that one or more of the following conditions applied:

1. The grading decision was based on something other than course performance; unless the grade was a result of penalty for academic dishonesty or the grade was WI (withdrawn involuntarily).
2. The grading decision was based on standards that were unreasonably different from those applied to other students in the same section of that course.
3. The grading decision was based on standards that differed substantially and unreasonably from those previously articulated by the instructor.

To appeal a grade, the student must proceed as follows:

1. The student must prepare a written appeal of the grade received in the course. This appeal must clearly define the basis for the appeal and must present all relevant evidence supporting the student's case.
2. After preparing the written appeal, the student must deliver this appeal to the course instructor and attempt to resolve the issue directly with the instructor. Written grade appeals must be delivered to the instructor no later than 10 business days after the start of the regular (fall or spring) semester immediately following the semester in which the contested grade was received. In the event that the course instructor is unavailable, the course coordinator (first) or the Department Head/Division Director (second) will represent the instructor.
3. If after discussion with the instructor, the student is still dissatisfied, he or she can proceed with the appeal by submitting three copies of the written appeal plus three copies of a summary of the instructor/student meetings held in connection with the previous step to the President of the Faculty Senate. These must be submitted to the President of the Faculty Senate no later than 25 business

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days after the start of the regular semester immediately following the semester in which the contested grade was received. The President of the Faculty Senate will forward the student's appeal and supporting documents to the Faculty Affairs Committee, the course instructor's Department Head/Division Director, and the instructor.

4. The Faculty Affairs Committee will request a response to the appeal from the instructor and begin an investigation of the student's allegations and basis for appealing the grade. During the course of performing its investigation, the Committee may: 1) interview the student, the student's advisor, the course instructor and other witnesses deemed relevant to the investigation; 2) review all documentation related to the appeal under consideration; 3) secure the assistance of outside expertise, if needed; and 4) obtain any other information deemed necessary to consider and resolve the appeal.

Upon request, the Faculty Affairs Committee may share summaries of testimony and other information examined by the Committee with both the student and the instructor. Certain information, however, may be redacted from materials forwarded to the student and instructor to maintain other students' rights subject to protection under the Family Educational Rights and Privacy Act (FERPA), or other state and federal law.

Based on its investigation, the Faculty Affairs Committee will determine whether the grade should be revised. The decision rendered will be either: 1) the original grading decision is upheld, or 2) sufficient evidence exists to indicate a grade has been assigned unfairly. In this latter case, the Faculty Affairs Committee will assign the student a new grade for the course. The Committee's written decision and supporting documentation will be delivered to the President of the Faculty Senate, the office of the EVPAA, the student, the instructor, and the instructor's Department Head/Division Director no later than 25 business days following the Senate's receipt of the grade appeal. The Faculty Affairs Committee's decision shall constitute the final decision of the grade appeal. There is no further internal appeal available to the parties.

The schedule, but not the process, outlined above may be modified upon mutual agreement of the student, the instructor, and the Faculty Affairs Committee

## **Graduation**

*All students expecting to graduate must submit a graduation application to the Office of Graduate Studies.*

Graduation application deadlines are scheduled well in advance of the date of Commencement to allow time for engraving diplomas and for printing graduation invitations and programs. Students who submit applications after the stated deadline cannot be guaranteed a diploma dated for that graduation, and cannot be assured inclusion in the graduation program or ceremony.

All graduating students must officially check out of their degree program, including paying the mandatory graduation fee. Checkout cards may be obtained from the Graduate Office and must be completed and returned by the established deadline. Students must register for the next term unless the graduation checkout process is completed by the last day of registration for the following semester.

The awarding of a degree is contingent upon the student's successful completion of all program requirements with at least a 3.0 GPA before the date of graduation. Students who fail to graduate at the time originally anticipated must re-apply for the next graduation before the appropriate deadline date stated in the Graduate Handbook.

Students who have completed all of their degree requirements before the specific graduation date, but who have not applied for graduation can, if necessary, request a letter from the Graduate Office certifying the completion of their programs. The student should apply for the next graduation, and the diploma will show the date of that graduation.

Graduation exercises are held in December and May. Students eligible to graduate at these times are expected to attend their respective graduation exercises. Students in thesis-based degree programs may not, under any circumstances, attend graduation exercises before completing all degree requirements.

Diplomas, transcripts, and letters of completion will not be released by the School for any student or graduate who has an unsettled obligation of any kind to the School.

## **Withdrawing from School**

To officially withdraw from CSM, a graduate student must process a withdrawal form through the Graduate Office. When the form is completed, the student will receive grades of W in courses in progress. If the student does not officially withdraw the course grades are recorded as F's. Leaving school without having paid tuition and fees will result in the encumbrance of the transcript.



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## Nondegree Students

A nondegree student is one who has not applied to pursue a degree program at CSM but wishes to take courses regularly offered on campus. Nondegree students register for courses through the Registrar's office after degree students have registered. Such students may take any course for which they have the prerequisites as listed in the CSM Bulletin or have the permission of the instructor. Transcripts or evidence of the prerequisites are required. Nondegree students pay all applicable tuition, but do not pay student fees except for the technology fee.

## Veterans' Benefits

Colorado School of Mines is approved by the Colorado State Approving Agency for Veteran Benefits under chapters 30, 31, 32, 35, and 1606. Graduate students must register for and maintain nine hours of graduate work in any semester to be certified as a full-time student for full-time benefits. Any hours taken under the full-time category will decrease the benefits to 3/4 time, 1/2 time, or tuition payment only.

Students receiving benefits must report all changes in hours, addresses, marital status, or dependents to the Veterans' Counseling Office located in the Registrar's Office as soon as possible to avoid overpayment or underpayment. Veterans must see the Veterans' Counselor each semester to be certified for any benefits for which they may be eligible. In order for veterans to continue to receive benefits, they must make satisfactory progress as defined by CSM.

## Graduate Grading System

### Grades

When a student registers in a graduate (500 and 600 level) course, one of the following grades will appear on the academic record. Grades are based on the level of performance and represent the extent of the student's demonstrated mastery of the material listed in the course outline and achievement of the stated course objectives. These are CSM's grade symbols and their qualitative interpretations:

A and A-:	Excellent
B+, B and B-:	Good
C +, C and C-:	Satisfactory
D+, D and D-:	Unsatisfactory (not acceptable for graduate credit)
F:	Failed
S Satisfactory:	C- or better, used only as a mid-term grade
U Unsatisfactory:	below C-, used only as a mid-term grade
INC:	Incomplete
PRG:	Satisfactory Progress
PRU:	Unsatisfactory Progress

Graduate students enrolled in undergraduate-level courses (400-level and below) are graded using the undergraduate grading system. See the CSM Undergraduate Bulletin for a description of this system.

In addition to these performance symbols, the following is a list of additional registration symbols that may appear on a CSM transcript.

WI:	Involuntarily Withdrawn
W:	Withdrew, No Penalty
T:	Transfer Credit
NC:	Not for Credit
Z:	Grade not yet Submitted

### *Incomplete Grade*

If a graduate student fails to complete a course because of illness or other reasonable excuse, the student receives a grade of Incomplete, a temporary grade which indicates a deficiency in the quantity of work done. A graduate student must remove all Incomplete grades within the first four weeks of the first semester of attendance following that in which the grade was received. If not removed within the four weeks, the Incomplete will become an F.

### *Satisfactory Progress Grades*

A graduate student may receive a grade of Satisfactory Progress, PRG, in either one of two possible situations: 1) as a grade for a course extending more than one semester and 2) as a grade indicating completion of research credit hours.

For students completing independent study, or seminar courses that extend for more than one semester, the progress grade has no point value and is used only for multi-semester courses, or for special sections of one-semester courses that are spread over two terms. In such cases, the student receives a grade of PRG, which indicates that the work is not completed. This grade is replaced by a letter grade when the course work is completed.

The student must register again in the same course in the next semester of attendance. If a progress grade is received for a course taken in the second semester of the school year, the student may, with the permission of the department head, re-register in that course in the summer session, in which case the letter grade must be given at the end of the summer session.

When applied to research credits, the Satisfactory Progress grade, PRG, also has no point value toward a student's GPA, but indicates satisfactory progress toward completion of the research component of a student's thesis-based degree program. In this situation, a grade of PRU, Unsatisfactory Progress, may be given, and if given, indicates that a student has not made satisfactory progress toward the research component of a thesis-based degree program. In this case, receipt of a grade of PRU may trigger academic disciplinary proceedings as described in the Unsatisfactory Academic Performance portion of this Bulletin (see page 28).

Unless faculty submit change of grade forms to the Registrar, grades of PRU delivered for unsatisfactory research performance, are not changed to PRG upon the successful completion of a student's degree program.

### *NC Grade*

For special reasons and with the instructor's permission, a student may register in a course for no credit (NC). To have the grade NC appear on the transcript, the student must enroll at registration time as a NC student in the course and comply with all conditions stipulated by the course instructor. If a student registered as NC fails to satisfy all conditions, no record of this registration in the course will be made.

### *Quality Hours and Quality Points*

For graduation a student must successfully complete a certain number of required semester hours and must maintain grades at a satisfactory level. Numerical values assigned to each letter grade are given in the table below.

Grade	Numerical Value
A	4.000
A-	3.700
B+	3.300
B	3.000
B-	2.700
C+	2.300
C	2.000
C-	1.700
D+	1.300
D	1.000
D-	0.700
F	0.000

The number of quality points earned in any course is the number of semester hours assigned to that course multiplied by the numerical value of the grade received. The quality hours earned are the number of semester hours in which grades are awarded. To compute a grade-point average, the number of cumulative quality hours is divided into the cumulative quality points earned. Grades of W, WI, INC, PRG, PRU, or NC are not counted in quality hours.

### *Semester Hours*

The number of times a class meets during a week (for lecture, recitation, or laboratory) determines the number of semester hours assigned to that course. Class sessions are normally 50 minutes long and represent one hour of credit for each hour meeting. Two to four hours of laboratory work per week are equivalent to 1-semester hour of credit. For the average student, each hour of lecture and recitation requires at least two hours of preparation.

### *Grade-Point Averages*

Grade-Point Averages shall be specified, recorded, reported, and used to three figures following the decimal point for any and all purposes to which said averages may apply.

### *Overall Grade-Point Average*

The overall grade-point average includes all attempts at courses taken at Colorado School of Mines with the exception of courses which fall under the repeat policy implemented during the 2007-2008 academic year.

If a course completed during the Fall 2007 term or after is a repeat of a course completed in any previous term and the course is not repeatable for credit, the grade and credit hours earned for the most recent occurrence of the course will count toward the student's grade-point average and the student's degree requirements. The most recent course occurrence must be an exact match to the previous course completed (subject and number). The most recent grade will be applied to the overall grade-point average even if the previous grade is higher.

Courses from other institutions transferred to Colorado School of Mines are not counted in any grade-point average, and cannot be used under this repeat policy. Only courses originally completed and subsequently repeated at Colorado School of Mines during Fall 2007 or after with the same subject code and number apply to this repeat policy.

For courses that may be repeated for credit such as special topics courses, credit is awarded and grades are counted in the grade-point average up to the maximum hours allowed for the course.

All occurrences of every course taken at Colorado School of Mines will appear on the official transcript along with the associated grade.

### **Access to Student Records**

Students at the Colorado School of Mines are protected by the Family Educational Rights and Privacy Act of 1974, as amended. This Act was designed to protect the privacy of education records, to establish the right of students to inspect and review their education records, and to provide guidelines for the correction of inaccurate or misleading data through informal and formal hearings. Students also have the right to file complaints with The Family Educational Rights and Privacy Act Office (FERPA) concerning alleged failures by the institution to comply with the Act. Copies of local policy can be found in the Registrar's Office. Contact information for FERPA complaints is

Family Policy Compliance Office  
U.S. Department of Education  
400 Maryland Avenue, SW  
Washington, D. C. 20202-4605

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**Directory Information.** The school maintains lists of information which may be considered directory information as defined by the regulations. This information includes name, current and permanent addresses and phone numbers, date of birth, major field of study, dates of attendance, degrees awarded, last school attended, participation in officially recognized activities and sports, class, and academic honors. Students who desire that this information not be printed or released must so inform the Registrar before the end of the first two weeks of the fall semester for which the student is registered. Information will be withheld for the entire academic year unless the student changes this request. The student's signature is required to make any changes for the current academic year. The request must be renewed each fall term for the upcoming year. The following student records are maintained by Colorado School of Mines at the various offices listed below:

1. General Records: Registrar and Graduate Dean
2. Transcript of Grades: Registrar
3. Computer Grade Lists: Registrar
4. Encumbrance List: Controller and Registrar
5. Academic Probation/Suspension List: Graduate Dean
6. Advisor File: Academic Advisor
7. Option/Advisor/Enrolled/ Minority/Foreign List: Registrar, Dean of Students, and Graduate Dean
8. Externally Generated SAT/GRE Score Lists: Graduate Dean
9. Financial Aid File: Financial Aid (closed records)
10. Medical History File: School Physician (closed records)

**Student Access to Records.** The graduate student wishing access to his or her educational records will make a written request to the Graduate Dean. This request will include the student's name, date of request and type of record to be reviewed. It will be the responsibility of the Dean to arrange a mutually satisfactory time for review. This time will be as soon as practical but is not to be later than 30 business days from receipt of the request. The record will be reviewed in the presence of the Dean or designated representative. If the record involves a list including other students, steps will be taken to preclude the viewing of the other student name and information.

**Challenge of the Record.** If the student wishes to challenge any part of the record, the Dean will be so notified in writing. The Dean may then (1) remove and destroy the disputed document, or (2) inform the student that it is his decision that the document represents a necessary part of the record; and, if the student wishes to appeal, (3) convene a meeting of the student and the document originator (if reasonably available) in the presence of the Executive Vice President for Academic Affairs as mediator, whose decision will be final.

**Destruction of Records.** Records may be destroyed at any time by the responsible official if not otherwise precluded by law except that no record may be destroyed between the dates of access request and the viewing of the record. If during the viewing of the record any item is in dispute, it may not be destroyed.

**Access to Records by Other Parties.** Colorado School of Mines will not permit access to student records by persons outside the School except as follows:

1. In the case of open record information as specified in the section under Directory Information.
2. To those people specifically designated by the student. Examples would include request for transcript to be sent to graduate school or prospective employer.
3. Information required by a state or federal agency for the purpose of establishing eligibility for financial aid.
4. Accreditation agencies during their on-campus review.
5. In compliance with a judicial order or lawfully issued subpoena after the student has been notified of the intended compliance.
6. Any institutional information for statistical purposes which is not identifiable with a particular student.
7. In compliance with any applicable statute now in effect or later enacted. Each individual record (general, transcript, advisor, and medical) will include a log of those persons not employed by Colorado School of Mines who have requested or obtained access to the student record and the legitimate interest that the person has in making the request.

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# Tuition, Fees, Financial Assistance

Tuition and fees are established by the Board of Trustees of the Colorado School of Mines following the annual budget process and action by the Colorado General Assembly and Governor.

## Graduate Tuition

The official tuition and approved charges for the 2007-2008 academic year will be available prior to the start of the 2007-2008 academic year located at [http://www.is.mines.edu/budget/budget\\_current/tuition\\_rates.pdf](http://www.is.mines.edu/budget/budget_current/tuition_rates.pdf)

## Fees

The official fees, approved charges, and fee descriptions for the 2007-2008 academic year will be available prior to the start of the 2007-2008 academic year and can be found at: [http://www.is.mines.edu/budget/budget\\_current/fees.pdf](http://www.is.mines.edu/budget/budget_current/fees.pdf)

Please note that graduate students who register for undergraduate courses to satisfy deficiencies may be assessed the same fee that an undergraduate student would pay.

## Payments and Refunds

### *Payment Information*

A student is expected to complete the registration process, including the payment of tuition and fees, before attending class. Students should mail their payments to: Cashier Colorado School of Mines 1500 Illinois St. Golden, CO 80401-1869 or pay at the Cashier's Office in The Ben Parker Student Center. Please write your student ID on payment.

### *Late Payment Penalties*

A penalty will be assessed against a student if payment is not received in full by the official day of registration. The penalty is described in the schedule of courses for each semester. If payment is not completed by the sixth week of class, the student may be officially withdrawn from classes.

### *Financial Responsibility*

Registration for classes at CSM implies an obligation by the student to meet all related financial responsibilities in a timely manner. Students who do not fulfill their financial obligations according to published deadlines are subject to the following: late payment penalties accrued on any outstanding balance, and the withholding of transcripts. Past due accounts will be turned over to Colorado Central Collection Services in accordance with Colorado law. Collection costs will be added to the student's account, and delinquencies may be reported to national credit bureaus.

### *Encumbrances*

A student will not be permitted to register for future classes, to graduate, or to get an official transcript of his academic record while indebted in any way to CSM.

### *Refunds*

Refunds for tuition and fees are made according to the following policy:

The amount of tuition and fee assessment is based primarily on each student's enrolled courses. In the event a student withdraws from a course or courses, assessments will be adjusted as follows:

- ✓ If the withdrawal is made prior to the end of the add/drop period for the term of enrollment, as determined by the Registrar, tuition and fees will be adjusted to the new course level without penalty.
- ✓ If the withdrawal from a course or courses is made after the add/drop period, and the student does not officially withdraw from school, no adjustment in charges will be made.
- ✓ If the withdrawal from courses is made after the add/drop period, and the student withdraws from school, tuition and fee assessments will be reduced according to the following schedule:
  - ✓ Within the 7 calendar days following the end of the add/drop period, 60 percent reduction in charges.
  - ✓ Within the next following 7 calendar days, a 40 percent reduction in charges.
  - ✓ Within the next following 7 calendar days, a 20 percent reduction in charges.
  - ✓ After that period, no reduction of charges will be made.

The schedule above applies to the Fall and Spring semesters. The time periods for the Summer sessions - Field and Summer - will be adjusted in proportion to the reduced number of days in these semesters.

Room and board refunds are pro-rated to the date of checkout from the Residence Hall. Arrangements must be made with the Housing Office. Student health insurance charges are not refundable. The insurance remains in effect for the entire semester.

PLEASE NOTE: Students receiving federal financial aid under the Title IV programs may have a different refund determined as required by federal law or regulations.

### *Financial Assistance for Graduate Studies*

Graduate study is a considerable investment of time, energy, and money by serious students who expect a substantial return not only in satisfaction but also in future earnings. Applicants are expected to weigh carefully the investment they are willing to make against expected benefits before applying for admission.

Students are also expected to make full use of any resources available, including personal and loan funds, to cover expenses, and the School can offer some students financial aid through graduate research and teaching assistantships and through industry, state, and federal fellowships.



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### *Purpose of Financial Aid*

The Graduate School's limited financial aid is used

1. To give equal access to graduate study by assisting students with limited personal resources;
2. To compensate graduate students who teach and do research;
3. To give an incentive to exceptional students who can provide academic leadership for continually improving graduate programs.

### *Employment Restrictions and Agreements*

Students who are employed full time or who are enrolled part time are not eligible for financial aid through the Graduate School.

Students who are awarded assistantships must sign an appointment agreement, which gives the terms of appointment and specifies the amount and type of work required. Graduate assistants who hold regular appointments are expected to devote all of their efforts to their educational program and may not be otherwise employed without the written permission of their supervisor and the Graduate Dean. Students with assistantships during the academic year must be registered as full time. During the summer session they must be registered for a minimum of three credit hours, unless they qualify for the summer research registration exception. Please see [http://www.mines.edu/admiss/grad/grad\\_contracts.html](http://www.mines.edu/admiss/grad/grad_contracts.html) for details on summer registration exception eligibility.

### *Aid Application Forms.*

New students interested in applying for financial aid are encouraged to apply early. Financial aid forms are included in Graduate School application packets and may be filled out and returned with the other application papers.

### *Graduate Fellowships.*

The departments and divisions award Colorado Fellowships based on the student's academic performance.

### *Graduate Student Loans.*

Need-based federal student loans are available for graduate students who need additional funding beyond their own resources and any assistantships or fellowships they may receive. The Free Application for Federal Student Aid (FAFSA) must be completed to apply for these loan funds.

Specific information and procedures for filing the FAFSA can be found on the Financial Aid Office web site at [www.finaid.mines.edu](http://www.finaid.mines.edu). The Financial Aid Office telephone number is 303-273-3220, and the e-mail address is [finaid@mines.edu](mailto:finaid@mines.edu).

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# Graduate Degrees and Requirements

Colorado School of Mines offers post-baccalaureate programs leading to the awarding of Graduate Certificates, Professional Masters degrees, thesis and non-thesis Master of Science and Master of Engineering degrees, and Doctor of Philosophy degrees. This section describes these degrees and explains the minimum institutional requirements for each.

Students may apply to, and be admitted in, multiple graduate degrees simultaneously. In this case, a student may use the same graduate course credits to satisfy the degree requirements for each degree. Before the Graduate School will count these credits toward each degree requirement, however, the student must obtain written permission to do so from each department, division or program granting degree. This permission should be submitted with the student's Admission to Candidacy forms and should clearly indicate that each degree program is aware that credits are being counted toward the requirements of multiple degrees. For thesis-based students this permission should be provided by the student's thesis committee. For non-thesis and certificate programs, permission should be obtained from program coordinators or department/division chairs.

## I. Professional Programs

### A. Graduate Certificate Program

Graduate Certificate Programs at CSM are designed to have selective focus, short time to completion and consist of course work only. For more information about specific professional programs, please refer to the "Graduate Degree Programs and Description of Courses" portion of this Bulletin.

#### 1. Academic Requirements

Each Graduate Certificate requires a minimum of 12 total credit hours. No more than 3 credit hours at the 400 level may be applied toward the minimum credit-hours requirement. All other credits must be at or above the 500 level. Students may not, on an individual basis, request credit hours be transferred from other institutions as part of the Certificate requirements. Some Graduate Certificates, however, may allow the application of specific, pre-approved transfer credits, or credits from other institutions with whom CSM has formal agreements for this purpose toward fulfilling the requirements of the Certificate. All courses applied to a Graduate Certificate are subject to approval by the program offering the certificate.

If a student has earned a Graduate Certificate and subsequently applies, and is accepted into a Master's or PhD program at CSM, credits earned in the Certificate Program may, with the approval of the advanced degree program, be applied to the advanced degree subject to all the applicable restrictions on credit hours that may be applied toward fulfilling the requirements of the advanced degree.

#### 2. Admission to Candidacy

Full-time students must complete the following requirements within the first semester after enrolling into a Graduate Certificate degree program.

- ◆ complete all prerequisites and core curriculum course requirements of their program, and
- ◆ be admitted into full candidacy for the certificate.

A list of prerequisites and core curriculum requirements for Graduate Certificate degrees is published by each program. When a student is admitted with deficiencies, the appropriate department head, division director or program director will provide the student with a written list of courses required to remove these deficiencies. This list will be given to the student no later than one week after the start of classes of his/her first semester in order to allow for adding/dropping courses as necessary.

Upon completion of the above-defined requirements, a student must submit an Admission to Candidacy and a Statement of Work Completion forms documenting satisfactory completion of the prerequisites and core curriculum requirements. The form must have the written approval of the program offering the Graduate Certificate.

### B. Professional Master's Program

CSM awards specialized, career-oriented non-thesis Master degrees with the title of "Professional Master (descriptive title)." These are custom-designed, interdisciplinary degrees, each with a curriculum meeting the career advancement needs of a particular group of professionals in a field that is part of CSM's role and mission. For more information about these programs, please refer to the "Graduate Degree Programs and Description of Courses" portion of this Bulletin.

#### 1. Academic Requirements

Each Professional Master's degree consists of a minimum of 30 total credit hours. Students must complete at least 21 credit hours at CSM in the degree program. The remaining hours may be transferred into the program. Requests for transfer credit must be approved by the faculty according to a process defined by the student's home department or division. Transfer credits must not have been used as credit toward a Bachelor degree. The transfer limit includes CSM distance learning courses. Up to six credit hours of Special Topic or Independent Study may be in the form of project credits done on the job as an employee or as a graduate intern. If project credits are to be used, the project proposal and final report must be approved by a CSM faculty advisor, although direct supervision may be provided by the employer. Students must maintain a cumulative grade point average of 3.0 or better in CSM course work.

#### 2. Admission to Candidacy

Full-time students must complete the following requirements within the first calendar year after enrolling into a Professional Master's degree program.

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- ◆ complete all prerequisite and core curriculum course requirements of their program, and
  - ◆ be admitted into full candidacy for the degree.

Each program publishes a list of prerequisites and core curriculum requirements for Professional Master's degrees. When a student is admitted with deficiencies, the appropriate department head, division director or program director will provide the student with a written list of courses required to remove these deficiencies. This list will be given to the student no later than one week after the start of classes of his/her first semester in order to allow for adding/dropping courses as necessary.

Upon completion of the above-defined requirements, a student must submit an Admission to Candidacy form documenting satisfactory completion of the prerequisites and core curriculum requirements. The form must have the written approval of the program offering the Professional Masters degree.

## II. Master of Science and Engineering Programs

### A. General Requirements

Graduate study at CSM can lead to one of a number of thesis and non-thesis based Master's degrees, depending on the interests of the student. All Master's degree programs share the same academic requirements for grades, definition of minor programs, and the need to apply for admission to candidacy.

#### 1. Academic Requirements

A Master's degree at CSM requires a minimum of 30 total credit hours. As part of this 30 hours, departments and divisions are required to include a research or design experience supervised by CSM faculty. For more information about the specific research/design requirements, please refer to the appropriate department/division section of the "Graduate Degree Programs and Description of Courses" portion of this Bulletin.

For non-thesis Master's degrees, students must complete at least 21 credit hours at CSM in the degree program. All other credits may be completed as transfer credits into the degree program. For thesis Master's degrees, no more than 9 credits may transfer. The transfer credit limit includes CSM distance learning courses. Transfer credits must not have been used as credit toward a Bachelor degree. Requests for transfer credit must be approved by the faculty according to the process defined by a student's home department or division. All credits applied toward degree, except transfer credits, must be earned on campus. Students must maintain a cumulative grade point average of 3.0 or better in CSM course work.

Students are normally admitted into the Master of Science degree program in the department/division to which they have applied. If, however, a candidate would like to obtain the Master of Engineering degree, the candidate must, in

addition to the requirements described above, either have a Bachelor's degree in engineering, or complete no fewer than 16 credit hours of engineering courses as part of their Master's program. Courses satisfying the engineering course requirement are determined by the department/division hosting the degree.

#### 2. Minor Programs

Students may choose to have a minor program or programs at the Master's level. A minor program may not be taken in the student's major area of study. A designated minor requires a minimum of 9 semester hours of course work and must be approved by the student's advisor, home department head, and a faculty representative of the minor area of study.

#### 3. Admission to Candidacy

Full-time students must complete the following requirements within the first calendar year after enrolling into the Master's degree program.

- ◆ have a thesis committee appointment form on file in the Graduate Office;
- ◆ complete all prerequisite and core curriculum course requirements of their department, division or program; and
- ◆ be admitted into full candidacy for the degree.

Each degree program publishes a list of prerequisite and core curriculum requirements for that degree. If students are admitted with deficiencies, the appropriate department heads, division directors or program directors will provide the students written lists of courses required to remove the deficiencies. These lists will be given to the students no later than one week after the start of classes of their first semester in order to allow them to add/drop courses as necessary.

Upon completion of the above defined requirements, students must submit an Admission to Candidacy form documenting satisfactory completion of the prerequisite and core curriculum requirements and granting permission to begin Master's level research. The form must have the written approval of all members of the advisor and thesis committee, if appropriate.

#### B. Non-thesis Option

Non-thesis Master's degrees are offered by a number of departments, divisions and programs. In lieu of preparing a thesis, non-thesis master's program students are required to complete a research or design experience taken as a special problem or as an independent study course. See the department/division section of the "Graduate Degree Programs and Description of Courses" portion of this Bulletin for more information. Although non-thesis master's students are not assigned a Thesis Committee, students in this program do select a faculty advisor, subject to the approval of the student's home department.

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### *C. Thesis Option*

Thesis-based Master of Science and Master of Engineering degrees require completion of a satisfactory thesis and successful oral defense of this thesis. Academic credit toward completion of the thesis must include successful completion of no fewer than 6 credit hours of masters-level research credit. The Master of Science thesis is expected to report on original research that results in new knowledge and/or techniques. The Master of Engineering thesis is expected to report on creative engineering design that applies state-of-the-art knowledge and techniques to solve an important problem. In both cases, the thesis should be an exemplary product that meets the rigorous scholarship standards of the Colorado School of Mines. The student's faculty advisor and the Master's Thesis Committee must approve the program of study and the topic for the thesis. The format of the thesis must comply with the appropriate guidelines promulgated by the Graduate School.

#### **1. Faculty Advisor Appointment**

Each thesis-based Master's student must select a faculty advisor to provide advice regarding the student's thesis direction, research and selection of courses by the middle of their second semester at CSM. The faculty advisor will serve as a voting member of the student's Thesis Committee. The student's department head or division director and the Graduate Dean must approve all faculty advisor appointments.

Advisors must be full-time members of the CSM faculty and must hold the rank of professor, associate professor, assistant professor, research professor, associate research professor or assistant research professor. Upon approval by the Graduate Dean, adjunct professors and off-campus representatives may be designated co-advisors. When appropriate and upon approval by the Graduate Dean, faculty members outside the student's home department may serve as the student's faculty co-advisor. In either of these cases, a co-advisor must be selected from the student's home department.

#### **2. Thesis Committee**

The Graduate Dean appoints a Thesis Committee whose members have been recommended by the student, the student's faculty advisor, and the student's department head. Students should have a thesis committee appointed by the end of their second semester. This Committee will have a minimum of three voting members, including the student's advisor, who are familiar with the student's area of study. Of these Committee members, two must be from the home department or, in the case of interdisciplinary degree programs, an allied department. Off-campus members can be assigned to the Committee to serve either with full voting status or in a non-voting capacity. Off-campus members with voting status assume all of the responsibilities of on-campus Committee members with respect to attendance of Committee meetings, review of thesis drafts and participation in oral examinations and thesis defense sessions. If a thesis co-advisor is assigned, an additional faculty member from the home or allied depart-

ment must be added to the committee. Students who choose to have a minor program at the Master's level must select a representative from their minor area of study to serve on the Thesis Committee. Minor representatives must be full-time members of the CSM faculty.

A Thesis Committee Chairperson is designated by the student at the time he/she requests the formation of his/her thesis committee. The chairperson is responsible for leading all meetings of the thesis committee and for directing the student's thesis defense. In selecting a Thesis Committee chairperson, the following guidelines must be met: 1) the chairperson cannot be the student's advisor or co-advisor and 2) the chairperson must be a full-time CSM faculty member.

Shortly after its appointment, the Committee will meet with the student to hear a presentation of the proposed course of study and thesis topic. The Committee and the student must agree on a satisfactory program and the student must obtain the Committee approval of the written thesis proposal at least one semester prior to the thesis defense. The student's faculty advisor assumes the primary responsibility for monitoring the program and directing the thesis work. The award of the thesis-based Master's degree is contingent upon the student's researching and writing a thesis acceptable to the student's faculty advisor and Thesis Committee.

#### **3. Thesis Defense**

The student submits an initial draft of his or her thesis to the faculty advisor, who will work with the student on necessary revisions. Upon approval of the student's advisor, the revised thesis is circulated to the Thesis Committee members at least one week prior to the oral defense of the thesis. The oral defense of the thesis is scheduled during the student's final semester of study. Students must be registered to defend. This defense session, which may include an examination of material covered in the student's course work, will be open to the public.

Following the defense, the Thesis Committee will meet privately to vote on whether the student has successfully defended the thesis. Three outcomes are possible: the student may pass the oral defense; the student may fail the defense; or the Committee may vote to adjourn the defense to allow the student more time to address and remove weaknesses or inadequacies in the thesis or underlying research. Two negative votes will constitute a failure regardless of the number of Committee members present at the thesis defense. In the event of either failure or adjournment, the Chair of the Thesis Committee will prepare a written statement indicating the reasons for this action and will distribute copies to the student, the Thesis Committee members, the student's department head and the Graduate Dean. In the case of failure or adjournment, the student may request a re-examination, which must be scheduled no less than one week after the original defense. A second failure to defend the thesis satisfactorily will result in the termination of the student's graduate program.



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Upon passing the oral defense of thesis or report, the student must make any corrections in the thesis required by the Thesis Committee. The final, corrected copy and an executed signature page indicating approval by the student's advisor and department head must be submitted to the Office of Graduate Studies for format approval. (Format instructions are available in the Office of Graduate Studies and should be obtained before beginning work on the thesis.)

### **III. Doctor of Philosophy**

#### ***A. Credits, Academic and Campus Residence Requirements***

The Doctor of Philosophy degree requires completion of a minimum of 72 semester hours beyond the Bachelor degree. At least 24 semester hours must be research credits earned under the supervision of a CSM faculty advisor and at least 18 credit hours of course work must be applied to the degree program. Course requirements for each department or division are contained in the "Graduate Degree Programs and Description of Courses" section of this Bulletin.

The degree also requires completion of a satisfactory doctoral thesis and successful oral defense of this thesis. The Doctoral Thesis is expected to report on original research that results in a significant contribution of new knowledge and/or techniques. The student's faculty advisor and the Doctoral Thesis Committee must approve the program of study and the topic for the thesis.

Doctoral students must complete at least two semesters of full-time residence at CSM (as defined in the Registration and Residency section above) during the course of their graduate studies.

#### ***B. Transfer of Credits***

Up to 24 semester hours of graduate-level course work may be transferred from other institutions toward the PhD degree subject to the restriction that those courses must not have been used as credit toward a Bachelor degree. Requests for transfer credit must be approved by the faculty according to a process defined by the student's home department or division. Transfer credits are not included in calculating the student's grade point average at CSM.

In lieu of transfer credit for individual courses, students who enter the PhD program with a thesis-based master degree from another institution may transfer up to 36 semester hours in recognition of the course work and research completed for that degree. The request must be approved by the faculty according to a process defined by the student's home department or division.

#### ***C. Faculty Advisor Appointments***

Each doctoral student must select a faculty advisor to advise with respect to the student's thesis direction and research and selection of courses by the middle of their second semester at CSM. The faculty advisor will serve as a voting member of the student's Doctoral Thesis Committee. The student's

department head and the Graduate Dean must approve all faculty advisor appointments.

Advisors must be full-time members of the CSM faculty and must hold the rank of professor, associate professor, assistant professor, research professor, associate research professor or assistant research professor. Upon approval by the Graduate Dean, adjunct professors and off-campus representatives may be designated co-advisors. When appropriate and upon approval by the Graduate Dean, faculty members outside the student's home department may serve as the student's faculty co-advisor. In either of these cases, a co-advisor must be selected from the student's home department.

#### ***D. Minor Programs***

Students may choose a minor program or programs at the PhD level consisting of 12 course credits in the minor program. The student's faculty advisor and Doctoral Thesis Committee, including an appropriate minor committee member as described below, approve the course selection and sequence in the selected minor program. Students may choose to complete multiple minor programs. Each program must consist of at least 12 credit hours approved by the faculty advisor and Doctoral Thesis Committee, including the appropriate minor committee members.

#### ***E. Doctoral Thesis Committees***

The Graduate Dean appoints a Doctoral Thesis Committee whose members have been recommended by the student's home department or division. Students should have a thesis committee appointed by the end of their second semester. This Committee must have a minimum of five voting members that fulfill the following criteria:

1. The Committee must include an advisor who is assigned responsibility for directing the research. If two advisors are appointed, they both shall be considered co-advisors and shall be voting members of the Committee.
2. Either the advisor or at least one co-advisor must be a full-time permanent faculty member in the home department, division or program in order to ensure compliance with degree requirements.
3. The Committee must have at least four other voting members in addition to the advisor and co-advisors, and a majority of the voting members (including the advisor or co-advisors) must be full-time permanent CSM faculty members.
4. At least two of the "additional" committee members must be knowledgeable in the technical areas of the thesis, and at least one of them must be a member of the student's home or allied department, division or program.
5. If a minor field is designated, the third "additional" committee member must be an expert in that field. In the case of an interdisciplinary degree, the third committee member must be an expert in one of the fields



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represented in the research. Minor representatives must be full-time members of the CSM faculty. If multiple minor programs are being pursued, each must have a committee representative as defined above.

6. The fourth “additional” committee member must be from outside the home and allied departments or divisions and the minor field if applicable.
7. If off-campus members are nominated for voting status, the committee request form must include a brief resume of their education and/or experience that demonstrates their competence to judge the quality and validity of the thesis. Such members also must agree to assume the same responsibilities expected of on-campus Committee members including, but not limited to, attendance at Committee meetings, review of thesis proposals and drafts, and participation in oral examinations and defenses.

A Thesis Committee Chairperson is designated by the student at the time he/she requests the formation of his/her thesis committee. The chairperson is responsible for leading all meetings of the thesis committee and for directing the student's thesis defense. In selecting a Thesis Committee chairperson, the following guidelines must be met: 1) the chairperson cannot be the student's advisor or co-advisor, 2) the chairperson must be a full-time CSM faculty member, and 3) the chairperson must be from outside the student's home department, division or program and, if possible, should not be a representative of a minor program of study.

Shortly after its appointment, the Doctoral Thesis Committee meets with the student to hear a presentation of the proposed course of study and thesis topic. The Committee and student must agree on a satisfactory program. The student's faculty advisor then assumes the primary responsibility for monitoring the program, directing the thesis work, arranging qualifying examinations, and scheduling the thesis defense.

#### *F. Admission to Candidacy*

Full-time students must complete the following requirements within the first two calendar years after enrolling into the PhD program.

- ◆ have a thesis committee appointment form on file in the Graduate Office;
- ◆ complete all prerequisite and core curriculum course requirements of their department, division or program;
- ◆ demonstrate adequate preparation for, and satisfactory ability to conduct, doctoral research; and
- ◆ be admitted into full candidacy for the degree.

Each degree program publishes a list of prerequisite and core curriculum requirements for that degree. If students are admitted with deficiencies, the appropriate department heads, division directors or program directors will provide the students written lists of courses required to remove the deficiencies. These lists will be given to the students no later than

one week after the start of classes of their first semester in order to allow them to add/drop courses as necessary. Each program also defines the process for determining whether its students have demonstrated adequate preparation for, and have satisfactory ability to do, high-quality, independent doctoral research in their specialties. These requirements and processes are described under the appropriate program headings in the section of this Bulletin on Graduate Degree Programs and Description of Courses.

Upon completion of these requirements, students must submit an Admission to Candidacy form documenting satisfactory completion of the prerequisite and core curriculum requirements and granting permission to begin doctoral research. The form must have the written approval of all members of the Ph.D. Committee.

#### *G. Thesis Defense*

The doctoral thesis must be based on original research of excellent quality in a suitable technical field, and it must exhibit satisfactory literary merit. In addition, the format of the thesis must comply with guidelines promulgated by the Office of Graduate Studies. (Students should obtain a copy of these guidelines from the Office of Graduate Studies before beginning work on the thesis.)

The thesis topic must be submitted in the form of a written proposal to the student's faculty advisor and the Committee. The Committee must approve the proposal at least one year before the thesis defense.

The student's faculty advisor is responsible for supervising the student's research work and consulting with other Doctoral Thesis Committee members on the progress of the work. The advisor must consult with the Committee on any significant change in the nature of the work. The student submits an initial draft of his or her thesis to the advisor, who will work with the student on necessary revisions. Upon approval of the student's advisor, the revised thesis is distributed to the other members of the Committee at least one week prior to the oral defense of the thesis.

The student must pass an oral defense of his or her thesis during the final semester of studies. Students must be registered to defend. This oral defense may include an examination of material covered in the student's course work. The defense will be open to the public.

Following the defense, the Doctoral Thesis Committee will meet privately to vote on whether the student has successfully defended the thesis. Three outcomes are possible: the student may pass the oral defense; the student may fail the defense; or the Committee may vote to adjourn the defense to allow the student more time to address and remove weaknesses or inadequacies in the thesis or underlying research. Two negative votes will constitute a failure regardless of the number of Committee members present at the thesis defense. In the event of either failure or adjournment, the Chair of the Doctoral Thesis Committee will prepare a writ-

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ten statement indicating the reasons for this action and will distribute copies to the student, the Thesis Committee members, the student's department head and the Graduate Dean. In the case of failure, the student may request a re-examination, which must be scheduled no less than one week after the original defense. A second failure to defend the thesis satisfactorily will result in the termination of the student's graduate program.

Upon passing the oral defense of thesis, the student must make any corrections in the thesis required by the Doctoral Thesis Committee. The final, corrected copy and an executed signature page indicating approval by the student's advisor and department head must be submitted to the Office of Graduate Studies for format approval.

## **IV. Individualized, Interdisciplinary Graduate Degrees<sup>1</sup>**

### **A. General**

In addition to its traditional graduate degree programs, CSM offers students the opportunity to earn research degrees by solving problems that fit Mines' institutional role and mission but would not easily be addressed solely within a single discipline or existing degree program. Each student in the Individualized, Interdisciplinary Graduate (IIG) Program will work with faculty advisors from two departments or divisions at Mines, and the composition of the thesis committee will reflect the fields involved in the research. Upon satisfactory completion of the program, they will be awarded the appropriate degree (MS, ME, or PhD) bearing the name Interdisciplinary.

### **B. Admission Process**

Before applying, prospective candidates for IIG degrees should meet with the IIG Program Coordinator to explore the match between their interdisciplinary interests and existing programs available on campus. The IIG Coordinator will provide feedback with recommendations about the application. However, it is the responsibility of the student to seek out faculty members willing to serve as co-advisors and other members of a potential thesis committee.

An application package will include a cover page listing the potential thesis committee, a summary of the proposed research and course of study, along with a justification for how this research and course of study fits with the Mines scope, mission, and resources (Further specifications are available from the IIG Coordinator). If the student is not already enrolled in a graduate program at CSM, the application package must also include the standard application for admission to the Graduate School. It is also customary to have a provisional meeting of the thesis committee as part of the application development process.

Once an application package has been completed and submitted to the IIG Coordinator, it will be circulated for commentary to the student's existing home department or division (if the student is already enrolled in a CSM graduate program) and to the departments or divisions of the potential co-advisors. For currently enrolled students, advisors and home department heads or division directors may veto an IIG application.

The application package together with commentary from the relevant departments or divisions is then forwarded to the IIG Studies Committee, which is chaired by the IIG Coordinator. Admissions decisions made by the IIG Studies Committee take into account the following considerations:

1. the interdisciplinary scope of the proposal,
2. the relation of the program to the Mines mission,
3. educational and research resources at Mines,
4. the quality of the proposed course of study and research,
5. the qualifications of the student, and
6. the recommendations of the department heads or division directors.

### **C. Graduation Requirements**

Candidates for IIG degrees must meet all graduation requirements in the general section of the CSM Graduate Bulletin. During their course of study they must also participate in a required interdisciplinary seminar. In addition, as a condition of their endorsement of admission to the IIG program, the heads or directors of both departments or divisions may recommend that the candidates be required to meet some or all of their department or division requirements. The IIG Thesis Committee will nevertheless make the final decision on the course of study for each student, taking into consideration the department or division recommendations and the technical content of the proposed research program.

### **D. Transfer Credits**

Transfer of credits from other institutions will be allowed as indicated in the section of this Bulletin for the equivalent disciplinary degree (MS, ME or PhD), except that approval authority shall rest with the IIG Thesis Committee.

### **E. Minor Programs**

A minor program is not required for an IIG degree.

### **F. Thesis Advisors**

Each IIG program student must have two co-advisors. At least one co-advisor must be a full-time member of the CSM faculty holding the rank of professor, associate professor, assistant professor, research professor, associate research professor, or assistant research professor. With the approval of the Dean of Graduate Studies, the other co-advisor may be from outside CSM.

<sup>1</sup>Degree program is currently under review. No new admissions are being accepted at this time.

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### G. Thesis Committees

The Dean of Graduate Studies will appoint a Thesis Committee based on recommendations from the student and the director of the IIG program. The composition, authority and operation of the Committee will be as indicated in the Board-approved policy available from the Graduate Office.

### H. Admission to Candidacy

Requirements and procedures for admission to candidacy will be as indicated in the section of this Bulletin for the equivalent disciplinary degree.

### I. Thesis Defense

Requirements and procedures for defense of thesis will be as indicated in the section of this Bulletin for the equivalent disciplinary degree.

### J. For More Information

For more information about admission or requirements, or for the name of the IIG Coordinator, contact the Graduate Office at [grad-school@mines.edu](mailto:grad-school@mines.edu) or 303-273-3248.

## V. Combined Undergraduate/Graduate Degree Programs

### A. Overview

Many degree programs offer CSM undergraduate students the opportunity to begin work on a Graduate Certificate, Professional Master's Degree, or Master's Degree while completing the requirements for their Bachelor's Degree. These combined Bachelors-Masters programs have been created by CSM faculty in those situations where they have deemed it academically advantageous to treat BS and MS degree programs as a continuous and integrated process. These are accelerated programs that can be valuable in fields of engineering and applied science where advanced education in technology and/or management provides the opportunity to be on a fast track for advancement to leadership positions. These programs also can be valuable for students who want to get a head start on graduate education.

The combined programs at CSM offer several advantages to students who choose to enroll in them:

1. Students can earn a graduate degree in their undergraduate major or in a field that complements their undergraduate major.
2. Students who plan to go directly into industry leave CSM with additional specialized knowledge and skills which may allow them to enter their career path at a higher level and advance more rapidly. Alternatively, students planning on attending graduate school can get a head start on their graduate education.
3. Students can plan their undergraduate electives to satisfy prerequisites, thus ensuring adequate preparation for their graduate program.

4. Early assignment of graduate advisors permits students to plan optimum course selection and scheduling in order to complete their graduate program quickly.
5. Early acceptance into a Combined Degree Program leading to a Graduate Certificate, Professional Master's Degree, or Non-Thesis Master's Degree assures students of automatic acceptance into full graduate status if they maintain good standing while in early-acceptance status.
6. In many cases, students will be able to complete both Bachelor's and Master's Degrees in five years of total enrollment at CSM.

Certain graduate programs may allow Combined Degree Program students to fulfill part of the requirements of their graduate degree by including up to six hours of specified course credits which also were used in fulfilling the requirements of their undergraduate degree. These courses may only be applied toward fulfilling Master's degree requirements beyond the institutional minimum Master's degree requirement of 30 credit hours. Courses must meet all requirements for graduate credit, but their grades are not included in calculating the graduate GPA. Check the departmental section of the Bulletin to determine which programs provide this opportunity.

### B. Admission Process

A student interested in applying into a graduate degree program as a Combined Degree Program student should first contact the department or division hosting the graduate degree program into which he/she wishes to apply. Initial inquiries may be made at any time, but initial contacts made soon after completion of the first semester, Sophomore year are recommended. Following this initial inquiry, departments/divisions will provide initial counseling on degree application procedures, admissions standards and degree completion requirements.

Admission into a graduate degree program as a Combined Degree Program student can occur as early as the first semester, Junior year, and must be granted no later than the end of registration, last semester Senior year. Once admitted into a graduate degree program, students may enroll in 500-level courses and apply these directly to their graduate degree. To apply, students must submit the standard graduate application package for the graduate portion of their Combined Degree Program. Upon admission into a graduate degree program, students are assigned graduate advisors. Prior to registration for the next semester, students and their graduate advisors should meet and plan a strategy for completing both the undergraduate and graduate programs as efficiently as possible. Until their undergraduate degree requirements are completed, students continue to have undergraduate advisors in the home department or division of their Bachelor's Degrees.

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### *C. Requirements*

Combined Degree Program students are considered undergraduate students until such time as they complete their undergraduate degree requirements. Combined Degree Program students who are still considered undergraduates by this definition have all of the privileges and are subject to all expectations of both their undergraduate and graduate programs. These students may enroll in both undergraduate and graduate courses (see section D below), may have access to departmental assistance available through both programs, and may be eligible for undergraduate financial aid as determined by the Office of Financial Aid. Upon completion of their undergraduate degree requirements, a Combined Degree Program student is considered enrolled full-time in his/her graduate program. Once having done so, the student is no longer eligible for undergraduate financial aid, but may now be eligible for graduate financial aid. To complete their graduate degree, each Combined Degree Program student must register as a graduate student for at least one semester.

Once fully admitted into a graduate program, undergraduate Combined Program students must maintain good standing in the Combined Program by maintaining a minimum semester GPA of 3.0 in all courses taken. Students not meeting this requirement are deemed to be making unsatisfactory academic progress in the Combined Degree Program. Students for whom this is the case are subject to probation and, if occurring over two semesters, subject to discretionary dismissal from the graduate portion of their program as defined in the Unsatisfactory Academic Performance section of this Bulletin.

Upon completion of the undergraduate degree requirements, Combined Degree Program students are subject to all requirements (e.g., course requirements, departmental approval of transfer credits, research credits, minimum GPA, etc.) appropriate to the graduate program in which they are enrolled.

### *D. Enrolling in Graduate Courses as a Senior in a Combined Program*

As described in the Undergraduate Bulletin, seniors may enroll in 500-level courses. In addition, undergraduate seniors who have been granted admission through the Combined Degree Program into thesis-based MS degree programs may, with graduate advisor approval, register for 700-level research credits appropriate to Masters-level degree programs. With this single exception, while a Combined Degree Program student is still completing his/her undergraduate degree, all of the conditions described in the Undergraduate Bulletin for undergraduate enrollment in graduate-level courses apply. 700-level research credits are always applied to a student's graduate degree program. If an undergraduate Combined Degree Program student would like to enroll in a 500-level course and apply this course to his/her graduate degree, he/she must notify the Registrar of the intent to do so at the time of enrollment in the course. The Registrar will forward this information to Financial Aid for appropriate action. If prior consent is not received, all 500-level graduate courses taken as an undergraduate Combined Degree Program student will be applied to the student's undergraduate degree transcript.

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# Graduate Degree Programs and Description of Courses

In addition to the general degree requirements described in the previous pages, the following specific department, division, or program requirements must also be met:

## Chemical Engineering

JAMES F. ELY, Professor and Head of Department  
ANTHONY M. DEAN, W. K. Coors Distinguished Professor  
JOHN R. DORGAN, Professor  
DAVID W. M. MARR, Professor  
J. THOMAS MCKINNON, Professor  
RONALD L. MILLER, Professor  
E. DENDY SLOAN, Jr., Weaver Distinguished Professor  
J. DOUGLAS WAY, Professor  
ANDREW M. HERRING, Associate Professor  
CAROLYN A. KOH, Associate Professor  
COLIN A. WOLDEN, Associate Professor  
DAVID T. WU, Associate Professor (also Chemistry)  
SUMIT AGARWAL, Assistant Professor  
MATTHEW W. LIBERATORE, Assistant Professor  
TRACY Q. GARDNER, Lecturer  
JOHN M. PERSICHETTI, Lecturer  
ROBERT J. EVANS, Research Professor  
MICHAEL FRENKEL, Research Professor  
ROBERT D. KNECHT, Research Professor, Director of EPICS  
ANGEL ABBUD-MADRID, Research Associate Professor  
HANS HEINRICH-CARSTENSEN, Research Associate Professor  
SERGEI KISELEV, Research Associate Professor  
KELLY T. MILLER, Research Associate Professor  
GLENN MURRAY, Research Assistant Professor  
JOHN OAKEY, Research Assistant Professor  
BRIAN OPANSKY, Research Assistant Professor  
WAYNE ROMONCHUK, Research Assistant Professor  
EUN-JAE SHIN, Research Assistant Professor  
BERTHE STEMPFER, Research Assistant Professor  
PAUL M. THOEN, Research Assistant Professor  
ROBERT M. BALDWIN, Professor Emeritus  
ANNETTE L. BUNGE, Professor Emeritus  
JAMES H. GARY, Professor Emeritus  
JOHN O. GOLDEN, Professor Emeritus  
ARTHUR J. KIDNAY, Professor Emeritus  
VICTOR F. YESAVAGE, Professor Emeritus

### Degrees Offered:

- Master of Science (Chemical Engineering)
- Doctor of Philosophy (Chemical Engineering)

### Program Description:

The program of study for an advanced degree in chemical engineering is selected by the student in consultation with his/her advisor and with the approval of the thesis committee. Upon approval of the thesis committee, graduate credit may be earned for selected 400-level courses. All full-time graduate students are required to enroll for colloquium (ChEN605) for each semester that they are in residence at CSM.

### Program Requirements:

See Required Curriculum below.

### Prerequisites:

The program outlined here assumes that the candidate for an advanced degree has a background in chemistry, mathematics, and physics equivalent to that required for the B.S. degree in Chemical Engineering at the Colorado School of Mines. Undergraduate course deficiencies must be removed prior to enrollment in graduate coursework.

The essential undergraduate courses include ChEN201, ChEN307, ChEN308, ChEN357, ChEN375, and ChEN418.

### Required Curriculum:

#### Master of Science Program:

Students entering the Master of Science (with thesis) program with an acceptable undergraduate degree in chemical engineering are required to take a minimum of 18 semester hours of coursework. All students must complete the four chemical engineering core graduate courses (ChEN507, ChEN509, ChEN516, and ChEN518) and an additional six hours of approved electives. Student must take a minimum of 6 research credits. In addition, students must take a minimum of 6 research credits, complete, and defend an acceptable Masters dissertation. Between coursework and research credits a student must earn a minimum of 30 total semester hours. Full-time Masters students must enroll in graduate colloquium (ChEN605) each semester that they are in residence.

Students entering the Master of Science (non-thesis) program with an acceptable undergraduate degree in chemical engineering are required to take a minimum of 30 semester hours of coursework. All students must complete the four chemical engineering core graduate courses (ChEN507, ChEN509, ChEN516, and ChEN518) and at least an additional 18 hours of approved electives. Students may complete an acceptable engineering report for up to six hours of academic credit. Full-time Masters students must enroll in graduate colloquium (ChEN605) each semester they are in residence.

CSM undergraduates enrolled in the combined BS/MS degree program must meet the requirements described above for the MS portion of their degree (both thesis and non-thesis). Students accepted into the combined program may take graduate coursework and/or research credits as an undergraduate and have them applied to their MS degree.

#### Doctor of Philosophy Program:

The course of study for the Ph.D. degree consists of a minimum of 30 semester hours of coursework. All Ph.D. students must complete the four core courses (ChEN507, ChEN509, ChEN518, and ChEN516) and an additional 18 hours of approved electives. Students are required to complete a minor in a discipline outside of the department (minimum of 12 semester hours of graduate coursework). In addition, students must complete and defend an acceptable Doctoral disserta-



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tion. Full-time Ph.D. students must enroll in graduate colloquium (ChEN605) each semester they are in residence.

Students in the Ph.D. program are required to pass both a Qualifying Exam and the Ph.D. Proposal Defense. These requirements are described below:

#### **Ph.D. Qualifying Examination**

The Ph.D. qualifying examination will be offered twice each year, at the start and end of the Spring semester. All students who have entered the Ph.D. program must take the qualifying examination at the first possible opportunity. A student may retake the examination once if he/she fails the first time; however, the examination must be retaken at the next regularly scheduled examination time. Failure of the Ph.D. qualifying examination does not disqualify a student for the M.S. degree, although failure may affect the student's financial aid status.

The qualifying examination will cover the traditional areas of Chemical Engineering, and will consist of two sections: a written section and an oral section. The written section will contain six questions, three at the undergraduate level (covering fluid mechanics, heat transfer, and mass transfer/material and energy balances) and three at the graduate level (covering applied engineering mathematics, reaction kinetics, and thermodynamics). The qualifying examination is open-book and students are free to use any reference books or course notes during the written examination. The oral examination will consist of a presentation by the student on a technical paper from the chemical engineering literature. Students will choose a paper in one of four areas (thermodynamics, kinetics, transport, and materials) from a list determined by the faculty. The student is required to present an oral critique of the paper of approximately 20 minutes followed by questions from the faculty. Papers for the oral examination will be distributed well in advance of the oral portion of the exam so students have sufficient time to prepare their presentations.

#### **Ph.D. Proposal Defense**

After passing the Qualifying Exam, all Ph.D. candidates are required to prepare a detailed written proposal on the subject of their Ph.D. research topic. An oral examination consisting of a defense of the thesis proposal must be completed within approximately one year of passing the Qualifying Examination. Written proposals must be submitted to the student's thesis committee no later than one week prior to the scheduled oral examination.

Two negative votes from the doctoral committee members are required for failure of the Ph.D. Proposal Defense. In the case of failure, one re-examination will be allowed upon petition to the Department Head. Failure to complete the Ph.D. Proposal Defense within the allotted time without an approved postponement will result in failure. Under extenuating circumstances a student may postpone the exam with approval of the Graduate Affairs committee, based on the recommendation of the student's thesis committee. In such cases, a

student must submit a written request for postponement that describes the circumstances and proposes a new date. Requests for postponement must be presented to the thesis committee no later than two weeks before the end of the semester in which the exam would normally have been taken.

#### **Description of Courses**

ChEN402. CHEMICAL ENGINEERING DESIGN Process simulation and process optimization. Prerequisite: ChEN201, ChEN307, ChEN308, ChEN357, ChEN375, ChEN418, or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN403. PROCESS DYNAMICS AND CONTROL Mathematical modeling and analysis of transient systems. Applications of control theory to response of dynamic chemical engineering systems and processes. Prerequisite: ChEN307, ChEN308, ChEN375, MATH225, or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN408. NATURAL GAS PROCESSING Application of chemical engineering principles to the processing of natural gas. Emphasis on using thermodynamics and mass transfer operations to analyze existing plants. Relevant aspects of computer-aided process simulation. Prerequisites: ChEN201, ChEN307, ChEN308, ChEN357, ChEN375, or consent of instructor. 3 hours lecture, 3 semester hours.

ChEN409. PETROLEUM PROCESSES Application of chemical engineering principles to petroleum refining. Thermodynamics and reaction engineering of complex hydrocarbon systems. Relevant aspects of computer-aided process simulation for complex mixtures. Prerequisite: CHGN221, CHGN351 and 353, ChEN201, ChEN357, or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN415. POLYMER SCIENCE AND TECHNOLOGY Chemistry and thermodynamics of polymers and polymer solutions. Reaction engineering of polymerization. Characterization techniques based on solution properties. Materials science of polymers in varying physical states. Processing operations for polymeric materials and use in separations. Prerequisite: CHGN221, MATH225, ChEN357, or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN416. POLYMER ENGINEERING AND TECHNOLOGY Polymer fluid mechanics, polymer rheological response, and polymer shape forming. Definition and measurement of material properties. Interrelationships between response functions and correlation of data and material response. Theoretical approaches for prediction of polymer properties. Processing operations for polymeric materials; melt and flow instabilities. Prerequisite: ChEN307, MATH225, or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN418. REACTION ENGINEERING Applications of the fundamentals of thermodynamics, physical chemistry, and organic chemistry to the engineering of reactive processes. Reactor design; acquisition and analysis of rate data; heterogeneous catalysis. Relevant aspects of computer-aided process simula-

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tion. Prerequisite: ChEN307, ChEN308, ChEN357, MATH225, CHGN221, CHGN353, or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN420. MATHEMATICAL METHODS IN CHEMICAL ENGINEERING Formulation and solution of chemical engineering problems using exact analytical solution methods. Set-up and solution of ordinary and partial differential equations for typical chemical engineering systems and transport processes. Prerequisite: MATH225, ChEN307, ChEN308, ChEN375, or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN421. ENGINEERING ECONOMICS Economic analysis of engineering processes and systems. Interest, annuity, present value, depreciation, cost accounting, investment accounting and financing of engineering enterprises along with taxation, market evaluation and break-even analysis. Prerequisite: consent of instructor. 3 hours lecture; 3 semester hours.

ChEN430. TRANSPORT PHENOMENA Theory and chemical engineering applications of momentum, heat, and mass transport. Set up and solution of problems involving equations of motion and energy. Prerequisite: ChEN307, ChEN308, ChEN357, ChEN375, MATH225, or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN440. MOLECULAR PERSPECTIVES IN CHEMICAL ENGINEERING Applications of statistical and quantum mechanics to understanding and prediction of equilibrium and transport properties and processes. Relations between microscopic properties of materials and systems to macroscopic behavior. Prerequisite: ChEN307, ChEN308, ChEN357, ChEN375, CHGN351 and 353, CHGN221 and 222, MATH225, or consent of instructor. 3 hours lecture; 3 semester hours.

#### Graduate Courses

500-level courses are open to qualified seniors with permission of the department and the Dean of the Graduate School.

The 600-level courses are open only to students enrolled in the Graduate School.

ChEN501. ADVANCED HEAT TRANSFER Formulation of the laws governing the transport of energy. Transient and steady-state analysis for heat conduction. The transport of thermal energy in fluids in motion; free and forced convection in laminar and turbulent flow over surfaces and within conduits. Prerequisite: ChEN516 or consent of instructor. 3 hours lecture-discussion; 3 semester hours.

ChEN504. ADVANCED PROCESS ENGINEERING ECONOMICS Advanced engineering economic principles applied to original and alternate investments. Analysis of chemical and petroleum processes relative to marketing and return on investments. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

ChEN505. NUMERICAL METHODS IN CHEMICAL ENGINEERING Engineering applications of numerical methods. Numerical integration, solution of algebraic equations, matrix

algebra, ordinary differential equations, and special emphasis on partial differential equations. Emphasis on application of numerical methods to chemical engineering problems which cannot be solved by analytical methods. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

ChEN507. APPLIED MATHEMATICS IN CHEMICAL ENGINEERING This course stresses the application of mathematics to problems drawn from chemical engineering fundamentals such as material and energy balances, transport phenomena and kinetics. Formulation and solution of ordinary and partial differential equations arising in chemical engineering or related processes or operations are discussed. Mathematical approaches are restricted to analytical solutions or techniques for producing problems amenable to analytical solutions. Prerequisite: Undergraduate differential equations course; undergraduate chemical engineering courses covering reaction kinetics, and heat, mass and momentum transfer. 3 hours lecture-discussion; 3 semester hours.

ChEN508. ADVANCED FLUID MECHANICS Development of basic conservation equations for momentum transfer. Constitutive equations for Newtonian and elementary non-Newtonian fluids. Exact solutions of the Navier-Stokes equations. Ordering and approximations. Applications to low and high Reynolds number flows. Prerequisite: ChEN516 or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN509. ADVANCED CHEMICAL ENGINEERING THERMODYNAMICS Extension and amplification of undergraduate chemical engineering thermodynamics. Topics will include the laws of thermodynamics, thermodynamic properties of pure fluids and fluid mixtures, phase equilibria, and chemical reaction equilibria. Prerequisite: ChEN357 or equivalent or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN510. CHEMICAL REACTOR ANALYSIS AND DESIGN Non-ideal flow effects on reactor design. Stability of stirred tank and tubular flow reactors. Mass and heat transfer effects. Modeling of heterogeneous chemical reactors. Fluidized bed reactors. Prerequisite: ChEN418 or equivalent. 3 hours lecture; 3 semester hours.

ChEN511. INDIVIDUAL STUDIES Individual theoretical or experimental studies under the direction of a department faculty member, but not leading to a thesis. Course may be repeated for credit. Prerequisite: Consent of instructor. 1 to 3 semester hours; 6 semester hours maximum credit. Repeatable for credit to a maximum of 6 hours.

ChEN513. SELECTED TOPICS IN CHEMICAL ENGINEERING Selected topics chosen from special interests of instructor and students. Course may be repeated for credit on different topics. Prerequisite: Consent of instructor. 1 to 3 semester hours lecture/discussion; 1 to 3 semester hours.

ChEN514. ADVANCED STAGED SEPARATIONS Principles of stagewise separations with major emphasis on multicomponent processes for distillation, absorption, and extraction. Topics

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include brief review of ideal phase separations, classical stage-by-stage multicomponent methods, modern successive approximation methods for multicomponents, general short-cut methods, tray hydraulics and efficiency. Prerequisite: ChEN375 or equivalent. 3 hours lecture; 3 semester hours.

ChEN515. ADVANCED MASS TRANSFER Fundamental principles of mass transfer with application to design of mass transfer processes. Theory of diffusion in gases and liquids for single and multicomponent species. Mass transfer in laminar and turbulent flows. Transport analogies, simultaneous heat and mass transfer, with examples of drying and humidification processes. Mass transfer with chemical reaction; examples of slow, intermediate, and fast reactions with application to design of mass transfer processes. Interfacial mass transfer and mass transfer in two-phase flows. Design of packed beds and columns, gas-sparged reactors. Prerequisite: Graduate course in transport phenomena (ChEN516). 3 hours lecture-discussion; 3 semester hours.

ChEN516. TRANSPORT PHENOMENA Principles of momentum, heat, and mass transfer with application to chemical processes. Flow in ducts and around submerged objects. Heat conduction and molecular diffusion. Convective heat and mass transfer. Heat- and mass-transfer coefficients. Transport analogies and correlations. Prerequisite: ChEN507. 3 hours lecture-discussion; 3 semester hours.

ChEN517. PETROLEUM REFINERY PROCESSING Composition and evaluation of petroleum crude oils and other hydrocarbons. Basic refinery processes, including operating conditions, chemical reactions, catalysts, economics, and pollution control. Emphasis on needs for refinery processes, such as: distillation, desulfurization, coking, solvent extraction, hydrofining, hydrocracking, catalytic cracking, reforming, isomerization, polymerization. New process requirements for meeting fuel specifications. Prerequisite: ChEN409 or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN518. REACTION KINETICS AND CATALYSIS Homogeneous and heterogeneous rate expressions. Fundamental theories of reaction rates. Analysis of rate data and complex reaction networks. Properties of solid catalysts. Mass and heat transfer with chemical reaction. Heterogeneous non-catalytic reactions. Prerequisite: ChEN418 or equivalent. 3 hours lecture; 3 semester hours.

ChEN519. SYNTHETIC FUEL PROCESSES Processes that generate hydrocarbons from coal, tar sands, and oil shale. Other energy sources as well as direct conversion processes will also be considered in view of supply and economics. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

ChEN520. THERMODYNAMICS OF PHASE EQUILIBRIA Application of current theories in multicomponent phase equilibria to the solution of engineering problems. Topics include: introduction to the theory of intermolecular forces, theory of corresponding states, fugacities in gas and liquid mixtures, introduction to the theory of liquids. Prerequisite: ChEN509 or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN521. CRYOGENIC ENGINEERING Thermodynamic analysis of cryogenic systems. Survey of the properties of cryogenic fluids. Analysis of heat transfer, fluid flow, and separation processes at low temperatures. Introduction to superconductivity and superfluidity. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

ChEN523. ENGINEERING AND THE ENVIRONMENT Discussion of the many engineering problems that arise when man interacts with his environment. Comprehensive treatment of topics such as pollution, thermal pollution, treatment of industrial and municipal wastes, solid waste treatment, and the disposal of radioactive wastes. Economic and legislative aspects of these problems will also be considered. Prerequisite: Consent of instructor. 3 semester hours.

ChEN524. COMPUTER-AIDED PROCESS SIMULATION Advanced concepts in computer-aided process simulation are covered. Topics include optimization, heat exchanger networks, data regression analysis, and separations systems. Use of industry-standard process simulation software (Aspen Plus) is stressed. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

ChEN525. SELECTED TOPICS IN EMERGING CHEMICAL ENGINEERING TECHNOLOGY An introduction to new chemical engineering technologies. Current examples include biotechnology, supercritical fluid extraction and biomedical engineering. Emphasis is on providing students with appropriate terminologies, identifying new applications of chemical engineering principles and potential areas of research. Prerequisite: Consent of instructor. Lecture and/or laboratory; 1 to 3 semester hours.

ChEN527. ATMOSPHERIC CHEMISTRY This course provides students the opportunity to explore technical aspects of many important recent topics in air pollution. The course includes the chemistry, monitoring, health and environmental effects of air pollution including ozone layer depletion, acid rain, and global climate change. Technical aspects of environmental regulations and policy are included along with interpretation of laboratory experiments, field measurements, and computer modeling. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

ChEN535/PHGN535/MLGN535. INTERDISCIPLINARY MICROELECTRONICS PROCESSING LABORATORY (II) Application of science and engineering principles to the design, fabrication, and testing of microelectronic devices. Emphasis on specific unit operations and the interrelation among processing steps. Consent of instructor 1 hour lecture, 4 hours lab; 3 semester hours.

ChEN545. SIMULATION AND MODELING IN CHEMICAL PROCESS INDUSTRIES Application of basic principles of physics, chemistry, transport phenomena and reaction kinetics to real systems. The philosophy of process modeling at different levels of complexity is developed and numerous examples based

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on the chemical process industry and naturally occurring processes are used. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

**ChEN550. MEMBRANE SEPARATION TECHNOLOGY** This course is an introduction to the fabrication, characterization, and application of synthetic membranes for gas and liquid separations. Industrial membrane processes such as reverse osmosis, filtration, pervaporation, and gas separations will be covered as well as new applications from the research literature. The course will include lecture, experimental, and computational (molecular simulation) laboratory components. Prerequisites: ChEN375, ChEN430 or consent of instructor. 3 hours lecture; 3 semester hours.

**ChEN568. INTRODUCTION TO CHEMICAL ENGINEERING RESEARCH** Students will be expected to apply chemical engineering principles to critically analyze theoretical and experimental research results in the chemical engineering literature, placing it in the context of the related literature. Skills to be developed and discussed include oral presentations, technical writing, critical reviews, ethics, research documentation (the laboratory notebook), research funding, types of research, developing research, and problem solving. Students will use state-of-the-art tools to explore the literature and develop well-documented research proposals and presentations. Prerequisite: Graduate student in Chemical Engineering in good standing or consent of instructor. 3 semester hours.

**ChEN584. (CHGN584). FUNDAMENTALS OF CATALYSIS** The basic principles involved in the preparation, characterization, testing and theory of heterogeneous and homogeneous catalysts are discussed. Topics include chemisorption, adsorption isotherms, diffusion, surface kinetics, promoters, poisons, catalyst theory and design, acid base catalysis and soluble transition metal complexes. Examples of important industrial applications are given. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

**ChEN598. SPECIAL TOPICS IN CHEMICAL ENGINEERING** Pilot course of special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

**ChEN599. INDEPENDENT STUDY** Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

**ChEN601. ADVANCED TOPICS IN HEAT TRANSFER** In-depth analysis of selected topics in heat transfer with special emphasis on chemical engineering applications. Prerequisite: ChEN501 or consent of instructor. 1 to 3 hours lecture-discussion; 1 to 3 semester hours.

**ChEN604. TOPICAL RESEARCH SEMINARS** Lectures, reports, and discussions on current research in chemical engineering, usually related to the student's thesis topic. Sections are operated independently and are directed toward different research topics. Course may be repeated for credit. Prerequisite: Consent of instructor. 1 hour lecture-discussion; 1 semester hour. Repeatable for credit to a maximum of 3 hours.

**ChEN605. COLLOQUIUM** Students will attend a series of lectures by speakers from industry, academia, and government. Primary emphasis will be on current research in chemical engineering and related disciplines, with secondary emphasis on ethical, philosophical, and career-related issues of importance to the chemical engineering profession. Prerequisite: Graduate status. 1 hour lecture; 1 semester hour. Repeatable for credit to a maximum of 10 hours.

**ChEN607. ADVANCED TOPICS IN CHEMICAL ENGINEERING MATHEMATICS** In-depth analysis of selected topics in applied mathematics with special emphasis on chemical engineering applications. Prerequisite: ChEN507 or consent of instructor. 1 to 3 hours lecture-discussion; 1 to 3 semester hours.

**ChEN608. ADVANCED TOPICS IN FLUID MECHANICS** In-depth analysis of selected topics in fluid mechanics with special emphasis on chemical engineering applications. Prerequisite: ChEN508 or consent of instructor. 1 to 3 hours lecture-discussion; 1 to 3 semester hours.

**ChEN609. ADVANCED TOPICS IN THERMODYNAMICS** Advanced study of thermodynamic theory and application of thermodynamic principles. Possible topics include stability, critical phenomena, chemical thermodynamics, thermodynamics of polymer solutions and thermodynamics of aqueous and ionic solutions. Prerequisite: Consent of instructor. 1 to 3 semester hours.

**ChEN610. APPLIED STATISTICAL THERMODYNAMICS** Principles of relating behavior to microscopic properties. Topics include element of probability, ensemble theory, application to gases and solids, distribution theories of fluids, and transport properties. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

**ChEN611. APPLIED STATISTICAL MECHANICS** Continuation of ChEN610. Advanced applications of statistical thermodynamics and statistical mechanics including perturbation and integral equation theory, computer simulation and theory of electrolytes. Introduction to theory of nonequilibrium systems including Chapman-Enskog, Brownian motion and time correlation functions. Prerequisite: ChEN610 or equivalent; ChEN507 or equivalent; ChEN509. 3 hours lecture; 3 semester hours.

**ChEN612. ADVANCED INDIVIDUAL STUDIES** Advanced theoretical or experimental studies on chemical engineering subjects not currently covered in other department courses. Course may be repeated for credit. Prerequisite: Consent of instructor. 1 to 3 semester hours. Repeatable for credit to a maximum of 6 hours.



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ChEN615. ADVANCED TOPICS IN MASS TRANSFER In-depth analysis of selected topics in mass transfer with special emphasis on chemical engineering applications. Possible topics include ion-exchange or adsorption chromatography, theories of interfacial mass transfer, mass transfer with reaction, and simultaneous heat and mass transfer. Prerequisite: Graduate mass transfer course (ChEN515). 1 to 3 hours lecture-discussion; 1 to 3 semester hours.

ChEN618. ADVANCED TOPICS IN REACTION KINETICS Fundamental theories of reaction rates. Basic principles of chemical kinetics in homogeneous and heterogeneous systems. Reactions in solution, reactions on surfaces, and composite reactions. Homogeneous catalysis, and isotope effects in reaction dynamics. Photochemical reactions. Prerequisite: Graduate reaction engineering course (ChEN518). 1 to 3 hours lecture-discussion; 1 to 3 semester hours.

ChEN625/CHGN625/MLGN625. MOLECULAR SIMULATION Principles and practice of modern computer simulation techniques used to understand solids, liquids, and gases. Review of the statistical foundation of thermodynamics followed by in-depth discussion of Monte Carlo and Molecular Dynamics techniques. Discussion of intermolecular potentials, extended ensembles, and mathematical algorithms used in molecular simulations. ChEN509 or equivalent; ChEN610 or equivalent recommended. 3 hours lecture; 3 semester hours.

ChEN690. SUPERVISED TEACHING OF CHEMICAL ENGINEERING Individual participation in teaching activities. Discussion, problem review and development, guidance of laboratory experiments, course development, supervised practice teaching. Course may be repeated for credit. Prerequisite: Graduate standing, appointment as a graduate student instructor, or consent of instructor. 6 to 10 hours supervised teaching; 2 semester hours.

ChEN698. SPECIAL TOPICS IN CHEMICAL ENGINEERING Pilot course of special topics course. Topics chosen from special interests of instructor(s) and student(s). Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

ChEN699. INDEPENDENT STUDY Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

ChEN705. GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

ChEN706. GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty advisor. Repeatable for credit.

SYGN600. FUNDAMENTALS OF COLLEGE TEACHING Principles of learning and teaching in a college setting. Methods to foster and assess higher order thinking. Effective design, delivery, and assessment of college courses or presentations. Prerequisite: Graduate standing, or consent of instructor. 2 semester hours.



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## Chemistry and Geochemistry

DANIEL M. KNAUSS, Professor and Interim Department Head

PAUL W. JAGODZINSKI, Professor

PATRICK MACCARTHY, Professor

KENT J. VOORHEES, Professor

SCOTT W. COWLEY, Associate Professor

MARK E. EBERHART, Associate Professor

KEVIN W. MANDERNACK, Associate Professor

JAMES F. RANVILLE, Associate Professor

RYAN RICHARDS, Associate Professor

E. CRAIG SIMMONS, Associate Professor

BETTINA M. VOELKER, Associate Professor

KIM R. WILLIAMS, Associate Professor

DAVID T. WU, Associate Professor

STEPHEN G. BOYES, Assistant Professor

STEVEN F. DEC, Lecturer

BRAD HERRICK, Lecturer

EDWARD A. DEMPSEY, Instructor

RAMON E. BISQUE, Professor Emeritus

STEPHEN R. DANIEL, Professor Emeritus

DEAN W. DICKERHOOF, Professor Emeritus

KENNETH W. EDWARDS, Professor Emeritus

GEORGE H. KENNEDY, Professor Emeritus

RONALD W. KLUSMAN, Professor Emeritus

DONALD LANGMUIR, Professor Emeritus

GEORGE B. LUCAS, Professor Emeritus

DONALD L. MACALADY, Professor Emeritus

MICHAEL J. PAVELICH, Professor Emeritus

MAYNARD SLAUGHTER, Professor Emeritus

THOMAS R. WILDEMAN, Professor Emeritus

JOHN T. WILLIAMS, Professor Emeritus

ROBERT D. WITTERS, Professor Emeritus

CHARLES W. STARKS, Associate Professor Emeritus

### *Degrees Offered:*

Master of Science (Chemistry; thesis and non-thesis option)

Doctor of Philosophy (Applied Chemistry)

Master of Science (Geochemistry; thesis)

Professional Masters in Environmental Geochemistry  
(non-thesis)

Doctor of Philosophy (Geochemistry)

All graduate degree programs in the Department of Chemistry & Geochemistry have been admitted to the Western Regional Graduate Program (WICHE). This program allows residents of Alaska, Arizona, Hawaii, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming to register at Colorado resident tuition rates.

### *Program Description:*

The Department of Chemistry & Geochemistry offers graduate degrees in chemistry and in geochemistry. For students entering the Chemistry Program, undergraduate deficiencies will be determined by faculty in the Department of Chemistry & Geochemistry. Faculty from the Geochemistry Program will determine undergraduate deficiencies of students entering

that program. Undergraduate deficiencies will be established through interviews and/or placement examinations at the beginning of the student's first semester of graduate work.

### *Prerequisites:*

A candidate for an advanced degree in the chemistry program should have completed an undergraduate program in chemistry which is essentially equivalent to that offered by the Department of Chemistry & Geochemistry at the Colorado School of Mines. A candidate for an advanced degree in Geochemistry should have completed an undergraduate degree in chemistry or geology which is equivalent to that required for a bachelor's degree from an accredited university. Deficiencies in one or both of these areas will be determined on an individual basis.

### *Required Curriculum:*

#### **Chemistry:**

A student in the chemistry program, in consultation with the advisor and thesis committee, selects the program of study. Initially, before a thesis advisor and thesis committee have been chosen, the student is advised by the Graduate Affairs Committee in the Department of Chemistry & Geochemistry. The following four graduate courses are designated as core courses in the Department of Chemistry and Geochemistry: CHGN502 (inorganic), CHGN503 (physical), CHGN505 (organic), and CHGN507 (analytical).

M.S. Degree (chemistry, thesis option): The program of study includes the four core courses: (CHGN502, CHGN503, CHGN505, and CHGN507), the M.S.-level seminar (CHGN560), research, and the preparation and oral defense of an MS thesis based on the student's research. Students must be enrolled in CHGN560 for each Fall and Spring semester that they are in residence at CSM. A minimum of 36 semester hours, including at least 24 semester hours of course work, are required. At least 15 of the required 24 semester hours of course work must be taken in the Department of Chemistry & Geochemistry at CSM. The student's thesis committee makes decisions on transfer credit. Up to 9 semester hours of graduate courses may be transferred from other institutions, provided that those courses have not been used as credit toward a Bachelor degree.

Research-Intensive MS Degree: CSM undergraduates who enter the graduate program through the combined BS/MS program may use this option (thesis-based MS) to acquire a research-intensive MS degree by minimizing the time spent on coursework. This option requires a minimum of 12 hours of coursework up to six hours of which may be double counted from the student's undergraduate studies at CSM. Undergraduate courses that are eligible for dual counting toward the M.S. degree in this option are: CHGN401, CHGN410, CHGN403, CHGN422, CHGN428, CHGN430, CHGN475 and CHGN498 (with approval of faculty advisor and committee). Any 500 level lecture course taken as an undergraduate may also be counted as part of the six hours that

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can be double counted from the undergraduate program (with approval of faculty advisor and committee).

**M.S. Degree (chemistry, non-thesis option):** The non-thesis M.S. degree requires 36 semester hours of course credit, composed of 30 semester hours of course work and 6 hours of independent study. The program of study includes the four core courses: (CHGN502, CHGN503, CHGN505, and CHGN507), the M.S.-level seminar (CHGN560), independent study on a topic determined by the student and the student's faculty advisor, and the preparation of a report based on the student's study topic. Students must be enrolled in CHGN560 for each Fall and Spring semester that they are in residence at CSM. At least 21 of the required 36 semester hours of course work must be taken as a registered master's degree student at CSM. The student's committee makes decisions on courses to be taken, transfer credit, and examines the student's written report. Up to 15 semester hours of graduate courses may be transferred from other institutions, provided that those courses have not been used as credit toward a Bachelor degree.

CSM undergraduates may use the non-thesis option as part of a combined B.S./M.S. program in chemistry and count six hours from their undergraduate studies toward the M.S. degree. The undergraduate courses that are eligible for dual counting toward the M.S. degree are: CHGN401, CHGN410, CHGN403, CHGN422, CHGN428, CHGN430, CHGN475, and CHGN498 (with approval of faculty advisor and committee). Any 500 level lecture course taken as an undergraduate may also be counted as part of the six hours from the undergraduate program.

**Ph.D. Degree (Applied Chemistry):** The program of study for the Ph.D. degree in Applied Chemistry includes at least three of the departmental core courses (CHGN502, CHGN503, CHGN505, and CHGN507), the M.S.-level seminar (CHGN560), the Ph.D.-level seminar (CHGN660), a minor, a comprehensive examination, research, and the preparation and oral defense of a Ph.D. thesis based on the student's research. The total hours of course work required for the Ph.D. degree is determined on an individual basis by the student's thesis committee. Up to 24 semester hours of graduate-level course work may be transferred from other institutions toward the Ph.D. degree provided that those courses have not been used by the student toward a Bachelor's degree. The student's thesis committee may set additional course requirements and will make decisions on requests for transfer credit. Ph.D. students may base their M.S.-level seminar on any chemistry-related topic including the proposed thesis research. The M.S.-level seminar requirement must be completed no later than the end of the student's second year of graduate studies at CSM. After completion of the CHGN560 seminar, students must enroll in CHGN660. Students must be enrolled in either CHGN560 or CHGN660 for each Fall and Spring semester that they are in residence

at CSM. The Ph.D.-level seminar must be based on the student's Ph.D. research and must include detailed research findings and interpretation thereof. This CHGN 660 seminar must be presented close to, but before, the student's oral defense of the thesis. The minor requirement consists of a minimum of 12 hours of graduate courses intended to provide a breadth of knowledge in support of the student's principal research interests. The minor may comprise courses taken: (i) solely within the Department of Chemistry & Geochemistry, (ii) solely within another department or division outside of the Department of Chemistry & Geochemistry, or (iii) from a combination of departments/divisions, including transfer credit from another institution. In all cases the minor must constitute a coherent set of courses that supports, and adds breadth to, the student's principal research interests. Up to two, but no more than two, of the core courses may, with thesis committee approval, be used to fulfill the minor requirement. The student's thesis committee must approve the combination of courses that constitutes the minor. The comprehensive examination comprises a written non-thesis proposal wherein the student prepares an original proposal on a chemistry topic distinctly different from the student's principal area of research. The student must orally defend the non-thesis proposal before the thesis committee. The non-thesis proposal requirement must be completed prior to the end of the student's second year of graduate studies. A student's thesis committee may, at its discretion, require additional components to the comprehensive examination process such as inclusion of cumulative examinations, or other examinations.

#### **Geochemistry:**

The program of study is selected by the student in consultation with his or her advisor and thesis committee. Students entering with backgrounds in chemistry will take more coursework in geology to strengthen their backgrounds in this discipline; the converse is true for students with a background in geology. Deficiencies are determined at an entrance interview by members of the Geochemistry faculty. A thesis is required for the M.S. degree and a dissertation for the Ph.D.

The Geochemistry program comprises a core group of courses, required of all students unless individually exempted by the "Committee of the Whole" based on previous background. The core courses for M.S. students are CHGC503 - Introduction to Geochemistry, CHGC504 - Methods in Geochemistry, and a one hour laboratory course selected from several available. In addition, M.S. degree students must take two courses selected from the following list; CHGC509/GEQN509 - Introduction to Aqueous Geochemistry, CHGC610 - Nuclear and Isotopic Geochemistry, CHGN503 Advanced Physical Chemistry, GEOL512 - Mineralogy and Crystal Chemistry. Ph.D. degree students must take four core courses CHGC503, CHGC504, CHGN503, and a one hour laboratory course, and two additional courses selected from the list in the previous sentence.

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The doctoral student's dissertation committee approves the number of course and research credits required for graduation, as well as the specific courses beyond the above requirements. The Ph.D. in Geochemistry requires a minimum of 72 credit hours, of which at least 24 hours must be research credit. Up to 24 hours of course credits may be transferred from previous graduate-level work, upon approval of the dissertation committee. Research credits may not be transferred. Students who enter the Ph.D. program with a thesis-based master degree from another institution may transfer up to 36 semester hours, upon approval of the dissertation committee, in recognition of the course work and research completed for that degree.

### **Professional Masters Degree in Environmental Geochemistry (non-thesis)**

The Professional Masters Degree in Environmental Geochemistry is a custom-designed, interdisciplinary degree, with a curriculum that is intended to meet the career advancement needs of professional geochemists. This degree, which is administered through the Geochemistry Program, is intended for two classes of students:

- ◆ CSM undergraduate students who wish to continue at CSM for an additional year beyond their baccalaureate degree as part of a Combined **BS/MS Degree** program; and
- ◆ Individuals who already hold an appropriate undergraduate or advanced degree (from any institution) and are interested in a geochemistry graduate program that does not have the traditional research requirement.

The program consists primarily of coursework in geochemistry and allied fields, with an emphasis on environmental applications. No research is required though the program does allow for independent study, professional development, internship and coop experience.

### **Application to Professional M.S. Degree Program in Environmental Geochemistry**

Undergraduate students at CSM who are interested in this program must declare an interest during their third year at CSM to allow for planning of coursework that will apply towards the program; these students must have an overall GPA of at least 3.0. Students majoring in other departments besides Chemistry & Geochemistry and Geology & Geological Engineering may want to decide on the BS/MS option earlier to ensure that prerequisites are satisfied. Applicants other than CSM undergraduates who are applying for the Professional M.S. in Environmental Geochemistry must follow the same procedures that all prospective graduate students follow; however, the requirement of the general GRE may be waived.

A minimum of 36 credit hours are required, with an overall GPA of at least 3.0 in CSM coursework. The overall course requirements will depend on the background of the

individual, but may be tailored to professional objectives. Up to 15 of the 36 credits may be transfer-credit. The transfer limit includes CSM distance learning courses. No fewer than 21 credits must be earned on campus. Up to six of these credit hours may be in the form of project credits performed on the job as an employee or as a graduate intern. If project credits are to be used, the project proposal and final report must be approved by a CSM faculty advisor. Direct supervision may be provided by the employer.

CSM students who intend to follow the BS/MS format for this degree may double count 6 credits of 400-level or above courses (with grades of B or higher) taken as part of their undergraduate curriculum, provided those courses:

- ◆ fit into the overall professional objectives of the individual;
- ◆ complement the course program below; and,
- ◆ meet the approval of the Geochemistry Committee of the Whole.

No more than 9 credit hours of 400-level courses may be included in the 36 hour minimum credit requirement.

A 17 credit-hour core program for this degree consists of:

CHGC505 Introduction to Environmental Chemistry (3 hrs, Fall)  
GEGN467\* Ground-Water Engineering (4 hrs, Fall)  
CHGC503 Introduction to Geochemistry (4 hrs, Fall)  
GEGN509 Aqueous Geochemistry (3 hrs, Fall)  
GEOL530 Clay Characterization (1 hr, Fall)  
CHGC504 Methods in Geochemistry (2 hrs, Spring)

\*If this course is transferred from the undergraduate program, an advanced hydrogeology course may be substituted from the list below.

An additional 12 credit-hours of course work must be selected from the following list.

CHGC530 Environmental Chemistry and Geochemistry (3 hrs, Spring)  
CHGC555 Environmental Organic Chemistry (3 hrs, Spring)  
CHGC562 Microbiology and the Environment (3 hrs, Spring)  
CHGC563 Environmental Microbiology Laboratory (2 hrs, Fall)  
CHGC564 Biogeochemistry and Geomicrobiology (3 hrs, Fall)  
CHGC610 Nuclear and Isotopic Geochemistry (3 hrs, Spring)  
CHGC640 Soil Gas Geochemistry (3 hrs, Spring)  
CHGN503 Advanced Physical Chemistry (3 hrs, Fall)  
GEGN527 Organic Geochemistry of fossil fuels & ore deposits (3hrs, Spring)  
GEGN532 Geological Data Analysis (3 hrs, Fall)  
GEGN575 Applications of Geographic Information Systems (3 hrs, Spring)  
GEGN581 Advanced Ground-Water Engineering (3 hrs, Fall)  
GEGN582 Contaminant Hydrogeology (3 hrs, Spring) – proposed

GEGN583 Mathematical Modeling of Ground-Water Systems (3 hrs, Spring)

GEGN681 Vadose Zone Hydrology (3 hrs, Spring)

GEGN683 Advanced Ground- Water Modeling (3 hrs, Spring)

GEOL512 Mineralogy and Crystal Chemistry (3 hrs, Fall)

GEOL684 Chemical Modeling of Aqueous Systems (3 hrs, Spring)

GXGN571 Geochemical Exploration (3 hrs, Fall and Spring)

An additional 7 credit-hours of free electives may be selected to complete the 36 total credit-hour requirement. Free electives may be selected from the list above, and may also be independent study credits (CHGN599, GEGN599 or GEOL599) taken to fulfill a research, cooperative, or other professional development experience. A course program will be designed in advance through consultation between the student and an advisor from the Geochemistry Committee of the Whole.

#### *Fields of Research:*

Heterogeneous catalysis, surface chemistry.

Organic and analytical chemistry of hydrocarbon fuels; environmental analytical chemistry of organic compounds; coordination chemistry with organic ligands.

Theoretical and descriptive inorganic chemistry; bonding and symmetry; chemistry of materials; use of computers in chemistry.

Applied aspects of trace element, environmental, and aqueous geochemistry.

Applications of soil gas to petroleum and mineral exploration and environmental problems; water quality and modeling of biogeochemical processes in constructed wetlands used for treatment of acid drainage; sampling design in large-scale environmental studies.

Environmental microbiology, biogeochemistry of aquatic and terrestrial environment, stable isotope geochemistry.

Peat and humic substances; analytical chemistry. Geochemistry of igneous rocks; associated ore deposits.

Polymer synthesis and characterization, thermal stability, thermal degradation mechanisms of polymers; mass spectroscopy; chemometrics and chromatography.

Development and evaluation of teaching methods that foster higher-level thinking abilities.

Chemistry and geochemistry of pollutant organics in aqueous systems; chemical and physical transformations of such pollutants; surface interactions in aqueous systems.

Theory and simulation of complex materials including polymers and powders, complex fluids, phase equilibria, controlled self-assembly.

Separations; field flow fractionation; polymer, colloid, and particulate characterization; new separation surfaces.

Computational methods for design of materials.

Synthesis, characterization, and reactivity of inorganic and organometallic complexes with regard to bonding, structure, and catalysis.

#### *Description of Courses*

CHGN401. THEORETICAL INORGANIC CHEMISTRY (II) Periodic properties of the elements. Bonding in ionic and metallic crystals. Acid-base theories. Inorganic stereochemistry. Nonaqueous solvents. Coordination chemistry and ligand field theory. Prerequisite: CHGN341 or consent of instructor. 3 hours lecture; 3 semester hours.

CHGN402. BONDING THEORY AND SYMMETRY (II) Introduction to valence bond and molecular orbital theories, symmetry; introduction to group theory; applications of group theory and symmetry concepts to molecular orbital and ligand field theories. Prerequisite: CHGN401 or consent of instructor. 3 hours lecture; 3 semester hours.

CHGN410/MLGN510. SURFACE CHEMISTRY (II) Introduction to colloid systems, capillarity, surface tension and contact angle, adsorption from solution, micelles and microemulsions, the solid/gas interface, surface analytical techniques, van der Waal forces, electrical properties and colloid stability, some specific colloid systems (clays, foams and emulsions). Students enrolled for graduate credit in MLGN510 must complete a special project. Prerequisite: DCGN209 or consent of instructor. 3 hours lecture; 3 semester hours.

CHGN422. POLYMER CHEMISTRY LABORATORY (I) Prerequisites: CHGN221. 3 hours lab; 1 hour credit.

CHGN428. INTRODUCTORY BIOCHEMISTRY (I) Introductory study of the major molecules of biochemistry, including amino acids, proteins, enzymes, nucleic acids, lipids, and saccharides- their structure, chemistry, biological function, and biosynthesis. Stresses bioenergetics and the cell as a biological unit of organization. Discussion of classical genetics, molecular genetics, and protein synthesis. Prerequisite: CHGN221 or permission of instructor. 3 hours lecture; 3 semester hours.

CHGN430/MLGN530. INTRODUCTION TO POLYMER SCIENCE (I) An introduction to the chemistry and physics of macromolecules. Topics include the properties and statistics of polymer solutions, measurements of molecular weights, molecular weight distributions, properties of bulk polymers, mechanisms of polymer formation, and properties of thermosets and thermoplasts including elastomers. Prerequisite: CHGN221 or permission of instructor. 3 hour lecture, 3 semester hours.

CHGN475. COMPUTATIONAL CHEMISTRY (II) Prerequisites: CHGN351, CHGN402. 3 hours lecture; 3 credit hours.

CHGN490. SYNTHESIS AND CHARACTERIZATION (S) Advanced methods of organic and inorganic synthesis; high-temperature, high-pressure, inert-atmosphere, vacuum-line, and electrolytic methods. Prerequisites: CHGN323, CHGN341. 6-week summer field session; 6 credit hours.



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CHGN495. UNDERGRADUATE RESEARCH (I, II, S) Individual research project under direction of a member of the Departmental faculty. Prerequisites: Completion of chemistry curriculum through the junior year or permission of the department head. 1-6 credit hours.

CHGN497. INTERNSHIP (I, II, S) Individual internship experience with an industrial, academic, or governmental host supervised by a Departmental faculty member. Prerequisites: Completion of chemistry curriculum through the junior year or permission of the department head. 1-6 credit hours.

CHGN498. SPECIAL TOPICS IN CHEMISTRY (I, II) Topics chosen from special interests of instructor and students. Prerequisite: Consent of head of department. 1 to 3 semester hours. Repeatable for credit under different titles.

CHGN499. UNDERGRADUATE RESEARCH (I, II) Individual investigational problems under the direction of members of the chemistry staff. Written report on research required for credit. Prerequisite: Consent of head of department. 1 to 3 semester hours. Repeatable for credit.

### Graduate Courses

The following courses are offered at the graduate level. They will be given if sufficient qualified students register. Some 500-level courses are open to qualified seniors with the permission of the department and Dean of the Graduate School. 600-level courses are open only to students enrolled in the Graduate School. Geochemistry courses are listed after Chemistry courses.

### Chemistry Courses

CHGN502. ADVANCED INORGANIC CHEMISTRY (II) Detailed examination of topics such as ligand field theory, reaction mechanisms, chemical bonding, and structure of inorganic compounds. Emphasis is placed on the correlations of the chemical reactions of the elements with periodic trends and reactivities. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

CHGN503. ADVANCED PHYSICAL CHEMISTRY I (I) Quantum chemistry of classical systems. Principles of chemical thermodynamics. Statistical mechanics with statistical calculation of thermodynamic properties. Theories of chemical kinetics. Prerequisite: Consent of instructor. 4 hours lecture; 4 semester hours.

CHGN505. ADVANCED ORGANIC CHEMISTRY (I) Detailed discussion of the more important mechanisms of organic reaction. Structural effects and reactivity. The application of reaction mechanisms to synthesis and structure proof. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

CHGN506. WATER ANALYSIS LABORATORY (I) Instrumental analysis of water samples using spectroscopy and chromatography. Methods for field collection of water samples and field measurements. The development of laboratory skills for the use of ICP-AES, HPLC, ion chromatography, and GC. Laboratory

techniques focus on standard methods for the measurement of inorganic and organic constituents in water samples. Methods of data analysis are also presented. Prerequisite: Introductory chemistry or consent of instructor. 3 hours laboratory; 1 semester hour.

CHGN507. ADVANCED ANALYTICAL CHEMISTRY (I) Review of fundamentals of analytical chemistry. Literature of analytical chemistry and statistical treatment of data. Manipulation of real substances; sampling, storage, decomposition or dissolution, and analysis. Detailed treatment of chemical equilibrium as related to precipitation, acid-base, complexation and redox titrations. Potentiometry and UV-visible absorption spectrophotometry. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

CHGN508. ANALYTICAL SPECTROSCOPY (II) Detailed study of classical and modern spectroscopic methods; emphasis on instrumentation and application to analytical chemistry problems. Topics include: UV-visible spectroscopy, infrared spectroscopy, fluorescence and phosphorescence, Raman spectroscopy, arc and spark emission spectroscopy, flame methods, nephelometry and turbidimetry, reflectance methods, Fourier transform methods in spectroscopy, photoacoustic spectroscopy, rapid-scanning spectroscopy. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

CHGN510. CHEMICAL SEPARATIONS (II) Survey of separation methods, thermodynamics of phase equilibria, thermodynamics of liquid-liquid partitioning, various types of chromatography, ion exchange, electrophoresis, zone refining, use of inclusion compounds for separation, application of separation technology for determining physical constants, e.g., stability constants of complexes. Prerequisite: CHGN507 or consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

CHGN515/MLGN503. CHEMICAL BONDING IN MATERIALS (I) Introduction to chemical bonding theories and calculations and their applications to solids of interest to materials science. The relationship between a material's properties and the bonding of its atoms will be examined for a variety of materials. Includes an introduction to organic polymers. Computer programs will be used for calculating bonding parameters. Prerequisite: Consent of department. 3 hours lecture; 3 semester hours.

CHGN523/MLGN509. SOLID STATE CHEMISTRY (I) Dependence of properties of solids on chemical bonding and structure; principles of crystal growth, crystal imperfections, reactions and diffusion in solids, and the theory of conductors and semiconductors. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

CHGN536/MLGN536. ADVANCED POLYMER SYNTHESIS (II) An advanced course in the synthesis of macromolecules. Various methods of polymerization will be discussed with an emphasis on the specifics concerning the syntheses of different



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classes of organic and inorganic polymers. Prerequisite: CHGN430, ChEN415, MLGN530 or consent of instructor. 3 hours lecture, 3 semester hours

CHGN560. GRADUATE SEMINAR, M.S. (I, II) Required for all candidates for the M.S. and Ph.D. degrees in chemistry and geochemistry. M.S. students must register for the course during each semester of residency. Ph.D. students must register each semester until a grade is received satisfying the prerequisites for CHGN660. Presentation of a graded non-thesis seminar and attendance at all departmental seminars are required. Prerequisite: Graduate student status. 1 semester hour.

CHGN580/MLGN501. STRUCTURE OF MATERIALS (II) Application of X-ray diffraction techniques for crystal and molecular structure determination of minerals, inorganic and organometallic compounds. Topics include the heavy atom method, data collection by moving film techniques and by diffractometers, Fourier methods, interpretation of Patterson maps, refinement methods, direct methods. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

CHGN581. ELECTROCHEMISTRY (I) Introduction to theory and practice of electrochemistry. Electrode potentials, reversible and irreversible cells, activity concept. Interionic attraction theory, proton transfer theory of acids and bases, mechanisms and fates of electrode reactions. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

CHGN583/MLGN583. PRINCIPLES AND APPLICATIONS OF SURFACE ANALYSIS TECHNIQUES (II) Instrumental techniques for the characterization of surfaces of solid materials; Applications of such techniques to polymers, corrosion, metallurgy, adhesion science, microelectronics. Methods of analysis discussed: x-ray photoelectron spectroscopy (XPS), auger electron spectroscopy (AES), ion scattering spectroscopy (ISS), secondary ion mass spectrometry (SIMS), Rutherford backscattering (RBS), scanning and transmission electron microscopy (SEM, TEM), energy and wavelength dispersive x-ray analysis; principles of these methods, quantification, instrumentation, sample preparation. Prerequisite: B.S. in Metallurgy, Chemistry, Chemical Engineering, Physics, or consent of instructor. 3 hours lecture; 3 semester hours.

CHGN584/ChEN584. FUNDAMENTALS OF CATALYSIS (II) The basic principles involved in the preparation, characterization, testing and theory of heterogeneous and homogeneous catalysts are discussed. Topics include chemisorption, adsorption isotherms, diffusion, surface kinetics, promoters, poisons, catalyst theory and design, acid base catalysis and soluble transition metal complexes. Examples of important industrial applications are given. Prerequisite: CHGN222 or consent of instructor. 3 hours lecture; 3 semester hours.

CHGN585. CHEMICAL KINETICS (II) Study of kinetic phenomena in chemical systems. Attention devoted to various theoretical approaches. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

CHGN598. SPECIAL TOPICS IN CHEMISTRY (I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

CHGN599. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

CHGN660. GRADUATE SEMINAR, Ph.D. (I, II) Required of all candidates for the doctoral degree in chemistry or geochemistry. Students must register for this course each semester after completing CHGN560. Presentation of a graded nonthesis seminar and attendance at all department seminars are required. Prerequisite: CHGN560 or equivalent. 1 semester hour.

CHGN698. SPECIAL TOPICS IN CHEMISTRY (I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

CHGN699. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

CHGN705. GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

CHGN706. GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty advisor. Repeatable for credit.

SYGN600. FUNDAMENTALS OF COLLEGE TEACHING Principles of learning and teaching in a college setting. Methods to foster and assess higher order thinking. Effective design, delivery, and assessment of college courses or presentations. Prerequisite: Graduate standing, or consent of instructor. 2 semester hours.

### **Geochemistry Courses**

CHGC503. INTRODUCTION TO GEOCHEMISTRY (I) A comprehensive introduction to the basic concepts and principles of geochemistry, coupled with a thorough overview of the related principles of thermodynamics. Topics covered include: nucleosynthesis, origin of earth and solar system, chemical bonding, mineral chemistry, elemental distributions and geochemical cycles, chemical equilibrium and kinetics, isotope sys-

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tematics, and organic and biogeochemistry. Prerequisite: Introductory chemistry, mineralogy and petrology, or consent of instructor. 4 hours lecture, 4 semester hours.

CHGC504. METHODS IN GEOCHEMISTRY (II) Sampling of natural earth materials including rocks, soils, sediments, and waters. Preparation of naturally heterogeneous materials, digestions, and partial chemical extractions. Principles of instrumental analysis including atomic spectroscopy, mass separations, and chromatography. Quality assurance and quality control. Interpretation and assessment of geochemical data using statistical methods. Prerequisite: Graduate standing in geochemistry or environmental science and engineering. 2 hours lecture; 2 semester hours.

CHGC505. INTRODUCTION TO ENVIRONMENTAL CHEMISTRY (II) Processes by which natural and anthropogenic chemicals interact, react, and are transformed and redistributed in various environmental compartments. Air, soil, and aqueous (fresh and saline surface and groundwaters) environments are covered, along with specialized environments such as waste treatment facilities and the upper atmosphere. Meets with CHGN403. CHGN403 and CHGC505 may not both be taken for credit. Prerequisites: SYGN101, CHGN 124 and DCGN209 or permission of instructor. 3 hours lecture; 3 semester hours.

CHGC506. WATER ANALYSIS LABORATORY (I) Instrumental analysis of water samples using spectroscopy and chromatography. Methods for field collection of water samples and field measurements. The development of laboratory skills for the use of ICP-AES, HPLC, ion chromatography, and GC. Laboratory techniques focus on standard methods for the measurement of inorganic and organic constituents in water samples. Methods of data analysis are also presented. Prerequisite: Introductory chemistry, graduate standing or consent of instructor. 3 hour laboratory, 1 semester hour.

CHGC509/GEGN509. INTRODUCTION TO AQUEOUS GEOCHEMISTRY (I) Analytical, graphical and interpretive methods applied to aqueous systems. Thermodynamic properties of water and aqueous solutions. Calculations and graphical expression of acid-base, redox and solution-mineral equilibria. Effect of temperature and kinetics on natural aqueous systems. Adsorption and ion exchange equilibria between clays and oxide phases. Behavior of trace elements and complexation in aqueous systems. Application of organic geochemistry to natural aqueous systems. Light stable and unstable isotopic studies applied to aqueous systems. Prerequisite: DCGN209 or equivalent, or consent of instructor. 3 hours lecture; 3 semester hours.

CHGC511. GEOCHEMISTRY OF IGNEOUS ROCKS (II) A survey of the geochemical characteristics of the various types of igneous rock suites. Application of major element, trace element, and isotope geochemistry to problems of their origin and modification. Prerequisite: Undergraduate mineralogy and petrology or consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

CHGC527/GEGN527. ORGANIC GEOCHEMISTRY OF FOSSIL FUELS AND ORE DEPOSITS (II) A study of organic carbonaceous materials in relation to the genesis and modification of fossil fuel and ore deposits. The biological origin of the organic matter will be discussed with emphasis on contributions of microorganisms to the nature of these deposits. Biochemical and thermal changes which convert the organic compounds into petroleum, oil shale, tar sand, coal and other carbonaceous matter will be studied. Principal analytical techniques used for the characterization of organic matter in the geosphere and for evaluation of oil and gas source potential will be discussed. Laboratory exercises will emphasize source rock evaluation, and oil-source rock and oil-oil correlation methods. Prerequisite: CHGN221, GEGN438, or consent of instructor. 2 hours lecture; 3 hours lab; 3 semester hours. Offered alternate years.

CHGC530. ENVIRONMENTAL CHEMISTRY AND GEOCHEMISTRY (II) Mobility of the elements in air, water and the surficial environment. Geochemical cycles of elements and constituents of environmental interest. Plant composition, animal and human health in relation to the natural environment. Acid deposition and other processes affecting water quality. Environmental aspects of fossil fuel processing. Sampling design in large scale environmental studies. Prerequisite: CHGC503 or ESGN500 and ESGN501. 3 hours lecture; 3 semester hours.

CHGC555. ENVIRONMENTAL ORGANIC CHEMISTRY (II) A study of the chemical and physical interactions which determine the fate, transport and interactions of organic chemicals in aquatic systems, with emphasis on chemical transformations of anthropogenic organic contaminants. Prerequisites: A course in organic chemistry and CHGN503, Advanced Physical Chemistry or its equivalent, or consent of instructor. Offered in alternate years. 3 hours lecture; 3 semester hours.

CHGC562/CHGN462. MICROBIOLOGY AND THE ENVIRONMENT This course will cover the basic fundamentals of microbiology, such as structure and function of prokaryotic versus eukaryotic cells; viruses; classification of micro-organisms; microbial metabolism, energetics, genetics, growth and diversity; microbial interactions with plants, animals, and other microbes. Additional topics covered will include various aspects of environmental microbiology such as global biogeochemical cycles, bioleaching, bioremediation, and wastewater treatment. Prerequisite: ESGN301 or consent of Instructor. 3 hours lecture, 3 semester hours. Offered alternate years.

CHGC563. ENVIRONMENTAL MICROBIOLOGY (I) An introduction to the microorganisms of major geochemical importance, as well as those of primary importance in water pollution and waste treatment. Microbes and sedimentation, microbial leaching of metals from ores, acid mine water pollution, and the microbial ecology of marine and freshwater habitats are covered. Prerequisite: Consent of instructor. 1 hour lecture, 3 hours lab; 2 semester hours. Offered alternate years.

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CHGC564. BIOGEOCHEMISTRY AND GEOMICROBIOLOGY (I) Designed to give the student an understanding of the role of living things, particularly microorganisms, in the shaping of the earth. Among the subjects will be the aspects of living processes, chemical composition and characteristics of biological material, origin of life, role of microorganisms in weathering of rocks and the early diagenesis of sediments, and the origin of petroleum, oil shale, and coal. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

CHGC610. NUCLEAR AND ISOTOPIC GEOCHEMISTRY (II) A study of the principles of geochronology and stable isotope distributions with an emphasis on the application of these principles to important case studies in igneous petrology and the formation of ore deposits. U, Th, and Pb isotopes, K-Ar, Rb-Sr, oxygen isotopes, sulfur isotopes, and carbon isotopes included. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours Offered alternate years.

CHGC640. SOIL GAS GEOCHEMISTRY AND APPLICATIONS IN THE EARTH AND ENVIRONMENTAL SCIENCES (II) Thermal, chemical and microbiological reactions in the production of gases. Quantitative review of transport of gaseous species in the saturated and unsaturated zones. Sampling and analysis of soil gases. Applications of soil gas in the earth and environmental sciences, including exploration, contaminant mapping and global climate change. Prerequisites: CHGC503, or ESGN500 and ESGN501, or consent of instructor. 3 hours lecture; 3 semester hours.

CHGC699A. SELECTED TOPICS IN GEOCHEMISTRY (I, II) Detailed study of a geochemical topic under direction of a member of the staff. Work on the same or a different topic may be continued through later semesters and additional credits earned. Prerequisite: Consent of instructor. 1 to 3 semester hours.

CHGC699B. SPECIAL TOPICS IN AQUEOUS AND SEDIMENTARY GEOCHEMISTRY (I, II) Detailed study of a specific topic in the area of aqueous or sedimentary geochemistry under the direction of a member of the staff. Work on the same or a different topic may be continued through later semesters and additional credits earned. Prerequisite: Consent of instructor. 1 to 3 semester hours.

CHGC699C. SPECIAL TOPICS IN ORGANIC AND BIOGEOCHEMISTRY (I, II) Detailed study of a specific topic in the areas of organic geochemistry or biogeochemistry under the direction of a member of the staff. Work on the same or a different topic may be continued through later semesters and additional credits earned. Prerequisite: Consent of instructor. 1 to 3 semester hours.

CHGC699D. SPECIAL TOPICS IN PETROLOGIC GEOCHEMISTRY (I, II) Detailed study of a specific topic in the area of petrologic geochemistry under the direction of a member of the staff. Work on the same or a different topic may be continued through later semesters and additional credits earned. Prerequisite: Consent of instructor. 1 to 3 semester hours.

## Economics and Business

RODERICK G. EGGERT, Professor and Division Director  
JOHN T. CUDDINGTON, William J. Coulter Professor  
CAROL A. DAHL, Professor  
GRAHAM A. DAVIS, Professor  
MICHAEL R. WALLS, Professor  
ALEXANDRA M. NEWMAN, Associate Professor  
EDWARD J. BALISTRERI, Assistant Professor  
CIGDEM Z. GURGUR, Assistant Professor  
MICHAEL B. HEELEY, Assistant Professor  
DANIEL KAFFINE, Assistant Professor  
SCOTT HOUSER, Lecturer  
JOHN M. STERMOLE, Lecturer  
ANN DOZORETZ, Instructor  
FRANKLIN J. STERMOLE, Professor Emeritus  
JOHN E. TILTON, University Emeritus Professor  
ROBERT E. D. WOOLSEY, Professor Emeritus

### *Degrees Offered:*

Master of Science (Mineral Economics)

Doctor of Philosophy (Mineral Economics)

Master of Science (Engineering and Technology Management)

### *Mineral Economics Program Description:*

In an increasingly global and technical world, government and industry leaders in the mineral and energy areas require a strong foundation in economic and business skills. The Division of Economics and Business offers such skills in unique programs leading to M.S. and Ph.D. degrees in Mineral Economics. Course work and research in Mineral Economics emphasize the application of economic principles and business methods to mineral, energy, and related environmental and technological issues.

Students in the Mineral Economics Program select from one of two areas of specialization: Economics and Public Policy (E&PP) or Quantitative Business Methods/Operations Research (QBM/OR). The E&PP specialization focuses on the optimal use of scarce energy and mineral resources with a global perspective. It provides institutional knowledge coupled with economics, mathematical and statistical tools to analyze and understand how the world of energy and minerals works to guide and shape industry change. The QBM/OR specialization emphasizes the application of quantitative business methods such as optimization, simulation, decision analysis, and project management to minerals and energy related manufacturing, exploration, resource allocation, and other decision-making processes.

### *Fields of Research*

Faculty members carry out applied research in a variety of areas including international trade, resource economics, environmental economics, industrial organization, metal market analysis, energy economics, applied microeconomics, applied econometrics, management theory and practice, finance and investment analysis, exploration economics, decision analysis, utility theory, and corporate risk policy.

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### **Mineral Economics Program Requirements:**

**M.S. Degree** Students choose from either the thesis or non-thesis option in the Master of Science (M.S.) Program and are required to complete a minimum total of 36 credits (*a typical course has 3 credits*). Coursework is valid for seven years towards the M.S. degree; any exceptions must be approved by the division director and student advisor.

#### **Non-thesis option**

18 credits of core courses  
12 credits from one or both specializations  
6 credits of approved electives or a minor from another department

#### **Thesis option**

18 credits of core courses  
12 research credits  
6 credits from one or both specializations

**Ph.D. Degree.** Doctoral students develop a customized curriculum to fit their needs. The degree requires a minimum of 72 graduate credit hours that includes course work and a thesis. Coursework is valid for ten years towards a Ph.D. degree; any exceptions must be approved by the division director and student advisor.

#### **Course work**

24 credits of core courses  
12 credits from one or both specializations  
12 credits in a minor

#### **Research credits**

24 research credits. The student's faculty advisor and the doctoral thesis committee must approve the student's program of study and the topic for the thesis.

#### **Qualifying Examination Process**

Upon completion of the core course work, students must pass qualifying written examinations to become a candidate for the Ph.D. degree. The qualifying exam is given in two parts in August. Once qualified, the Ph.D. student is then required to complete an additional written and oral examination. This exam is prepared and administered by the student's thesis committee and is generally related to the student's thesis topic and the student's minor field.

#### **Minor from Another Department**

Non-thesis M.S. students may apply six elective credits towards a nine hour minor in another department. A minor is ideal for those students who want to enhance or gain knowledge in another field while gaining the economic and business skills to help them move up the career ladder. For example, a petroleum, chemical, or mining engineer might want to learn more about environmental engineering, a geophysicist or geologist might want to learn the latest techniques in their profession, or an economic policy analyst might want to learn about political risk. Students should check with the minor department for the opportunities and requirements for a minor.

#### **Transfer Credits**

Non-thesis M.S. students may transfer up to 6 credits (9 credits for a thesis M.S.). The student must have achieved a grade of B or better in all graduate transfer courses and the transfer credit must be approved by the student's advisor and the Division Director. Students who enter the Ph.D. program may transfer up to 24 hours of graduate-level course work from other institutions toward the Ph.D. degree subject to the restriction that those courses must not have been used as credit toward a Bachelor degree. The student must have achieved a grade of B or better in all graduate transfer courses and the transfer must be approved by the student's Doctoral Thesis Committee and the Division Director.

#### **Combined BS/MS Program**

Students enrolled in CSM's Combined Undergraduate/Graduate Program may double count 6 hours from their undergraduate course-work towards the non-thesis graduate program provided the courses satisfy the M.S. requirements.

#### **Joint Degrees**

The M.S. and Ph.D. degrees may be combined with a joint degree program with the Institut Français du Pétrole (IFP) in Petroleum Economics and Management (see <http://www.ifp.fr>)

The Division of Economic and Business (EB) at the Colorado School of Mines (CSM) and the IFP School at the Institut Français du Pétrole (IFP), in Paris France, together offer an advanced collaborative international graduate degree program geared to meet the needs of industry and government. Our unique program trains the next generation of technical, analytical and managerial professionals vital to the future of the petroleum and energy industries.

These two world-class institutions offer a rigorous and challenging program in an international setting. The program gives a small elite group of students a solid economics foundation combined with quantitative business skills, the historical and institutional background, and the interpersonal and intercultural abilities to in the fast paced, global world of oil and gas.

Degrees: After studying in English for only 16 months (8 months at CSM and 8 months at IFP) the successful student of Petroleum Economics and Management (PEM) receives not 1 but 2 degrees:

- ◆ Masters of Science in Mineral Economics from CSM and
- ◆ Diplôme D'Ingénieur or Mastère Spécialisé from IFP

Important: Applications for admission to the joint degree program should be submitted for consideration by March 1st to begin the program the following fall semester in August. A limited number of students are selected for the program each year.



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**Prerequisites for the Mineral Economics Programs:**

Students must have completed the following undergraduate prerequisite courses with a grade of B or better:

1. Principles of Microeconomics (EBGN311);
2. One semester of college-level Calculus (MATH111);
3. Probability and Statistics (MATH323 or MATH530)

Students entering in the fall semester must have completed the microeconomics and calculus prerequisites prior to starting the program; probability and statistics must be completed no later than the first semester of the graduate program. Students will only be allowed to enter in the spring semester if they have completed all three prerequisites courses previously, as well as an undergraduate course in mathematical economics.

**Required Course Curriculum in Mineral Economics:**

All M.S. and Ph.D. students in Mineral Economics are required to take a set of core courses that provide basic tools for the more advanced and specialized courses in the program.

**1. M.S. Curriculum**

**a. Core Courses (18 credits)**

EBGN509 Mathematical Economics  
EBGN510 Natural Resource Economics  
EBGN511 Microeconomics  
EBGN512 Macroeconomics  
EBGN525 Operations Research Methods  
EBGN590 Econometrics and Forecasting

**b. Area of Specialization Courses (12 credits for M.S. non-thesis option or 6 credits for M.S. thesis option)**

**Economics & Public Policy**

EBGN495 Economic Forecasting  
EBGN530 Economics of International Energy Markets  
EBGN535 Economics of Metal Industries and Markets  
EBGN536 Mineral Policies and International Investment  
EBGN541 International Trade  
EBGN542 Economic Development  
EBGN570 Environmental Economics  
EBGN610 Advanced Natural Resources  
EBGN611 Advanced Microeconomics  
EBGN690 Advanced Econometrics

**Quantitative Business Methods/Operations Research**

EBGN504 Economic Evaluation and Investment Decision Methods  
EBGN505 Industrial Accounting  
EBGN528 Industrial Systems Simulation  
EBGN545 Corporate Finance  
EBGN546 Investments and Portfolio Management  
EBGN547 Financial Risk Management  
EBGN552 Nonlinear Programming  
EBGN555 Linear Programming

EBGN556 Network Models  
EBGN557 Integer Programming  
EBGN559 Supply Chain Management  
EBGN560 Decision Analysis  
EBGN561 Stochastic Models in Management Science  
EBGN575 Advanced Mining and Energy Valuation  
EBGN580 Exploration Economics  
EBGN690 Advanced Econometrics

**2. Ph.D. Curriculum.**

**a. Common Core Courses (15 credits)**

EBGN509 Mathematical Economics  
EBGN510 Natural Resource Economics  
EBGN511 Microeconomics  
EBGN590 Econometrics and Forecasting  
EBGN695 Research Methodology

**b. Extended Core Courses - Economics (9 credits)**

EBGN512 Macroeconomics  
EBGN611 Advanced Microeconomics  
EBGN690 Advanced Econometrics

**c. Extended Core Courses - Operations Research (9 credits)**

EBGN528 Industrial Systems Simulation  
EBGN555 Linear Programming  
EBGN560 Decision Analysis

**d. Area of Specialization Courses (12 credits)**

**Economics & Public Policy**

EBGN495 Economic Forecasting  
EBGN530 Economics of International Energy Markets  
EBGN535 Economics of Metal Industries and Markets  
EBGN536 Mineral Policies and International Investment  
EBGN541 International Trade  
EBGN542 Economic Development  
EBGN570 Environmental Economics  
EBGN610 Advanced Natural Resources

**Quantitative Business Methods/Operations Research**

EBGN504 Economic Evaluation and Investment Decision Methods  
EBGN505 Industrial Accounting  
EBGN525 Operations Research Methods  
EBGN528 Industrial Systems Simulation  
EBGN545 Corporate Finance  
EBGN546 Investments and Portfolio Management  
EBGN547 Financial Risk Management  
EBGN552 Nonlinear Programming  
EBGN555 Linear Programming  
EBGN556 Network Models  
EBGN557 Integer Programming  
EBGN559 Supply Chain Management  
EBGN560 Decision Analysis



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EBGN561 Stochastic Models in Management Science  
EBGN575 Advanced Mining and Energy Valuation  
EBGN580 Exploration Economics

### *Engineering and Technology Management Program Description:*

The Division also offers an M.S. degree in Engineering and Technology Management (ETM). The ETM degree program is designed to integrate the technical elements of engineering practice with the managerial perspective of modern engineering and technology management. A major focus is on the business and management principles related to this integration. The ETM Program provides the analytical tools and managerial perspective needed to effectively function in a highly competitive and technologically complex business economy.

Students in the ETM Program may select from one of two areas of degree specialization: Operations/Engineering Management or Leadership and Strategy. The Operations/Engineering Management specialization emphasizes valuable techniques for managing large engineering and technical projects effectively and efficiently. In addition, special emphasis is given to advanced operations research, optimization, and decision making techniques applicable to a wide array of business and engineering problems. The Leadership and Strategy specialization teaches the correct match between organizational strategies and structures to maximize the competitive power of technology. This specialization has a particular emphasis on leadership and management issues associated with the modern business enterprise.

### *Engineering and Technology Management Program Requirements:*

Students choose either the thesis or non-thesis option and complete a minimum of 30 credit hours. Coursework is valid for seven years towards the M.S. degree in ETM; any exceptions must be approved by the division director and student advisor.

#### **Non-thesis option**

18 credits of core courses  
12 credits from one or both specializations

#### **Thesis option**

18 credits of core courses  
6 research credits  
6 credits from one or both specializations

Students must receive approval from their advisor in order to apply non-EB Division courses towards their ETM degree. Thesis students are required to complete 6 credit hours of thesis credit and complete a Master's level thesis under the direct supervision of the student's faculty advisor.

#### **Further Degree Requirements**

All thesis and non-thesis ETM Program students have two additional degree requirements: (1) the "Executive-in-Residence" seminar series; and (2) the ETM Communications Seminar. All students are required to attend the ETM

Program "Executive-in-Residence" seminar series during at least one semester of their attendance at CSM. The "Executive-in-Residence" series features executives from industry who pass on insight and knowledge to graduate students preparing for positions in industry. This series facilitates active involvement in the ETM program by industry executives through teaching, student advising activities and more. Every fall semester the "Executive-in-Residence" will present 5-7 one hour seminars on a variety of topics related to leadership and strategy in the engineering and technology sectors. In addition, all students are required to attend a two-day Communications Seminar during their attendance in the ETM Program. The seminar will be offered at the beginning of the fall semester. The seminar will provide students a comprehensive approach to good quality communication skills, including presentation proficiency, organizational skills, professional writing skills, meeting management, as well as other professional communication abilities. The Communications Seminar is designed to better prepare students for the ETM learning experience, as well as their careers in industry.

#### **Transfer Credits**

Students who enter the M.S. in Engineering and Technology Management program may transfer up to 6 graduate course credits from other educational institutions. The student must have achieved a grade of B or better in all graduate transfer courses and the transfer credit must be approved by the student's advisor and the Chair of the ETM Program.

#### *Prerequisites for ETM Program:*

1. Probability and Statistics (MATH323 or MATH530), and
2. Engineering Economics (EBGN321 or EBGN504).

Students not demonstrating satisfactory standing in these areas may be accepted; however, they will need to complete the deficiency prior to enrolling in courses that require these subjects as prerequisites. It is strongly suggested that students complete any deficiencies prior to enrolling in graduate degree course work.

### *Required Curriculum M.S. Degree Engineering and Technology Management*

Thesis and non-thesis students are required to complete the following 18 hours of core courses:

#### **a. Core Courses (18 credits)**

EBGN505 Industrial Accounting  
EBGN515 Economics and Decision Making  
EBGN525 Operations Research Methods  
EBGN545 Corporate Finance  
EBGN563 Management of Technology  
EBGN585 Engineering and Technology Management Capstone (to be taken during the final semester of coursework)

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**b. Areas of Specialization (12 credits required for non-thesis option or 6 credits required for thesis option)**

**Operations/Engineering Management:**

EBGN528 Industrial Systems Simulation  
EBGN552 Nonlinear Programming  
EBGN553 Project Management  
EBGN555 Linear Programming  
EBGN556 Network Models  
EBGN557 Integer Programming  
EBGN559 Supply Chain Management  
EBGN560 Decision Analysis  
EBGN561 Stochastic Models in Management Science  
EBGN568 Advanced Project Analysis

**Leadership and Strategy:**

EBGN564 Managing New Product Development  
EBGN565 Marketing for Technology-Based Companies  
EBGN566 Technology Entrepreneurship  
EBGN567 Business Law and Technology  
EBGN571 Marketing Research  
EBGN572 International Business Strategy  
EBGN574 Inventing, Patenting, and Licensing

***Course Descriptions in the Mineral Economics Program and the Engineering and Technology Management Program***

EBGN504 ECONOMIC EVALUATION AND INVESTMENT DECISION METHODS Time value of money concepts of present worth, future worth, annual worth, rate of return and break-even analysis are applied to after-tax economic analysis of mineral, petroleum and general investments. Related topics emphasize proper handling of (1) inflation and escalation, (2) leverage (borrowed money), (3) risk adjustment of analysis using expected value concepts, and (4) mutually exclusive alternative analysis and service producing alternatives. Case study analysis of a mineral or petroleum investment situation is required.

EBGN505 INDUSTRIAL ACCOUNTING Concepts from both financial and managerial accounting. Preparation and interpretation of financial statements and the use of this financial information in evaluation and control of the organization. Managerial concepts include the use of accounting information in the development and implementation of a successful global corporate strategy, and how control systems enhance the planning process.

EBGN509 MATHEMATICAL ECONOMICS This course reviews and re-enforces the mathematical and computer tools that are necessary to earn a graduate degree in Mineral Economics. It includes topics from differential and integral calculus; probability and statistics; algebra and matrix algebra; difference equations; and linear, mathematical and dynamic programming. It shows how these tools are applied in an economic and business context with applications taken from the

mineral and energy industries. It requires both analytical as well as computer solutions. At the end of the course you will be able to appreciate and apply mathematics for better personal, economic and business decision making. Prerequisites: MATH111, EBG311; or permission of instructor.

EBGN510 NATURAL RESOURCE ECONOMICS The threat and theory of resource exhaustion; commodity analysis and the problem of mineral market instability; cartels and the nature of mineral pricing; the environment; government involvement; mineral policy issues; and international mineral trade. This course is designed for entering students in mineral economics. Prerequisites: EBG311 or permission of instructor.

EBGN511 MICROECONOMICS The first of two courses dealing with applied economic theory. This part concentrates on the behavior of individual segments of the economy, the theory of consumer behavior and demand, the theory of production and costs, duality, welfare measures, price and output level determination by business firms, and the structure of product and input markets. Prerequisites: MATH111, EBG311, EBG509; or permission of instructor.

EBGN512 MACROECONOMICS This course will provide an introduction to contemporary macroeconomic concepts and analysis. Macroeconomics is the study of the behavior of the economy as an aggregate. Topics include the equilibrium level of inflation, interest rates, unemployment and the growth in national income. The impact of government fiscal and monetary policy on these variables and the business cycle, with particular attention to the effects on the mineral industry. Prerequisites: MATH111, EBG311, EBG509; or permission of instructor.

EBGN515 ECONOMICS AND DECISION MAKING The application of microeconomic theory to business strategy. Understanding the horizontal, vertical, and product boundaries of the modern firm. A framework for analyzing the nature and extent of competition in a firm's dynamic business environment. Developing strategies for creating and sustaining competitive advantage. Mineral Economics students will not receive degree credits for this course (except joint degree IFP students, see Division Director).

EBGN525 OPERATIONS RESEARCH METHODS The core of this course is a scientific approach to planning and decision-making problems that arise in business. The course covers deterministic optimization models (linear programming, integer programming and network modeling) and a brief introduction to stochastic (probabilistic) models with Monte-Carlo simulation. Applications of the models are covered using spreadsheets. The intent of the course is to enhance logical modeling ability and to develop quantitative managerial and spreadsheet skills. The models cover applications in the areas of energy and mining, marketing, finance, production, transportation, logistics and work-force scheduling.

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**EBGN528 INDUSTRIAL SYSTEMS SIMULATION** The course focuses on creating computerized models of real or proposed complex systems for performance evaluation. Simulation provides a cost effective way of pre-testing proposed systems and answering “what-if” questions before incurring the expense of actual implementations. The course is instructed in the state-of-the-art computer lab (CTLM), where each student is equipped with a personal computer and interacts with the instructor during the lecture. Professional version of a widely used commercial software package, “Arena”, is used to build models, analyze and interpret the results. Other business analysis and productivity tools that enhance the analysis capabilities of the simulation software are introduced to show how to search for optimal solutions within the simulation models. Both discrete-event and continuous simulation models are covered through extensive use of applications including call centers, various manufacturing operations, production/inventory systems, bulk-material handling and mining, port operations, high-way traffic systems and computer networks. Prerequisite: MATH530, <sup>1</sup> or permission of instructor.

**EBGN530 ECONOMICS OF INTERNATIONAL ENERGY MARKETS** Application of models to understand markets for oil, gas, coal, electricity, and renewable energy resources. Models, modeling techniques, and issues included are supply and demand, market structure, transportation models, game theory, futures markets, environmental issues, energy policy, energy regulation, input/output models, energy conservation, and dynamic optimization. The emphasis in the course is on the development of appropriate models and their application to current issues in energy markets. Prerequisites: MATH111, EBG311, EBG509, EBG511 or permission of instructor.

**EBGN535 ECONOMICS OF METAL INDUSTRIES AND MARKETS** Metal supply from main product, byproduct, and secondary production. Metal demand and intensity of use analysis. Market organization and price formation. Public policy, comparative advantage, and international metal trade. Metals and economic development in the developing countries and former centrally planned economies. Environmental policy and mining and mineral processing. Students prepare and present a major research paper. Prerequisites: MATH111, EBG311, EBG510; or permission of instructor.

**EBGN536 MINERAL POLICIES & INTERNATIONAL INVESTMENT** Identification and evaluation of international mineral investment policies and company responses using economic, business and legal concepts. Assessment of policy issues in light of stakeholder interests and needs. Theoretical issues are introduced and then applied to case studies, policy drafting, and negotiation exercises to assure both conceptual and practical understanding of the issues. Special attention is given to the formation of national policies and corporate decision making concerning fiscal regimes, project financing, environmental protection, land use and

local community concerns and the content of exploration and extraction agreements. Prerequisite: permission of instructor.

**EBGN541 INTERNATIONAL TRADE** Theories and evidence on international trade and development. Determinants of static and dynamic comparative advantage. The arguments for and against free trade. Economic development in non-industrialized countries. Sectoral development policies and industrialization. The special problems and opportunities created by extensive mineral resource endowments. The impact of value-added processing and export diversification on development. Prerequisites: MATH111, EBG311, EBG509, EBG511; or permission of instructor.

**EBGN542 ECONOMIC DEVELOPMENT** Role of energy and minerals in the development process. Sectoral policies and their links with macroeconomic policies. Special attention to issues of revenue stabilization, resource largesse effects, downstream processing, and diversification. Prerequisites: MATH111, EBG311, EBG509, EBG511, EBG512; or permission of instructor.

**EBGN545 CORPORATE FINANCE** The fundamentals of corporate finance as they pertain to the valuation of investments, firms, and the securities they issue. Included are the relevant theories associated with capital budgeting, financing decisions, and dividend policy. This course provides an in-depth study of the theory and practice of corporate financial management including a study of the firm’s objectives, investment decisions, long-term financing decisions, and working capital management. Prerequisite: EBG505<sup>2</sup> or permission of instructor.

**EBGN546 INVESTMENT AND PORTFOLIO MANAGEMENT** The theory and practice of investment, providing a comprehensive understanding of the dynamics of securities markets, valuation techniques and trading strategies for stocks, bonds, and derivative securities. It includes the mean-variance efficient portfolio theory, the arbitrage pricing theory, bond portfolio management, investment management functions and policies, and portfolio performance evaluation. Prerequisites: MATH111, EBG311, EBG545, EBG505,<sup>2</sup> or permission of instructor. Recommended: EBG509, EBG511.

**EBGN547 FINANCIAL RISK MANAGEMENT** Analysis of the sources, causes and effects of risks associated with holding, operating and managing assets by individuals and organizations; evaluation of the need and importance of managing these risks; and discussion of the methods employed and the instruments utilized to achieve risk shifting objectives. The course concentrates on the use of derivative assets in the risk management process. These derivatives include futures, options, swaps, swaptions, caps, collars and floors. Exposure to market and credit risks will be explored and ways of handling them will be reviewed and critiqued through analysis of case studies from the mineral and energy

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industries. Prerequisites: MATH111, EBG311, EBG505<sup>2</sup>, EBG545 or EBG546; or permission of instructor. Recommended: EBG509, EBG511.

**EBGN552 NONLINEAR PROGRAMMING** As an advanced course in optimization, this course will address both unconstrained and constrained nonlinear model formulation and corresponding algorithms (e.g., Gradient Search and Newton's Method, and Lagrange Multiplier Methods and Reduced Gradient Algorithms, respectively). Applications of state-of-the-art hardware and software will emphasize solving real-world problems in areas such as mining, energy, transportation, and the military. Prerequisite: EBG555 or permission of instructor.

**EBGN553 PROJECT MANAGEMENT** An introductory course focusing on analytical techniques for managing projects and on developing skills for effective project leadership and management through analysis of case studies. Topics include project portfolio management, decomposition of project work, estimating resource requirements, planning and budgeting, scheduling, analysis of uncertainty, resource loading and leveling, project monitoring and control, earned value analysis and strategic project leadership. Guest speakers from industry discuss and amplify the relevance of course topics to their specific areas of application (construction, product development, engineering design, R&D, process development, etc.). Students learn Microsoft Project and complete a course project using this software, demonstrating proficiency analyzing project progress and communicating project information to stakeholders. Prerequisite: EBG504<sup>3</sup> or permission of instructor.

**EBGN555 LINEAR PROGRAMMING** This course addresses the formulation of linear programming models, examines linear programs in two dimensions, covers standard form and other basics essential to understanding the Simplex method, the Simplex method itself, duality theory, complementary slackness conditions, and sensitivity analysis. As time permits, multi-objective programming, an introduction to linear integer programming, and the interior point method are introduced. Applications of linear programming models discussed in this course include, but are not limited to, the areas of manufacturing, finance, energy, mining, transportation and logistics, and the military. Prerequisite: MATH332 or EBG509 or permission of instructor. 3 hours lecture; 3 semester hours.

**EBGN556 NETWORK MODELS** Network models are special cases of linear programming problems that possess special mathematical structures. This course examines a variety of network models, specifically, spanning tree problems, shortest path problems, maximum flow problems, minimum cost flow problems, and transportation and assignment problems. For each class of problem, we present applications in areas such as manufacturing, finance, energy, mining, transportation and logistics, and the military. We also discuss an

algorithm or two applicable to each problem class. As time permits, we explore combinatorial problems that can be depicted on graphs, e.g., the traveling salesman problem and the Chinese postman problem, and discuss the tractability issues associated with these problems in contrast to "pure" network models. Prerequisites: EBG555 or EBG525 or permission of the instructor.

**EBGN557 INTEGER PROGRAMMING** As an advanced course in optimization, this course will address computational performance of linear and linear-integer optimization problems, and, using state-of-the-art hardware and software, will introduce solution techniques for "difficult" optimization problems. We will discuss such methodologies applied to the monolith (e.g., branch-and-bound and its variations, cutting planes, strong formulations), as well as decomposition and reformulation techniques (e.g., Lagrangian relaxation, Benders decomposition, column generation). Additional "special topics" may be introduced, as time permits. Prerequisite: EBG555 or permission of instructor.

**EBGN559 SUPPLY CHAIN MANAGEMENT** The focus of the course is to show how a firm can achieve better "supply-demand matching" through the implementation of rigorous mathematical models and various operational/tactical strategies. We look at organizations as entities that must match the supply of what they produce with the demand for their products. A considerable portion of the course is devoted to mathematical models that treat uncertainty in the supply-chain. Topics include managing economies of scale for functional products, managing market-mediation costs for innovative products, make-to order versus make-to-stock systems, quick response strategies, risk pooling strategies, supply-chain contracts and revenue management. Additional "special topics" may be introduced, such as reverse logistics issues in the supply-chain or contemporary operational and financial hedging strategies, as time permits. Prerequisite: MATH530,<sup>1</sup> or permission of instructor.

**EBGN560 DECISION ANALYSIS** Introduction to the science of decision making and risk theory. Application of decision analysis and utility theory to the analysis of strategic decision problems. Focuses on the application of quantitative methods to business problems characterized by risk and uncertainty. Choice problems such as decisions concerning major capital investments, corporate acquisitions, new product introductions, and choices among alternative technologies are conceptualized and structured using the concepts introduced in this course. Prerequisite: EBG504,<sup>3</sup> or permission of instructor.

**EBGN561 STOCHASTIC MODELS IN MANAGEMENT SCIENCE** The course introduces tools of "probabilistic analysis" that are frequently used in the formal studies of management. We see methodologies that help to quantify the dynamic relationships of sequences of "random" events that evolve over time. Topics include static and dynamic Monte-Carlo simulation, discrete and continuous time Markov



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Chains, probabilistic dynamic programming, Markov decision processes, queuing processes and networks, Brownian motion and stochastic control. Applications from a wide range of fields will be introduced including marketing, finance, production, logistics and distribution, energy and service systems. In addition to an intuitive understanding of analytical techniques to model stochastic processes, the course emphasizes how to use related software packages for managerial decision-making. Prerequisite: MATH530,<sup>1</sup> or permission of instructor.

**EBGN563 MANAGEMENT OF TECHNOLOGY** Case studies and reading assignments explore strategies for profiting from technology assets and technological innovation. The roles of strategy, core competencies, product and process development, manufacturing, R&D, marketing, strategic partnerships, alliances, intellectual property, organizational architectures, leadership and politics are explored in the context of technological innovation. The critical role of organizational knowledge and learning in a firm's ability to leverage technological innovation to gain competitive advantage is explored. The relationships between an innovation, the competencies of the innovating firm, the ease of duplication of the innovation by outsiders, the nature of complementary assets needed to successfully commercialize an innovation and the appropriate strategy for commercializing the innovation are developed. Students explore the role of network effects in commercialization strategies, particularly with respect to standards wars aimed at establishing new dominant designs. Prerequisite: EBG504<sup>3</sup> recommended.

**EBGN564 MANAGING NEW PRODUCT DEVELOPMENT** Develops interdisciplinary skills required for successful product development in today's competitive marketplace. Small product development teams step through the new product development process in detail, learning about available tools and techniques to execute each process step along the way. Each student brings his or her individual disciplinary perspective to the team effort, and must learn to synthesize that perspective with those of the other students in the group to develop a sound, marketable product. Prerequisite: EBG563 recommended.

**EBGN565 MARKETING FOR TECHNOLOGY-BASED COMPANIES** This class explores concepts and practices related to marketing in this unique, fast-paced environment, including the defining characteristics of high-technology industries; different types and patterns of innovations and their marketing implications; the need for (and difficulties in) adopting a customer-orientation; tools used to gather marketing research/intelligence in technology-driven industries; use of strategic alliances and partnerships in marketing technology; adaptations to the "4 P's"; regulatory and ethical considerations in technological arenas. Prerequisite: Permission of instructor.

**EBGN566 TECHNOLOGY ENTREPRENEURSHIP** Introduces concepts related to starting and expanding a technological-based corporation. Presents ideas such as developing a business and financing plan, role of intellectual property, and the importance of a good R&D program. Prerequisite: Permission of instructor.

**EBGN567 BUSINESS LAW AND TECHNOLOGY** Computer software and hardware are the most complex and rapidly developing intellectual creations of modern man. Computers provide unprecedented power in accessing and manipulating data. Computers work in complex systems that require standardization and compatibility to function. Each of these special features has engendered one or more bodies of law. Complex intellectual creation demands comprehensive intellectually property protection. Computer technology, however, differs fundamentally from previous objects of intellectual property protection, and thus does not fit easily into traditional copyright and patent law. This course covers topics that relate to these complex special features of computer and technology. Prerequisite: Permission of instructor.

**EBGN568 ADVANCED PROJECT ANALYSIS** An advanced course in economic analysis that will look at more complex issues associated with valuing investments and projects. Discussion will focus on development and application of concepts in after-tax environments and look at other criteria and their impact in the decision-making and valuation process. Applications to engineering and technology aspects will be discussed. Effective presentation of results will be an important component of the course. Prerequisite: Permission of instructor.

**EBGN570 ENVIRONMENTAL ECONOMICS** The role of markets and other economic considerations in controlling pollution; the effect of environmental policy on resource allocation incentives; the use of benefit/cost analysis in environmental policy decisions and the associated problems with measuring benefits and costs. Prerequisite: EBG509 or permission of instructor.

**EBGN571 MARKETING RESEARCH** The purpose of this course is to gain a deep understanding of the marketing research decisions facing product managers in technology based companies. While the specific responsibilities of a product manager vary across industries and firms, three main activities common to the position are: (1) analysis of market information, (2) marketing strategy development, and (3) implementing strategy through marketing mix decisions. In this course students will develop an understanding of available marketing research methods and the ability to use marketing research information to make strategic and tactical decisions. Prerequisite: MATH530<sup>1</sup>.

**EBGN572 INTERNATIONAL BUSINESS STRATEGY** The purpose of this course is to gain understanding of the complexities presented by managing businesses in an international environment. International business has grown



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rapidly in recent decades due to technological expansion, liberalization of government policies on trade and resource movements, development of institutions needed to support and facilitate international transactions, and increased global competition. Due to these factors, foreign countries increasingly are a source of both production and sales for domestic companies. Prerequisite: Permission of the instructor.

#### EBGN574 INVENTING, PATENTING, AND LICENSING

The various forms of intellectual property, including patents, trademarks, copyrights, trade secrets and unfair competition are discussed; the terminology of inventing, patenting and licensing is reviewed, and an overview of the complete process is given; the statutes most frequently encountered in dealing with patents (35 USC §101, §102, §103 and §112) are introduced and explained; the basics of searching the prior art are presented; participants 'walk through' case histories illustrating inventing, patenting, licensing, as well as patent infringement and litigation; the importance of proper documentation at all stages of the process is explained; the "do's" and "don't" of disclosing inventions are presented; various types of agreements are discussed including license agreements; methods for evaluating the market potential of new products are presented; the resources available for inventors are reviewed; inventing and patenting in the corporate environment are discussed; the economic impacts of patents are addressed. Prerequisite: Permission of instructor. Offered in Field session and Summer session only.

EBGN575 ADVANCED MINING AND ENERGY VALUATION The use of stochastic and option pricing techniques in mineral and energy asset valuation. The Hotelling Valuation Principle. The measurement of political risk and its impact on project value. Extensive use of real cases. Prerequisites: MATH111, EBG311, EBG504,<sup>3</sup> EBG505,<sup>2</sup> EBG509, EBG510, EBG511; or permission of instructor.

EBGN580 EXPLORATION ECONOMICS Exploration planning and decision making for oil and gas, and metallic minerals. Risk analysis. Historical trends in exploration activity and productivity. Prerequisites: EBG311, EBG510; or permission of instructor. Offered when student demand is sufficient.

EBGN585 ENGINEERING AND TECHNOLOGY MANAGEMENT CAPSTONE This course represents the culmination of the ETM Program. This course is about the strategic management process – how strategies are developed and implemented in organizations. It examines senior management's role in formulating strategy and the role that all an organization's managers play in implementing a well thought out strategy. Among the topics discussed in this course are (1) how different industry conditions support different types of strategies; (2) how industry conditions change and the implication of those changes for strategic management; and (3) how organizations develop and maintain capabilities that lead to sustained competitive advantage. This course consists of learning fundamental concepts associated with strategic

management process and competing in a web-based strategic management simulation to support the knowledge that you have developed.

#### EBGN590 ECONOMETRICS AND FORECASTING

Using statistical techniques to fit economic models to data. Topics include ordinary least squares and single equation regression models; two stage least squares and multiple equation econometric models; specification error, serial correlation, heteroskedasticity; distributive lag; applications to mineral commodity markets; hypothesis testing; forecasting with econometric models, time series analysis, and simulation. Prerequisites: MATH111, MATH530,<sup>1</sup> EBG311.

EBGN598 SPECIAL TOPICS IN ECONOMICS AND BUSINESS Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Repeatable for credit under different titles.

EBGN599 INDEPENDENT STUDY Individual research or special problem projects supervised by a faculty member when a student and instructor agree on a subject matter, content, and credit hours. Contact the Economics and Business Division office for credit limits toward the degree.

EBGN610 ADVANCED NATURAL RESOURCE ECONOMICS Optimal resource use in a dynamic context using mathematical programming, optimal control theory and game theory. Constrained optimization techniques are used to evaluate the impact of capital constraints, exploration activity and environmental regulations. Offered when student demand is sufficient. Prerequisites: MATH111, MATH530,<sup>1</sup> EBG311, EBG509, EBG510, EBG511; or permission of instructor.

EBGN611 ADVANCED MICROECONOMICS A second graduate course in microeconomics, emphasizing state-of-the-art theoretical and mathematical developments. Topics include consumer theory, production theory and the use of game theoretic and dynamic optimization tools. Prerequisites: MATH111, MATH530,<sup>1</sup> EBG311, EBG509, EBG511; or permission of instructor.

EBGN690 ADVANCED ECONOMETRICS A second course in econometrics. Compared to EBG590, this course provides a more theoretical and mathematical understanding of econometrics. Matrix algebra is used and model construction and hypothesis testing are emphasized rather than forecasting. Prerequisites: MATH111, MATH530,<sup>1</sup> EBG311, EBG509, EBG590; or permission of instructor. Recommended: EBG511.

EBGN695 RESEARCH METHODOLOGY Lectures provide an overview of methods used in economic research relating to EPP and QBA/OR dissertations in Mineral Economics and information on how to carry out research and present research results. Students will be required to write and present a research paper that will be submitted for publication. It is expected that this paper will lead to a Ph.D.

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dissertation proposal. It is a good idea for students to start thinking about potential dissertation topic areas as they study for their qualifier. This course is also recommended for students writing Master's thesis or who want guidance in doing independent research relating to the economics and business aspects of energy, minerals and related environmental and technological topics. Prerequisites: MATH530,<sup>1</sup> EBG509, EBG510, EBG511, EBG590, or permission of instructor.

**EBGN698 SPECIAL TOPICS IN ECONOMICS AND BUSINESS** Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Repeatable for credit under different titles.

**EBGN699 INDEPENDENT STUDY** Individual research or special problem projects supervised by a faculty member when a student and instructor agree on a subject matter, content, and credit hours. Contact the Economics and Business Division office for credit limits toward the degree.

**EBGN705. GRADUATE RESEARCH: MASTER OF SCIENCE** Research credit hours required for completion of the Master of Science with Thesis degree. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

**EBGN706. GRADUATE RESEARCH: DOCTOR OF PHILOSOPHY** Research credit hours required for completion of the Doctor of Philosophy degree. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

#### *Notes*

<sup>1</sup>MATH323 may be substituted for MATH530.

<sup>2</sup>EBGN305 and EBG306 together may be substituted for EBG505 with permission.

<sup>3</sup>EBGN321 may be substituted for EBG504.

## **Engineering**

TERENCE E. PARKER, Professor and Division Director  
WILLIAM A. HOFF, Associate Professor and Assistant Division Director

D. VAUGHAN GRIFFITHS, Professor

ROBERT J. KEE, George R. Brown Distinguished Professor

ROBERT H. KING, Professor

KEVIN MOORE, Gerard August Dobelman Chair and Professor  
NING LU, Professor

MARK T. LUSK, Professor (and Professor of Physics)

NIGEL T. MIDDLETON, Professor, Executive Vice President for Academic Affairs, and Dean of Faculty

GRAHAM G. W. MUSTOE, Professor

PANKAJ K. (PK) SEN, Professor

JOEL M. BACH, Associate Professor

JOHN R. BERGER, Associate Professor

PANOS D. KIOUSIS, Associate Professor

MICHAEL MOONEY, Associate Professor

DAVID MUNOZ, Associate Professor

PAUL PAPAS, Associate Professor

MARCELO GODOY SIMOES, Associate Professor

JOHN P. H. STEELE, Associate Professor

CATHERINE K. SKOKAN, Associate Professor

TYRONE VINCENT, Associate Professor

RAY RUICHONG ZHANG, Associate Professor

CRISTIAN V. CIOBANU, Assistant Professor

KATHRYN JOHNSON, Clare Boothe Luce Assistant Professor

CARSTEN R. MEHRING, Assistant Professor

ANTHONY J. PETRELLA, Assistant Professor

SIDDHARTH SURYANARAYANAN, Assistant Professor

NEAL SULLIVAN, Assistant Professor

MONEESH UPMANYU, Assistant Professor

JUDITH WANG, Assistant Professor

MANOJA WEISS, Assistant Professor

RICHARD PASSAMANECK, Senior Lecturer

SANAA ABDEL-AZIM, Lecturer

RAVEL F. AMMERMAN, Lecturer

CARA COAD, Lecturer

JOSEPH P. CROCKER, Lecturer

TOM GROVER, Lecturer

CANDACE S. SULZBACH, Lecturer

ROBERT D. SUTTON, Lecturer

HAROLD W. OLSEN, Research Professor

CHRISTOPHER B. DRYER, Assistant Research Assistant Professor

JOAN P. GOSINK, Emerita Professor

MICHAEL B. McGRATH, Emeritus Professor

KARL R. NELSON, Emeritus Associate Professor

GABRIEL M. NEUNZERT, Emeritus Associate Professor

Note: Faculty for the environmental engineering specialty are listed in the Environmental Science and Engineering section of this Bulletin.

### *Degrees Offered:*

Master of Science (Engineering)

Doctor of Philosophy (Engineering)

### *Program Overview:*

The Engineering program offers a multidisciplinary graduate education **with an option to specialize in one of the three disciplines—Civil, Electrical or Mechanical Engineering**. Students may also choose a more interdisciplinary

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degree with a specialty title “Engineering Systems”. The program demands academic rigor and depth yet also addresses the real-world problems in advanced engineering and technology. The Division of Engineering has seven areas of research activities: (1) Sensing, Communications and Control, (2) Energy Systems and Power Electronics, (3) Geotechnical Engineering, (4) Structural Engineering, (5) Material Mechanics, (6) Fluid Mechanics and Thermal Sciences and (7) Bioengineering. Note that in many cases, individual research projects encompass more than one research area.

**Sensing, Communications and Control** is an interdisciplinary research area that encompasses the fields of control systems, wireless communications, signal and image processing, robotics, and mechatronics. Focus areas include adaptive and nonlinear control, intelligent and learning control systems, fault detection and system identification, wireless communication circuits, computer vision and pattern recognition, sensor development, mobile manipulation and autonomous systems. Applications can be found in renewable energy and power systems, materials processing, sensor and control networks, bio-engineering, intelligent structures, and geosystems. Participating graduate students come from a variety of backgrounds, and may specialize in civil, mechanical or electrical engineering, or engineering systems.

**Energy Systems and Power Electronics** is focused on both fundamental and applied research in the interrelated fields of conventional electric power systems and electric machinery, renewable energy and distributed generation, power electronics and drives. The overall scope of research encompasses a broad spectrum of electrical energy applications including investor-owned utilities, rural electric associations, manufacturing facilities, regulatory agencies, and consulting engineering firms.

**Geotechnical Engineering** has current activity in computational and analytical geomechanics, probabilistic geotechnics, experimental and theoretical investigations into coupled flows and unsaturated soil behavior, and intelligent geosystems including geo-construction sensing and automation. The geotechnical faculty and students work primarily within the Civil Specialty of the Engineering graduate programs, however strong interdisciplinary ties are maintained with other groups in Engineering and with other Departments at CSM.

**Structural Engineering** focuses on frontier, multidisciplinary research in the following areas: high strength and self-consolidating concrete, experimental and computational structural dynamics, vibration control, damage diagnosis, and advanced data processing and analysis for sensory systems, disaster assessment and mitigation, and structural non-destructive evaluation.

**Material Mechanics** investigations consider solid-state material behavior as it relates to microstructural evolution and control, nano-mechanics, functionally graded materials, biomaterial analysis and characterization, artificial bio-

material design, and fracture mechanics. Research in this area tends to have a strong computational physics component covering a broad range of length and time scales that embrace ab initio calculations, molecular dynamics, Monte Carlo and continuum modeling. These tools are used to study metallic and ceramic systems as well as natural biomaterials. Strong ties exist between this group and activities within the campus communities of physics, materials science, mathematics and chemical engineering.

**Fluid Mechanics and Thermal Sciences** is a research area with a wide array of multidisciplinary applications including clean energy systems, materials processing, combustion, and bioengineering. Graduate students in this area typically specialize in Mechanical Engineering but also have the opportunity to specialize in interdisciplinary programs such as Materials Science.

**BioEngineering** focuses on the application of engineering principles to the musculoskeletal system and other connective tissues. Research activities include experimental, computational, and theoretical approaches with applications in the areas of computer assisted surgery and medical robotics, medical imaging, patient specific biomechanical modeling, intelligent prosthetics and implants, bioinstrumentation, and supermolecular biomaterials. The Bioengineering group has strong research ties with other campus departments, the local medical community, and industry partners.

### **Program Details**

The M.S. Engineering degree (Thesis or Non-Thesis Option) requires 30 credit hours. Requirements for the thesis M.S. are 24 hours of coursework and 6 hours of thesis research. The non-thesis option requires 30 hours of coursework. For the M.S. degree, a maximum of 9 credits can be transferred in from another institution. Graduate level courses taken at other universities for which a grade equivalent to a “B” or better was received will be considered for transfer credit via a petition to the Division Director.

In addition, the Division of Engineering in collaboration with the Departments of Physics and Chemistry offers five-year programs in which students have the opportunity to obtain specific engineering skills to complement their physics or chemistry background. The Physics five-year program offers tracks in Electrical Engineering and Mechanical Engineering. Details on these five-year programs can be found in the CSM Undergraduate Bulletin. Course schedules for these five-year programs can be obtained in the Engineering, Physics and Chemistry Departmental Offices.

The Ph.D. Engineering degree requires 72 credit hours of course work and research credits. Graduate level courses taken at other universities for which a grade equivalent to a “B” or better was received will be considered for transfer credit via a petition to the Division Director.

Students must have an advisor from the Engineering Division Graduate Faculty to direct and monitor their academic plan, research and independent studies. Master of Science (thesis option) students must have at least three members on their graduate committee, two of whom must be permanent faculty in the Engineering Division. Ph.D. graduate committees must have at least five members; at least three members must be permanent faculty in the Engineering Division, and at least one member must be from the department in which the student is pursuing a minor program. The minor program of study provides breadth in the degree through formal coursework.

Doctoral students must pass a Qualifying Examination, which is intended to gauge the student's capability to pursue research in Engineering. Normally, Ph.D. students will take the Qualifying Examination in their first year, but it must be taken within three semesters of entering the program. Within 18 months after passing the Qualifying Examination, the Ph.D. student must prepare a written Thesis Proposal and present it formally to the graduate committee and other interested faculty. Approval of the Thesis Proposal by the graduate thesis committee constitutes admission to candidacy for the Ph.D. Students should endeavor to achieve this milestone within twelve months of passing the Qualifying Examination.

At the conclusion of the M.S. (Thesis Option) and Ph.D. programs, the student will be required to make a formal presentation and defense of her/his thesis research.

### *Prerequisites*

The requirements for admission for the M.S., and Ph.D. degrees in Engineering are a baccalaureate degree in engineering, computer science, a physical science, or math with a grade-point average over 3.0/4.0; Graduate Record Examination score of 650 (math) and a TOEFL score of 550 or higher (paper based), 213 (computer based) for applicants whose native language is not English. Applicants from an engineering program at CSM are not required to submit GRE scores.

The Engineering Graduate committee evaluating an applicant may require that the student take undergraduate remedial coursework to overcome technical deficiencies, which does not count toward the graduate program. The committee will decide whether to recommend to the Dean of Graduate Studies and Research regular or provisional admission, and may ask the applicant to come for an interview.

As stipulated by the CSM Graduate School, no more than 9 400-level credits of course work may be counted towards any graduate degree. In general, the student cannot use 400 level course credits that have been previously used to obtain the Bachelor of Science degree. This requirement must be taken into account as students choose courses for each degree program detailed below. For all of the Engineering Degrees, a maximum of 6 Independent Study course units, as appropri-

ate to the degree structure, can be used to fulfill degree requirements.

### *Engineering Systems Specialty (EGGN)*

Graduate students who choose an interdisciplinary education in Engineering Systems may do so using the curriculum below.

#### **M.S. Degree (EGGN)**

##### *Required Core:*

EGGN501 Advanced Engineering Measurements	4 cr
EGGN502 Interdisciplinary Modeling and Simulation	4 cr
EGGN504 Engineering Systems (Any Specialty) Seminar	1 cr

##### Technical Electives

(Thesis Option: Courses must be approved by the graduate thesis committee) 15 cr

(Non-Thesis Option: Courses must be approved by the faculty advisor) 21 cr

Thesis Research (Thesis Option) 6 cr

*Total* 30 cr

#### **Ph.D. Degree (EGGN)**

##### *Required Core:*

EGGN501 Advanced Engineering Measurements	4 cr
EGGN502 Interdisciplinary Modeling and Simulation	4 cr
EGGN504 Engineering Systems (Any Specialty) Seminar	1 cr

Minor Program of Study 12 cr

##### Technical Electives

(must be approved by the graduate thesis committee) 27 cr

Thesis Research 24 cr

*Total* 72 cr

### *Civil Engineering Specialty (EGGN-CE)*

There are two main emphasis areas within the Civil Engineering specialty in: (1) Geotechnical engineering, and (2) Structural engineering. However thesis research activities will regularly overlap with the other emphasis areas within the Division as listed in the Program Description above. The intent is to offer a highly flexible curriculum that will be attractive to candidates seeking Civil Engineering careers in either industry or academe. In addition to the Civil Engineering courses offered within the Engineering Division, technical electives will be available from other CSM departments such as Environmental Science and Engineering, Geological Engineering and Mining, as well as Electrical and Mechanical courses from within the Engineering Division.



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**M.S. Degree (EGGN-CE)**

Must take at least three courses from the list of Engineering (Civil Speciality) Courses.	9 cr
EGGN504 Engineering (Civil) Seminar	1 cr
Technical Electives (Thesis option: Courses must be approved by the Thesis Committee)	14 cr
(Non-Thesis option: Courses must be approved by the Faculty Advisor)	20 cr
Non-thesis students may include up to 6 cr hours of Independent Study (EGGN 599)	
Thesis Research (Thesis Option)	6 cr
<i>Total</i>	30 cr

**Ph.D. Degree (EGGN-CE)**

Must take at least three courses from the list of Civil Engineering Courses	9 cr
EGGN504 Engineering Systems (Civil) Seminar	1 cr
Minor Program of Study	12 cr
Technical Electives Approved by the graduate committee	26 cr
Thesis Research	24 cr
<i>Total</i>	72 cr

**Ph.D. Qualifying Exam (Civil Speciality)**

Engineering (Civil Specialty) students wishing to enroll in the PhD program will be required to pass a Qualifying Exam. Normally, PhD. students will take the Qualifying Exam in their first year, but it must be taken within three semesters of entering the program.

The exam will have two parts:

1. The Advisor will coordinate with the Civil faculty to generate a written take-home exam based on materials covered in the students area of interest. This will typically involve two questions, and may cover material from the Engineering (Civil Specialty) core courses.

2. A written report (approx 10 pages) and oral presentation based on a topic that will be chosen by the graduate student's committee. The report will typically be a review paper on a research theme that will be related to the student's area of interest and likely thesis topic. The purpose of this requirement, is to examine some of the attributes expected of a successful PhD candidate. These include, but are not restricted to:

- ◆ The ability to perform a literature review through libraries and internet sites;
- ◆ The ability to distill information into a written report;
- ◆ The ability to produce a high quality written and oral presentation.

The research theme for the written report will be provided at the same time as the questions in part one above. All written material will be due one week later. As early as pos-

sible after that time, a one hour meeting will be scheduled for the student to make his/her oral presentation. After the oral, the student will be questioned on the presentation and on any other issues relating to the written report and take home examination.

**Electrical Engineering Specialty (EGGN-EE)**

Within the Electrical Engineering specialty, there are two emphasis areas: (1) Sensing, Communications and Control, and (2) Energy Systems and Power Electronics. Students are encouraged to decide between emphasis areas before pursuing an advanced degree. Students are also encouraged to speak to members of the EE graduate faculty before registering for classes and to select an academic advisor as soon as possible.

**M.S. Degree (EGGN-EE)**

Must take at least two courses from the list of core Electrical Engineering Courses	6 cr
EGGN504 Engineering (Electrical) Seminar	1 cr
Must take at least four courses in one of the two emphasis areas	12 cr
Technical Electives (Thesis Option: Courses must be approved by the thesis committee)	5 cr
<i>or</i>	
(Non-Thesis Option: Courses must be approved by the faculty advisor)	11 cr
Thesis Research (Thesis Option)	6 cr
<i>Total</i>	30 cr

**Ph.D. Degree (EGGN-EE)**

Must take at least two courses from the list of core Electrical Engineering Courses	6 cr
EGGN504 Engineering (Electrical) Seminar	1 cr
Must take at least four courses in one of the two emphasis areas	12 cr
Thesis Research	24 cr
Minor Program of Study (approved by the thesis committee)	12 cr
Technical Electives (must be approved by the thesis committee)	17 cr
<i>Total</i>	72 cr

**Ph.D. Qualifying Exam (Electrical Specialty)**

Doctoral students must pass a Qualifying Examination, which is intended to gauge the student's capability to pursue research in the Electrical Engineering specialty. The Qualifying Examination includes both written and oral sections. The written section is based on material from the Division's undergraduate Engineering degree with Electrical Specialty and is given once per year at the beginning of the Spring semester. The oral part of the exam covers either two of the core courses (of the student's choice) in the Electrical Specialty, or a paper



from the literature chosen by the student and the student's advisor. The student's advisor and two additional Electrical Specialty faculty members (typically from the student's thesis committee) administer the oral exam.

Normally, Ph.D. students will take both parts of the Qualifying Examination in their first year, but they must both be taken within three semesters of entering the graduate program.

### **Mechanical Engineering Specialty (EGGN-ME)**

Within the Mechanical Engineering specialty, there are two emphasis areas: (1) Material Mechanics, and (2) Thermal Sciences. Within the material mechanics emphasis area, materials processing, materials simulation and process control are investigated from perspectives ranging from fundamental physical underpinnings to industrial application. Within the thermal sciences emphasis area, the focus is upon energy conversion devices as framed by traditional subjects such as fluid mechanics, heat transfer, and combustion. Students are required to complete a set of core classes intended to prepare them for both theoretical and experimental aspects of research in mechanical engineering. The program has strong ties to the chemical engineering, materials science and physics communities, and students will typically take courses in one or more of these areas after completing the core class requirements.

### **M.S. Degree (EGGN-ME)**

#### *Required Core:*

EGGN501 Advanced Engineering Measurements	4 cr
EGGN502 Interdisciplinary Modeling and Simulation	4 cr
EGGN504 Engineering Systems (Mechanical) Seminar	1 cr

From the list of Mechanical Engineering Courses (Thesis Option: Courses must be approved by the thesis committee)

9 cr

or

(Non-Thesis Option: Courses must be approved by the faculty advisor)

15 cr

Thesis Research (Thesis option)

6 cr

Technical Electives (thesis option: approved by thesis committee; non-thesis option: approved by faculty advisor)

6 cr

*Total*

30 cr

### **Ph.D. Degree (EGGN-ME)**

#### *Required Core:*

EGGN501 Advanced Engineering Measurements	4 cr
EGGN502 Interdisciplinary Modeling and Simulation	4 cr
EGGN504 Engineering (Mechanical) Seminar	1 cr

Minor Program of Study

12 cr

From the list of Mechanical Engineering Courses

18 cr

Thesis Research

24 cr

Technical Electives (must be approved by the thesis committee)

9 cr

*Total*

72 cr

### **Ph.D. Qualifying Exam (Mechanical Specialty)**

Doctoral students must pass a Qualifying Examination, which is intended to gauge the academic qualifications of the candidate for conducting dissertation research in Mechanical Engineering. The Qualifying Examination tests the student on instrumentation and measurement theory as well as interdisciplinary simulation and modeling. Students are required to take EGGN501 and EGGN502 prior to taking this exam. The exam is typically offered in May each year. Normally, Ph.D. students will take the Qualifying Examination at the end of their first year, but they must take the exam within three semesters of entering the graduate program.

### **Courses Offered Under Each Of The Engineering Specialties:**

#### **Engineering (Civil Specialty)**

EGGN501 Advanced Engineering Measurements	4 cr
EGGN502 Interdisciplinary Modeling and Simulation	4 cr
EGGN531 Soil Dynamics	3 cr
EGGN533 Unsaturated Soil Mechanics	3 cr
EGGN534 Soil Behavior	3 cr
EGGN541 Advanced Structural Theory	3 cr
EGGN542 Finite Element Methods for Engineers	3 cr
EGGN547 Timber and Masonry Design	3 cr
EGGN548 Advanced Soil Mechanics	3 cr
EGGN549 Advanced Design of Steel Structures	3 cr
EGGN550 Design of Reinf. Concrete Structures II	3 cr
EGGN560 Numerical Methods for Engineers	3 cr

#### **Engineering (Electrical Specialty)**

##### *Core classes in the Electrical Specialty*

EGGN501 Advanced Engineering Measurements	4 cr
EGGN502 Interdisciplinary Modeling and Simulation	4 cr
EGGN503 Modern Engineering Design and Project Management	3 cr
EGGN515 Mathematical Methods for Signals and Systems	3 cr
EGGN560 Numerical Methods for Engineers	3 cr
MATH401 Real Analysis	3 cr
CSCI404 Artificial Intelligence	3 cr
MATH/CSCI407 Introduction to Scientific Computing	3 cr
MATH500 Linear Vector Spaces	3 cr
MATH506 Complex Analysis II	3 cr
MATH514 Applied Mathematics I	3 cr
MATH530 Statistical Methods I	3 cr

##### *Energy Systems Track*

EGGN521 Mechatronics	3 cr
EGGN581 Modern Adjustable Speed Electric Drives	3 cr
EGGN582 Renewable Energy and Distributed Generation	3 cr
EGGN583 Advanced Electrical Machine Dynamics	3 cr
EGGN584 Power Distribution Systems Engineering	3 cr
EGGN585 Advanced High Power Electronics	3 cr

EGGN586	High Voltage AC and DC Power Transmission	3 cr	EGGN525	Musculoskeletal Biomechanics	3 cr
EGGN599	Independent Study (limited to 6 credits)		EGGN527	Prosthetic And Implant Engineering	3 cr
EGGN683	Computer Methods in Electric Power Systems	3 cr	EGGN528	Computational Biomechanics	3 cr
<b><i>Sensing, Communications and Control Track</i></b>					
EGGN510	Image and Multidimensional Signal Processing	3 cr	EGGN530	Biomedical Instrumentation	3 cr
EGGN511	Digital Signal Processing	3 cr	EGGN532	Fatigue and Fracture	3 cr
EGGN512	Computer Vision	3 cr	EGGN535	Introduction to Discrete Element Methods	3 cr
EGGN513	Wireless Communication Systems	3 cr	EGGN540	Continuum Mechanics	3 cr
EGGN514	Advanced Robot Control	4 cr	EGGN542	Finite Element Methods for Engineers	3 cr
EGGN515	Mathematical Methods for Signals and Systems	3 cr	EGGN544	Solid Mechanics of Nonlinear Materials	3 cr
EGGN517	Theory and Design of Advanced Control Systems	3 cr	EGGN545	Boundary Element Analysis	3 cr
EGGN519	Estimation Theory and Kalman Filtering	3 cr	EGGN546	Advanced Engineering Dynamics	3 cr
EGGN521	Mechatronics	3 cr	EGGN551	Mechanics of Incompressible Fluids	3 cr
EGGN599	Independent Study (limited to 6 cr)		EGGN552	Viscous Flow and Boundary Layers	3 cr
EGGN617	Intelligent Control Systems	3 cr	EGGN555	Kinetic Phenomena In Materials	3 cr
EGGN618	System Identification and Adaptive Control	3 cr	EGGN559	Mechanics of Particulate Media	3 cr
EGGN619	Applied Intelligent Control and Failure Diagnostics	3 cr	EGGN560	Numerical Methods for Engineers	3 cr
<b>Engineering (Mechanical Specialty)</b>					
EGGN503	Modern Engineering Design and Project Management	3 cr	EGGN564	Physical Gas Dynamics	3 cr
EGGN514	Advanced Robot Control	4 cr	EGGN566	Combustion	3 cr
EGGN515	Mathematical Methods for Signals and Systems	3 cr	EGGN567	Radiation Heat Transfer	3 cr
EGGN517	Theory and Design of Advanced Control Systems	3 cr	EGGN569	Fuel Cell Science And Technology	3 cr
EGGN518	Robot Mechanics: Kinematics, Dynamics and Control	3 cr	EGGN572	Multiple Phase Flows and Transport Phenomena with Droplets and Particles	3 cr
EGGN520	Introduction To Biomedical Engineering	3 cr	EGGN573	Introduction to Computational Techniques for Fluid Dynamics and Transport Phenomena	3 cr
EGGN521	Mechatronics	3 cr	EGGN617	Intelligent Control	3 cr
			EGGN619	Intelligent Structures	3 cr
			EGGN642	Advanced Finite Element Analysis for Engineers	3 cr
			EGGN659	Optical Measurements in Reacting and Nonreacting Flow Systems	4 cr
Any graduate level course taught by a member of the CSM Mechanical Engineering faculty is also a member of the list of acceptable Mechanical Engineering Courses.					

Table 1. Summary of courses required for the Master of Science Degree In Engineering Systems

<b>Master of Science, Engineering</b>				
	Engineering Systems	Civil	Electrical	Mechanical
Core	EGES 501, 502, 504 9 cr	EGES 504 and choose from list 10 cr	EGES 504 and choose from list 7 cr	EGES 501, 502, 504 9 cr
Technical Electives and Other Courses with Advisor Approval	Choose 15 cr (thesis), 21 cr (non-thesis)	Choose 14 cr (thesis), 20 cr (non-thesis) from list and/or other technical courses	Choose 12 cr from chosen track plus 5 cr (thesis), 11 cr of other technical courses (non-thesis)	Choose 9 cr (thesis), 15 cr (non-thesis) from list plus 6 cr of other technical courses
Thesis Research (thesis only)	6 cr	6 cr	6 cr	6 cr

Table 2. Summary of courses required for the Ph.D. Degree in Engineering Systems

<b>Doctor of Philosophy, Engineering</b>				
	Engineering Systems	Civil	Electrical	Mechanical
Core	EGES 501, 502, 504 9 cr	EGES 504 and choose from list 10 cr	EGES 504 and choose from list 7 cr	EGES 501, 502, 504 9 cr
Minor	12 cr	12 cr	12 cr	12 cr
Technical Electives and Other Courses with Advisor Approval	27 cr (non-thesis)	26 cr from list and/or other technical courses	Choose 12 cr from chosen track plus 17 cr of other technical courses	Choose 18 cr from list plus 9 cr of other technical courses
Thesis Research (thesis only)	24 cr	24 cr	24 cr	24 cr

### *Description of Courses*

EGGN400/MNGN400. INTRODUCTION TO ROBOTICS (II) Overview and introduction to the science and engineering of intelligent mobile robotics and robotic manipulators. Covers guidance and force sensing, perception of the environment around a mobile vehicle, reasoning about the environment to identify obstacles and guidance path features and adaptively controlling and monitoring the vehicle health. A lesser emphasis is placed on robot manipulator kinematics, dynamics, and force and tactile sensing. Surveys manipulator and intelligent mobile robotics research and development. Introduces principles and concepts of guidance, position, and force sensing; vision data processing; basic path and trajectory planning algorithms; and force and position control. Prerequisite: CSC1261, EGGN381. 3 hours lecture; 3 semester hours.

EGGN403. THERMODYNAMICS II (I, II) Thermodynamic relations, Maxwell's Relations, Clapeyron equation, fugacity, mixtures and solutions, thermodynamics of mixing, Gibbs function, activity coefficient, combustion processes, first and second law applied to reacting systems, third law of thermodynamics, real combustion processes, phase and chemical equilibrium, Gibbs rule, equilibrium of multi-component systems, simultaneous chemical reaction of real combustion processes, ionization, application to real industrial problems. Prerequisite: EGGN351, EGGN371. 3 hours lecture; 3 semester hours.

EGGN411. MACHINE DESIGN (I, II) Introduction to the principles of mechanical design. Consideration of the behavior of materials under static and cyclic loading; failure considerations. Application of the basic theories of mechanics, kinematics, and mechanics of materials to the design of basic machine elements, such as shafts, keys, and coupling; journal bearings, antifriction bearings, wire rope, gearing; brakes and clutches, welded connections and other fastenings. Prerequisite: EPIC251, EGGN315, and EGGN320. 3 hours lecture; 3 hours lab; 4 semester hours.

EGGN413. COMPUTER AIDED ENGINEERING (I, II) This course introduces the student to the concept of computer-aided engineering. The major objective is to provide the student with the necessary background to use the computer as a tool for engineering analysis and design. The Finite Element Analysis (FEA) method and associated computational engineering software have become significant tools in engineering analysis and design. This course is directed to learning the concepts of FEA and its application to civil and mechanical engineering analysis and design. Note that critical evaluation of the results of a FEA using classical methods (from statics and mechanics of materials) and engineering judgment is employed throughout the course. Prerequisite: EGGN320. 3 hours lecture; 3 semester hours.

EGGN 417. MODERN CONTROL DESIGN (I) Control system design with an emphasis on observer-based methods, from initial open-loop experiments to final implementation. The course begins with an overview of feedback control design technique from the frequency domain perspective, including sensitivity and fundamental limitations. State space realization theory is introduced, and system identification methods for parameter estimation are introduced. Computer-based methods for control system design are presented. Prerequisites: EGGN307. 3 hours lecture, 3 semester hours.

EGGN422. ADVANCED MECHANICS OF MATERIALS (II) General theories of stress and strain; stress and strain transformations, principal stresses and strains, octahedral shear stresses, Hooke's law for isotropic material, and failure criteria. Introduction to elasticity and energy methods. Torsion of noncircular and thin-walled members. Unsymmetrical bending and shear-center, curved beams, and beams on elastic foundations. Introduction to plate theory. Thick-walled cylinders and contact stresses. Prerequisite: EGGN320, EGGN413. 3 hours lecture; 3 semester hours.

EGGN 425. MUSCULOSKELETAL BIOMECHANICS (II) This course is intended to provide engineering students with an introduction to musculoskeletal biomechanics. At the end

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of the semester, students should have a working knowledge of the special considerations necessary to apply engineering principles to the human body. The course will focus on the biomechanics of injury since understanding injury will require developing an understanding of normal biomechanics. Prerequisite: DCGN421, EGGN320, EGGN420/BELS420, (or instructor permission). 3 hours lecture; 3 semester hours.

EGGN 430. BIOMEDICAL INSTRUMENTATION The acquisition, processing, and interpretation of biological signals present many unique challenges to the Biomedical Engineer. This course is intended to provide students with an introduction to, and appreciation for, many of these challenges. At the end of the semester, students should have a working knowledge of the special considerations necessary to gathering and analyzing biological signal data. Prerequisite: EGGN250, DCGN381, EGGN420/BELS420, (or permission of instructor). 3 hours lecture; 3 semester hours.

EGGN441. ADVANCED STRUCTURAL ANALYSIS (II) Introduction to advanced structural analysis concepts. Non-prismatic structures. Arches, Suspension and cable-stayed bridges. Structural optimization. Computer Methods. Structures with nonlinear materials. Internal force redistribution for statically indeterminate structures. Graduate credit requires additional homework and projects. Prerequisite: EGGN342. 3 hour lectures, 3 semester hours.

EGGN442. FINITE ELEMENT METHODS FOR ENGINEERS (II) A course combining finite element theory with practical programming experience in which the multidisciplinary nature of the finite element method as a numerical technique for solving differential equations is emphasized. Topics covered include simple "structural" element, solid elasticity, steady state analysis, transient analysis. Students get a copy of all the source code published in the course textbook. Prerequisite: EGGN320. 3 hours lecture; 3 semester hours.

EGGN444. DESIGN OF STEEL STRUCTURES (I) To learn application and use the American Institute of Steel Construction (AISC) Steel Construction Manual. Course develops an understanding of the underlying theory for the design specifications. Students learn basic steel structural member design principles to select the shape and size of a structural member. The design and analysis of tension members, compression members, flexural members, and members under combined loading is included, in addition to basic bolted and welded connection design. Prerequisite: EGGN342. 3 hours lecture; 3 semester hours.

EGGN445. DESIGN OF REINFORCED CONCRETE STRUCTURES (II) This course provides an introduction to the materials and principles involved in the design of reinforced concrete. It will allow students to develop an understanding of the fundamental behavior of reinforced concrete under compressive, tensile, bending, and shear loadings, and gain a working knowledge of strength design theory and its application to the design of reinforced concrete beams,

columns, slabs, footings, retaining walls, and foundations. Prerequisite: EGGN342. 3 hours lecture; 3 semester hours.

EGGN 447. TIMBER AND MASONRY DESIGN (II) The course develops the theory and design methods required for the use of timber and masonry as structural materials. The design of walls, beams, columns, beam-columns, shear walls, and structural systems are covered for each material. Gravity, wind, snow, and seismic loads are calculated and utilized for design. Prerequisite: EGGN320 or equivalent. 3 hours lecture; 3 semester hours.

EGGN448. ADVANCED SOIL MECHANICS (I) Advanced soil mechanics theories and concepts as applied to analysis and design in geotechnical engineering. Topics covered will include seepage, consolidation, shear strength and probabilistic methods. The course will have an emphasis on numerical solution techniques to geotechnical problems by finite elements and finite differences. Prerequisite: EGGN361. 3 hour lectures, 3 semester hours.

EGGN450. MULTIDISCIPLINARY ENGINEERING LABORATORY III (I, II) Laboratory experiments integrating electrical circuits, fluid mechanics, stress analysis, and other engineering fundamentals using computer data acquisition and transducers. Students will design experiments to gather data for solving engineering problems. Examples are recommending design improvements to a refrigerator, diagnosing and predicting failures in refrigerators, computer control of a hydraulic fluid power circuit in a fatigue test, analysis of structural failures in an off-road vehicle and redesign, diagnosis and prediction of failures in a motor/generator system. Prerequisites: DCGN381, EGGN250, EGGN352, EGGN350, EGGN351, EGGN320; concurrent enrollment in EGGN407. 3 hours lab; 1 semester hour.

EGGN451. HYDRAULIC PROBLEMS (I) Review of fundamentals, forces on submerged surfaces, buoyancy and flotation, gravity dams, weirs, steady flow in open channels, backwater curves, hydraulic machinery, elementary hydrodynamics, hydraulic structures. Prerequisite: EGGN351. 3 hours lecture; 3 semester hours.

EGGN460. NUMERICAL METHODS FOR ENGINEERS(S) Introduction to the use of numerical methods in the solution of problems encountered in engineering analysis and design, e.g. linear simultaneous equations (e.g. analysis of elastic materials, steady heat flow); roots of nonlinear equations (e.g. vibration problems, open channel flow); eigenvalue problems (e.g. natural frequencies, buckling and elastic stability); curve fitting and differentiation (e.g. interpretation of experimental data, estimation of gradients); integration (e.g. summation of pressure distributions, finite element properties, local averaging); ordinary differential equations (e.g. forced vibrations, beam bending) All course participants will receive source code consisting of a suite of numerical methods programs. Prerequisite: CSC1260 or 261, MATH225, EGGN320. 3 hours lecture; 3 semester hours.



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EGGN464. FOUNDATIONS (I, II) Techniques of subsoil investigation, types of foundations and foundation problems, selection of and basis for design of foundation types. Prerequisite: EGGN461. 3 hours lecture; 3 semester hours.

EGGN471. HEAT TRANSFER (I, II) Engineering approach to conduction, convection, and radiation, including steady-state conduction, nonsteady-state conduction, internal heat generation conduction in one, two, and three dimensions, and combined conduction and convection. Free and forced convection including laminar and turbulent flow, internal and external flow. Radiation of black and grey surfaces, shape factors and electrical equivalence. Prerequisite: MATH225, EGGN351, EGGN371. 3 hours lecture; 3 semester hours.

EGGN473. FLUID MECHANICS II (I) Review of elementary fluid mechanics and engineering. Two-dimensional internal and external flows. Steady and unsteady flows. Fluid engineering problems. Compressible flow. Computer solutions of various practical problems for mechanical and related engineering disciplines. Prerequisite: EGGN351 or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN478. ENGINEERING DYNAMICS (I) Applications of dynamics to design, mechanisms and machine elements. Kinematics and kinetics of planar linkages. Analytical and graphical methods. Four-bar linkage, slider-crank, quick-return mechanisms, cams, and gears. Analysis of nonplanar mechanisms. Static and dynamic balancing of rotating machinery. Free and forced vibrations and vibration isolation. Prerequisite: EGGN315; concurrent enrollment in MATH225. 3 hours lecture; 3 semester hours.

EGGN482. MICROCOMPUTER ARCHITECTURE AND INTERFACING (II) Microprocessor and microcontroller architecture focusing on hardware structures and elementary machine and assembly language programming skills essential for use of microprocessors in data acquisition, control and instrumentation systems. Analog and digital signal conditioning, communication, and processing. A/D and D/A converters for microprocessors. RS232 and other communication standards. Laboratory study and evaluation of microcomputer system; design and implementation of interfacing projects. Prerequisite: EGGN384 or consent of instructor. 3 hours lecture; 3 hours lab; 4 semester hours.

EGGN483. ANALOG AND DIGITAL COMMUNICATION SYSTEMS (I) Signal classification; Fourier transform; filtering; sampling; signal representation; modulation; demodulation; applications to broadcast, data transmission, and instrumentation. Prerequisite: EGGN388 or consent of department. 3 hours lecture; 3 hours lab; 4 semester hours.

EGGN484. POWER SYSTEMS ANALYSIS (I) 3-phase power systems, per-unit calculations, modeling and equivalent circuits of major components, voltage drop, fault calculations, symmetrical components and unsymmetrical faults, system grounding, power-flow, selection of major equipment,

design of electric power distribution systems. Prerequisite: EGGN389. 3 hours lecture; 3 semester hours.

EGGN485. INTRODUCTION TO HIGH POWER ELECTRONICS (II) Power electronics are used in a broad range of applications from control of power flow on major transmission lines to control of motor speeds in industrial facilities and electric vehicles, to computer power supplies. This course introduces the basic principles of analysis and design of circuits utilizing power electronics, including AC/DC, AC/AC, DC/DC, and DC/AC conversions in their many configurations. Prerequisite: EGGN385 and EGGN389. 3 hours lecture; 3 semester hours.

EGGN488. RELIABILITY OF ENGINEERING SYSTEMS (I) This course addresses uncertainty modeling, reliability analysis, risk assessment, reliability-based design, predictive maintenance, optimization, and cost-effective retrofit of engineering systems such as structural, sensory, electric, pipeline, hydraulic, lifeline and environmental facilities. Topics include introduction of reliability of engineering systems, stochastic engineering system simulation, frequency analysis of extreme events, reliability and risk evaluation of engineering systems, and optimization of engineering systems. Prerequisite: MATH323. 3 hours lecture; 3 semester hours.

EGGN491. SENIOR DESIGN I (I, II) The first of a two-semester course sequence giving the student experience in the engineering design process. Realistic, open-ended design problems are addressed at the conceptual, engineering analysis, and the synthesis stages, and include economic and ethical considerations necessary to arrive at a final design. Several design projects are completed during the two-semester sequence. The design projects are chosen to develop student creativity, use of design methodology and application of prior course work paralleled by individual study and research. Prerequisites: permission of the Capstone Design Course Committee. 1 hour lecture; 6 hours lab; 3 semester hours.

EGGN492. SENIOR DESIGN II (I, II) This is the second of a two-semester course sequence to give the student experience in the engineering design process. This course will consist of a single comprehensive design project covering the entire semester. Design integrity and performance are to be demonstrated by building a prototype or model and performing pre-planned experimental tests, wherever feasible. Prerequisite: EGGN491. 1 hour lecture; 6 hours lab; 3 semester hours.

EGGN498. SPECIAL TOPICS IN ENGINEERING (I, II) Pilot course or special topics course. Topics chosen from special interest of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

EGGN499. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty



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member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit under different topics/experiences.

### Graduate Courses

500-level courses are open to qualified seniors with the permission of the department and Dean of the Graduate School.

**EGGN501. ADVANCED ENGINEERING MEASUREMENTS (I)** Introduction to the fundamentals of measurements within the context of engineering systems. Topics that are covered include: errors and error analysis, modeling of measurement systems, basic electronics, noise and noise reduction, and data acquisition systems. Prerequisite: EGGN250, DCGN381 or equivalent, and MATH323 or equivalent; graduate student status or consent of the instructor. 3 hours lecture, 1 hour lab; 4 semester hours.

**EGGN502. INTERDISCIPLINARY MODELING AND SIMULATION (I)** Introduce modern simulation and modeling techniques, as used to solve traditional and multidisciplinary engineering problems. Static and dynamic phenomena are described in space and space-time domains as well as in transform space. Analytical as well as computational solution methods are developed and applied for linear and nonlinear systems. Simulation and modeling approaches are applied to solve multidisciplinary engineering problems. Prerequisite: This is an introductory graduate class. The student must have a solid understanding of linear algebra, calculus, ordinary differential equations, and Fourier theory. 3 hours lecture; 1 hour lab; 4 semester hours.

**EGGN503. MODERN ENGINEERING DESIGN AND PROJECT MANAGEMENT (II)** Contemporary technical and behavioral issues in engineering design and project management. Implementation of project organization techniques to plan thesis research projects or projects selected at the beginning of the semester. Elements of quality control in manufacturing and numerous marketing tools. Prerequisite: EGGN491 and EGGN492, or equivalent senior design project experience, or equivalent industrial design experience, or consent of the Engineering Division. 3 hours lecture; 3 semester hours.

**EGGN504. ENGINEERING SYSTEMS SEMINAR (I, II)** This is a seminar forum for graduate students to present their research projects, critique others' presentations, understand the breadth of engineering projects both within their specialty area and across the Division, hear from leaders of industry about contemporary engineering as well as socio-economical and marketing issues facing today's competitive global environment. In order to improve communication skills, each student is required to present a seminar in this course before his/her graduation from the Engineering graduate program. Prerequisite: Graduate standing. 1 hour seminar, 1 semester

hour. Repeatable; maximum 1 hour granted toward degree requirements.

**EGGN510. IMAGE AND MULTIDIMENSIONAL SIGNAL PROCESSING (I)** This course provides the student with the theoretical background to allow them to apply state of the art image and multi-dimensional signal processing techniques. The course teaches students to solve practical problems involving the processing of multidimensional data such as imagery, video sequences, and volumetric data. The types of problems students are expected to solve are automated mensuration from multidimensional data, and the restoration, reconstruction, or compression of multidimensional data. The tools used in solving these problems include a variety of feature extraction methods, filtering techniques, segmentation techniques, and transform methods. Students will use the techniques covered in this course to solve practical problems in projects. Prerequisite: EGGN388 or equivalent. 3 hours lecture; 3 semester hours.

**EGGN511. DIGITAL SIGNAL PROCESSING (I)** This course introduces the engineering aspects of digital signal processing (DSP). It deals with the theoretical foundations of DSP combined with applications and implementation technologies. While the bulk of the course addresses one-dimensional signals and emphasizes digital filters, there are extensions to specialized and contemporary topics such as sigma-delta conversion techniques. The course will be useful to all students who are concerned with information bearing signals and signal-processing in a wide variety of applications settings, including sensing, instrumentation, control, communications, signal interpretation and diagnostics, and imaging. Prerequisite: EGGN483 and EGGN407 or consent of instructor. 3 hours lecture; 3 semester hours.

**EGGN512. COMPUTER VISION (II)** Computer vision is the process of using computers to acquire images, transform images, and extract symbolic descriptions from images. This course concentrates on how to recover the structure and properties of a possibly dynamic three-dimensional world from its two-dimensional images. We start with an overview of image formation and low level image processing, including feature extraction techniques. We then go into detail on the theory and techniques for estimating shape, location, motion, and recognizing objects. Applications and case studies will be discussed from areas such as scientific image analysis, robotics, machine vision inspection systems, photogrammetry, multimedia, and human interfaces (such as face and gesture recognition). Design ability and hands-on projects will be emphasized, using image processing software and hardware systems. Prerequisite: Linear algebra, Fourier transforms, knowledge of C programming language. 3 hours lecture; 3 semester hours.

**EGGN513. WIRELESS COMMUNICATION SYSTEMS (I)** This course explores aspects of electromagnetics, stochastic modeling, signal processing, and RF/microwave components as applied to the design of wireless systems. In particular,

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topics on (a) physical and statistical models to represent the wireless channel, (b) advanced digital modulation techniques, (c) temporal, spectral, code-division and spatial multiple access techniques, (d) space diversity techniques and (d) the effects of RF/microwave components on wireless systems will be discussed. Pre-requisite: EGGN 386, EGGN 483, and consent of instructor. 3 hours lecture; 3 semester hours.

EGGN514/MNGN. ADVANCED ROBOT CONTROL (I) The focus is on mobile robotic vehicles. Topics covered are: navigation, mining applications, sensors, including vision, problems of sensing variations in rock properties, problems of representing human knowledge in control systems, machine condition diagnostics, kinematics, and path planning real time obstacle avoidance. Prerequisite: EGGN407 or consent of instructor. 3 hours lecture; 3 hours lab; 4 semester hours. Every two years.

EGGN515. MATHEMATICAL METHODS FOR SIGNALS AND SYSTEMS (I) An introduction to mathematical methods for modern signal processing using vector space methods. Topics include signal representation in Hilbert and Banach spaces; linear operators and the geometry of linear equations; LU, Cholesky, QR, eigen- and singular value decompositions. Applications to signal processing and linear systems are included throughout, such as Fourier analysis, wavelets, adaptive filtering, signal detection, and feedback control.

EGGN517. THEORY AND DESIGN OF ADVANCED CONTROL SYSTEMS (II) This course will introduce and study the theory and design of multivariable and nonlinear control systems. Students will learn to design multivariable controllers that are both optimal and robust, using tools such as state space and transfer matrix models, nonlinear analysis, optimal estimator and controller design, and multi-loop controller synthesis Prerequisite: EGGN417 or consent of instructor. 3 hours lecture; 3 semester hours. Spring semester.

EGGN518. ROBOT MECHANICS: KINEMATICS, DYNAMICS, AND CONTROL (I) Mathematical representation of robot structures. Mechanical analysis including kinematics, dynamics, and design of robot manipulators. Representations for trajectories and path planning for robots. Fundamentals of robot control including, linear, nonlinear and force control methods. Introduction to off-line programming techniques and simulation. Prerequisite: EGGN407, EGGN400 or consent of instructor. 3 hours lecture; 3 semester hours. Fall semesters, even year, or every other year, depending on interest.

EGGN519. ESTIMATION THEORY AND KALMAN FILTERING (II) Estimation theory considers the extraction of useful information from raw sensor measurements in the presence of signal uncertainty. Common applications include navigation, localization and mapping, but applications can be found in all fields where measurements are used. Mathematical descriptions of random signals and the response of linear

systems are presented. The discrete-time Kalman Filter is introduced, and conditions for optimality are described. Implementation issues, performance prediction, and filter divergence are discussed. Adaptive estimation and nonlinear estimation are also covered. Contemporary applications will be utilized throughout the course. Pre-requisite: EGGN407 and MATH323 or equivalent. Spring semester of odd years.

EGGN520. INTRODUCTION TO BIOMEDICAL ENGINEERING (II) The application of engineering principles and techniques to the human body presents many unique challenges. The discipline of Biomedical Engineering has evolved over the past 50 years to address these challenges. Biomedical Engineering is a diverse, seemingly all-encompassing field that includes such areas as biomechanics, biomaterials, bioinstrumentation, medical imaging, rehabilitation. This course is intended to provide an introduction to, and overview of, Biomedical Engineering. At the end of the semester, graduate students should have a working knowledge of the special considerations necessary to apply various engineering principles to the human body. Prerequisites: DCGN 421 Statics, DCGN381 Circuits, EGGN 320 Mechanics of Materials, EGGN 351 Fluids I (or instructor permission). 3 hours lecture; 3 semester hours.

EGGN521. MECHATRONICS (II) Fundamental design of electromechanical systems with embedded microcomputers and intelligence. Design of microprocessor based systems and their interfaces. Fundamental design of machines with active sensing and adaptive response. Microcontrollers and integration of micro-sensors and micro-actuators in the design of electromechanical systems. Introduction to algorithms for information processing appropriate for embedded systems. Smart materials and their use as actuators. Students will do projects involving the design and implementation of smart-systems. Prerequisite: DCGN 381 and EGGN482 recommended. 3 hours lecture; 3 semester hours. Spring semesters, every other year.

EGGN525. MUSCULOSKELETAL BIOMECHANICS (I) This course is intended to provide graduate engineering students with an introduction to musculoskeletal biomechanics. At the end of the semester, students should have a working knowledge of the special considerations necessary to apply engineering principles to the human body. The course will focus on the biomechanics of injury since understanding injury will require developing an understanding of normal biomechanics. Prerequisites: DCGN421 Statics, EGGN320 Mechanics of Materials, EGGN420/BELS420 Introduction to Biomedical Engineering (or instructor permission). 3 hours lecture; 3 semester hours.

EGGN527. PROSTHETIC AND IMPLANT ENGINEERING (I) Prosthetics and implants for the musculoskeletal and other systems of the human body are becoming increasingly sophisticated. From simple joint replacements to myoelectric limb replacements and functional electrical stimulation, the engineering opportunities continue to expand. This course

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builds on musculoskeletal biomechanics and other BELS courses to provide engineering students with an introduction to prosthetics and implants for the musculoskeletal system. At the end of the semester, students should have a working knowledge of the challenges and special considerations necessary to apply engineering principles to augmentation or replacement in the musculoskeletal system. Prerequisites: Musculoskeletal Biomechanics (EGGN/BELS425 or EGGN/BELS525), 3 hours lecture; 3 semester hours.

EGGN528. COMPUTATIONAL BIOMECHANICS Computational Biomechanics provides an introduction to the application of computer simulation to solve some fundamental problems in biomechanics and bioengineering. Musculoskeletal mechanics, medical image reconstruction, hard and soft tissue modeling, joint mechanics, and inter-subject variability will be considered. An emphasis will be placed on understanding the limitations of the computer model as a predictive tool and the need for rigorous verification and validation of computational techniques. Clinical application of biomechanical modeling tools is highlighted and impact on patient quality of life is demonstrated. Prerequisite: EGGN413, EGGN420 or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN530. BIOMEDICAL INSTRUMENTATION (I) The acquisition, processing, and interpretation of biological signals presents many unique challenges to the Biomedical Engineer. This course is intended to provide students with the knowledge to understand, appreciate, and address these challenges. At the end of the semester, students should have a working knowledge of the special considerations necessary to gathering and analyzing biological signal data. Prerequisites: EGGN250 MEL I, DCGN381 Introduction to Electrical Circuits, Electronics, and Power, EGGN420/BELS420 Introduction to Biomedical Engineering (or permission of instructor). 3 hours lecture; 3 semester hours.

EGGN531. SOIL DYNAMICS Dynamic phenomena in geotechnical engineering, e.g., earthquakes, pile and foundation vibrations, traffic, construction vibrations; behavior of soils under dynamic loading, e.g., small, medium and large strain behavior, soil liquefaction; wave propagation through soil and rock; laboratory and field techniques to assess dynamic soil properties; analysis and design of shallow and deep foundations subjected to dynamic loading; analysis of construction vibrations. Prerequisites: EGGN361, EGGN315, EGGN464 or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN532/MTGN545. FATIGUE AND FRACTURE (I) Basic fracture mechanics as applied to engineering materials, S-N curves, the Goodman diagram, stress concentrations, residual stress effects, effect of material properties on mechanisms of crack propagation. Prerequisite: Consent of department. 3 hours lecture; 3 semester hours. Fall semesters, odd numbered years.

EGGN533. UNSATURATED SOIL MECHANICS (I) The focus of this course is on soil mechanics for unsaturated soils. It provides an introduction to thermodynamic potentials in partially saturated soils, chemical potentials of adsorbed water in partially saturated soils, phase properties and relations, stress state variables, measurements of soil water suction, unsaturated flow laws, measurement of unsaturated permeability, volume change theory, effective stress principle, and measurement of volume changes in partially saturated soils. The course is designed for seniors and graduate students in various branches of engineering and geology that are concerned with unsaturated soil's hydrologic and mechanics behavior. Prerequisites: EGGN461 or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN534. SOIL BEHAVIOR (II) The focus of this course is on interrelationships among the composition, fabric, and geotechnical and hydrologic properties of soils that consist partly or wholly of clay. The course will be divided into two parts. The first part provides an introduction to the composition and fabric of natural soils, their surface and pore-fluid chemistry, and the physico-chemical factors that govern soil behavior. The second part examines what is known about how these fundamental characteristics and factors affect geotechnical properties, including the hydrologic properties that govern the conduction of pore fluid and pore fluid constituents, and the geomechanical properties that govern volume change, shear deformation, and shear strength. The course is designed for graduate students in various branches of engineering and geology that are concerned with the engineering and hydrologic behavior of earth systems, including geotechnical engineering, geological engineering, environmental engineering, mining engineering, and petroleum engineering. Prerequisites: EGGN461 Soil Mechanics or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN535. INTRODUCTION TO DISCRETE ELEMENT METHODS (DEMS) (II) Review of particle/rigid body dynamics, numerical DEM solution of equations of motion for a system of particles/rigid bodies, linear and nonlinear contact and impact laws dynamics, applications of DEM in mechanical engineering, materials processing and geomechanics. Prerequisites: EGGN320, EGGN315 and some scientific programming experience in C/C++ or Fortran or the consent of the instructor. 3 hours lecture; 3 semester hours Spring semester of even numbered years.

EGGN540. CONTINUUM MECHANICS (I) Introduction to Cartesian tensor analysis; consideration of stress, strain, and strain rates as tensor quantities including their transformation laws; decomposition theorems for stress and strain; constitutive theory of materials; use of conservation principles in continuum mechanics. Prerequisite: EGGN322 and MATH225 or consent of instructor. 3 hours lecture; 3 semester hours. Fall semesters, odd numbered years.

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EGGN541. ADVANCED STRUCTURAL ANALYSIS (I) Introduction to advanced structural analysis concepts. Non-prismatic structures. Arches, Suspension and cable-stayed bridges. Structural optimization. Computer Methods. Structures with nonlinear materials. Internal force redistribution for statically indeterminate structures. Graduate credit requires additional homework and projects. Prerequisite: EGGN342. 3 hour lectures, 3 semester hours.

EGGN542. FINITE ELEMENT METHODS FOR ENGINEERS (II) A course combining finite element theory with practical programming experience in which the multidisciplinary nature of the finite element method as a numerical technique for solving differential equations is emphasized. Topics covered include simple “structural” elements, beams on elastic foundations, solid elasticity, steady state analysis and transient analysis. Some of the applications will lie in the general area of geomechanics, reflecting the research interests of the instructor. Students get a copy of all the source code published in the course textbook. Prerequisite: Consent of the instructor. 3 hours lecture; 3 semester hours.

EGGN543. SOLID MECHANICS OF MATERIALS (II) Introduction to the algebra of vectors and tensors; coordinate transformations; general theories of stress and strain; principal stresses and strains; octahedral stresses; Hooke’s Law introduction to the mathematical theory of elasticity and to energy methods; failure theories for yield and fracture. Prerequisite: EGGN320 or equivalent, MATH225 or equivalent. 3 hours lecture; 3 semester hours.

EGGN544. SOLID MECHANICS OF NONLINEAR MATERIALS (II) Introduction to the internal state variable modeling of inelastic deformation. Topics covered include: review of continuum thermomechanics; physics of plastic deformation in crystalline solids and in geo-materials; viscoplasticity; rate-independent plasticity; yield criteria; isotropic and kinematic hardening rules; numerical solution of sets of internal state variable equations; numerical coupling of internal state variable equations with finite element models of elastic deformation. Prerequisite EGGN320 and EGGN543 or consent of instructor. 3 hours lecture; 3 semester hours. Spring semester, even numbered years.

EGGN545. BOUNDARY ELEMENT METHODS (II) Development of the fundamental theory of the boundary element method with applications in elasticity, heat transfer, diffusion, and wave propagation. Derivation of indirect and direct boundary integral equations. Introduction to other Green’s function based methods of analysis. Computational experiments in primarily two dimensions. Prerequisite: EGGN502, EGGN540 or consent of instructor. 3 hours lecture; 3 semester hours Spring Semester, odd numbered years.

EGGN546. ADVANCED ENGINEERING VIBRATION (I) Vibration theory as applied to single- and multi-degree-of-freedom systems. Free and forced vibrations to different types of loading-harmonic, impulse, periodic and general.

Natural frequencies. Role of Damping. Importance of resonance. Modal superposition method. Prerequisite: EGGN315, 3 hours lecture; 3 semester hours.

EGGN547. TIMBER AND MASONRY DESIGN (II) The course develops the theory and design methods required for the use of timber and masonry as structural materials. The design of walls, beams, columns, beam-columns, shear walls, and structural systems are covered for each material. Gravity, wind, snow, and seismic loads are calculated and utilized for design. Connection design and advanced seismic analysis principles are introduced. Prerequisite: EGGN342 or equivalent. 3 hours lecture; 3 semester hours.

EGGN548. ADVANCED SOIL MECHANICS (I) Advanced soil mechanics theories and concepts as applied to analysis and design in geotechnical engineering. Topics covered will include seepage, consolidation, shear strength, failure criteria and constitutive models for soil. The course will have an emphasis on numerical solution techniques to geotechnical problems by finite elements and finite differences. Prerequisites: A first course in soil mechanics or consent of instructor. 3 Lecture Hours, 3 semester hours.

EGGN549. ADVANCED DESIGN OF STEEL STRUCTURES (II) The course extends the coverage of steel design to include the topics: slender columns, beam-columns, frame behavior, bracing systems and connections, stability, moment resisting connections, composite design, bolted and welded connections under eccentric loads and tension, and semi-rigid connections. Prerequisite: EGGN444 or equivalent. 3 hours lecture; 3 semester hours.

EGGN 550. DESIGN OF REINFORCED CONCRETE STRUCTURES II (I) Advanced problems in the analysis and design of concrete structures, design of slender columns; biaxial bending; two-way slabs; strut and tie models; lateral and vertical load analysis of multistory buildings; introduction to design for seismic forces; use of structural computer programs. Prerequisite: EGGN445. 3 hour lectures; 3 semester hours.

EGGN551. MECHANICS OF INCOMPRESSIBLE FLUIDS (I) Newtonian and non-Newtonian fluids. Mechanics of two- and three-dimensional viscous incompressible flows, flows of homogeneous and nonhomogeneous fluids, and engineering applications. Multi-phase flows. Steady and unsteady Bernoulli equation. Similarity of flows. Potential flows and basic source-sink flows inside and around body. Random ocean waves. Inertia and damping forces on submerged bodies. Vortex shedding. Engineering applications and computer simulations. Prerequisites; EGGN351 and MATH225 or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN552. VISCOUS FLOW AND BOUNDARY LAYERS (I) This course establishes the theoretical underpinnings of fluid mechanics, including fluid kinematics, stress-strain



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relationships, and derivation of the fluid-mechanical conservation equations. These include the mass-continuity and Navier-Stokes equations as well as the multi-component energy and species-conservation equations. Fluid-mechanical boundary-layer theory is developed and applied to situations arising in chemically reacting flow applications including combustion, chemical processing, and thin-film materials processing. Prerequisite: EGGN473, or CHEN430 or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN553. ENGINEERING HYDROLOGY (I) The hydrologic cycle, precipitation and runoff relationships, and the Rational Method. Hydrograph analysis and synthesis and the unit hydrograph. Basin analysis, flood routing, urban hydrology and design. Prerequisite: EGGN351 or consent of instructor. 3 hours lecture; 3 semester hours. Fall semesters, even years.

EGGN554. OPEN CHANNEL FLOW (II) Fluid mechanics applied to flow in natural and manmade channels. The principles of momentum and energy, flow resistance in uniform and non-uniform channels. Backwater and drawdown curves, channel controls and transitions. Gradually, rapidly and spatially varied flow regimes. Unsteady flow and flood routing methods. Prerequisite: EGGN351 or consent of instructor. 3 hours lecture; 3 semester hours. Spring semesters, odd years.

EGGN555. KINETIC PHENOMENA IN MATERIALS (I) Linear irreversible thermodynamics, force-flux couplings, diffusion, crystalline materials, amorphous materials, defect kinetics in crystalline materials, interface kinetics, morphological evolution of interfaces, nucleation theory, crystal growth, coarsening phenomena and grain growth, solidification, spinodal decomposition. Prerequisites: MATH225: Differential equations (or equivalent), MLGN504/MTGN555/CHEN509: Thermodynamics (or its equivalent)

EGGN559. MECHANICS OF PARTICULATE MEDIA (I) This course allows students to establish fundamental knowledge of quasi-static and dynamic particle behavior that is beneficial to interdisciplinary material handling processes in the chemical, civil, materials, metallurgy, geophysics, physics, and mining engineering. Issues of interest are the definition of particle size and size distribution, particle shape, nature of packing, quasi-static behavior under different external loading, particle collisions, kinetic theoretical modeling of particulate flows, molecular dynamic simulations, and a brief introduction of solid-fluid two-phase flows. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Fall semesters, every other year.

EGGN560. NUMERICAL METHODS FOR ENGINEERS (S) Introduction to the use of numerical methods in the solution of commonly encountered problems of engineering analysis. Structural/solid analysis of elastic materials (linear simultaneous equations); vibrations (roots of nonlinear equations, initial value problems); natural frequency and beam

buckling (eigenvalue problems); interpretation of experimental data (curve fitting and differentiation); summation of pressure distributions (integration); beam deflections (boundary value problems). All course participants will receive source code of all the numerical methods programs published in the course textbook which is coauthored by the instructor. Prerequisite: MATH225 or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN564. PHYSICAL GASDYNAMICS (I) Selected topics in gas-phase thermodynamics for high speed and/or reacting flows: kinetic theory; transport properties; chemical equilibrium; vibrational, rotational and chemical rate processes; statistical mechanics; and the equations of radiative transfer from a microscopic viewpoint. Prerequisite: EGGN351, EGGN371 or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN566. COMBUSTION (II) An introduction to combustion. Course subjects include: the development of the Chapman-Jouget solutions for deflagration and detonation, a brief review of the fundamentals of kinetics and thermochemistry, development of solutions for diffusion flames and premixed flames, discussion of flame structure, pollutant formation, and combustion in practical systems. Prerequisite: EGGN473, or CHEN430 or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN567. RADIATION HEAT TRANSFER (I) Review of radiative properties, blackbody radiation, Planck's distribution, Wien's Displacement Law, Kirchhoff's Law, view factors. Radiation exchange within enclosures with black and diffuse-gray surfaces. Radiation in absorbing, emitting and scattering (semi-transparent, participating) media. An engineering treatment of gas radiation in enclosures. Prerequisite: EGGN471, or equivalent or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN569. FUEL CELL SCIENCE AND TECHNOLOGY Investigate fundamentals of fuel-cell operation and electrochemistry from a chemical-thermodynamics and materials-science perspective. Review types of fuel cells, fuel-processing requirements and approaches, and fuel-cell system integration. Examine current topics in fuel-cell science and technology. Fabricate and test operational fuel cells in the Colorado Fuel Cell Center. 3 credit hours.

EGGN572. MULTIPHASE FLOWS AND TRANSPORT PHENOMENA WITH DROPLETS AND PARTICLES (II) Derivation of the basic heat, mass, and momentum transfer equations for the analysis of multiphase flows with droplets and particles. Flow patterns in two-phase pipe flows. Analysis of spray and particulate systems. Formation and breakup of droplets. Particle/fluid, particle/wall, particle/particle interactions. Prerequisite: EGGN552 or consent of instructor. 3 hours lecture; 3 semester hours. Spring semesters, every other year.

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EGGN573. INTRODUCTION TO COMPUTATIONAL TECHNIQUES FOR FLUID DYNAMICS AND TRANSPORT PHENOMENA (II) Introduction to Computational Fluid Dynamics (CFD) for graduate students with no prior knowledge of this topic. Basic techniques for the numerical analysis of fluid flows. Acquisition of hands-on experience in the development of numerical algorithms and codes for the numerical modeling and simulation of flows and transport phenomena of practical and fundamental interest. Capabilities and limitations of CFD. Prerequisite: EGGN473 or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN581. MODERN ADJUSTABLE SPEED ELECTRIC DRIVES (I) An introduction to electric drive systems for advanced applications. The course introduces the treatment of vector control of induction and synchronous motor drives using the concepts of general flux orientation and the feed-forward (indirect) and feedback (direct) voltage and current vector control. AC models in space vector complex algebra are also developed. Other types of drives are also covered, such as reluctance, stepper-motor and switched-reluctance drives. Digital computer simulations are used to evaluate such implementations. Pre-requisite: Familiarity with power electronics and power systems, such as covered in EGGN484 and EGGN485. 3 lecture hours; 3 semester hours.

EGGN582. RENEWABLE ENERGY AND DISTRIBUTED GENERATION (II) A comprehensive electrical engineering approach on the integration of alternative sources of energy. One of the main objectives of this course is to focus on the inter-disciplinary aspects of integration of the alternative sources of energy which will include most common and also promising types of alternative primary energy: hydropower, wind power, photovoltaic, fuel cells and energy storage with the integration to the electric grid. Pre-requisite: It is assumed that students will have some basic and broad knowledge of the principles of electrical machines, thermodynamics, power electronics, direct energy conversion, and fundamentals of electric power systems such as covered in basic engineering courses plus EGGN484 and EGGN485. 3 lecture hours; 3 semester hours.

EGGN583. ADVANCED ELECTRICAL MACHINE DYNAMICS (I) This course deals primarily with the two rotating AC machines currently utilized in the electric power industry, namely induction and synchronous machines. The course is divided in two halves: the first half is dedicated to induction and synchronous machines are taught in the second half. The details include the development of the theory of operation, equivalent circuit models for both steady-state and transient operations, all aspects of performance evaluation, IEEE methods of testing, and guidelines for industry applications including design and procurement. Prerequisites: EGGN484 or equivalent, and/or consent of instructor. 3 lecture hours; 3 semester hours.

EGGN584. POWER DISTRIBUTION SYSTEMS ENGINEERING (II) This course deals with the theory and applications of problems and solutions as related to electric power distribution systems engineering from both ends: end-users like large industrial plants and electric utility companies. The primary focus of this course is on the medium voltage (4.16 kV – 69 kV) power systems. Some references will be made to the LV power system. The course includes: per-unit methods of calculations; voltage drop and voltage regulation; power factor improvement and shunt compensation; short-circuit calculations; theory and fundamentals of symmetrical components; unsymmetrical faults; overhead distribution lines and power cables; basics and fundamentals of distribution protection. Prerequisites: EGGN484 or equivalent, and/or consent of instructor. 3 lecture hours; 3 semester hours.

EGGN585. ADVANCED HIGH POWER ELECTRONICS (II) Basic principles of analysis and design of circuits utilizing high power electronics. AC/DC, DC/AC, AC/AC, and DC/DC conversion techniques. Laboratory project comprising simulation and construction of a power electronics circuit. Prerequisites: EGGN385; EGGN389 or equivalent. 3 hours lecture; 3 semester hours.

EGGN586. HIGH VOLTAGE AC AND DC POWER TRANSMISSION (II) This course deals with the theory, modeling and applications of HV and EHV power transmission systems engineering. The primary focus is on overhead AC transmission line and voltage ranges between 115 kV – 500 kV. HVDC and underground transmission will also be discussed. The details include the calculations of line parameters (RLC); steady-state performance evaluation (voltage drop and regulation, losses and efficiency) of short, medium and long lines; reactive power compensation; FACTS devices; insulation coordination; corona; insulators; sag-tension calculations; EMTP, traveling wave and transients; fundamentals of transmission line design; HV and EHV power cables: solid dielectric, oil-filled and gas-filled; Fundamentals of DC transmission systems including converter and filter. Prerequisites: EGGN484 or equivalent, and/or consent of instructor. 3 lecture hours; 3 semester hours.

EGGN588. ADVANCED RELIABILITY OF ENGINEERING SYSTEMS (I) This course addresses uncertainty modeling, reliability analysis, risk assessment, reliability-based design, predictive maintenance, optimization, and cost-effective retrofit of engineering systems such as structural, sensory, electric, pipeline, hydraulic, lifeline and environmental facilities. Topics include Introduction of Reliability of Engineering Systems, Network Modeling and Evaluation of Complex Engineering Systems, Stochastic Engineering System Simulation, Frequency Analysis of Extreme Events, Reliability and Risk Evaluation of Engineering Systems, and Optimization of Engineering Systems. Prerequisite: MATH324. 3 hours lecture; 3 semester hours.

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EGGN598. SPECIAL TOPICS IN ENGINEERING (I, II) Pilot course of special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually course is offered only once. Prerequisite: Consent of the instructor. Variable credit; 1 to 6 hours. Repeatable for credit under different titles.

EGGN599. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 hours. Repeatable for credit to a maximum of 6 hours.

EGGN617. INTELLIGENT CONTROL SYSTEMS (II) Fundamental issues related to the design on intelligent control systems are described. Neural networks analysis for engineering systems are presented. Neural-based learning, estimation, and identification of dynamical systems are described. Qualitative control system analysis using fuzzy logic is presented. Fuzzy mathematics design of rule-based control, and integrated human-machine intelligent control systems are covered. Real-life problems from different engineering systems are analyzed. Prerequisite: EGGN517 or consent of instructor. 3 hours lecture; 3 semester hours. Spring semester of even years.

EGGN618. SYSTEM IDENTIFICATION AND ADAPTIVE CONTROL (II) Modeling is the first step in control design, and for many processes a physical model is not appropriate for control design, either because it is too complex, or because of unknown parameters. System identification is an important tool, which with proper use can help a control designer develop empirical models from experimental input/output data. These models are suitable for control system design. Adaptive control systems can make use of on-line system identification to continually update the process model and/or control parameters. The course will begin with coverage of unconstrained optimization and maximum likelihood (ML) estimation. Discrete time dynamic system models are introduced, including transfer function and state space models, random sequences, and ARMAX and Box-Jenkins model structures. State estimation and Kalman filtering is developed. System identification is then an application of ML estimation to various model structures. The final portion of the course covers adaptive control as an application of on-line system identification. Prerequisite: EGGN517 or EGGN523 or consent of instructor. 3 hours lecture; 3 semester hours. Spring, odd numbered years.

EGGN619. APPLIED INTELLIGENT CONTROL AND FAILURE DIAGNOSTICS (II) Application of intelligent control to system diagnostics and failure prediction. Fundamentals of machinery condition monitoring and health assessment. Survey of techniques used for signal analysis and interpretation of machine condition. Experiments involving servo hydraulic, electromechanical drives, refrigeration, and

power electronics, and the detection of faults in these systems. Presentation of current techniques for pattern recognition, signature analysis, sensor fusion, and intelligent control, including FFT, wavelets, and time-frequency analysis. Failure modes, effects and criticality analysis. Case studies and review of active research in failure prevention and predictive maintenance. Use of expert systems, fuzzy logic, and neural networks for intelligent machine decision making. Prerequisite: EGGN411, EGGN478 or consent of instructor. EGGN617 recommended. 3 hours lecture; 3 semester hours. Spring semesters, every other year.

EGGN642. ADVANCED FINITE ELEMENT ANALYSIS FOR ENGINEERS (I) Solution of nonlinear equations, Transient finite element analysis, Finite elements for nonlinear material behavior, Finite elements for large deformations and contact problems Applications of finite elements in mechanical engineering, materials processing and geomechanics. Prerequisites: EGGN320, EGGN315, EGGN542 and some scientific programming experience in C/C++ or Fortran, or the consent of the instructor. 3 hours lecture; 3 semester hours. Fall Semester of even numbered years.

EGGN649. HYDRODYNAMICS (II) Basic principles of hydrodynamics treat fundamentals, basic equations, and general theorems. Potential solutions include hydrodynamic singularities (sources, sinks, etc) and nonhomogeneous fluids flows. Nonhomogeneous fluids flows related to the resources recovery technologies. Waves of finite amplitude in stratified fluid. Surface waves and random waves. Motion by capilarity. Solution methods and engineering applications with computer-aided solutions. Prerequisites : EGGN551, MATH514 or consent of the instructor. 3 hours lecture; 3 semester hours Spring semester, every third year.

EGGN657/CHEN657. RADIATION HEAT TRANSFER (I) Review of radiative properties, blackbody radiation, Planck's distribution, Wien's Displacement Law, Kirchhoff's Law, view factors. Radiation exchange within enclosures and black and diffuse-gray surfaces. Radiation in absorbing, emitting and scattering (semi-transparent, participating) media. An engineering treatment of gas radiation in enclosures. Prerequisite: EGGN471, or equivalent or consent of instructor. 3 lecture hours, 3 semester hours.

EGGN658. MOLECULAR SPECTROSCOPY FOR THE THERMOSCIENCES (II) A detailed review of spectroscopy for engineers who use it diagnostics for flowfield research. Introduction to quantum mechanics including the one-electron atom problem, Zeeman effect and electron spin. Spectroscopy of multi-electron atoms, with a discussion of perturbation solutions to the Schrödinger equation. Development of a transition moment, and its relation to the Einstein A coefficient. Molecular spectroscopy is introduced via the harmonic oscillator and rigid rotator problems. Simple infrared spectroscopy, with the anharmonic oscillators and non-rigid rotators. Electronic transitions & the full diatomic molecular description. Topics such as the rate equations, the density

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matrix equations, or the spectroscopy of polyatomic species. Prerequisite: EGGN564, or consent of instructor. 3 hours lecture; 3 semester hours. Spring semesters, every other year (opposite EGGN659 Optical Measurements in Reacting and Nonreacting Flow Systems).

EGGN659. OPTICAL MEASUREMENTS IN REACTING AND NONREACTING FLOW SYSTEMS (II) An introduction to passive and active optical diagnostic techniques for species concentrations, gas temperature and flowfield velocity. Radiation methods for particulate and molecular species. Particulate methods for velocity (e.g. Particle Image Velocimetry). Line-of-sight measurements for both particulate and molecules (e.g. Rayleigh and Mie scattering, absorption). Spatially resolved measurements including nonresonant scattering (e.g. Raman), linear resonant methods (Laser Induced Fluorescence) and nonlinear methods (e.g. Degenerate Four-Wave Mixing). Prerequisite: EGGN501, EGGN564, PH optics course (no number at present), or consent of instructor. 3 hours lecture; 1 hour lab; 4 semester hours. Spring semesters, every other year (opposite Molecular Spectroscopy).

EGGN683. COMPUTER METHODS IN ELECTRIC POWER SYSTEMS (I, II) This course deals with the computer methods and numerical solution techniques applied to large scale power systems. Primary focus includes load flow, short circuit, voltage stability and transient stability studies and contingency analysis. The details include the modeling of various devices like transformer, transmission lines, FACTS devices, and synchronous machines. Numerical techniques include solving a large set of linear or non-linear algebraic equations, and solving a large set of differential equations. A number of simple case studies (as per IEEE standard models) will be performed. Prerequisites: EGGN583, 584 and 586 or equivalent, and/or consent of instructor; a strong knowledge of digital simulation techniques. 3 lecture hours; 3 semester hours.

EGGN698. SPECIAL TOPICS IN ENGINEERING (I, II) Pilot course of special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually course is offered only once. Prerequisite: Consent of the Instructor. Variable credit; 1 to 6 hours. Repeatable for credit under different titles.

EGES699. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 hours. Repeatable for credit under different topics/experience.

EGGN705. GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

EGGN706. GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty advisor. Repeatable for credit.



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## Environmental Science and Engineering

ROBERT L. SIEGRIST, Professor and Division Director

BRUCE D. HONEYMAN, Professor

TISSA ILLANGASEKARE, Professor and AMAX Distinguished Chair

PHILIPPE ROSS, Professor

RONALD R.H. COHEN, Associate Professor

JÖRG DREWES, Associate Professor

LINDA A. FIGUEROA, Associate Professor

JOHN E. McCRAY, Associate Professor

JUNKO MUNAKATA MARR, Associate Professor

TZAHY Y. CATH, Assistant Professor

JOHN R. SPEAR, Assistant Professor

MICHAEL SEIBERT, Research Professor

MARIA L. GHIRARDI, Research Associate Professor

MATTHIAS KOHLER, Research Associate Professor

MICHELLE L. CRIMI, Research Assistant Professor

MATTHEW C. POSEWITZ, Research Assistant Professor

PEI XU, Research Assistant Professor

KATHRYN LOWE, Senior Research Associate

JILL BRANNOCK, Research Associate

FREDERICO CHEEVER, Adjunct Professor

GEORGE W. PRING, Adjunct Professor

PAUL B. QUENEAU, Adjunct Professor

DANIEL T. TEITELBAUM, Adjunct Professor

### Degrees Offered:

Master of Science (Environmental Science and Engineering)

Doctor of Philosophy (Environmental Science and Engineering)

### Program Description:

The Environmental Science and Engineering (ESE) Division offers programs of study in environmental science and engineering within the context of risk-based decision-making, environmental law and policy leading to M.S. and Ph.D. graduate degrees as well as supporting several undergraduate degrees. Programs are designed to prepare students to investigate and analyze environmental systems and assess risks to public health and ecosystems as well as evaluate and design natural and engineered solutions to mitigate risks and enable beneficial outcomes. Programs of study are interdisciplinary in scope, and consequently the appropriate coursework may be obtained from multiple departments at CSM as well as other local universities.

To achieve the Master of Science (M.S.) degree, full-time students may elect the Non-Thesis option, based exclusively upon coursework and project activities, or the Thesis option, in which laboratory and/or field research is incorporated into the curriculum under the guidance of a faculty advisor. For working professional or part time M.S. students the ESE Executive Program is offered, consisting of an evening curriculum leading to a Non-Thesis M.S. degree. ESE also offers a combined baccalaureate/masters degree program in which CSM students obtain an undergraduate degree as well

as a Thesis or Non-Thesis M.S. in Environmental Science and Engineering. Please see the Combined Undergraduate/Graduate Programs sections in the *Graduate and Undergraduate Bulletins* for additional information. The availability of daytime, evening, and summer courses allows all students a high degree of flexibility in planning their coursework to achieve their degrees in a timely fashion.

To achieve the Doctor of Philosophy (Ph.D.) degree, students are expected to complete a combination of coursework and original research, under the guidance of a faculty advisor and Doctoral committee, that culminates in a significant scholarly contribution to a specialized field in environmental science or engineering. The Ph.D. Program may build upon one of the ESE M.S. Programs or a comparable M.S. Program at another university. Full-time enrollment is expected and leads to the greatest success, although part-time enrollment may be allowed under special circumstances.

The ESE Division offers areas of emphasis for study such as: Water Treatment, Reclamation & Reuse, Contaminant Hydrology & Water Resources, Applied Environmental Microbiology & Biotechnology, Characterization & Risk Analysis, and Environmental Remediation, that correspond to areas of significant career opportunities for graduates as well as expertise and active research by members of the ESE faculty. Each area of emphasis is designed to give students a rigorous, in-depth background in the subject matter relevant to the area while allowing opportunity, through electives, for breadth and exploration of related areas. For more information on ESE curriculum please refer to the Division Website at <http://www.mines.edu/academic/envsci/>.

The ESE M.S. and Ph.D. Programs have been admitted to the Western Regional Graduate Program (WRGP/WICHE), a recognition that designates this curriculum as unique within the Western United States. An important benefit of this designation is that students from Alaska, Arizona, Hawaii, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming are given the tuition status of Colorado residents.

### Combined Degree Program Option

CSM undergraduate students have the opportunity to begin work on a M.S. degree in Environmental Science and Engineering while completing their Bachelor's degree. The CSM Combined Degree Program provides the vehicle for students to use undergraduate coursework as part of their Graduate Degree curriculum. For more information please contact the ESE Office or visit <http://www.mines.edu/academic/envsci/ucombine.html>.

### Program Requirements:

M.S. Non-Thesis Option: 30 total credit hours, consisting of coursework (27 h), Independent Study (ESGN599A) (3 h), and seminar .

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M.S. Thesis Option: 30 total credit hours, consisting of coursework (24 h), seminar, and research (6h). Students must also write and orally defend a research thesis.

Students in the ESE M.S. degree program who are not registered full time must be enrolled in the part time ESE Executive Program.

M.S. Students entering the ESE Program in prior CSM Bulletins may not elect to change to the 2007-2008 CSM Bulletin requirements.

Ph.D.: 72 total credit hours, consisting of area of emphasis coursework (at least 18 h), seminar, and research (at least 24 h). Students must also successfully complete written and oral Qualifying examinations, prepare and present a dissertation proposal, and write and defend a doctoral dissertation. PhD students are also expected to submit the dissertation work for publication in scholarly journals.

#### **Prerequisites:**

- ◆ baccalaureate degree: required, preferably in a science or engineering discipline
- ◆ college calculus: two semesters required
- ◆ college physics: one semester required, one year highly recommended
- ◆ college chemistry: one year required
- ◆ college statistics: one semester required
- ◆ area of emphasis “recommended & required background” courses

#### **Required Curriculum:**

Curriculum areas of emphasis consist of recommended background courses, core courses, and electives. Students will work with their academic advisors and area coordinators to establish plans of study that best fit their individual interests and goals. Each student will develop and submit, a plan of study during the first semester of enrollment. Recommended background courses may be taken for credit while a student is enrolled in one of the ESE programs, with the limitation that only 9 credits from undergraduate-level courses may be applied toward graduate credit requirements. Area of emphasis core courses are prescribed, and some elective courses are recommended as highly suitable for particular areas. Other electives may be chosen freely from courses offered at CSM and other local universities. Please visit the ESE website for a complete outline of curriculum tracks and examples of elective courses offered by the Division and at CSM (<http://www.mines.edu/Academic/envsci/>).

#### **Fields of Research:**

Consistent with the Division’s areas of emphasis, research is focused in five main areas: 1) development of innovative processes for water and wastewater treatment, reclamation and reuse; 2) applications of biological processes in environmental remediation, water treatment, and renewable energy generation; 3) understanding fundamental chemical and ra-

diochemical processes governing the fate and transport of contaminants, and engineering these processes to achieve environmental goals; 4) geological, hydrological, and biological characterization of pristine and anthropogenically disturbed natural systems, both for elucidating natural system function and for informing remediation and restoration efforts; and 5) mathematical representation and modeling of hydrological and hydrogeological phenomena in soil and water systems. Within these areas, established research programs have developed investigating the treatment of emerging organic chemicals in water and wastewater, membrane technologies for water treatment, onsite and decentralized wastewater systems, beneficial reuse of produced water, transport/fate and treatment of pathogens in water and wastewater, transport/fate and treatment of non-aqueous phase liquids (NAPLs), environmental adsorption chemistry, bioavailability and toxicity of metals in the environment, biotreatment of metal- and radionuclide-containing wastes, molecular analysis of microbial communities, *in situ* remediation of soil and groundwater systems, and evaluation of the roles of riparian zones and wetlands in regulating water quality. In support of these research activities, ESE has modern facilities, including state-of-the-art laboratories for water/waste treatment, environmental radiochemistry, biotechnology, and toxicology. Specialized facilities include the Integrated Environmental Teaching Lab complex, Center for Experimental Study of Subsurface Environmental Processes, CSM/City of Golden Water Treatment Pilot Plant, and the Mines Park Test Site.

#### **Description of Courses**

ESGN401. FUNDAMENTALS OF ECOLOGY Biological and ecological principles are discussed and industrial examples of their use are given. Analysis of ecosystem processes, such as erosion, succession, and how these processes relate to engineering activities, including engineering design and plant operation, are investigated. Criteria and performance standards are analyzed for facility siting, pollution control, and mitigation of impacts. North American ecosystems are analyzed. Concepts of forestry, range, and wildlife management are integrated as they apply to all the above. Three to four weekend field trips will be arranged during the semester. Prerequisite: ESGN301 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN440. ENVIRONMENTAL POLLUTION: SOURCES, CHARACTERISTICS, TRANSPORT AND FATE This course describes the environmental behavior of inorganic and organic chemicals in multimedia environments, including water, air, sediment, and biota. Sources and characteristics of contaminants in the environment are discussed as broad categories, with some specific examples from various industries. Attention is focused on the persistence, reactivity, and partitioning behavior of contaminants in environmental media. Both steady and unsteady state multimedia environmental models are developed and applied to contaminated sites. The principles of contaminant transport in surface

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water, groundwater and air are also introduced. The course provides students with the conceptual basis and mathematical tools for predicting the behavior of contaminants in the environment. Prerequisite: ESGN353 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN/EGGN453. WASTEWATER ENGINEERING The goal of this course is to familiarize students with the fundamental phenomena involved in wastewater treatment processes (theory) and the engineering approaches used in designing such processes (design). This course will focus on the physical, chemical and biological processes applied to liquid wastes of municipal origin. Treatment objectives will be discussed as the driving force for wastewater treatment. Prerequisite: ESGN353 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN/EGGN454. WATER SUPPLY ENGINEERING This course presents contemporary issues relating to the supply of safe drinking water to the public. The theory and design of conventional potable water treatment unit processes and operations as well as water distribution systems will be covered. Prerequisite: ESGN353 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN455. SOLID AND HAZARDOUS WASTE ENGINEERING This course provides an introduction and overview of the engineering aspects of solid and hazardous waste management. The focus is on control technologies for solid wastes from common municipal and industrial sources and the end-of-pipe waste streams and process residuals that are generated in some key industries. Prerequisite: ESGN/EGGN353 and ESGN/EGGN354. 3 hours lecture; 3 semester hours.

ESGN/EGGN456. SCIENTIFIC BASIS OF ENVIRONMENTAL REGULATIONS This course offers a critical examination of the experiments, calculations, and assumptions underpinning numerical and narrative standards contained in federal and state environmental regulations. Top-down investigations of the historical development of selected regulatory guidelines and permitting procedures will be discussed, and students will design improved regulations. Prerequisite: ESGN353 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN/EGGN457. SITE REMEDIATION ENGINEERING This course describes the engineering principles and practices associated with the characterization and remediation of contaminated sites. Methods for site characterization and risk assessment will be highlighted with emphasis on remedial action screening processes, technology principles, and conceptual design. Common isolation and containment and *in situ* and *ex situ* treatment technology will be covered. Computerized decision-support tools will be used and case studies will be presented. Prerequisites: ESGN354 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN462/MTGN527. SOLID WASTE MINIMIZATION AND RECYCLING The objective of this course is to place the student into the role of a plant manager with process responsibility for waste minimization, focusing on recycling. Emphasis is on proven and emerging solutions, especially those associated with heavy metals, as well as understanding of alternative raw materials and process technologies in combination with creativity and sensitivity to economic realities. Prerequisites: ESGN500 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN463 POLLUTION PREVENTION: FUNDAMENTALS AND PRACTICE The objective of this course is to introduce the principles of pollution prevention, environmentally benign products and processes, and manufacturing systems. The course provides a thorough foundation in pollution prevention concepts and methods. Engineers and scientists are given the tools to incorporate environmental consequences into decision-making. Sources of pollution and its consequences are detailed. Focus includes sources and minimization of industrial pollution; methodology for life-cycle assessments and developing successful pollution prevention plans; technological means for minimizing the use of water, energy, and reagents in manufacturing; and tools for achieving a sustainable society. Materials selection, process and product design, and packaging are also addressed. Prerequisite: EGGN/ESGN353 or EGGN/ESGN354 or consent of instructor. 3 hours lecture; 3 semester hours.

#### **Graduate Courses**

ESGN500. ENVIRONMENTAL WATER CHEMISTRY This course provides an introduction to chemical equilibria in natural waters and engineered systems. Topics covered include chemical thermodynamics and kinetics, acid/base chemistry, open and closed carbonate systems, precipitation reactions, coordination chemistry, adsorption and redox reactions. Prerequisites: none. 3 hours lecture; 3 semester hours.

ESGN500L. ENVIRONMENTAL WATER CHEMISTRY LABORATORY This course provides students with laboratory exercises that complement lectures given in ESGN500. Topics covered include thermodynamics, weak acids and bases, buffers, metal-ion complexation and oxidation/reduction reactions. This course must be taken concurrently with ESGN500. Prerequisite: co-enrollment in ESGN500. 3 hours laboratory; 1 semester hour.

ESGN501. RISK ASSESSMENT This course evaluates the basic principles, methods, uses, and limitations of risk assessment in public and private sector decision making. Emphasis is on how risk assessments are made and how they are used in policy formation, including discussion of how risk assessments can be objectively and effectively communicated to decision makers and the public. Prerequisite: ESGN502 and one semester of statistics or consent of the instructor. 3 hours lecture; 3 semester hours.

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ESGN502. ENVIRONMENTAL LAW This is a comprehensive introduction to U.S. Environmental Law, Policy, and Practice, especially designed for the professional engineer, scientist, planner, manager, consultant, government regulator, and citizen. It will prepare the student to deal with the complex system of laws, regulations, court rulings, policies, and programs governing the environment in the USA. Course coverage includes how our legal system works, sources of environmental law, the major USEPA enforcement programs, state/local matching programs, the National Environmental Policy Act (NEPA), air and water pollution (CAA, CWA), EPA risk assessment training, toxic/hazardous substances laws (RCRA, CERCLA, EPCRA, TSCA, LUST, etc.), and a brief introduction to international environmental law. Prerequisites: none. 3 hours lecture; 3 semester hours.

ESGN503. ENVIRONMENTAL POLLUTION: SOURCES, CHARACTERISTICS, TRANSPORT AND FATE This course describes the environmental behavior of inorganic and organic chemicals in multimedia environments, including water, air, sediment and biota. Sources and characteristics of contaminants in the environment are discussed as broad categories, with some specific examples from various industries. Attention is focused on the persistence, reactivity, and partitioning behavior of contaminants in environmental media. Both steady and unsteady state multimedia environmental models are developed and applied to contaminated sites. The principles of contaminant transport in surface water, groundwater, and air are also introduced. The course provides students with the conceptual basis and mathematical tools for predicting the behavior of contaminants in the environment. Prerequisite: none. 3 hours lecture; 3 semester hours.

ESGN504. WATER AND WASTEWATER TREATMENT Unit operations and processes in environmental engineering are discussed in this course, including physical, chemical, and biological treatment processes for water and wastewater. Treatment objectives, process theory, and practice are considered in detail. Prerequisites: Consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN505. EXPERIMENTAL DESIGN AND ENVIRONMENTAL DATA ANALYSIS This course covers experimental design and analysis for studies of environmental media, including those involving characterization and assessment, treatment, and remediation technologies, and compliance monitoring. Principal media covered are water and wastewaters, soil and sediments, and surface and ground waters. Topics covered include properties of environmental datasets, data quality objectives, statistical designs for data collection, methods of sample collection and analysis, data analysis and visualization, inference making. Issues of data worth and sufficiency for decision making will also be addressed. Laboratory includes gravimetric, electrometric, spectrophotometric, chromatographic, and microbiological analyses. Prerequisite:

Consent of instructor. 3 hours lecture and laboratory; 3 semester hours.

ESGN510. ENVIRONMENTAL RADIOCHEMISTRY This course covers the phenomena of radioactivity (e.g., modes of decay, methods of detection and biological effects) and the use of naturally-occurring and artificial radionuclides as tracers for environmental processes. Discussions of tracer applications will range from oceanic trace element scavenging to contaminant transport through groundwater aquifers. Prerequisites: ESGN500 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN513. LIMNOLOGY This course covers the natural chemistry, physics, and biology of lakes as well as some basic principles concerning contamination of such water bodies. Topics include heat budgets, water circulation and dispersal, sedimentation processes, organic compounds and their transformations, radionuclide limnology, redox reactions, metals and other major ions, the carbon dioxide system, oxygen, nutrients; planktonic, benthic and other communities, light in water and lake modeling. Prerequisite: none. 3 hours lecture; 3 semester hours.

ESGN520. SURFACE WATER QUALITY MODELING This course will cover modeling of water flow and quality in rivers, lakes, and reservoirs. Topics will include introduction to common analytical and numerical methods used in modeling surface water flow, water quality, modeling of kinetics, discharge of waste water into surface systems, sedimentation, growth kinetics, dispersion, and biological changes in lakes and rivers. Prerequisites: ESGN440 or ESGN503 recommended, or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN522. SUBSURFACE CONTAMINANT TRANSPORT This course will investigate physical, chemical, and biological processes governing the transport and fate of contaminants in the saturated and unsaturated zones of the subsurface. Basic concepts in fluid flow, groundwater hydraulics, and transport will be introduced and studied. The theory and development of models to describe these phenomena, based on analytical and simple numerical methods, will also be discussed. Applications will include prediction of extents of contaminant migration and assessment and design of remediation schemes. Prerequisites: ESGN503 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN525. CHEMISTRY OF THE SOIL/WATER INTERFACE The fate of many elements in the soil/water environment is regulated by sorption reactions. The content of this course focuses on the physical chemistry of reactions occurring at the soil-particle/water interface. The emphasis is on the use of surface complexation models to interpret solute sorption at the particle/water interface. Prerequisites: ESGN500 or consent of the instructor. 3 hours lecture; 3 semester hours.



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ESGN527. WATERSHED SYSTEMS ANALYSIS Basic principles of watershed systems analysis required for water resources evaluation, watershed-scale water quality issues, and watershed-scale pollutant transport problems. The dynamics of watershed-scale processes and the human impact on natural systems, and for developing remediation strategies are studied, including terrain analysis and surface and subsurface characterization procedures and analysis. Prerequisite: none. 3 hours lecture per week; 3 semester hours.

ESGN528. MATHEMATICAL MODELING OF ENVIRONMENTAL SYSTEMS This is an advanced graduate-level course designed to provide students with hands-on experience in developing, implementing, testing, and using mathematical models of environmental systems. The course will examine why models are needed and how they are developed, tested, and used as decision-making or policy-making tools. Typical problems associated with environmental systems, such as spatial and temporal scale effects, dimensionality, variability, uncertainty, and data insufficiency, will be addressed. The development and application of mathematical models will be illustrated using a theme topic such as Global Climate Change, *In Situ* Bioremediation, or Hydrologic Systems Analysis. Prerequisites: ESGN503 and knowledge of basic statistics and computer programming. 3 hours lecture; 3 semester hours.

ESGN530. ENVIRONMENTAL ENGINEERING PILOT PLANT LABORATORY This course provides an introduction to bench and pilot-scale experimental methods used in environmental engineering. Unit operations associated with water and wastewater treatment for real-world treatment problems are emphasized, including multi-media filtration, oxidation processes, membrane treatment, and disinfection processes. Investigations typically include: process assessment, design and completion of bench- and pilot-scale experiments, establishment of analytical methods for process control, data assessment, up-scaling and cost estimation, and project report writing. Projects are conducted both at CSM and at the City of Golden Water Treatment Pilot Plant Laboratory. Prerequisites: ESGN500 and ESGN504 or consent of the instructor. 6 hours laboratory; 4 semester hours.

ESGN541/BELS541. MICROBIAL PROCESSES, ANALYSIS AND MODELING Microorganisms facilitate the transformation of many organic and inorganic constituents. Tools for the quantitative analysis of microbial processes in natural and engineered systems are presented. Stoichiometries, energetics, mass balances and kinetic descriptions of relevant microbial processes allow the development of models for specific microbial systems. Simple analytical models and complex models that require computational solutions will be presented. Systems analyzed include suspended growth and attached growth reactors for municipal and industrial wastewater treatment as well as in-situ bioremediation systems.

Prerequisites: ESGN500, ESGN504 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN544/BELS544. AQUATIC TOXICOLOGY This course provides an introduction to assessment of the effects of toxic substances on aquatic organisms, communities, and ecosystems. Topics include general toxicological principles, water quality standards, sediment quality guidelines, quantitative structure-activity relationships, single species and community-level toxicity measures, regulatory issues, and career opportunities. The course includes hands-on experience with toxicity testing and subsequent data reduction. Prerequisite: none. 2.5 hours lecture; 1 hour laboratory; 3 semester hours.

ESGN545/BELS545. ENVIRONMENTAL TOXICOLOGY This course provides an introduction to general concepts of ecology, biochemistry, and toxicology. The introductory material will provide a foundation for understanding why, and to what extent, a variety of products and by-products of advanced industrialized societies are toxic. Classes of substances to be examined include metals, coal, petroleum products, organic compounds, pesticides, radioactive materials, and others. Prerequisite: none. 3 hours lecture; 3 semester hours.

ESGN552. RECLAMATION OF DISTURBED LANDS Basic principles and practices in reclaiming disturbed lands are considered in this course, which includes an overview of present legal requirements for reclamation and basic elements of the reclamation planning process. Reclamation methods, including recontouring, erosion control, soil preparation, plant establishment, seed mixtures, nursery stock, and wildlife habitat rehabilitation, will be examined. Practitioners in the field will discuss their experiences. Prerequisite: consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN556. MINING AND THE ENVIRONMENT The course will cover many of the environmental problems and solutions associated with each aspect of mining and ore dressing processes. Mining is a complicated process that differs according to the type of mineral sought. The mining process can be divided into four categories: Site Development; Extraction; Processing; Site Closure. Procedures for hard rock metals mining; coal mining; underground and surface mining; and in situ mining will be covered in relation to environmental impacts. Beneficiation, or purification of metals will be discussed, with cyanide and gold topics emphasized. Site closure will be focused on; stabilization of slopes; process area cleanup; and protection of surface and ground water. After discussions of the mining and beneficiation processes themselves, we will look at conventional and innovative measures to mitigate or reduce environmental impact.

ESGN562/MTGN527. SOLID WASTE MINIMIZATION AND RECYCLING This course will examine, using case studies, ways in which industry applies engineering principles to minimize waste formation and to meet solid waste recycling challenges. Both proven and emerging solutions to solid waste

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environmental problems, especially those associated with metals, will be discussed. 3 hours lecture; 3 semester hours.

**ESGN563 POLLUTION PREVENTION: FUNDAMENTALS AND PRACTICE** The objective of this course is to introduce the principles of pollution prevention, environmentally benign products and processes, and manufacturing systems. The course provides a thorough foundation in pollution prevention concepts and methods. Engineers and scientists are given the tools to incorporate environmental consequences into decision-making. Sources of pollution and its consequences are detailed. Focus includes sources and minimization of industrial pollution; methodology for life-cycle assessments and developing successful pollution prevention plans; technological means for minimizing the use of water, energy, and reagents in manufacturing; and tools for achieving a sustainable society. Materials selection, process and product design, and packaging are also addressed. 3 hours lecture; 3 semester hours.

**ESGN571. ENVIRONMENTAL PROJECT MANAGEMENT** This course investigates environmental project management and decision making from government, industry, and contractor perspectives. Emphasis is on (1) economics of project evaluation; (2) cost estimation methods; (3) project planning and performance monitoring; (4) and creation of project teams and organizational/communications structures. Extensive use of case studies. Prerequisite: consent of the instructor. 3 hours lecture; 3 semester hours.

**ESGN575. HAZARDOUS WASTE SITE REMEDIATION** This course covers remediation technologies for hazardous waste contaminated sites, including site characteristics and conceptual model development, remedial action screening processes, and technology principles and conceptual design. Institutional control, source isolation and containment, subsurface manipulation, and *in situ* and *ex situ* treatment processes will be covered, including unit operations, coupled processes, and complete systems. Case studies will be used and computerized tools for process selection and design will be employed. Prerequisite: ESGN500 and ESGN503, or consent of the instructor. 3 hours lecture; 3 semester hours.

**ESGN575L. HAZARDOUS WASTE SITE REMEDIATION: TREATABILITY TESTING** This laboratory module is designed to provide hands-on experience with treatability testing to aid selection and design of remediation technologies for a contaminated site. The course will be comprised of laboratory exercises in Coolbaugh Hall and possibly some field site work near CSM. Pre-requisite: ESGN575 or consent of instructor. 2 hours laboratory; 1 semester hour.

**ESGN586/BELS586. MICROBIOLOGY OF ENGINEERED ENVIRONMENTAL SYSTEMS** This course explores applications of microbial physiological processes in wastewater treatment and bioremediation. Topics include biofilm formation in engineered systems, fermentation and respiration, environmental induction of microbial activities, biological denitrification, enhanced biological phosphorus removal,

activated sludge microbiology, biodegradation of organic contaminants, sulfate reduction in remediation of acid mine drainage, and redox biotransformations of metallic contaminants. Prerequisite: CHGC562 or equivalent or enrollment in an ESE program. 3 hours lecture, 3 semester hours.

**ESGN591. ANALYSIS OF ENVIRONMENTAL IMPACT** Techniques for assessing the impact of mining and other activities on various components of the ecosystem. Training in the procedures of preparing Environmental Impact Statements. Course will include a review of pertinent laws and acts (i.e. Endangered Species Act, Coordination Act, Clean Air Act, etc.) that deal with environmental impacts. Prerequisite: consent of the instructor. 3 hours lecture, some field trips; 3 semester hours.

**ESGN593. ENVIRONMENTAL PERMITTING AND REGULATORY COMPLIANCE** The purpose of this course is to acquaint students with the permit writing process, developing information requirements for permit applications, working with ambiguous regulations, negotiating with permit writers, and dealing with public comment. In addition, students will develop an understanding of the process of developing an economic and legally defensible regulatory compliance program. Prerequisite: ESGN502 or consent of the instructor. 3 hours lecture; 3 semester hours.

**ESGN596/BELS596. MOLECULAR ENVIRONMENTAL BIOTECHNOLOGY** This course investigates applications of recombinant DNA technology to the development of enzymes and organisms used for environmentally friendly industrial purposes. Topics include genetic engineering technology, biocatalysis of industrial processes by extremozymes, dye synthesis, biodegradation of aromatic compounds and chlorinated solvents, biosynthesis of polymers and sustainable fuels, and agricultural biotechnology. Prerequisite: introductory microbiology or consent of the instructor. 3 hours lecture; 3 semester hours.

**ESGN598. SPECIAL TOPICS IN ENVIRONMENTAL SCIENCE** Topics are chosen from special interests of instructor and students; see website for current offerings. Each topic is usually offered only once. Prerequisite: consent of the instructor. Variable class and semester hours. Repeatable for credit under different titles.

**ESGN598S. ENVIRONMENTAL SCIENCE AND ENGINEERING SEMINAR** Research presentations covering current research in a variety of environmental topics. 1.5 hours seminar. Repeatable for credit.

**ESGN599. INDEPENDENT STUDY** Individual master's level research or special project supervised by a faculty member. Prerequisite: Independent Study form must be completed and submitted to the Registrar. Variable class and semester hours. Repeatable for credit under different titles.

**ESGN602. INTERNATIONAL ENVIRONMENTAL LAW** The course covers an introductory survey of International Environmental Law, including multi-nation treaties, regulations,

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policies, practices, and politics governing the global environment. It surveys the key issues of sustainable development, natural resources projects, transboundary pollution, international trade, hazardous waste, climate change, and protection of ecosystems, wildlife, and human life. New international laws are changing the rules for engineers, project managers, scientists, teachers, businesspersons, and others both in the US and abroad, and this course is especially designed to keep professionals fully, globally informed and add to their credentials for international work. Prerequisites: ESGN502 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN603. ADVANCED WATER TREATMENT ENGINEERING AND WATER REUSE This course presents issues relating to theory, design, and operation of advanced water and wastewater treatment unit processes and water reuse systems. Topics include granular activated carbon (GAC), advanced oxidation processes ( $O_3/H_2O_2$ ), UV disinfection, pressure-driven and current-driven membranes (MF, UF, NF, RO, and electrodialysis), and natural systems such as riverbank filtration (RBF) and soil-aquifer treatment (SAT). The course includes hands-on experience using bench- and pilot-scale unit operations. Prerequisite: ESGN504 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN 603L. ADVANCED WATER TREATMENT ENGINEERING AND WATER REUSE -- LABORATORY This course provides hands-on experience using bench- and pilot-scale unit operations and computer exercises using state-of-the-art software packages to design advanced water treatment unit processes. Topics include adsorption processes onto powdered and granular activated carbon, advanced disinfection and oxidation processes (low- and medium pressure UV radiation;  $O_3/H_2O_2$ ), low-pressure membrane processes (microfiltration, ultrafiltration), and high-pressure and current-driven membrane processes (nanofiltration, reverse osmosis, and electrodialysis). Co- or Pre-requisite: ESGN 603 or consent of instructor. 1 semester hour.

ESGN622. MULTIPHASE CONTAMINANT TRANSPORT Principles of multiphase and multicomponent flow and transport are applied to contaminant transport in the unsaturated and saturated zones. Focus is on immiscible phase, dissolved phase, and vapor phase transport of low solubility organic contaminants in soils and aquifer materials. Topics discussed include: capillarity, interphase mass transfer, modeling, and remediation technologies. Prerequisites: ESGN500 or equivalent, ESGN503 or ESGN522 or equivalent, or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN698. ADVANCED SPECIAL TOPICS IN ENVIRONMENTAL SCIENCE Topics chosen from special interests of instructor(s) and students; see website for current offerings. Each topic is usually offered only once. Prerequisite: consent of the instructor. Variable class and semester hours. Repeatable for credit under different titles.

ESGN699. ADVANCED INDEPENDENT STUDY Individual doctoral level research or special project supervised by a faculty member. Prerequisite: Independent Study form must be completed and submitted to the Registrar. Variable class and semester hours. Repeatable for credit under different titles.

ESGN705. GRADUATE RESEARCH: MASTER OF SCIENCE Research credit hours required for completion of the Master of Science with Thesis degree. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

ESGN706. GRADUATE RESEARCH: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the Doctor of Philosophy degree. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

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## Geochemistry

JOHN D. HUMPHREY, Associate Professor Geology and

Geological Engineering and Interim Department Head

JOHN B. CURTIS, Professor Geology and Geological Engineering

WENDY J. HARRISON, Professor Geology and Geological Engineering

MURRAY W. HITZMAN, Professor, Charles F. Fogarty Professor of Economic Geology

PATRICK MACCARTHY, Professor Chemistry and Geochemistry

RICHARD F. WENDELANDT, Professor Geology and Geological Engineering

L. GRAHAM CLOSS, Associate Professor of Geology and Geological Engineering

KEVIN W. MANDERNACK, Associate Professor Chemistry and Geochemistry

JAMES F. RANVILLE, Associate Professor Chemistry and Geochemistry

E. CRAIG SIMMONS, Associate Professor Chemistry and Geochemistry

BETTINA M. VOELKER, Associate Professor Chemistry and Geochemistry

RONALD W. KLUSMAN, Professor Emeritus Chemistry and Geochemistry

DONALD L. MACALADY, Professor Emeritus Chemistry and Geochemistry

SAMUEL B. ROMBERGER, Professor Emeritus Geology and Geological Engineering

THOMAS R. WILDEMAN, Professor Emeritus Chemistry and Geochemistry

### Degrees Offered:

Professional Masters in Environmental Geochemistry

Master of Science (Geochemistry)

Doctor of Philosophy (Geochemistry)

### Program Description:

The Geochemistry Program is an interdisciplinary graduate program administered by the departments of Geology and Geological Engineering and Chemistry and Geochemistry.

The geochemistry faculty from each department are responsible for the operations of the program. Students reside in either the Department of Geology and Geological Engineering, or the Department of Chemistry and Geochemistry.

### Program Requirements:

The program of study is selected by the student in consultation with his or her advisor and thesis committee. Students entering with backgrounds in chemistry will take more coursework in geology to strengthen their backgrounds in this discipline; the converse is true for students with a background in geology. Due to the interdisciplinary nature of the Geochemistry Program, students are not required to take a minor.

### Qualifying Examination for Ph.D. Degree

A qualifying examination must be taken. It is expected that this exam will be completed within three years of matriculation or after the bulk of course work is finished, whichever occurs later. This examination will be administered by the student's Doctoral committee and will consist of an oral and

a written examination, administered in a format to be determined by the Doctoral Committee. Two negative votes in the Doctoral Committee constitute failure of the examination.

In case of failure of the qualifying examination, a re-examination may be given upon the recommendation of the Doctoral Committee and approval of the Graduate Dean. Only one re-examination may be given.

### Prerequisites:

Each entering student will have an entrance interview with members of the Geochemistry faculty. Each department recognizes that entering students may not be proficient in both areas. A placement examination in geology and/or chemistry may be required upon the discretion of the interviewing faculty. If a placement examination is given, the results may be used to establish deficiency requirements. Credit toward a graduate degree will not be granted for courses taken to fulfill deficiencies.

### Thesis Degrees (M.S. & Ph.D.) Required Curriculum:

A thesis is required for the M.S. degree and a dissertation for the Ph.D. The Geochemistry program comprises a core group of courses, required of all students unless individually exempted by the "Committee of the Whole" based on previous background. The core courses for M.S. students are

CHGC503 - Introduction to Geochemistry,

CHGC504 - Methods in Geochemistry, and a one hour laboratory course selected from several available.

In addition, MS degree students must take two courses selected from the following list

CHGC509/GEGN509 - Introduction to Aqueous Geochemistry,

CHGC610 - Nuclear and Isotopic Geochemistry,

CHGN503 - Advanced Physical Chemistry,

GEOL512 - Mineralogy and Crystal Chemistry.

Ph.D. degree students must take four core courses CHGC503, CHGC504, CHGN503, and a one hour laboratory course, and two additional courses selected from the list in the previous sentence.

The doctoral student's dissertation committee approves the number of course and research credits required for graduation, as well as the specific courses beyond the above requirements. The Ph.D. in Geochemistry requires a minimum of 72 credit hours, of which at least 24 hours must be research credit. Up to 24 hours of course credits may be transferred from previous graduate-level work upon approval of the dissertation committee. Research credits may not be transferred. Students who enter the Ph.D. program with a thesis-based master degree from another institution may transfer up to 36 semester hours, upon approval of the dissertation committee, in recognition of the course work and research completed for that degree.



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Graduate students resident in the Department of Chemistry and Geochemistry or the Department of Geology and Geological Engineering shall adhere to the seminar rules and requirements of the department of residence.

The Geochemistry Program at CSM has been admitted to the Western Regional Graduate Program. This entity recognizes the CSM Geochemistry Program as unique in the region. Designation of the Geochemistry Program by WRGP allows residents of western states (excluding California) to enroll in the program at Colorado resident tuition rates. Eligible states include Alaska, Arizona, Hawaii, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming.

### **Professional Masters**

#### **Introduction**

The Professional Masters in Environmental Geochemistry program is intended to provide: [1] an opportunity for CSM undergraduates to obtain, as part of a fifth year of study, a Masters in addition to the Bachelors degree; and [2] additional education for working professionals in the area of geochemistry as it applies to problems relating to the environment. This is a non-thesis masters degree program administered by the Geochemistry Program, and may be completed as part of a combined degree program by individuals already matriculated as undergraduate students at The Colorado School of Mines, or by individuals already holding undergraduate or advanced degrees and are interested in a graduate program that does not have the traditional research requirement. The program consists primarily of coursework in Geochemistry and allied fields, with an emphasis on environmental applications. No research is required though the program does allow for independent study, professional development, internship and coop experience.

#### **Application**

Undergraduate students at CSM must declare an interest during their 3rd year to allow for planning of coursework that will apply towards the program; these students must have an overall GPA of at least 3.0. Students majoring in other departments besides Chemistry & Geochemistry and Geology & Geological Engineering may want to decide on the combined degree program option earlier to be sure prerequisites are satisfied. Applicants other than CSM undergraduates who are applying for the Environmental Geochemistry program must follow the same procedures that all prospective graduate students follow; however, the requirement of the general GRE may be waived.

#### **Requirements**

A minimum of 36 credit hours are required, with an overall GPA of at least 3.0. The overall course requirements will depend on the background of the individual, but may be tailored to professional objectives.

CSM students that intend to follow the combined degree program format may double count into the program 6 credits

of 400-level or above courses taken as part of their undergraduate curriculum, provided those courses fit into the overall professional objectives of the individual, and compliment the course program below. Approval of those courses will be given by the Geochemistry Committee of the Whole. No more than 9 credits of 400-level courses may constitute the 36 minimum credit requirement.

#### **A 17 credit-hour core program consists of:**

- CHGN403: Environmental Chemistry (3 hrs, Fall)
- GEGN467\*: Ground-Water Engineering (4 hrs, Fall)
- CHGC503: Introduction to Geochemistry (4 hrs, Fall)
- GEGN509: Aqueous Geochemistry (3 hrs, Fall)
- GEOL530: Clay Characterization (1 hr, Fall)
- CHGC504: Methods in Geochemistry (2 hrs, Spring)

\*If this course is transferred from the undergraduate program, an advanced hydrogeology course may be substituted from the list below)

#### **An additional 12 credit-hours must be selected from the following list.**

- CHGC530: Environmental Chemistry and Geochemistry (3 hrs, Spring)
- CHGC555: Environmental Organic Chemistry (3 hrs, Spring)
- CHGC562: Microbiology and the Environment (3 hrs, Spring)
- CHGC563: Environmental Microbiology Laboratory (2 hrs, Fall)
- CHGC564: Biogeochemistry and Geomicrobiology (3 hrs, Fall)
- CHGC610: Nuclear and Isotopic Geochemistry (3 hrs, Spring)
- CHGC640: Soil Gas Geochemistry (3 hrs, Spring)
- CHGN503: Advanced Physical Chemistry (3 hrs, Fall)
- GEGN527: Organic Geochemistry of fossil fuels & ore deposits (3hrs, Spring)
- GEGN532: Geological Data Analysis (3 hrs, Fall)
- GEGN575: Applications of Geographic Information Systems (3 hrs, Spring)
- GEGN581: Advanced Ground- Water Engineering (3 hrs, Fall)
- GEGN582: Contaminant Hydrogeology (3 hrs, Spring) – proposed
- GEGN583: Mathematical Modeling of Ground-Water Systems (3 hrs, Spring)
- GEGN681: Vadose Zone Hydrology (3 hrs, Spring)
- GEGN683: Advanced Ground- Water Modeling (3 hrs, Spring)
- GEOL512: Mineralogy and Crystal Chemistry (3 hrs, Fall)
- GEOL684: Chemical Modeling of Aqueous Systems (3 hrs, Spring)
- GXGN571: Geochemical Exploration (3 hrs, Fall and Spring)

An additional 7 credit-hours of free electives may be selected to complete the 36 credit-hour requirement. Free

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electives may be selected from the list above, and may also be independent study credits (CHGN599, GEGN599 or GEOL599) taken to fulfill a research, cooperative, or other professional development experience. A course program will be designed in advanced through consultation between the student and an advisor from the Geochemistry Committee of the Whole.

### *Description of Courses*

CHGC503. INTRODUCTION TO GEOCHEMISTRY (I) A comprehensive introduction to the basic concepts and principles of geochemistry, coupled with a thorough overview of the related principles of thermodynamics. Topics covered include: nucleosynthesis, origin of earth and solar system, chemical bonding, mineral chemistry, elemental distributions and geochemical cycles, chemical equilibrium and kinetics, isotope systematics, and organic and biogeochemistry. Prerequisite: Introductory chemistry, mineralogy and petrology, or consent of instructor. 4 hours lecture; 4 semester hours.

GPGN/GEOL503. INTEGRATED EXPLORATION (I) Integration of scientific data in the analysis and modeling of subsurface reservoir systems. Prerequisite: GPGN315 or GEOL501 or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours.

CHGC504. METHODS IN GEOCHEMISTRY (II) Sampling of natural earth materials including rocks, soils, sediments, and waters. Preparation of naturally heterogeneous materials, digestions, and partial chemical extractions. Principles of instrumental analysis including atomic spectroscopy, mass separations, and chromatography. Quality assurance and quality control. Interpretation and assessment of geochemical data using statistical methods. Prerequisite: Graduate standing in geochemistry or environmental science and engineering. 2 hours lecture; 2 semester hours.

CHGC509/GEGN509. INTRODUCTION TO AQUEOUS GEOCHEMISTRY (I) Analytical, graphical, and interpretive methods applied to aqueous systems. Thermodynamic properties of water and aqueous solutions. Calculation and graphical expression of acid-base, redox and solution-mineral equilibria. Effect of temperature and kinetics on natural aqueous systems. Adsorption and ion exchange equilibria between clays and oxide phases. Behavior of trace elements and complexation in aqueous systems. Application of organic geochemistry to natural aqueous systems. Light stable and unstable isotopic studies applied to aqueous systems. Prerequisite: DCGN209 or equivalent, or consent of instructor. 3 hours lecture; 3 semester hours.

CHGC511. GEOCHEMISTRY OF IGNEOUS ROCKS (II) A survey of the geochemical characteristics of the various types of igneous rock suites. Application of major element, trace element, and isotope geochemistry to problems of their origin and modification. Prerequisite: Undergraduate mineralogy and petrology or consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

GEOL512. MINERALOGY AND CRYSTAL CHEMISTRY (I) Relationships among mineral chemistry, structure, crystallography, and physical properties. Systematic treatments of structural representation, defects, mineral stability and phase transitions, solid solutions, substitution mechanisms, and advanced methods of mineral identification and characterization. Applications of principles using petrological and environmental examples. Prerequisite: GEOL212, DCGN209, or equivalent, or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours.

GEOL515. ADVANCED MINERAL DEPOSITS - MAGMATIC AND SYNGENETIC ORES (I) Time-space aspects of metallogenesis in relation to regional and local geological evolution of the Earth. Processes leading to the formation of ore magmas and fluids within tectonic and stratigraphic frameworks, and to the development of favorable ore-forming environments. Emphasis will be placed on processes responsible for ore genesis in magmatic systems, such as layered complexes, carbonatites and pegmatites, and on the submarine hydrothermal processes responsible for syndepositional deposits in volcanic and sedimentary terrains, including massive base and precious metal sulfide ores. Ore deposits in certain sedimentary rocks, including copper, paleoplacer gold-uranium, marine evaporite, barite, and phosphate ores are considered in context of their generative environments and processes. Prerequisite: GEGN401 or equivalent, or consent of instructor. 2 hours lecture, 2 hours lab; 3 semester hours.

GEOL516. ADVANCED MINERAL DEPOSITS - EPIGENETIC HYDROTHERMAL SYSTEMS (II) Time-space aspects of metallogenesis in relation to regional and local geological evolution of the Earth. Processes leading to the generation of metalliferous hydrothermal mineralizing solutions within tectonic and lithologic frameworks, and to the development of favorable ore-forming environments. Emphasis will be placed on processes responsible for ore genesis in magmatic-hydrothermal systems such as porphyry copper-molybdenum-gold deposits, epithermal precious metal deposits, metamorphogenic gold deposits, volcanic and sedimentary rock-hosted epigenetic base metal ores and epigenetic sedimentary-rock hosted and unconformity-related uranium deposits. Prerequisite: GEGN401 or equivalent, or consent of instructor. 2 hours lecture, 2 hours lab; 3 semester hours.

GEGN518. MINERAL EXPLORATION (I) Mineral industry overview, deposit economics, target selection, deposit modeling, exploration technology, international exploration, environmental issues, program planning, proposal development. Team development and presentation of an exploration proposal. Prerequisite: GEOL515, GEOL516, or equivalent. 2 hours lecture/seminar; 2 hours lab; 3 semester hours. Offered alternate years: Fall 1996.

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CHGC527/GEGN527. ORGANIC GEOCHEMISTRY OF FOSSIL FUELS AND ORE DEPOSITS (II) A study of organic carbonaceous materials in relation to the genesis and modification of fossil fuel and ore deposits. The biological origin of the organic matter will be discussed with emphasis on contributions of microorganisms to the nature of these deposits. Biochemical and thermal changes which convert the organic compounds into petroleum, oil shale, tar sand, coal and other carbonaceous matter will be studied. Principal analytical techniques used for the characterization of organic matter in the geosphere and for evaluation of oil and gas source potential will be discussed. Laboratory exercises will emphasize source rock evaluation, and oil-source rock and oil-oil correlation methods. Prerequisite: CHGN221, GEGN438, or consent of instructor. 2 hours lecture; 3 hours lab; 3 semester hours. Offered alternate years. Spring 1999.

CHGC530. ENVIRONMENTAL CHEMISTRY AND GEOCHEMISTRY (II) Mobility of the elements in air, water and the surficial environment. Geochemical cycles of elements and constituents of environmental interest. Plant composition, animal and human health in relation to the natural environment. Acid deposition and other processes affecting water quality. Environmental aspects of fossil fuel processing. Sampling design in large scale environmental studies. Prerequisite: CHGC503 or ESGN500 and ESGN501. 3 hours lecture; 3 semester hours.

GEGN530. CLAY CHARACTERIZATION (I) Clay mineral structure, chemistry and classification, physical properties (flocculation and swelling, cation exchange capacity, surface area and charge), geological occurrence, controls on their stabilities. Principles of X-ray diffraction, including sample preparation techniques, data collection and interpretation, and clay separation and treatment methods. The use of scanning electron microscopy to investigate clay distribution and morphology. Methods of measuring cation exchange capacity and surface area. Prerequisite: GEOL210 and GEGN306 or equivalent, or consent of instructor. 1 hour lecture, 2 hours lab; 1 semester hour.

GEGN532. GEOLOGICAL DATA ANALYSIS (I or II) Techniques and strategy of data analysis in geology and geological engineering: basic statistics review, analysis of data sequences, mapping, sampling and sample representativity, univariate and multivariate statistics, geostatistics, and geographic information systems (GIS). Practical experience with geological applications via supplied software and data sets from case histories. Prerequisites: Introductory statistics course (MATH323 or MATH530 or equivalent); and previous or concurrent enrollment in MACS532 or permission of instructor. 2 hours lecture/discussion; 3 hours lab; 3 semester hours.

CHGC555. ENVIRONMENTAL ORGANIC CHEMISTRY (II) A study of the chemical and physical interactions which determine the fate, transport and interactions of organic chemicals in aquatic systems, with emphasis on chemical

transformations of anthropogenic organic contaminants. Prerequisites: A course in organic chemistry and CHGN503, Advanced Physical Chemistry or its equivalent, or consent of instructor. Offered on demand. 3 hours lecture; 3 semester hours.

CHGC562/CHGN462. MICROBIOLOGY AND THE ENVIRONMENT This course will cover the basic fundamentals of microbiology, such as structure and function of procaryotic versus eucaryotic cells; viruses; classification of micro-organisms; microbial metabolism, energetics, genetics, growth and diversity; microbial interactions with plants, animals, and other microbes. Additional topics covered will include various aspects of environmental microbiology such as global biogeochemical cycles, bioleaching, bioremediation, and wastewater treatment. Prerequisite: ESGN301 or consent of Instructor. 3 hours lecture, 3 semester hours. Offered alternate years.

CHGC563. ENVIRONMENTAL MICROBIOLOGY (I) An introduction to the microorganisms of major geochemical importance, as well as those of primary importance in water pollution and waste treatment. Microbes and sedimentation, microbial leaching of metals from ores, acid mine water pollution, and the microbial ecology of marine and freshwater habitats are covered. Prerequisite: Consent of instructor. 1 hour lecture, 3 hours lab; 2 semester hours. Offered alternate years. Fall 1998.

CHGC564. BIOGEOCHEMISTRY AND GEOMICROBIOLOGY (I) Designed to give the student an understanding of the role of living things, particularly microorganisms, in the shaping of the earth. Among the subjects will be the aspects of living processes, chemical composition and characteristics of biological material, origin of life, role of microorganisms in weathering of rocks and the early diagenesis of sediments, and the origin of petroleum, oil shale, and coal. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

GXGN571. GEOCHEMICAL EXPLORATION (I, II) Dispersion of trace metals from mineral deposits and their discovery. Laboratory consists of analysis and statistical interpretation of data from soils, stream sediments, vegetation, and rock in connection with field problems. Term report required. Prerequisite: Consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours.

GEGN575. APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS (II) An introduction to Geographic Information Systems (GIS) and their applications to all areas of geology and geological engineering. Lecture topics include: principles of GIS, data structures, digital elevation models, data input and verification, data analysis and spatial modeling, data quality and error propagation, methods of GIS evaluation and selection. Laboratories will use Macintosh and DOS-based personal computer systems for GIS projects, as well as video-presentations. Visits to local GIS

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laboratories, and field studies will be required. 2 hours lecture, 3 hours lab; 3 semester hours.

GEOL609. ADVANCED PETROLEUM GEOLOGY (II) Subjects to be covered involve consideration of basic chemical, physical, biological and geological processes and their relation to modern concepts of oil/gas generation (including source rock deposition and maturation), and migration/accumulation (including that occurring under hydrodynamic conditions). Concepts will be applied to the historic and predictive occurrence of oil/gas to specific Rocky Mountain areas. In addition to lecture attendance, course work involves review of topical papers and solution of typical problems. Prerequisite: GEGN438. 3 hours lecture; 3 semester hours.

CHGC610. NUCLEAR AND ISOTOPIC GEOCHEMISTRY (II) A study of the principles of geochronology and stable isotope distributions with an emphasis on the application of these principles to important case studies in igneous petrology and the formation of ore deposits. U, Th, and Pb isotopes, K-Ar, Rb-Sr, oxygen isotopes, sulfur isotopes, and carbon isotopes included. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours Offered alternate years. Spring 1998.

GEOL615. GEOCHEMISTRY OF HYDROTHERMAL MINERAL DEPOSITS (I) Detailed study of the geochemistry of selected hydrothermal mineral deposits. Theory and application of stable isotopes as applied to mineral deposits. Origin and nature of hydrothermal fluids and the mechanisms of transport and deposition of ore minerals. Review of wall-rock alteration processes. Fundamental solution chemistry and the physical chemistry of hydrothermal fluids. Prerequisite: GEGN401 or equivalent or consent of instructor. 3 hours lecture; 3 semester hours.

GEOL617. THERMODYNAMICS AND MINERAL PHASE EQUILIBRIA (I) Basic thermodynamics applied to natural geologic systems. Evaluation of mineral-vapor mineral solution, mineral-melt, and solid solution equilibria with special emphasis on oxide, sulfide, and silicate systems. Experimental and theoretical derivation, use, and application of phase diagrams relevant to natural rock systems. An emphasis will be placed on problem solving rather than basic theory. Prerequisite: DCGN209 or equivalent or consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years; Fall 1995.

GEOL621. PETROLOGY OF DETRITAL ROCKS (II) Compositions and textures of sandstones, siltstones, and mudrocks. Relationship of compositions and textures of provenance, environment of deposition, and burial history. Development of porosity and permeability. Laboratory exercises emphasize use of petrographic thin sections, x-ray diffraction analysis, and scanning electron microscopy to examine detrital rocks. A term project is required, involving petrographic analysis of samples selected by student. Prerequisites: GEOL212 or 210, GEOL221 or equivalent or

consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours. Offered on demand.

GEOL624. CARBONATE SEDIMENTOLOGY AND PETROLOGY (II) Processes involved in the deposition of carbonate sediments with an emphasis on Recent environments as analogs for ancient carbonate sequences. Carbonate facies recognition through bio- and lithofacies analysis, three-dimensional geometries, sedimentary dynamics, sedimentary structures, and facies associations. Laboratory stresses identification of Recent carbonate sediments and thin section analysis of carbonate classification, textures, non-skeletal and biogenic constituents, diagenesis, and porosity evolution. Prerequisite: GEOL221 and GEGN306 or GEGN307 or consent of instructor. 2 hours lecture/seminar, 2 hours lab; 3 semester hours.

GEOL625. ADVANCED METAMORPHIC PETROLOGY Metamorphic processes and concepts, emphasizing physical and chemical controls in the development of mineral assemblages. Petrographic examination of rock suites from representative metamorphic zones and facies. Emphasis on the interrelationships of crystallization and deformation and an interpretation of metamorphic history. Prerequisite: GEGN307 (or equivalent) or consent of instructor. 2 hours lecture and seminar, 3 hours lab; 3 semester hours. Offered alternate years; Fall 1996.

GEOL626. ISOTOPE GEOLOGY (II) The application of radioactive and stable isotope analysis to problems in igneous and metamorphic petrology and ore genesis. Studies of polymetamorphic terrains with special reference to the geochronology of the Front Range. The utilization of isotopic tracers to evaluate petrogenic models. The distribution of heavy radiogenic and light stable isotopes as indicators of source terrain and subsequent evolution of mineral deposits. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years; Spring 2003.

GEOL628. ADVANCED IGNEOUS PETROLOGY (I) Igneous processes and concepts, emphasizing the genesis, evolution, and emplacement of tectonically and geochemically diverse volcanic and plutonic occurrences. Tectonic controls on igneous activity and petrochemistry. Petrographic study of igneous suites, mineralized and non-mineralized, from diverse tectonic settings. Prerequisites: GEOL221, GEOL212, or GEGN307. 3 hours lecture, 3 hours lab; 3 semester hours. Offered alternate years; Fall 1997.

GXGN633. LITHOGEOCHEMICAL MINERAL EXPLORATION (II) Principles and application of primary dispersion to the search for metallic mineral deposits. Evaluation of the design, sampling, analytical, and interpretational techniques used in lithogeochemical exploration. Practical laboratory exercises. Term projects required. Prerequisite: GXGN571, GEGN401 or equivalent or consent of instructor. 3 hours lecture/seminar/lab; 3 semester hours. Offered alternate years; Spring 1999.



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GXGN635. SURFICIAL EXPLORATION GEOCHEMISTRY (II) Secondary dispersion processes (mechanical and chemical) applied to the search for metalliferous mineral deposits. A variety of sampling media, analytical procedures, and interpretive techniques are evaluated. Landscape geochemistry framework for exploration program design. Prerequisite: GXGN571 or equivalent or consent of instructor. A course in geomorphology recommended. 3 hours lecture/seminar/lab; 3 semester hours. Offered alternate years; Spring 1997.

CHGC640. SOIL GAS GEOCHEMISTRY AND APPLICATIONS IN THE EARTH AND ENVIRONMENTAL SCIENCES (II) Thermal, chemical, and microbiological reactions in the production of gases. Quantitative review of transport of gaseous species in the saturated and unsaturated zones. Sampling and analysis of soil gases. Applications of soil gas in the earth and environmental sciences, including exploration, contaminant mapping, and global climate change. Prerequisites: CHGC503, or ESGN500 and ESGN501, or consent of instructor. 3 hours lecture; 3 semester hours.

GEOL645. VOLCANOLOGY (II) Assigned readings and seminar discussions on volcanic processes and products. Principal topics include pyroclastic rocks, craters and calderas, caldron subsidence, diatremes, volcanic domes, origin and evolution of volcanic magmas, and relation of volcanism to alteration and mineralization. Petrographic study of selected suites of lava and pyroclastic rocks in the laboratory. Prerequisite: Consent of instructor. 1 hour seminar, 6 hours lab; 3 semester hours.

GEOL653. CARBONATE DIAGENESIS AND GEOCHEMISTRY (II) Petrologic, geochemical, and isotopic approaches to the study of diagenetic changes in carbonate sediments and rocks. Topics covered include major near-surface diagenetic environments, subaerial exposure, dolomitization, burial diagenesis, carbonate aqueous equilibria, and the carbonate geochemistry of trace elements and stable isotopes. Laboratory stresses thin section recognition of diagenetic textures and fabrics, x-ray diffraction, and geochemical/isotopic approaches to diagenetic problems. Prerequisite: GEOL624 or equivalent or consent of instructor. 4 to 6 hours lecture/seminar/lab; 3 semester hours.

GEGN684. CHEMICAL MODELING OF AQUEOUS SYSTEMS (II) Provides theoretical background and practical experience in the application of chemical equilibrium and reaction path models to problems in diverse fields of theoretical and applied aqueous geochemistry. Advanced topics in aqueous geochemistry are presented and subsequently investigated using computer simulation approaches. Includes hands-on experience with the software EQ3/6. Instruction is provided in the use of basic UNIX commands. The course progressively builds user ability through a wide variety of applications including problems in thermodynamic data quality evaluation, ore deposition, sediment diagenesis,

groundwater evolution, contaminant geochemistry, leachate generation, and enhanced oil recovery treatments. Course ends with student presentations of a chemical modeling study applied to a problem of their choosing. Prerequisite: GEGN585 or consent of instructor. 3 hours lecture/computer lab; 3 semester hours.

CHGC699A. SELECTED TOPICS IN GEOCHEMISTRY (I, II) Detailed study of a geochemical topic under direction of a member of the staff. Work on the same or a different topic may be continued through later semesters and additional credits earned. Prerequisite: Consent of instructor. 1 to 3 semester hours. Repeatable for credit.

CHGC699B. SPECIAL TOPICS IN AQUEOUS AND SEDIMENTARY GEOCHEMISTRY (I, II) Detailed study of a specific topic in the area of aqueous or sedimentary geochemistry under the direction of a member of the staff. Work on the same or a different topic may be continued through later semesters and additional credits earned. Prerequisite: Consent of instructor. 1 to 3 semester hours. Repeatable for credit.

CHGC699C. SPECIAL TOPICS IN ORGANIC AND BIOGEOCHEMISTRY (I, II) Detailed study of a specific topic in the areas of organic geochemistry or biogeochemistry under the direction of a member of the staff. Work on the same or a different topic may be continued through later semesters and additional credits earned. Prerequisite: Consent of instructor. 1 to 3 semester hours. Repeatable for credit.

CHGC699D. SPECIAL TOPICS IN PETROLOGIC GEOCHEMISTRY (I, II) Detailed study of a specific topic in the area of petrologic geochemistry under the direction of a member of the staff. Work on the same or a different topic may be continued through later semesters and additional credits earned. Prerequisite: Consent of instructor. 1 to 3 semester hours. Repeatable for credit.

CHGC705 GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

CHGC706 GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty advisor. Repeatable for credit.

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## Geology and Geological Engineering

JOHN D. HUMPHREY, Associate Professor and Interim Department Head

JOHN B. CURTIS, Professor

WENDY J. HARRISON, Professor

MURRAY W. HITZMAN, Professor, Charles F. Fogarty Professor of Economic Geology

EILEEN POETER, Professor

SAMUEL B. ROMBERGER, Professor

STEPHEN A. SONNENBERG, Professor, Charles Boettcher Distinguished Chair in Petroleum Geology

RICHARD F. WENDLANDT, Professor

DAVID A. BENSON, Associate Professor

L. GRAHAM CLOSS, Associate Professor

JERRY D. HIGGINS, Associate Professor

JOHN E. McCRAY, Associate Professor

KEVIN W. MANDERNACK, Associate Professor

ERIC P. NELSON, Associate Professor

PIRET PLINK-BJORKLUND, Associate Professor

PAUL SANTI, Associate Professor

BRUCE TRUDGILL, Associate Professor

WEI ZHOU, Associate Professor

NIGEL M. KELLY, Assistant Professor

CHRISTIAN V. SHOREY, Instructor

CHARLES F. KLUTH, Distinguished Scientist

DAVID PYLES, Research Professor

DONNA S. ANDERSON, Research Associate Professor

MASON DYKSTRA, Research Associate Professor

NICHOLAS B. HARRIS, Research Associate Professor

KARIN HOAL, Research Associate Professor

MAEVE BOLAND, Research Assistant Professor

RENAUD BOUROULLEC, Research Assistant Professor

MARY CARR, Research Assistant Professor

THOMAS L.T. GROSE, Professor Emeritus

JOHN D. HAUN, Professor Emeritus

NEIL F. HURLEY, Professor Emeritus, Charles Boettcher

Distinguished Chair in Petroleum Geology

RICHARD W. HUTCHINSON, Professor Emeritus

KEENAN LEE, Professor Emeritus

A. KEITH TURNER, Professor Emeritus

JOHN E. WARME, Professor Emeritus

ROBERT J. WEIMER, Professor Emeritus

TIMOTHY A. CROSS, Associate Professor Emeritus

GREGORY S. HOLDEN, Associate Professor Emeritus

### Degrees Offered:

Professional Master's Degree

(Petroleum Reservoir Systems) (Non-Thesis)

Professional Master's Degree (Mineral Exploration and Mining Geosciences) (Non-Thesis)

Professional Master's Degree (Geochemistry) (Non-Thesis)

Master of Engineering (Geological Engineer) (Non-Thesis)

Master of Science (Geology)

Master of Science (Geological Engineering)

Master of Science (Geochemistry)

Doctor of Philosophy (Geology)

Doctor of Philosophy (Geochemistry)

Doctor of Philosophy (Geological Engineering)

### Program Description:

The Department of Geology and Geological Engineering offers Master of Science and Doctor of Philosophy degrees in Geology and Geochemistry; and Master of Engineering, Master of Science and Doctor of Philosophy degrees in Geological Engineering. Geological Engineering degrees require possession or acquisition of an undergraduate engineering degree or its equivalent.

Graduate students desiring to study ground water, engineering geology/geotechnics, mining engineering geology and some environmental applications are generally expected to pursue the Geological Engineering degree. Students desiring to study petroleum or minerals exploration or development sciences, geochemistry and/or geology generally pursue Geology or Geochemistry degrees. Students are initially admitted to either geoscience or geological engineering degree programs and must receive approval of the GE department Graduate Advisory Committee to switch degree categories.

### Program Requirements:

#### Geology Degrees:

The **Master of Science (Geology)** academic program will require 36 semester hours of course and research credit hours (a maximum of 9 credit hours may be 400-level course work), plus a thesis. Twelve of the 36 credit hours may be research credits. To ensure breadth of background, the course of study for the Master of Science (Geology) degree must include at least one graduate course in each of the fields of stratigraphy/sedimentology, structural geology/tectonics, and petrology. At the discretion of the student's thesis advisory committee, an appropriate course taken from a degree program other than Geology may be substituted for one (and only one) of the fields above. Candidates must also complete GEOL607, Graduate Seminar, as part of their course programs. All Master of Science (Geology) candidates must also complete an appropriate thesis, based upon original research they have completed. A thesis proposal and course of study must be approved by a candidate's thesis committee before the candidate begins substantial work on the thesis research.

The requirement for **Doctor of Philosophy (Geology)** academic programs will be established individually by a candidate's Doctoral Thesis Advisory Committee, but must meet the minimum requirements presented below. The Doctor of Philosophy (Geology) academic program will require a minimum of 72 hours of course and research credit hours (a maximum of 9 credit hours may be 400-level course work), plus a qualifying examination and a thesis. All candidates must complete a minimum of 24 research credit hours and must complete a minimum of 48 course credit hours, including 12 hours in a minor field. Up to 24 course credit hours (including those for the minor field) may be awarded by the candidate's Doctoral Thesis Advisory Committee for completion of a Master of Science degree (at CSM or elsewhere). The Doctor of Philosophy (Geology) course program must satisfy the breadth requirements required of Master of Science

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(Geology) candidates (including GEOL607) and must also include GEOL511 (History of Geological Concepts).

Prospective students should submit the results of the Graduate Record Examination with their application for admission to graduate study. In the event that it is not possible, because of geographic and other restrictions, to take the Graduate Record Examination prior to enrolling at Colorado School of Mines, enrollment may be granted on a provisional basis subject to satisfactory completion of the examination within the first year of residence.

### **Professional Masters – Geochemistry Introduction**

The proposed program is intended to provide: [1] an opportunity for CSM undergraduates to obtain, as part of a fifth year of study, a Masters in addition to the Bachelors degree; and [2] additional education for working professionals in the area of geochemistry as it applies to problems relating to the environment.

The program outlined below is a non-thesis masters degree program administered by the Geochemistry Program, and may be completed as a combined degree program by individuals already matriculated as undergraduate students at The Colorado School of Mines, or by individuals already holding undergraduate or advanced degrees and are interested in a graduate program that does not have the traditional research requirement. The program consists primarily of coursework in Geochemistry and allied fields, with an emphasis on environmental applications. No research is required though the program does allow for independent study, professional development, internship and coop experience.

### **Application**

Undergraduate students at CSM must declare an interest during their 3rd year to allow for planning of coursework that will apply towards the program; these students must have an overall GPA of at least 3.0. Students majoring in other departments besides Chemistry & Geochemistry and Geology & Geological Engineering may want to decide on the combined degree program option earlier to be sure prerequisites are satisfied. External people applying for the program must follow the same procedures that all prospective graduate students follow; however, the requirement of the general GRE may be waived.

### **Requirements**

A minimum of 36 credit hours are required, with an overall GPA of at least 3.0. The overall course requirements will depend on the background of the individual, but may be tailored to professional objectives.

CSM students that intend to follow the 4+1 format may transfer into the program 6 credits of 400-level or above courses taken as part of their undergraduate curriculum, provided those courses fit into the overall professional objectives of the individual, and compliment the course program

below. Approval of those courses will be given by the Geochemistry Committee of the Whole. No more than 9 credits of 400-level courses may constitute the 36 minimum credit requirement.

### **A 17 credit-hour core program consists of:**

CHGN403: Environmental Chemistry (3 hrs, Fall)  
GEGN467\*: Ground-Water Engineering (4 hrs, Fall)  
CHGC503: Introduction to Geochemistry (4 hrs, Fall)  
GEGN509: Aqueous Geochemistry (3 hrs, Fall)  
GEOL530: Clay Characterization (1 hr, Fall)  
CHGC504: Methods in Geochemistry (2 hrs, Spring)

\*If this course is transferred from the undergraduate program, an advanced hydrogeology course may be substituted from the list below)

### **An additional 12 credit-hours must be selected from the following list.**

CHGC530: Environmental Chemistry and Geochemistry (3 hrs., Spring)  
CHGC555: Environmental Organic Chemistry (3 hrs., Spring)  
CHGC562: Microbiology and the Environment (3 hrs., Spring)  
CHGC563: Environmental Microbiology Laboratory (2 hrs., Fall)  
CHGC564: Biogeochemistry and Geomicrobiology (3 hrs., Fall)  
CHGC610: Nuclear and Isotopic Geochemistry (3 hrs., Spring)  
CHGC640: Soil Gas Geochemistry (3 hrs., Spring)  
CHGN503: Advanced Physical Chemistry (3 hrs., Fall)  
GEGN527: Organic Geochemistry of Fossil Fuels & Ore Deposits (3 hrs., Spring)  
GEGN532: Geological Data Analysis (3 hrs., Fall)  
GEGN575: Applications of Geographic Information Systems (3 hrs., Spring)  
GEGN581: Advanced Ground- Water Engineering (3 hrs., Fall)  
GEGN583: Mathematical Modeling of Ground-Water Systems (3 hrs., Spring)  
GEGN681: Vadose Zone Hydrology (3 hrs., Spring)  
GEGN683: Advanced Ground-Water Modeling (3 hrs., Spring)  
GEOL512: Mineralogy and Crystal Chemistry (3 hrs., Fall)  
GEOL684: Chemical Modeling of Aqueous Systems (3 hrs., Spring)  
GXGN571: Geochemical Exploration (3 hrs., Fall and Spring)

An additional 7 credit-hours of free electives may be selected to complete the 36 credit-hour requirement. Free electives may be selected from the list above, and may also be independent study credits (CHGN599, GEGN599 or GEOL599) taken to fulfill a research, cooperative, or other professional development experience. A course program will be designed

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in advance through consultation between the student and an advisor from the Geochemistry Committee of the Whole.

### **Professional Masters in Mineral Exploration and Mining Geosciences**

This is a non-thesis, masters degree program jointly administered by Geology and Geological Engineering, Geochemistry, and Geophysics. Students gain admission to the program by application to any of the sponsoring departments and acceptance through the normal procedures of that department. This appendix lists course requirements and options.

#### **Requirements**

A minimum of 36 credit hours. Up to 9 credit hours may be at the 400-level. All other credits toward the degree must be 500-level or above.

- ◆ A 15 credit hour core program from the relevant departments and consists of:
  - GEGN403: Mineral Exploration Design (3 hrs., Spring)
  - GEOL515: Advanced Mineral Deposits-Magmatic & Syngenetic Ores (3 hrs., Fall) *or*
  - GEOL516: Advanced Mineral Deposits-Epithermal Hydrothermal Systems (3 hrs., Spring) *or*
  - GEGN528 Mining Geology (3 hrs., Spring, even years)
  - GEGX571: Geochemical Exploration (3 hrs., Fall)
  - GPGN530: Applied Geophysics (3 hrs., Spring)
  - EBGN504 Economic Evaluation and Investment Decision Methods (3 hrs., Spring) *or*
  - EBGN510 Natural Resource Economics (3 hrs., Fall) *or*
  - EBGN512 Macroeconomics (3 hours, Spring) *or*
  - MNGN585 Mining Economics (3 hrs., Spring, even years)
- ◆ 15 additional credit hours must be selected from the following list. Selection of courses will be undertaken by the student in consultation with their degree committee consisting of three faculty from the respective programs that have admitted the student (GC, GE, GP, MN):

#### **Geochemistry:**

- GEGX633: Lithgeochemical Mineral Exploration (3 hrs. Spring)
- GEGX635: Surficial Exploration Geochemistry (3 hrs Spring)

#### **Geology and Geological Engineering:**

- GEOL404: Ore Microscopy (3 hrs., Spring)
- GEGN517: Field Methods in Economic Geology (3 hrs., Spring and Fall)
- GEOL505: Applied Structural Geology (3 hrs., Spring)
- GEOL509: Introduction to Aqueous Geochemistry (3 hrs., Fall)
- GEGN518: Mineral Exploration (3 hrs., Spring)
- GEGN528: Mining Geology (3 hrs., Spring)
- GEGN532: Geological Data Analysis (3 hrs., Fall)
- GEOL545: Introduction to Remote Sensing (3 hrs., Spring)
- GEOL575: Geographic Information Systems (GIS) (3 hrs., Fall)

#### **Geophysics:**

- GPGN507 Near-Surface Field Methods (3 hrs., Fall)
- GPGN509 Physical and Chemical Properties and Processes in Rock, Soil, and Fluids (3 hrs., Fall)
- GPGN510 Gravity and Magnetic Exploration (3 hrs., Spring)
- GPGN511 Advanced Gravity and Magnetic Exploration (4 hrs., Spring, even years)
- GPGN520 Electrical and Electromagnetic Exploration (4 hrs., Fall, odd years)
- GPGN521 Advanced Electrical and Electromagnetic Exploration (4 hrs., Spring, even years)
- GPGN540 Mining Geophysics (3 hrs., Fall)

Other:

#### **Economics and Business:**

- EBGN535 Economics of Metal Industries and Markets (3 hrs., Spring)
- EBGN536 Mineral Policies and International Investment (3 hrs., Spring)
- EBGN541 International Trade (3 hrs., Spring)
- EBGN575 Advanced Mining and Energy Valuation (3 hrs., Fall)
- EBGN580 Exploration Economics (3 hrs., Fall)

#### **Environmental Science and Engineering:**

- ESGN456 Scientific Basis of Environmental Regulations (3 hrs., Fall)
- ESGN500 Environmental Water Chemistry (4 hrs., Fall)
- ESGN502 Environmental Law (3 hrs., Fall)

#### **Metallurgy and Materials Engineering:**

- MTGN429 Metallurgical Environment (3 hrs., Spring)
- MTGN431 Hydro- and Electrometallurgy (2 hrs., Spring)
- MTGN432 Pyrometallurgy (3 hrs., Spring)

Other courses may be selected from the CSM offerings with the approval of representatives from the administering departments or program.

6 credit hours may be independent study in the student's home department or additional course work from the list above.

#### **Professional Masters in Petroleum Reservoir Systems:**

This is a non-thesis, interdisciplinary masters degree program jointly administered by the departments of Geology and Geological Engineering, Geophysics, and Petroleum Engineering. This program consists only of coursework in petroleum geoscience and engineering. No research is required. The degree is particularly suited for employees of service companies and non-U.S. professionals from the international petroleum sector. It is also attractive for individuals with a B.S. degree who desire a graduate-level credential for employment in the petroleum industry.

#### **General Administration:**

The three participating departments share oversight for this program through a committee consisting of one faculty member from each of the three departments. Students gain



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admission to the program by application to any of the three sponsoring departments. Students are administered by that department into which they first matriculate.

**Requirements:**

A minimum of 36 credit hours. Up to 9 credit hours may be at the 400 level. All other credits toward the degree must be 500 level or above.

**9 hours must consist of:**

1 course selected from the following:

GPGN419/PEGN 419 Well Log Analysis and Formation Evaluation

GPGN519/PEGN519 Advanced Formation Evaluation

2 courses selected from the following:

GEGN439/GPGN439/PEGN439 Multi-Disciplinary Petroleum Design

GEGN503/GPGN503/PEGN503 Integrated Exploration and Development I

GEGN504/GPGN504/PEGN504 Integrated Exploration and Development II

9 additional hours must consist of one course each from the 3 participating departments.

The remaining 18 hours may consist of graduate courses from any of the 3 participating departments, or other courses approved by the committee. Up to 6 hours may consist of independent study, including an industry project.

**Geological Engineering Degrees:**

The **Masters of Engineering (Non-Thesis) Program in Geological Engineering** outlined below may be completed by individuals already holding undergraduate or advanced degrees or as a **combined degree program** by individuals already matriculated as undergraduate students at The Colorado School of Mines. The program is comprised of 36 credit hours with 30 course credit hours and 6 credit hours of independent study (GEGN 599). Up to nine credit hours can be at the 400 level and the remainder will be 500 or 600 level. For the combined degree program, courses recommended as appropriate for double counting may be chosen from GEGN 403, 439, 469, and 470. The typical program plan includes 15 course credit hours in both the fall and the spring terms followed by 6 independent study credit hours during the summer term. The non-thesis degree includes three areas of specialization (engineering geology/geotechnics, ground-water engineering, and mining geological engineering).

All Masters of Engineering (Non-Thesis) program will include the following core requirements:

GEGN532 Geological Data Analysis (3)

GEGN599 Independent Study in Geological Engineering (6)

GEGN599 requires a project and report that demonstrate competence in the application of geological engineering principles that merits a grade of B or better. The project topic and

content of the report is determined by the student's advisor, in consultation with the student, and is approved by the Geological Engineering Graduate Program Committee. The format of the report will follow the guidelines for a professional journal paper.

The student, in consultation with the advisor, must prepare a formal program of courses and independent study topic for approval by the Geological Engineering Graduate Program Committee. The program must be submitted to the committee on or before the end of the first week of classes of the first semester.

The most common difficulty in scheduling completion of the degree involves satisfaction of prerequisites. Common deficiency courses are Statics, Mechanics of Materials, and Fluid Mechanics. These are essential to the engineering underpinnings of the degree. An intense program at CSM involving 18 credit hours each semester including Statics in the fall and Fluid Mechanics in the spring and 9 credits in the summer including Mechanics of Materials, allows these classes to be taken along with the standard program. Some students may choose to take these prerequisites elsewhere before arriving on the CSM campus.

**Engineering Geology/Geotechnics Specialty (Non-Thesis)**

Students working towards a Masters of Engineering (non-thesis) with specialization in Engineering Geology/Geotechnics must meet the prerequisite course requirements listed later in this section. Required courses for the degree are:

**Fall Semester (15 hours)**

GEGN468 Engineering Geology & Geotechnics (4)

GEGN467 Groundwater Engineering (4)

GEGN532 Geological Data Analysis (3)

GEGN570 Case Histories in Engineering Geology (3), *or*

GEGN571 Advanced Engineering Geology (3)

Electives\* (1)

**Spring Semester (15 hours)**

GEGN573 Geological Engineering Site Investigation (3)

GEGN671 Landslides: Investigation, Analysis & Mitigation (3), *or*

GEGN672 Advanced Geotechnics (3)

Electives\* (9)

**Summer (6 hours)**

GEGN599 Independent Study in Geological Engineering (6)

\*Electives and course substitutions are approved by the Geological Engineering Graduate Program Committee and must be consistent with the program specialization. As part of their elective courses, students are required to have an advanced course in both soil and rock engineering. Possibilities for other electives include graduate-level rock mechanics and rock engineering, soil mechanics and foundations, ground

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water, site characterization, geographical information systems (GIS), project management and geophysics, for example.

### **Ground Water Engineering/Hydrogeology Specialty (Non-Thesis)**

Students working towards a Masters of Engineering (non-thesis) with specialization in Ground Water Engineering and Hydrogeology must meet the prerequisite course requirements listed later in this section. Required courses for the degree (36 hours) are:

- GEGN467 Ground Water Engineering (3) Fall
- GEGN532 Geological Data Analysis (3) Fall
- GEGN681 Vadose Zone Hydrology (3) Fall, *or*
- GEGN581 Advanced Hydrogeology (3) Fall
- GEGN509 Aqueous Geochemistry (3) Fall, *or*
- ESGN500 Environmental Water Chemistry (3)  
Fall or Spring
- GEGN583 Mathematical Modeling of Ground Water Systems (3) Spring
- GEGN470 Ground Water Engineering Design (3)  
Spring, *or*
- ESGN575 Hazardous Waste Site Remediation (3) Spring
- GEGN575 Applications of Geographic Information Systems (3) Fall or Spring
- GEGN599 Independent Study in Geological Engineering (6) Summer
- Electives\* (9)

\*Electives and course substitutions are approved by the Geological Engineering Graduate Program Committee and must be consistent with the program specialization. As part of their elective courses, students are required to have at least one additional advanced course in hydrogeochemistry. Possibilities for other electives include courses in site characterization, environmental science and engineering, geographical information systems (GIS), geochemistry, and geophysics, for example.

### **Mining Geological Engineering Specialty (Non-Thesis)**

Students working towards a Masters of Engineering (non-thesis) with specialization in Mining Geology must meet the prerequisite course requirements listed later in this section. Required courses for the degree are:

#### **Fall Semester (15 hours)**

- GEGN468 Engineering Geology & Geotechnics (4), *or*
- GEGN467. Groundwater Engineering (4)
- GEGN532 Geological Data Analysis (3)
- GEOL515 Advanced Mineral Deposits-Magmatic & Syngenetic Ores (3)
- MNGN523. Special Topics-Surface Mine Design (2), *or*
- MNGN523 Special Topics-Underground Mine Design (2)
- Electives\* (3)

#### **Spring Semester (15 hours)**

- GEOL516 Advanced Mineral Deposits-Epigenetic Hydrothermal Systems (3)
- GEGN518 Mineral Exploration (3) *or* Mining Geology (3)
- GEGN505. Applied Structural Geology (3)
- Electives\* (6)

#### **Summer (6 hours)**

- GEGN599 Independent Study in Geological Engineering (6)

\*Electives and course substitutions are approved by the Geological Engineering Graduate Program Committee and must be consistent with the program specialization. Typically, the elective courses are selected from the following topical areas: mineral deposits geology, ore microscopy, applied geophysics, applied geochemistry, remote sensing, engineering geology, environmental geology, engineering economics / management, mineral processing, geostatistics, geographic information systems, environmental or exploration and mining law, and computers sciences.

The **Master of Science Degree Program in Geological Engineering** requires a minimum of 36 semester hours of course and project/research credit hours (a maximum of 9 credit hours may be 400-level course work), plus a Graduate Thesis. The degree includes three areas of specialization (engineering geology/geotechnics, groundwater engineering, and mining geological engineering) with common requirements as follows:

1. GEGN532 Geological Data Analysis (3)
2. GEOL607 Graduate Geology Seminar (1)
3. At least twelve hours of research credits are required: Master of Science Research (GEGN705).
4. At least 24 course credit hours are required, and must be approved by the student's thesis committee.

The content of the thesis is to be determined by the student's advisory committee in consultation with the student. The Masters thesis must demonstrate creative and comprehensive ability in the development or application of geological engineering principles. The format of the thesis will follow the guidelines described under the *Thesis Writer's Guide*.

In addition to the common course requirements, the Master of Science degree with **specialization in Engineering Geology/Geotechnics** requires:

- GEGN467 Groundwater Engineering (4)
- GEGN468 Engineering Geology & Geotechnics (4)
- GEGN570 Case Histories in Engineering Geology (3)

And at least two of the following courses:

- GEGN571 Advanced Engineering Geology (3)
- GEGN573 Geological Engineering Site Investigation (3)
- GEGN671 Landslides: Investigation, Analysis & Mitigation
- GEGN672 Advanced Geotechnics (3)

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Typically, the additional courses are selected from the following topical areas: engineering geology, groundwater engineering, groundwater modeling, soil mechanics and foundations, rock mechanics, underground construction, seismic hazards, geomorphology, geographic information systems, construction management, finite element modeling, waste management, environmental engineering, environmental law, engineering management, and computer programming.

In addition to the common course requirements, the Master of Science degree with **specialization in Ground Water** also requires the following courses:

- GEGN467 Groundwater Engineering (4)
- GEGN468 Engineering Geology & Geotechnics (4)
- GEGN572 Ground-Water Engineering (3)
- GEGN583 Mathematical Modeling Of Groundwater (3)

2 courses selected as follows:

- ESGN500 Environmental Water Chemistry (3) *or*
- GEGN509/CHGC509 (3) Introduction To Aqueous Geochemistry

- ESGN503 Environmental Pollution (3) *or*
- GEGN581 (3) Advanced Groundwater

As nearly all ground water software is written in Fortran, if the student does not know Fortran, a Fortran course must be taken before graduation, knowledge of other computer languages is encouraged

In addition to the common course requirements, the Master of Science degree with **specialization in Mining Geology** also requires:

1. GEGN528 Mining Geology (3) or GEGN518 Mineral Exploration (3)
2. Specialty Areas (17 credits minimum.)

This will include about 5–6 courses (predominantly at 500 and 600 level) selected by the student in conjunction with the Masters program advisory committee. Specialty areas might include: mineral deposits geology, mineral exploration, mining geology, mineral processing, applied geophysics, applied geochemistry, engineering geology, environmental geology, geostatistics, geographic information systems, environmental or exploration and mining law, engineering economics/management, and computer sciences.

The **Doctor of Philosophy (Geological Engineering)** degree requires a minimum of 72 hours course work and research combined. Requirements include the same courses as for the Master of Science (Geological Engineering) with the additions noted below and the exception that a PhD Dissertation must be executed under GEGN/GEOL706 Graduate Research Credit: Doctor Of Philosophy. After completing all coursework and an admission to candidacy application, the Dissertation is completed under GEGN/GEOL706 Graduate Research Doctor Of Philosophy. The content of the dissertation is to be determined by the student's advisory committee

in consultation with the student. The dissertation must make a new contribution to the geological engineering profession. The format of the dissertation will follow the guidelines described under the *Thesis Writer's Guide*. A minimum of 24 research credits must be taken. A minor area of study, including 12 credit hours of course work, must be included in the program.

In addition to the common course requirements, a PhD **specializing in Engineering Geology/Geotechnics** requires additional course work tailored to the student's specific interests and approved by the doctoral program committee. (Typically, the additional courses are selected from the following topical areas: engineering geology, groundwater engineering, groundwater modeling, soil mechanics and foundations, rock mechanics, underground construction, seismic hazards, geomorphology, geographic information systems, construction management, finite element modeling, waste management, environmental engineering, environmental law, engineering management, and computer programming.) The minor area of study typically is in geotechnical engineering, rock mechanics/earth systems engineering, environmental engineering, groundwater engineering or geology.

In addition to the common course requirements listed previously, a PhD **specializing in Ground Water** also requires:

- GEGN581 (3) Advanced Groundwater Engineering
- GEGN669 (3) Advanced Topics In Engineering Hydrogeology
- GEGN681 (3) Vadose Zone Hydrology
- GEGN683 (3) Advanced Ground Water Modeling

and additional course work tailored to the student's specific interests, which are likely to include chemistry, engineering, environmental science, geophysics, math (particularly Partial Differential Equations), microbiology, organic chemistry, contaminant transport, soil physics, optimization, shallow resistivity or seismic methods. The student's advisory committee has the authority to approve elective courses and any substitutions for required courses.

If a student selects the ESGN elective courses from the Masters courses, then ESGN is their likely minor.

In addition to the common course requirements, a PhD **specializing in Mining Geology** also requires:

- GEGN468. Engineering Geology & Geotechnics (4) *or*
- GEGN467. Groundwater Engineering (4)
- GEGN518. Mineral Exploration (3) *or*
- GEGN528. Mining Geology (3)
- GEGN505. Applied Structural Geology (3)
- GEOL515. Advanced Mineral Deposits-Magmatic & Syngenetic Ores (3)
- GEOL516 Advanced Mineral Deposits-Epigenetic Hydrothermal Systems (3)
- MNGN523. Special Topics-Surface Mine Design (2) *or*
- MNGN523. Special Topics- Underground Mine Design (2)

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Additional course work suited to the student's specific interests and approved by the doctoral program committee. (Typically, the additional courses are selected from the following topical areas: mineral deposits geology, mineral exploration, mining geology, mineral processing, applied geophysics, applied geochemistry, engineering geology, environmental geology, geostatistics, geographic information systems, environmental or exploration and mining law, engineering economics/management, and computer sciences). The minor area of study may be in geotechnical engineering, rock mechanics/earth systems engineering, environmental engineering, groundwater engineering, mining engineering, mineral economics/engineering economics or geology.

**Geochemistry Program Requirements:**

The geochemistry program comprises a core group of courses and four optional tracks: Mineralogy-Petrology, Aqueous-Environmental, Ore Deposits-Exploration, and Organic-Petroleum. Satisfactory performance in all core courses is required of all geochemistry students. Required core courses are:

- CHGC503 Introduction to Geochemistry,
- CHGC504 Methods in Geochemistry and
- CHGN503 Advanced Physical Chemistry

See the Geochemistry program section in this bulletin for further details.

**Qualifying Examination**

Ph.D. students must pass a qualifying examination by the end of the second year of their programs. This timing may be adjusted for part-time students. This examination will be administered by the student's Doctoral committee and will consist of an oral and a written examination, administered in a format to be determined by the Doctoral Committee. Two negative votes in the Doctoral Committee constitute failure of the examination.

In case of failure of the qualifying examination, a re-examination may be given upon the recommendation of the Doctoral Committee and approval of the Graduate Dean. Only one re-examination may be given.

**Prerequisites:**

**Geology Programs:**

The candidate for the degree of Master of Science (Geology) or Doctor of Philosophy (Geology) must have completed the following or equivalent subjects, for which credit toward an advanced degree will not be granted.

- General Geology
- Structural Geology
- Field Geology (6 weeks)
- Mineralogy
- Petrology
- Historical Geology
- Stratigraphy
- Chemistry (3 semesters, including at least 1 semester of physical or organic)

- Mathematics (2 semesters of calculus)
- An additional science course (other than geology) or advanced mathematics
- Physics (2 semesters)

**Professional Masters Degree Programs:**

Candidates for the Professional Masters Degree must possess an appropriate geosciences undergraduate degree or its equivalent. Prerequisites are the same as those required for the Master of Science (Geology) Degree.

**Engineering Programs:**

The candidate for the degree of Master of Engineering (Geological Engineer), Master of Science (Geological Engineering) or Doctor of Philosophy (Geological Engineering) must have completed the following or equivalent subjects. Graduate credit may be granted for courses at or above the 400 level, if approved by the student's advisory committee.

**Mathematics:**

Four semesters including: Calculus (2 semesters) and one semester of any two of: calculus III, differential equations, probability and statistics, numerical analysis, linear algebra, operations research, optimization

**Basic Science:**

- Chemistry (2 semesters)
- Mineralogy and Petrology
- Physics (2 semesters)
- Stratigraphy or Sedimentation
- Physical Geology
- Computer Programming or GIS

**Engineering Science:**

Structural Geology and one semester in four of the following subjects:

- Physical Chemistry or Thermodynamics
- Statics
- Mechanics of Materials
- Fluid Mechanics
- Dynamics
- Soil Mechanics
- Rock Mechanics

**Engineering Design:**

- Field Geology

As part of the graduate program each student must take one semester in two of the following subjects if such courses were not taken for a previous degree:

- Mineral Deposits/Economic Geology
- Hydrogeology
- Engineering Geology

and also as part of the graduate program one semester in three of the following subjects if such courses were not taken for a previous degree:

- Foundation Engineering
- Engineering Hydrology



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Geomorphology  
Airphoto Interpretation, Photogeology, or Remote Sensing  
Petroleum Geology  
Introduction to Mining  
Introductory Geophysics  
Engineering Geology Design  
Mineral Exploration Design  
Groundwater Engineering Design  
Other engineering design courses as approved by the program committee

### *Description of Courses*

GEGN401. MINERAL DEPOSITS (I) Introductory presentation of magmatic, hydrothermal, and sedimentary metallic ore deposits. Chemical, petrologic, structural, and sedimentological processes that contribute to ore formation. Description of classic deposits representing individual deposit types. Review of exploration sequences. Laboratory consists of hand specimen study of host rock-ore mineral suites and mineral deposit evaluation problems. Prerequisite: GEGN316 and DCGN209. 3 hours lecture, 3 hours lab; 4 semester hours.

GEGN403. MINERAL EXPLORATION DESIGN (II) (WI) Exploration project design: commodity selection, target selection, genetic models, alternative exploration approaches and associated costs, exploration models, property acquisition, and preliminary economic evaluation. Lectures and laboratory exercises to simulate the entire exploration sequence from inception and planning through implementation to discovery, with initial ore reserve calculations and preliminary economic evaluation. Prerequisite: GEGN401 and EPIC251. 2 hours lecture, 3 hours lab; 3 semester hours.

GEGN404. ORE MICROSCOPY/ FLUID INCLUSIONS (II) Identification of ore minerals using reflected light microscopy, micro-hardness, and reflectivity techniques. Petrographic analysis of ore textures and their significance. Guided research on the ore mineralogy and ore textures of classic ore deposits. Prerequisites: GEOL321, GEGN401, or consent of instructor. 6 hours lab; 3 semester hours.

GEGN405. MINERAL DEPOSITS (I) Physical and chemical characteristics and geologic and geographic setting of magmatic, hydrothermal, and sedimentary metallic mineral deposits from the aspects of genesis, exploration, and mining. For non-majors. Prerequisite: GEOL308, DCGN209 or concurrent enrollment. 2 hours lecture; 2 semester hours.

GEOC407. ATMOSPHERE, WEATHER AND CLIMATE (II) An introduction to the Earth's atmosphere and its role in weather patterns and long term climate. Provides basic understanding of origin and evolution of the atmosphere, Earth's heat budget, global atmospheric circulation and modern climatic zones. Long- and short-term climate change including paleoclimatology, the causes of glacial periods and global warming, and the depletion of the ozone layer. Causes and effects of volcanic eruptions on climate, El Nino, acid rain, severe thunderstorms, tornadoes, hurricanes, and ava-

lanches are also discussed. Microclimates and weather patterns common in Colorado. Prerequisite: Completion of CSM freshman technical core, or equivalent. 3 hours lecture; 3 semester hours. Offered alternate years; Spring 2003.

GEOC408. INTRODUCTION TO OCEANOGRAPHY (II) An introduction to the scientific study of the oceans, including chemistry, physics, geology, biology, geophysics, and mineral resources of the marine environment. Lectures from pertinent disciplines are included. Recommended background: basic college courses in chemistry, geology, mathematics, and physics. 3 hours lecture; 3 semester hours. Offered alternate years; Spring 2002.

GEGN 432. GEOLOGICAL DATA MANAGEMENT (I) Techniques for managing and analyzing geological data, including statistical analysis procedures and computer programming. Topics addressed include elementary probability, populations and distributions, estimation, hypothesis testing, analysis of data sequences, mapping, sampling and sample representativity, linear regression, and overview of univariate and multivariate statistical methods. Practical experience with principles of software programming and statistical analysis for geological applications via supplied software and data sets from geological case histories. Prerequisites: Senior standing in Geological Engineering or permission of instructor. 1 hour lecture, 6 hours lab; 3 semester hours.

GEGN438. PETROLEUM GEOLOGY (I) Source rocks, reservoir rocks, types of traps, temperature and pressure conditions of the reservoir, theories of origin and accumulation of petroleum, geology of major petroleum fields and provinces of the world, and methods of exploration of petroleum. Term report required. Laboratory consists of well log analysis, stratigraphic correlation, production mapping, hydrodynamics and exploration exercises. Prerequisite: GEOL309 and GEOL314; GEGN316 or GPGN486 or PEGN316. 3 hours lecture, 3 hours lab; 4 semester hours.

GEGN439/GPGN439/PEGN439. MULTI-DISCIPLINARY PETROLEUM DESIGN (II) (WI) This is a multidisciplinary design course that integrates fundamentals and design concepts in geological, geophysical, and petroleum engineering. Students work in integrated teams consisting of students from each of the disciplines. Multiple open-end design problems in oil and gas exploration and field development, including the development of a prospect in an exploration play and a detailed engineering field study, are assigned. Several detailed written and oral presentations are made throughout the semester. Project economics including risk analysis are an integral part of the course. Prerequisites: GP majors: GPGN302, 303 and EPIC251. PE majors: PEGN316, PEGN414, PEGN422, PEGN423, PEGN424 (or concurrent) GEOL308 and EPIC251; GE Majors: GEOL308 or GEOL309, GEGN438, GEGN316, and EPIC251. 2 hours lecture, 3 hours lab; 3 hours lecture; 3 semester hours.

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GEGN442. ADVANCED ENGINEERING GEOMORPHOLOGY (II) Application of quantitative geomorphic techniques to engineering problems. Map interpretation, photointerpretation, field observations, computer modeling, and GIS analysis methods. Topics include: coastal engineering, fluvial processes, river engineering, controlling water and wind erosion, permafrost engineering. Multi-week design projects and case studies. Prerequisite: GEGN342 and GEGN468, or graduate standing; GEGN475/575 recommended. 2 hours lecture, 3 hours lab; 3 semester hours.

GEGN466. GROUNDWATER ENGINEERING (I) Theory of groundwater occurrence and flow. Relation of groundwater to surface water; potential distribution and flow; theory of aquifer tests; water chemistry, water quality, and contaminant transport. Laboratory sessions on water budgets, water chemistry, properties of porous media, solutions to hydraulic flow problems, analytical and digital models, and hydrogeologic interpretation. Prerequisite: mathematics through calculus and MATH225, GEOL309, GEOL315, and EGGN351, or consent of instructor. 3 hours lecture, 3 semester hours.

GEGN467. GROUNDWATER ENGINEERING (I) Theory of groundwater occurrence and flow. Relation of groundwater to surface water; potential distribution and flow; theory of aquifer tests; water chemistry, water quality, and contaminant transport. Laboratory sessions on water budgets, water chemistry, properties of porous media, solutions to hydraulic flow problems, analytical and digital models, and hydrogeologic interpretation. Prerequisite: mathematics through calculus and MATH225, GEOL309, GEOL314 or GEOL315, and EGGN351, or consent of instructor. 3 hours lecture, 3 hours lab; 4 semester hours.

GEGN468. ENGINEERING GEOLOGY AND GEOTECHNICS (I) Application of geology to evaluation of construction, mining, and environmental projects such as dams, waterways, tunnels, highways, bridges, buildings, mine design, and land-based waste disposal facilities. Design projects including field, laboratory, and computer analysis are an important part of the course. Prerequisite: MNGN321 and concurrent enrollment in EGGN361/EGGN363 or consent of instructor. 3 hours lecture, 3 hours lab, 4 semester hours.

GEGN469. ENGINEERING GEOLOGY DESIGN (II) (WI) This is a capstone design course that emphasizes realistic engineering geologic/geotechnics projects. Lecture time is used to introduce projects and discussions of methods and procedures for project work. Several major projects will be assigned and one to two field trips will be required. Students work as individual investigators and in teams. Final written design reports and oral presentations are required. Prerequisite: GEGN468 or equivalent and EPIC251. 2 hours lecture, 3 hours lab; 3 semester hours.

GEGN470. GROUND-WATER ENGINEERING DESIGN (II) (WI) Application of the principles of hydrogeology and ground-water engineering to water supply, geotechnical, or

water quality problems involving the design of well fields, drilling programs, and/or pump tests. Engineering reports, complete with specifications, analysis, and results, will be required. Prerequisite: GEGN467 or equivalent or consent of instructor and EPIC251. 2 hours lecture, 3 hours lab; 3 semester hours.

GEGN473. GEOLOGICAL ENGINEERING SITE INVESTIGATION (II) (WI) Methods of field investigation, testing, and monitoring for geotechnical and hazardous waste sites, including: drilling and sampling methods, sample logging, field testing methods, instrumentations, trench logging, foundation inspection, engineering stratigraphic column and engineering soils map construction. Projects will include technical writing for investigations (reports, memos, proposals, workplans). Class will culminate in practice conducting simulated investigations (using a computer simulator). 3 hours lecture; 3 semester hours.

GEGN475. APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS (II) An introduction to Geographic Information Systems (GIS) and their applications to all areas of geology and geological engineering. Lecture topics include: principles of GIS, data structures, digital elevation models, data input and verification, data analysis and spatial modeling, data quality and error propagation, methods of GIS evaluation and selection. Laboratories will use personal computer systems for GIS projects, as well as video presentations. Prerequisite: SYGN101. 2 hours lecture, 3 hours lab; 3 semester hours.

GEGN476. DESKTOP MAPPING APPLICATIONS FOR PROJECT DATA MANAGEMENT (I, II) Conceptual overview and hands-on experience with a commercial desktop mapping system. Display, analysis, and presentation mapping functions; familiarity with the software components, including graphical user interface (GUI); methods for handling different kinds of information; organization and storage of project documents. Use of raster and vector data in an integrated environment; basic raster concepts; introduction to GIS models, such as hill shading and cost/distance analysis. Prerequisite: No previous knowledge of desktop mapping or GIS technology assumed. Some computer experience in operating within a Windows environment recommended. 1 hour lecture; 1 semester hour.

GEGN481. ADVANCED HYDROGEOLOGY (I) Lectures, assigned readings, and discussions concerning the theory, measurement, and estimation of ground water parameters, fractured-rock flow, new or specialized methods of well hydraulics and pump tests, tracer methods, and well construction design. Design of well tests in variety of settings. Prerequisites: GEGN467 or consent of instructor. 3 hours lecture; 3 semester hours.

GEGN483. MATHEMATICAL MODELING OF GROUND-WATER SYSTEMS (II) Lectures, assigned readings, and direct computer experience concerning the fundamentals and applications of analytical and finite-difference solutions to

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ground water flow problems as well as an introduction to inverse modeling. Design of computer models to solve ground water problems. Prerequisites: Familiarity with computers, mathematics through differential and integral calculus, and GEGN467. 3 hours lecture; 3 semester hours.

GEGN/GEOL498. SEMINAR IN GEOLOGY OR GEOLOGICAL ENGINEERING (I, II) Special topics classes, taught on a one-time basis. May include lecture, laboratory and field trip activities. Prerequisite: Approval of instructor and department head. Variable credit; 1 to 3 semester hours. Repeatable for credit under different topics.

GEGN499. INDEPENDENT STUDY IN ENGINEERING GEOLOGY OR ENGINEERING HYDROGEOLOGY (I, II) Individual special studies, laboratory and/or field problems in geological engineering or engineering hydrogeology. Prerequisite: Approval of instructor and department head. Variable credit; 1 to 3 semester hours. Repeatable for credit.

GEOL499. INDEPENDENT STUDY IN GEOLOGY (I, II) Individual special studies, laboratory and/or field problems in geology. Prerequisite: Approval of instructor and department. Variable credit; 1 to 3 semester hours. Repeatable for credit.

#### **Courses**

The following courses are not all offered each academic year. Any of those offered for which fewer than five students have registered may be omitted in any semester. All 500-level courses are open to qualified seniors with permission of the department and Dean of Graduate School. The 600-level courses are open only to students enrolled in the Graduate School.

GEOL501. APPLIED STRATIGRAPHY (I) Review of basic concepts in siliciclastic and carbonate sedimentology and stratigraphy. Introduction to advanced concepts and their application to exploration and development of fossil fuels and stratiform mineral deposits. Modern facies models and sequence-stratigraphic concepts applied to solving stratigraphic problems in field and subsurface settings. Prerequisites: GEOL314 or equivalent or consent of instructor. 3 hours lecture, 4 hours lab; 4 semester hours.

GEOL502. STRUCTURAL METHODS FOR SEISMIC INTERPRETATION (I) A practical course that covers the wide variety of structural methods and techniques that are essential to produce a valid and coherent interpretation of 2D and 3D seismic reflection data in structurally complex areas. Topics covered include: Extensional tectonics, fold and thrust belts, salt tectonics, inversion tectonics and strike-slip fault systems. Laboratory exercises are based on seismic datasets from a wide variety of structural regimes from across the globe. The course includes a 4 day field trip to SE Utah. Prerequisite: GEOL309 and GEOL 314 or GEOL 315, or equivalents, or consent of instructor. 3 hours lecture/lab; 3 semester hours.

GEGN503/GPGN503/PEGN503. INTEGRATED EXPLORATION AND DEVELOPMENT (I) Students work alone and in teams to study reservoirs from fluvial-deltaic and valley fill depositional environments. This is a multidisciplinary course that shows students how to characterize and model subsurface reservoir performance by integrating data, methods and concepts from geology, geophysics and petroleum engineering. Activities and topics include field trips to surface outcrops, well logs, borehole cores, seismograms, reservoir modeling of field performance, written exercises and oral team presentations. Prerequisite: Consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours. Offered fall semester, odd years.

GEGN504/GPGN504/PEGN504. INTEGRATED EXPLORATION AND DEVELOPMENT (I) Students work in multidisciplinary teams to study practical problems and case studies in integrated subsurface exploration and development. The course addresses emerging technologies and timely topics with a general focus on carbonate reservoirs. Activities include field trips, 3D computer modeling, written exercises and oral team presentation. Prerequisite: Consent of instructor. 3 hours lecture and seminar; 3 semester hours. Offered fall semester, even years.

GEOL505. APPLIED STRUCTURAL GEOLOGY (II) Structural geology with emphasis on solving problems in field and lab exercises using systematic analysis by geometric and mapping techniques. Interpretation of the structural aspects of ore control, fossil fuels, and environmental geology. Relationships between mechanical properties and structural behavior of geological materials. Prerequisite: GEGN316 or equivalent. 2 hours lecture, 4 hours lab; 3 semester hours.

GEOL506. PHYSICS OF ROCK DEFORMATION (II) A material-oriented, mechanistic approach to understanding brittle and ductile rock deformation. Starts with fundamental understanding of stress and strain. Physical processes of rock fracture, friction, and flow will be studied as they relate to earthquakes, crustal fluid movement, creep, and folding. Emphasis on relating initial and derived microstructure, such as grain size, micro-cracks, and intracrystalline dislocation, to stresses, temperatures, and fluids in the Earth. Rock anisotropy, heterogeneity, and scale effects discussed. Prerequisite: GEGN309 or equivalent. 3 hours lecture; 3 semester hours. Offered alternate years, Spring 2002.

GEGN509/CHGC509. INTRODUCTION TO AQUEOUS GEOCHEMISTRY (II) Analytical, graphical and interpretive methods applied to aqueous systems. Thermodynamic properties of water and aqueous solutions. Calculation and graphical expression of acid-base, redox and solution-mineral equilibria. Effect of temperature and kinetics on natural aqueous systems. Adsorption and ion exchange equilibria between clays and oxide phases. Behavior of trace elements and complexation in aqueous systems. Application of organic geochemistry to natural aqueous systems. Light stable and un-

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stable isotopic studies applied to aqueous systems. Prerequisite: DCGN209 or equivalent, or consent of instructor. 3 hours lecture; 3 semester hours.

GEOL510. IMPACT GEOLOGY (II) A seminar-based course of inquiry into the nature, process, and geological significance of extra-terrestrial impacts on the Earth. Course topics include the nature of impactors, impact processes, morphology of impact structures, shock metamorphism, case studies of impacts, and the role of impacts in Earth evolution, biologic extinctions, and economic deposits. Optional field trips to Meteor Crater and other impact sites over Spring Break. 2 hours seminar, 3 hours lab, 3 credit hours.

GEOL511. HISTORY OF GEOLOGIC CONCEPTS (II) Lectures and seminars concerning the history and philosophy of the science of geology; emphasis on the historical development of basic geologic concepts. 3 hours lecture and seminar; 3 semester hours. Required of all doctoral candidates in department. Offered alternate years. Spring 2001.

GEOL512. MINERALOGY AND CRYSTAL CHEMISTRY (I) Relationships among mineral chemistry, structure, crystallography, and physical properties. Systematic treatments of structural representation, defects, mineral stability and phase transitions, solid solutions, substitution mechanisms, and advanced methods of mineral identification and characterization. Applications of principles using petrological and environmental examples. Prerequisites: GEOL321, DCGN 209 or equivalent or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours. Offered alternate years. Fall 2001.

GEOL515. ADVANCED MINERAL DEPOSITS - MAGMATIC AND SYNGENETIC ORES (I) Time-space aspects of metallogenesis in relation to regional and local geological evolution of the earth. Processes leading to the formation of ore magmas and fluids within tectonic and stratigraphic frameworks, and to the development of favorable ore-forming environments. Emphasis will be placed on processes responsible for ore genesis in magmatic systems, such as layered complexes, carbonatites and pegmatites, and on the submarine hydrothermal processes responsible for syndepositional deposits in volcanic and sedimentary terrains, including massive base and precious metal sulfide ores. Ore deposits in certain sedimentary rocks, including copper, paleoplacer gold-uranium, marine evaporite, barite, and phosphate ores are considered in context of their generative environments and processes. Prerequisite: GEGN401 or equivalent, or consent of instructor. 2 hours lecture, 2 hours lab; 3 semester hours.

GEOL516. ADVANCED MINERAL DEPOSITS - EPIGENETIC HYDROTHERMAL SYSTEMS (II) Time-space aspects of metallogenesis in relation to regional and local geological evolution of the earth. Processes leading to the generation of metalliferous hydrothermal mineralizing solutions within tectonic and lithologic frameworks, and to the development of favorable ore-forming environments. Emphasis will be placed on processes responsible for ore genesis in mag-

matic-hydrothermal systems such as porphyry copper-molybdenum-gold deposits, epithermal precious metal deposits, metamorphogenetic gold deposits, volcanic and sedimentary rock-hosted epigenetic base metal ores and epigenetic sedimentary-rock hosted and unconformity-related uranium deposits. Prerequisite: GEGN401 or equivalent, or consent of instructor. 2 hours lecture, 2 hours lab; 3 semester hours.

GEGN517. FIELD METHODS FOR ECONOMIC GEOLOGY (II) Methods of field investigation for economic geology including underground mapping at the CSM test mine in Idaho Springs, logging of drill core, logging of drill chips, and surface mapping. Technical reports will be written for each of the projects. 9 hours lab; 3 semester hours.

GEGN518. MINERAL EXPLORATION (II) Mineral industry overview, deposit economics, target selection, deposit modeling, exploration technology, international exploration, environmental issues, program planning, proposal development. Team development and presentation of an exploration proposal. Prerequisite: GEOL515, GEOL516, or equivalent. 2 hours lecture/seminar, 2 hours lab; 3 semester hours. Offered when student demand is sufficient.

GEGN 520. URANIUM GEOCHEMISTRY AND GEOLOGY (I) In-depth study of the geochemical and geological controls on the distribution of uranium and associated elements in the crust of the earth. Emphasis will be placed on geochemical and geological models for the formation of economically recoverable concentrations of uranium, including, but not limited to paleoplacer, unconformity-related, sandstone-hosted, volcanic-hydrothermal, breccia-hosted, pegmatite, and shale and phosphorite-hosted deposits. Source of metals, mechanisms of transport and deposition will be considered. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours.

GEGN527/CHGC527. ORGANIC GEOCHEMISTRY OF FOSSIL FUELS AND ORE DEPOSITS (II) A study of organic carbonaceous materials in relation to the genesis and modification of fossil fuel and ore deposits. The biological origin of the organic matter will be discussed with emphasis on contributions of microorganisms to the nature of these deposits. Biochemical and thermal changes which convert the organic compounds into petroleum, oil shale, tar sand, coal, and other carbonaceous matter will be studied. Principal analytical techniques used for the characterization of organic matter in the geosphere and for evaluation of oil and gas source potential will be discussed. Laboratory exercises will emphasize source rock evaluation, and oil-source rock and oil-oil correlation methods. Prerequisite: CHGN221, GEGN438, or consent of instructor. 2 hours lecture; 3 hours lab; 3 semester hours. Offered alternate years, Spring 2003.

GEGN528/MNGN528. MINING GEOLOGY (II) Role of geology and the geologist in the development and production stages of a mining operation. Topics addressed: mining operation sequence, mine mapping, drilling, sampling, reserve es-



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timation, economic evaluation, permitting, support functions. Field trips, mine mapping, data evaluation exercises, and term project. Prerequisite: GEGN401 or GEGN405 or permission of instructors. 2 hours lecture/seminar, 3 hours lab; 3 semester hours. Offered alternate years when student demand is sufficient.

GEGN530. CLAY CHARACTERIZATION (I) Clay mineral structure, chemistry and classification, physical properties (flocculation and swelling, cation exchange capacity, surface area and charge), geological occurrence, controls on their stabilities. Principles of X-ray diffraction, including sample preparation techniques, data collection and interpretation, and clay separation and treatment methods. The use of scanning electron microscopy to investigate clay distribution and morphology. Methods of measuring cation exchange capacity and surface area. Prerequisite: GEGN206 or equivalent, or consent of instructor. 1 hour lecture, 2 hours lab; 1 semester hour.

GEGN532. GEOLOGICAL DATA ANALYSIS (I or II) Techniques and strategy of data analysis in geology and geological engineering: basic statistics review, analysis of data sequences, mapping, sampling and sample representativity, univariate and multivariate statistics, geostatistics, and geographic information systems (GIS). Practical experience with geological applications via supplied software and data sets from case histories. Prerequisites: Introductory statistics course (MATH323 or MATH530 equivalent) or permission of instructor. 2 hours lecture/discussion; 3 hours lab; 3 semester hours.

GEGN542. ADVANCED ENGINEERING GEOMORPHOLOGY (II) Application of quantitative geomorphic techniques to engineering problems. Map interpretation, photointerpretation, field observations, computer modeling, and GIS analysis methods. Topics include: coastal engineering, fluvial processes, river engineering, controlling water and wind erosion, permafrost engineering. Multi-week design projects and case studies. Prerequisite: GEGN342 and GEGN468, or graduate standing; GEGN475 or GEGN575 recommended. 2 hours lecture, 3 hours lab; 3 semester hours.

GEOL543. MODERN SEDIMENTS FIELD PROGRAM (S) Detailed field study of modern transitional and shallow marine environments of sedimentary deposition. Both detrital and carbonate environments are included. Emphasis on energy and mineral resources. Conducted at field locations such as southeastern United States and the Bahamas. Fees are assessed for field and living expenses and transportation. Prerequisite: Background in sedimentary geology and consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours.

GEOL545. INTRODUCTION TO REMOTE SENSING (I) Theory and application of remote sensing techniques using visible, infrared, and microwave electromagnetic energy. Spectral information from cameras and scanning instruments, including infrared photography, radar imagery, Landsat imagery, and imaging spectroscopy. Survey of applications to

geology and global change. Lab interpretation of remote sensing imagery and introduction to digital image processing. 2 hours lecture, 3 hours lab; 3 semester hours.

GEOL546. GEOLOGIC APPLICATIONS OF REMOTE SENSING (II) Application of remote sensing to regional geologic studies and to mineral and energy resource assessments. Study of remote sensing techniques, including spectral analysis, lineament analysis, and digital image processing. Reviews of case studies and current literature. Student participation in discussion required. Prerequisite: GEOL545 or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours.

GEOL550. INTEGRATED BASIN MODELING (I) This course introduces students to principal methods in computer-based basin modeling: structural modeling and tectonic restoration; thermal modeling and hydrocarbon generation; and stratigraphic modeling. Students apply techniques to real data set that includes seismic and well data and learn to integrate results from multiple approaches in interpreting a basin's history. The course is primarily a lab course. Prerequisite: Consent of instructor. A course background in structural geology, sedimentology/stratigraphy or organic geochemistry will be helpful. 1 hour lecture, 5 hours labs; 3 semester hours.

GEGN570. CASE HISTORIES IN GEOLOGICAL ENGINEERING AND HYDROGEOLOGY (I) Case histories in geological and geotechnical engineering, ground water, and waste management problems. Students are assigned problems and must recommend solutions and/or prepare defensible work plans. Discussions center on the role of the geological engineer in working with government regulators, private-sector clients, other consultants, and other special interest groups. Prerequisite: GEGN442, GEGN467, GEGN468, GEGN469, GEGN470 or consent of instructor. 3 hours lecture; 3 semester hours.

GEOL570/GPGN570. APPLICATIONS OF SATELLITE REMOTE SENSING (II) Students are introduced to geoscience applications of satellite remote sensing. Introductory lectures provide background on satellites, sensors, methodology, and diverse applications. One or more areas of applications are presented from a systems perspective. Guest lecturers from academia, industry, and government agencies present case studies focusing on applications, which vary from semester to semester. Students do independent term projects, under the supervision of a faculty member or guest lecturer, that are presented both written and orally at the end of the term. Prerequisite: PHGN200, MATH225, GEOL309 or consent of instructor. 3 hours lecture; 3 semester hours.

GEGN571. ADVANCED ENGINEERING GEOLOGY (I) Emphasis will be on engineering geology mapping methods, and geologic hazards assessment applied to site selection and site assessment for a variety of human activities. Prerequisite: GEGN468 or equivalent. 2 hours lecture, 3 hours lab; 3 semester hours. Offered alternate years, Fall 2004.

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GEGN573. GEOLOGICAL ENGINEERING SITE INVESTIGATION (II) Methods of field investigation, testing, and monitoring for geotechnical and hazardous waste sites, including: drilling and sampling methods, sample logging, field testing methods, instrumentation, trench logging, foundation inspection, engineering stratigraphic column and engineering soils map construction. Projects will include technical writing for investigations (reports, memos, proposals, workplans). Class will culminate in practice conducting simulated investigations (using a computer simulator). 3 hours lecture; 3 semester hours.

GEGN574. GEOTECHNICAL ASPECTS OF WASTE DISPOSAL (II) Analysis and review of the legal and technical problems surrounding the shallow land burial of waste materials, with special emphasis on hazardous solid waste. Methods of investigation of new and abandoned or inactive waste sites. Measurement of contaminant movement in the ground, design of contaminant and monitoring systems, case histories of field performance, and current research findings. Prerequisite: GEGN468 and EGGN361/EGGN363. 3 hours lecture; 3 semester hours. Offered alternate years, Spring 2004.

GEGN575. APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS (II) An introduction to Geographic Information Systems (GIS) and their applications to all areas of geology and geological engineering. Lecture topics include: principles of GIS, data structures, digital elevation models, data input and verification, data analysis and spatial modeling, data quality and error propagation, methods of GIS evaluation and selection. Laboratories will use Macintosh and DOS-based personal computer systems for GIS projects, as well as video-presentations. Visits to local GIS laboratories, and field studies will be required. 2 hours lecture, 3 hours lab; 3 semester hours.

GEGN576. FUNDAMENTALS OF VECTOR GEOGRAPHIC INFORMATION SYSTEMS (I, II) Fundamentals of relational vector GIS; topological relationships; spatial coordinate systems; data capture and conversion; displaying and correcting errors; mapping precision; spatial data attribute accuracy; and database models. Case studies. Prerequisite: GEGN475 or GEGN575. 2 hours lecture; 2 semester hours. Offered on demand.

GEGN577. VECTOR GIS ANALYSIS FUNCTIONS (I, II) Classification of relational vector GIS analysis functions; topological relationships; constructing a database; associating attributes with spatial data; relating and joining attribute tables; selecting and manipulating data records; edgematching and merging maps; displaying data; query and analysis functions; topological overlay operations; distance functions. Case studies of spatial analysis projects. Prerequisite: GEGN475 or GEGN575, and GEGN576. 2 hours lecture; 2 semester hours. Offered on demand.

GEGN578. GIS PROJECT DESIGN (I, II) Project implementation of GIS analysis. Projects may be undertaken by individual students, or small student teams. Documentation of all project design stages, including user needs assessment, implementation procedures, hardware and software selection, data sources and acquisition, and project success assessment. Various GIS software may be used; projects may involve 2-dimensional GIS, 3-dimensional subsurface models, or multi-dimensional time-series analysis. Prerequisite: Consent of instructor. Variable credit, 1-3 semester hours, depending on project. Offered on demand.

GEOL580/GPGN580/MNGN580. INDUCED SEISMICITY (II) Earthquakes are sometimes caused by the activities of man. These activities include mining and quarrying, petroleum and geothermal energy production, building water reservoirs and dams, and underground nuclear testing. This course will help students understand the characteristics and physical causes of man-made earthquakes and seismicity induced in various situations. Students will read published reports and objectively analyze the seismological and ancillary data therein to decide if the causative agent was man or natural processes. Prerequisites: Undergraduate geology and physics. 3 hours lecture; 3 semester hours. Offered spring semester, odd years.

GEGN581. ADVANCED GROUNDWATER ENGINEERING (I) Lectures, assigned readings, and discussions concerning the theory, measurement, and estimation of ground water parameters, fractured-rock flow, new or specialized methods of well hydraulics and pump tests, tracer methods. Prerequisite: GEGN467 or consent of instructor. 3 hours lecture; 3 semester hours.

GEGN583. MATHEMATICAL MODELING OF GROUNDWATER SYSTEMS (II) Lectures, assigned readings, and direct computer experience concerning the fundamentals and applications of finite-difference and finite-element numerical methods and analytical solutions to ground water flow and mass transport problems. Prerequisite: A knowledge of FORTRAN programming, mathematics through differential and integral calculus, and GEGN467 or consent of instructor. 3 hours lecture; 3 semester hours.

GEGN585. HYDROCHEMICAL EVOLUTION AND MODELING OF GROUND-WATER SYSTEMS (I) Application of hydrologic, geochemical, and isotopic concepts to the natural evolution of groundwater systems. Principles of groundwater evolution in the vadose zone, in evaporative environments, wetlands, unconfined and confined groundwater systems, and areas of interaquifer mixing. Introduction of use of geochemical modeling techniques to constrain problems of mass transfer and mass balance in groundwater systems. Course is designed to provide students with overview of hydrochemistry prior to taking advanced numerical modeling courses in hydrology and geochemistry. Prerequisites: DCGN209 and GEGN467 or equivalent or consent of instructor. 3 hours lecture; 3 semester hours.

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GEGN/GEOL598. SEMINAR IN GEOLOGY OR GEOLOGICAL ENGINEERING (I, II) Special topics classes, taught on a one-time basis. May include lecture, laboratory and field trip activities. Prerequisite: Approval of instructor and department head. Variable credit; 1 to 3 semester hours. Repeatable for credit under different topics.

GEGN599. INDEPENDENT STUDY IN ENGINEERING GEOLOGY OR ENGINEERING HYDROGEOLOGY(I, II) Individual special studies, laboratory and/or field problems in geological engineering or engineering hydrogeology. Prerequisite: Approval of instructor and department head. Variable credit; 1 to 6 credit hours. Repeatable for credit.

GEOL599. INDEPENDENT STUDY IN GEOLOGY (I, II). Individual special studies, laboratory and/or field problems in geology. Prerequisite: Approval of instructor and department. Variable credit; 1 to 3 semester hours. Repeatable for credit.

GEOL605. ADVANCED STRUCTURAL AND TECTONIC PRINCIPLES (I) Seminar discussions on geotectonic principles, mountain patterns and cycles, type regional and areal studies in tectonic style. Comparative tectonics. Includes field work in nearby areas on specific tectonic problems, review of recent literature, and tectonic analysis in mineral and fuel exploration. Prerequisite: GEOL309. 2 hours lecture and seminar, 3 hours field; 3 semester hours. Offered alternate years, Fall 2005.

GEOL606. ADVANCED STRUCTURAL GEOLOGY (REGIONAL) (II) Seminar discussion of the world's main tectonic provinces using modern methods of tectonic analysis; includes discussion of typical structures for each province and thorough review of recent literature. Assigned reports on analysis of regional structural patterns and their possible reproduction experimentally. Prerequisite: GEOL605. 3 hours lecture and seminar; 3 semester hours. Offered alternate years, Spring 2004.

GEOL607. GRADUATE SEMINAR (I, II) Recent geologic ideas and literature reviewed. Preparation and oral presentation of short papers. 1 hour seminar; 1 semester hour. Required of all geology candidates for advanced degrees during their enrollment on campus.

GEOL609. ADVANCED PETROLEUM GEOLOGY (II) Subjects to be covered involve consideration of basic chemical, physical, biological and geological processes and their relation to modern concepts of oil/gas generation (including source rock deposition and maturation), and migration/accumulation (including that occurring under hydrodynamic conditions). Concepts will be applied to the historic and predictive occurrence of oil/gas to specific Rocky Mountain areas. In addition to lecture attendance, course work involves review of topical papers and solution of typical problems. Prerequisite: GEGN438 or consent of instructor. 3 hours lecture; 3 semester hours.

GEOL610. ADVANCED SEDIMENTOLOGY (II) Keynote lectures and a seminar series on the physical depositional

processes, as the basic processes and key restrictions for building stratigraphy. Linkage of physical processes with depositional environments and stratigraphy. Learning the key observations for recognizing depositional environments in outcrops and cores. Linkage to well logs. Seminars, field trips, field labs and report required. Prerequisite: GEOL 501 or equivalent. 3 hours lecture and seminar; 3 semester hours.

GEOL611. DYNAMIC STRATIGRAPHY (II) Keynote lectures and a seminar series on the dynamics of depositional systems; understanding the dynamics of the depositional processes, depositional environments and how they behave in changing sea-level and sediment supply conditions; from basic processes to sequence stratigraphy of the siliciclasti systems. Field trips and report required. Prerequisite: GEOL501 or equivalent. 3 hours lecture and seminar; 3 semester hours.

GEOL613. GEOLOGIC RESERVOIR CHARACTERIZATION (I or II) Principles and practice of characterizing petroleum reservoirs using geologic and engineering data, including well logs, sample descriptions, routine and special core analysis and well tests. Emphasis is placed on practical analysis of such data sets from a variety of clastic petroleum reservoirs worldwide. These data sets are integrated into detailed characterizations, which then are used to solve practical oil and gas field problems. Prerequisites: GEGN438, GEOL501, GEOL505/605 or equivalents. 3 hours lecture; 3 semester hours.

GEOL614. PETROLEUM GEOLOGY OF DEEP-WATER CLASTIC DEPOSITIONAL SYSTEMS (I) Course combines local and regional deep-water sedimentology, sequence stratigraphy, reservoir geology, interpretation of outcrops, reflection seismic records, cores and well logs. Focus is on depositional processes, facies and their interpretation within deep-water depositional systems, turbidite models and their evolution, control of reservoir characteristics and performance, turbidites within a sequence stratigraphic framework, and the global occurrence of turbidite reservoirs. Laboratory exercises on seismic, well log, and core interpretation. Seven day field trip to study classic turbidites in Arkansas and to develop individual field mapping and interpretation projects. Prerequisites: GEGN438, GEOL501 or equivalents. 3 hours lecture, 3 hours lab; 4 semester hours. Offered alternate years. Fall 2003.

GEOL615. GEOCHEMISTRY OF HYDROTHERMAL MINERAL DEPOSITS (I) Detailed study of the geochemistry of selected hydrothermal mineral deposits. Theory and application of stable isotopes as applied to mineral deposits. Origin and nature of hydrothermal fluids and the mechanisms of transport and deposition of ore minerals. Review of wall-rock alteration processes. Fundamental solution chemistry and the physical chemistry of hydrothermal fluids. Prerequisite: GEGN401 or equivalent or consent of instructor. 3 hours lecture; 3 semester hours.

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GEOL616. ADVANCED MINERAL DEPOSITS (II) Reviews of current literature and research regarding selected topics in mineral deposits. Group discussion and individual participation expected. May be repeated for credit if different topics are involved. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

GEOL617. THERMODYNAMICS AND MINERAL PHASE EQUILIBRIA (I) Basic thermodynamics applied to natural geologic systems. Evaluation of mineral-vapor mineral solution, mineral-melt, and solid solution equilibria with special emphasis on oxide, sulfide, and silicate systems. Experimental and theoretical derivation, use, and application of phase diagrams relevant to natural rock systems. An emphasis will be placed on problem solving rather than basic theory. Prerequisite: DCGN209 or equivalent or consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years; Fall 2003.

GEOL618. EVOLUTION OF ORE DEPOSITS (II) The evolutionary changes in major types of ore deposits through time are described, and the causative changes in their geological environments and genetic processes are considered. The possible significance of these changes to tectonic processes, and to crustal evolution of the earth are evaluated. In this context ore deposits are of interest not only for their commercial value, but scientifically, as additional guides to the earth's evolutionary development through 4 billion years of earth history. Prerequisite: GEGN401, GEOL515, GEOL516 or equivalents or consent of instructor. 3 hours lectures and/or seminar/lab; 3 semester hours.

GEOL621. PETROLOGY OF DETRITAL ROCKS (II) Compositions and textures of sandstones, siltstones, and mudrocks. Relationship of compositions and textures of provenance, environment of deposition, and burial history. Development of porosity and permeability. Laboratory exercises emphasize use of petrographic thin sections, x-ray diffraction analysis, and scanning electron microscopy to examine detrital rocks. A term project is required, involving petrographic analysis of samples selected by student. Prerequisites: GEGN206, GEOL321 or equivalent or consent of instructor. 2 hours lecture and seminar, 3 hours lab; 3 semester hours. Offered on demand.

GEOL624. CARBONATE SEDIMENTOLOGY AND PETROLOGY (II) Processes involved in the deposition of carbonate sediments with an emphasis on Recent environments as analogs for ancient carbonate sequences. Carbonate facies recognition through bio- and lithofacies analysis, three-dimensional geometries, sedimentary dynamics, sedimentary structures, and facies associations. Laboratory stresses identification of Recent carbonate sediments and thin section analysis of carbonate classification, textures, non-skeletal and biogenic constituents, diagenesis, and porosity evolution. Prerequisite: GEGN321 and GEGN206 or consent of instructor. 2 hours lecture/seminar, 2 hours lab; 3 semester hours.

GEOL625. ADVANCED METAMORPHIC PETROLOGY (I) Metamorphic processes and concepts, emphasizing physical and chemical controls in the development of mineral assemblages. Petrographic examination of rock suites from representative metamorphic zones and facies. Emphasis on the interrelationships of crystallization and deformation and an interpretation of metamorphic history. Prerequisite: GEGN 307 or consent of instructor. 2 hours lecture and seminar, 3 hours lab; 3 semester hours. Offered alternate years; Fall 2002.

GEOL628. ADVANCED IGNEOUS PETROLOGY (I) Igneous processes and concepts, emphasizing the genesis, evolution, and emplacement of tectonically and geochemically diverse volcanic and plutonic occurrences. Tectonic controls on igneous activity and petrochemistry. Petrographic study of igneous suites, mineralized and non-mineralized, from diverse tectonic settings. Prerequisites: GEOL321, GEGN206. 3 hours lecture, 3 hours lab; 3 semester hours. Offered alternate years; Fall 2003.

GEOL642. FIELD GEOLOGY (S) Field program operated concurrently with GEGN316 field camp to familiarize the student with basic field technique, geologic principles, and regional geology of Rocky Mountains. Prerequisite: Undergraduate degree in geology and GEGN316 or equivalent. During summer field session; 1 to 3 semester hours.

GEOL643. GRADUATE FIELD SEMINARS (I, II, S) Special advanced field programs emphasizing detailed study of some aspects of geology. Normally conducted away from the Golden campus. Prerequisite: Restricted to Ph.D. or advanced M.S. candidates. Usually taken after at least one year of graduate residence. Background requirements vary according to nature of field study. Consent of instructor and department head is required. Fees are assessed for field and living expenses and transportation. 1 to 3 semester hours; may be repeated for credit with consent of instructor.

GEOL645. VOLCANOLOGY (II) Assigned readings and seminar discussions on volcanic processes and products. Principal topics include pyroclastic rocks, craters and calderas, caldron subsidence, diatremes, volcanic domes, origin and evolution of volcanic magmas, and relation of volcanism to alteration and mineralization. Petrographic study of selected suites of lava and pyroclastic rocks in the laboratory. Prerequisite: Consent of instructor. 1 hour seminar, 6 hours lab; 3 semester hours.

GEOL653. CARBONATE DIAGENESIS AND GEOCHEMISTRY (II) Petrologic, geochemical, and isotopic approaches to the study of diagenetic changes in carbonate sediments and rocks. Topics covered include major near-surface diagenetic environments, subaerial exposure, dolomitization, burial diagenesis, carbonate aqueous equilibria, and the carbonate geochemistry of trace elements and stable isotopes. Laboratory stresses thin section recognition of diagenetic textures and fabrics, x-ray diffraction, and geochemical/isotopic



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approaches to diagenetic problems. Prerequisite: GEOL624 or equivalent or consent of instructor. 4 to 6 hours lecture/seminar/lab; 3 semester hours.

GEGN669. ADVANCED TOPICS IN ENGINEERING HYDROGEOLOGY Review of current literature and research regarding selected topics in hydrogeology. Group discussion and individual participation. Guest speakers and field trips may be incorporated into the course. Prerequisite: Consent of instructor. 1 to 2 semester hours; may be repeated for credit with consent of instructor.

GEGN670. ADVANCED TOPICS IN GEOLOGICAL ENGINEERING Review of current literature and research regarding selected topics in engineering geology. Group discussion and individual participation. Guest speakers and field trips may be incorporated into the course. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Repeatable for credit under different topics.

GEGN671. LANDSLIDES: INVESTIGATION, ANALYSIS & MITIGATION Geological investigation, analysis, and design of natural rock and soil slopes and mitigation of unstable slopes. Topics include landslide types and processes, triggering mechanisms, mechanics of movements, landslide investigation and characterization, monitoring and instrumentation, soil slope stability analysis, rock slope stability analysis, rock fall analysis, stabilization and risk reduction measures. Prerequisites: GEGN468, EGGN 361, MNGN321, (or equivalents) or consent of instructor. 3 hours lecture; 3 semester hours.

GEGN672. ADVANCED GEOTECHNICS (II) Geological analysis, design, and stabilization of natural soil and rock slopes and rock foundations; computer modeling of slopes; use of specialized methods in earth construction. Prerequisite: GEGN468, EGGN361/EGGN363 and MNGN321. 3 hours lecture; 3 semester hours.

GEGN 673. ADVANCED GEOLOGICAL ENGINEERING DESIGN (II) Application of geological principles and analytical techniques to solve complex engineering problems related to geology, such as mitigation of natural hazards, stabilization of earth materials, and optimization of construction options. Design tools to be covered will include problem solving techniques, optimization, reliability, maintainability, and economic analysis. Students will complete independent and group design projects, as well as a case analysis of a design failure. 3 hours lecture; 3 semester hours. Offered alternate years, Spring 2007.

GEGN675. ADVANCED TOPICS IN GEOGRAPHIC INFORMATION SYSTEMS (I, II) Review of current developments and research in specific advanced topics concerning Geographic Information Systems (GIS) technology and their applications to all areas of geology and geological engineering. Topics will include 3-dimensional data systems, the problems of 3-dimensional data structures, visualization and

rendering of complex geological objects, interactions with analytical models, and the capabilities of new software and hardware. Prerequisites: GEGN575 and consent of instructor. 3 hours lecture; 3 semester hours. Repeatable for credit under different topics.

GEGN681. VADOSE ZONE HYDROLOGY (II) Study of the physics of unsaturated groundwater flow and contaminant transport. Fundamental processes and data collection methods will be presented. The emphasis will be on analytic solutions to the unsaturated flow equations and analysis of field data. Application to non-miscible fluids, such as gasoline, will be made. The fate of leaks from underground tanks will be analyzed. Prerequisites: GEGN467 or equivalent; Math through Differential Equations; or consent of instructor. 3 hours lecture; 3 semester hours.

GEGN682. FLOW AND TRANSPORT IN FRACTURED ROCK (I) Explores the application of hydrologic and engineering principles to flow and transport in fractured rock. Emphasis is on analysis of field data and the differences between flow and transport in porous media and fractured rock. Teams work together throughout the semester to solve problems using field data, collect and analyze field data, and do independent research in flow and transport in fractured rock. Prerequisites: GEGN581 or consent of instructor. 3 hours lecture; 3 credit hours. Offered alternate years; Fall 2001.

GEGN683. ADVANCED GROUND WATER MODELING (II) Flow and solute transport modeling including: 1) advanced analytical modeling methods; 2) finite elements, random-walk, and method of characteristics numerical methods; 3) discussion of alternative computer codes for modeling and presentation of the essential features of a number of codes; 4) study of selection of appropriate computer codes for specific modeling problems; 5) application of models to ground water problems; and 6) study of completed modeling projects through literature review, reading and discussion. Prerequisite: GEOL/CHGC509 or GEGN583, and GEGN585 or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours.

GEGN684. CHEMICAL MODELING OF AQUEOUS SYSTEMS (II) Provides theoretical background and practical experience in the application of chemical equilibrium and reaction path models to problems in diverse fields of theoretical and applied aqueous geochemistry. Advanced topics in aqueous geochemistry are presented and subsequently investigated using computer simulation approaches. Includes hands-on experience with the software EQ3/6. Instruction is provided in the use of basic UNIX commands. The course progressively builds user ability through a wide variety of applications including problems in thermodynamic data quality evaluation, ore deposition, sediment diagenesis, groundwater evolution, contaminant geochemistry, leachate generation, and enhanced oil recovery treatments. Course ends with student presentations of a chemical modeling

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study applied to a problem of their choosing. Prerequisite: GEGN585 or consent of instructor. 3 hours lecture/computer lab; 3 semester hours.

GEGN685. APPLIED GROUND-WATER MODELING PROBLEM SOLVING (I, II) Approach to and resolution of technical ground-water modeling problems from industrial applications. Conceptual analysis taught via Socratic Dialectic. Students reproduce, analyze, and resolve each problem. Each class offers new problems and learning experiences, thus the course can be repeated for credit with consent of instructor. By successful completion of this course, students earn certification to advise on the International Ground Water Modeling Center technical support line in a part-time employment mode. Prerequisite: GEGN583 or consent of instructor. 2 hours recitation alternate weeks; 3 hours lab every week; 2 semester hours.

GEGN/GEOL698. SEMINAR IN GEOLOGY OR GEOLOGICAL ENGINEERING (I, II) Special topics classes, taught on a one-time basis. May include lecture, laboratory and field trip activities. Prerequisite: Approval of instructor and department head. Variable credit; 1 to 3 semester hours. Repeatable for credit under different titles.

GEGN699. INDEPENDENT STUDY IN ENGINEERING GEOLOGY OR ENGINEERING HYDROGEOLOGY(I, II) Individual special studies, laboratory and/or field problems in geological engineering or engineering hydrogeology. Prerequisite: Approval of instructor and department head. Variable credit; 1 to 6 credit hours. Repeatable for credit.

GEOL699. INDEPENDENT STUDY IN GEOLOGY (I, II). Individual special studies, laboratory and/or field problems in geology. Prerequisite: Approval of instructor and department. Variable credit; 1 to 3 semester hours. Repeatable for credit.

GEGN700. GRADUATE ENGINEERING REPORT - MASTER OF ENGINEERING (I, II, S) Laboratory, field and library work for the Master of Engineering report under supervision of the student's advisory committee.

GEGN704 GRADUATE RESEARCH CREDIT: MASTER OF ENGINEERING Engineering design credit hours required for completion of the degree Master of Engineering - thesis. Engineering design must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

GEGN/GEOL705 GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

GEGN/GEOL706 GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty advisor. Repeatable for credit.

### **Geochemical Exploration**

#### **GEGX571. GEOCHEMICAL EXPLORATION (I)**

Dispersion of trace metals from mineral deposits and their discovery. Laboratory consists of analysis and statistical interpretation of data of soils, stream sediments, vegetation, and rock in connection with field problems. Term report required. Prerequisite: Consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours.

GEGX633. LITHOGEOCHEMICAL MINERAL EXPLORATION (II) Principles and application of primary dispersion to the search for metallic mineral deposits. Evaluation of the design, sampling, analytical, and interpretational techniques used in lithogeochemical exploration. Practical laboratory exercises. Term projects required. Prerequisite: GXGN571, GEGN401 or equivalent or consent of instructor. 3 hours lecture/seminar/lab; 3 semester hours. Offered alternate years, on demand.

GEGX635. SURFICIAL EXPLORATION GEOCHEMISTRY (II) Secondary dispersion processes (mechanical and chemical) applied to the search for metalliferous mineral deposits. A variety of sampling media, analytical procedures, and interpretive techniques are evaluated. Landscape geochemistry framework for exploration program design. Prerequisite: GEGX571 or equivalent or consent of instructor. A course in geomorphology recommended. 3 hours lecture/seminar/lab; 3 semester hours. Offered alternate years, on demand.

GEGX637. ADVANCED STUDIES IN EXPLORATION GEOCHEMISTRY (I, II) Individual special investigations of a laboratory or field problem in exploration geochemistry under the direction of a member of staff. Work on the same or a different topic may be continued through later semesters and additional credits earned. Prerequisite: GEGX571 and consent of instructor. 1 to 3 semester hours. Repeatable for credit.

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## Geophysics

TERENCE K. YOUNG, Professor and Department Head  
MICHAEL L. BATZLE, Baker Hughes Professor of Petrophysics and Borehole Geophysics  
THOMAS L. DAVIS, Professor  
DAVE HALE, Charles Henry Green Professor of Exploration Geophysics  
GARY R. OLHOEFT, Professor  
ROEL K. SNIEDER, Keck Foundation Professor of Basic Exploration Science  
ILYA D. TSVANKIN, Professor  
THOMAS M. BOYD, Associate Professor and Dean of Graduate Studies  
YAOGUO LI, Associate Professor  
ANDRÉ REVIL, Associate Professor  
PAUL SAVA, Assistant Professor  
NORMAN BLEISTEIN, Research Professor and University Emeritus Professor  
KENNETH L. LARNER, Research Professor and University Emeritus Professor  
ROBERT D. BENSON, Research Associate Professor  
MANIKA PRASAD, Research Associate Professor  
FENG SU, Research Associate Professor  
STEPHEN J. HILL, Adjunct Associate Professor  
DAVID J. WALD, Adjunct Associate Professor  
CHARLES P. ODEN, Adjunct Assistant Professor  
WARREN B. HAMILTON, Distinguished Senior Scientist  
PIETER HOEKSTRA, Distinguished Senior Scientist  
THOMAS R. LAFEHR, Distinguished Senior Scientist  
MISAC N. NABIGHIAN, Distinguished Senior Scientist  
ADEL ZOHDY, Distinguished Senior Scientist  
FRANK A. HADSELL, Emeritus Professor  
ALEXANDER A. KAUFMAN, Emeritus Professor  
GEORGE V. KELLER, Emeritus Professor  
PHILLIP R. ROMIG, JR., Emeritus Professor

### *Degrees Offered*

Professional Masters in Mineral Exploration and Mining Geosciences  
Professional Masters in Petroleum Reservoir Systems  
Master of Science (Geophysics)  
Master of Science (Geophysical Engineering)  
Doctor of Philosophy (Geophysics)  
Doctor of Philosophy (Geophysical Engineering)

### *Program Description*

Geophysicists study and explore the Earth's interior through physical measurements collected at the earth's surface, in boreholes, from aircraft, and from satellites. Using a combination of mathematics, physics, geology, chemistry, hydrology, and computer science, a geophysicist analyzes these measurements to infer properties and processes within the Earth's complex interior. Non-invasive imaging beneath the surface of Earth and other planets by geophysicists is analogous to non-invasive imaging of the interior of the human body by medical specialists.

The Earth supplies all materials needed by our society, serves as the repository of used products, and provides a home to all its inhabitants. Therefore, geophysics and geophysical engineering have important roles to play in the solution of challenging problems facing the inhabitants of this planet, such as providing fresh water, food, and energy for Earth's growing population, evaluating sites for underground construction and containment of hazardous waste, monitoring non-invasively the aging infrastructures (natural gas pipelines, water supplies, telecommunication conduits, transportation networks) of developed nations, mitigating the threat of geohazards (earthquakes, volcanoes, landslides, avalanches) to populated areas, contributing to homeland security (including detection and removal of unexploded ordnance and land mines), evaluating changes in climate and managing humankind's response to them, and exploring other planets.

Energy companies and mining firms employ geophysicists to explore for hidden resources around the world. Engineering firms hire geophysical engineers to assess the Earth's near-surface properties when sites are chosen for large construction projects and waste-management operations. Environmental organizations use geophysics to conduct groundwater surveys and to track the flow of contaminants. On the global scale, geophysicists employed by universities and government agencies (such as the United States Geological Survey, NASA, and the National Oceanographic and Atmospheric Administration) try to understand such Earth processes as heat flow, gravitational, magnetic, electric, thermal, and stress fields within the Earth's interior. For the past decade, 100% of CSM's geophysics graduates have found employment in their chosen field, with about 20% choosing to pursue graduate studies.

Founded in 1926, the Department of Geophysics at the Colorado School of Mines is recognized and respected around the world for its programs in applied geophysical research and education. With 20 active faculty members and small class sizes, students receive individualized attention in a close-knit environment. Given the interdisciplinary nature of geophysics, the graduate curriculum requires students to become thoroughly familiar with geological, mathematical, and physical theory, in addition to exploring the theoretical and practical aspects of the various geophysical methodologies.

### *Research Emphasis*

The Department conducts research in a wide variety of areas mostly related, but not restricted, to applied geophysics. Candidates interested in the research activities of a specific faculty member are encouraged to obtain a copy of the Department's view book and to contact that faculty member directly. To give prospective candidates an idea of the types of research activities available in geophysics at CSM, a list of the recognized research groups operating within the Department of Geophysics is given below.

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*The Center for Wave Phenomena (CWP)* is a research group with a total of four faculty members from the Department of Geophysics. With research sponsored by some 30 companies worldwide in the petroleum-exploration industry, plus U.S. government agencies, CWP emphasizes the development of theoretical and computational methods for imaging of the Earth's subsurface, primarily through use of the reflection seismic method. Researchers have been involved in forward and inverse problems of wave propagation as well as data processing for data obtained where the subsurface is complex, specifically where it is both heterogeneous and anisotropic. Further information about CWP can be obtained at <http://www.cwp.mines.edu>.

*The Reservoir Characterization Project (RCP)* integrates the acquisition and interpretation of multicomponent, three-dimensional seismic reflection and downhole data, with the geology and petroleum engineering of existing oil fields, in an attempt to understand the complex properties of petroleum reservoirs. Like CWP, RCP is a multidisciplinary group with faculty members from Geophysics, Petroleum Engineering, and Geology. More information about RCP can be obtained at <http://www.mines.edu/academic/geophysics/rcp>.

*The Rock Physics Laboratory* conducts research on the physical properties of rocks having varying porosity, permeability and fluid content. These properties are measured at various temperatures and pressures to simulate reservoir conditions.

*The Environmental Geophysics Group* investigates the uses of complex resistivity and ground-penetrating radar for the characterization of contaminated soils.

*The Center for Gravity, Electrical & Magnetic Studies (CGEM)* in the Department of Geophysics at the Colorado School of Mines is an academic research center that focuses on the quantitative interpretation of gravity, magnetic, electrical and electromagnetic data in applied geophysics. The center brings together the diverse expertise of faculty and students in these different geophysical methods and works towards advancing the state of art in geophysical data interpretation for real-world problems. The emphases of CGEM research are processing and inversion of applied geophysical data. The primary areas of application include petroleum exploration, mineral exploration, and unexploded ordnance (UXO) detection and discrimination. In addition, environmental problems, natural hazard monitoring, archaeological mapping, hydro-geophysics and crustal study are also within the scope of the center. There are currently four major research groups within the center: Gravity and Magnetism Research Consortium (GMRC), Unexploded Ordnance Research Group (UXO), Hydro-Geophysics Research Group (HGR), and Marine CSEM Consortium (CSEM). Research fundings are provided by petroleum companies, SERDP, ERDC, and other agencies. More information about CGEM is

available on the web at:  
<http://www.geophysics.mines.edu/cgem/>.

*The Center for Petrophysics (CENPET)* is an interdisciplinary facility that performs research and education in all aspects of petrophysics ranging from acoustic measurements on core material for the calibration of seismic surveys to the design of new borehole instruments to measure climatological parameters in the ice of the Antarctic. CENPET is dedicated to understanding the properties of the materials in the earth and how geophysical observations can be used to predict these properties. Several departments (Geology, Chemistry, Petroleum Engineering, Mathematics, and Geophysics) cooperate in the center. For more information consult <http://www.geophysics.mines.edu/petrophysics>

### **Program Requirements**

The Department offers both traditional, research-oriented graduate programs and a non-thesis professional education program designed to meet specific career objectives. The program of study is selected by the student, in consultation with an advisor, and with thesis committee approval, according to the student's career needs and interests. Specific degrees, have specific requirements as detailed below.

### **Geophysical Engineering Program Objectives**

Geophysical engineers and geophysicists must apply quantitative techniques to analyze an entity as complex as the Earth. Geophysical graduates, therefore, require a special combination of traits and abilities to thrive in this discipline. The Department of Geophysics strives to graduate students who:

1. Think for themselves and demonstrate the willingness to question conventional formulations of problems, and are capable of solving these problems independently.
2. Are creative and demonstrate the ability to conceive and validate new hypotheses, new problem descriptions, and new methods for analyzing data.
3. Are good experimentalists and have demonstrated the ability to design and carry out a geophysical field survey or laboratory experiment and ensure that the recorded data are of the highest-possible quality.
4. Can program a computer in a high-level language to acquire, process, model and display scientific data.
5. Can deal rationally with uncertainty and have demonstrated that they understand that geophysical data are always incomplete and uncertain; can quantify the uncertainty and recognize when it is not acceptable to make decisions based on these data.
6. Have demonstrated qualities that are the foundation of leadership; know the importance of taking risks, and are able to make good judgments about the level of risk that is commensurate with their knowledge, experience, and chance of failure; realize that failure is unavoidable if you want to learn and grow.



7. Have demonstrated they are capable of completing the scientific and engineering problem-solving process from beginning to end.
8. Can communicate scientific concepts, problems and solutions effectively in oral and written English.
9. Can present and defend their ideas effectively in public forums and debate.

In addition to the above, at the Doctor of Philosophy (Ph.D.) level, the Department of Geophysics strives to graduate students who:

10. Can teach college-level scientific and engineering concepts.
11. Can conceive, plan and write proposals to fund research.
12. Can publish in the peer-reviewed scientific and engineering literature.
13. Can communicate scientific concepts in a discipline outside geophysics.
14. Can communicate scientific concepts in a language other than English.
15. Have a broad background in the fundamentals of science and engineering in the earth sciences.

#### **Professional Masters in Mineral Exploration and Mining Geosciences**

This is a non-thesis, masters degree program jointly administered by Geology and Geological Engineering, Geochemistry, and Geophysics. Students gain admission to the program by application to any of the sponsoring departments and acceptance through the normal procedures of that department. This appendix lists course requirements and options.

#### **Requirements**

A minimum of 36 credit hours. Up to 9 credit hours may be at the 400-level. All other credits toward the degree must be 500-level or above.

- ◆ A 15 credit hour core program from the relevant departments consisting of:
  - GEGN403 Mineral Exploration Design (3 hrs. Spring)
  - GEOL515 Advanced Mineral Deposits-Magmatic & Syngenetic Ores (3 hrs. Fall) *or*
  - GEOL516 Advanced Mineral Deposits-Epithermal Hydrothermal Systems (3 hrs. Spring) *or*
  - GEGN528 Mining Geology (3 hrs. Spring even years)
  - GEGX571 Geochemical Exploration (3 hrs. Fall)
  - GPGN530 Applied Geophysics (3 hrs. Spring)
  - EBGN504 Economic Evaluation and Investment Decision Methods (3 hrs. Spring) *or*
  - EBGN510 Natural Resource Economics (3 hrs. Fall) *or*
  - EBGN512 Macroeconomics (3 hrs. Spring) *or*
  - MNGN585 Mining Economics (3 hrs. Spring even years)

- ◆ 15 additional credit hours must be selected from the following list. Selection of courses will be undertaken by the student in consultation with their degree committee consisting of three faculty from the respective programs that have admitted the student (GC, GE, GP, MN):

#### **Geochemistry:**

- GEGX633 Lithgeochemical Mineral Exploration (3 hrs. Spring)
- GEGX635 Surficial Exploration Geochemistry (3 hrs Spring)

#### **Geology and Geological Engineering:**

- GEOL404 Ore Microscopy (3 hrs.)
- GEOL498 Field Methods in Economic Geology (3 hrs)
- GEOL505 Applied Structural Geology (3 hrs. Spring)
- GEOL509 Introduction to Aqueous Geochemistry (3 hrs. Fall)
- GEGN518 Mineral Exploration (3 hrs. Fall)
- GEGN528 Mining Geology (3 hrs. Fall)
- GEGN532 Geological Data Analysis (3 hrs. Fall)
- GEOL545 Introduction to Remote Sensing (3 hrs. Spring)
- GEOL575 Geographic Information Systems (GIS) (3 hrs. Fall)

#### **Geophysics:**

- GPGN507 Near-Surface Field Methods (3 hrs. Fall)
- GPGN509 Physical and Chemical Properties and Processes in Rock, Soil, and Fluids (3 hrs. Fall)
- GPGN510 Gravity and Magnetic Exploration (3 hrs. Spring)
- GPGN511 Advanced Gravity and Magnetic Exploration (4 hrs. Spring, even years)
- GPGN520 Electrical and Electromagnetic Exploration (4 hrs. Fall, odd years)
- GPGN521 Advanced Electrical and Electromagnetic Exploration (4 hrs. Spring, even years)
- GPGN540 Mining Geophysics (3 hrs. Fall)

#### **Economics and Business:**

- EBGN535 Economics of Metal Industries and Markets (3 hrs. Spring)
- EBGN536 Mineral Policies and International Investment (3 hrs. Spring)
- EBGN541 International Trade (3 hrs. Spring)
- EBGN575 Advanced Mineral Asset Valuation (3 hrs. Fall)
- EBGN580 Exploration Economics (3 hrs. Fall)

#### **Environmental Science and Engineering:**

- ESGN 456 Scientific Basis of Environmental Regulations (3 hrs. Fall)
- ESGN 500 Principles of Environmental Chemistry (4 hrs. Fall)
- ESGN 502 Environmental Law (3 hrs. Fall)

#### **Metallurgy and Materials Engineering:**

- MTGN429 Metallurgical Environment (3 hrs. Spring)
- MTGN431 Hydro- and Electrometallurgy (2 hrs. Spring)
- MTGN432 Pyrometallurgy (3 hrs. Spring)

Other courses may be selected from the CSM offerings with the approval of representatives from the administering departments or program. 6 credit hours may be independent

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study in the student's home department or additional course work from the list above.

### **Professional Masters in Petroleum Reservoir Systems**

This is a multi-disciplinary, non-thesis master's degree for students interested in working as geoscience professionals in the petroleum industry. The Departments of Geophysics, Petroleum Engineering, and Geology and Geological Engineering share oversight for the Professional Masters in Petroleum Reservoir Systems program through a committee consisting of one faculty member from each department. Students gain admission to the program by application to any of the three sponsoring departments. Students are administered by that department into which they first matriculate. A minimum of 36 hours of course credit is required to complete the Professional Masters in Petroleum Reservoir Systems program. Up to 9 credits may be earned by 400 level courses. All other credits toward the degree must be 500 level or above. At least 9 hours must consist of:

(1) 1 course selected from the following:

- GPGN419/PEGN419 Well Log Analysis and Formation Evaluation
- GPGN519/PEGN519 Advanced Formation Evaluation

(2) 2 courses selected from the following:

- GEGN439/GPGN439/PEGN439 Multi-Disciplinary Petroleum Design
- GEGN503/GPGN503/PEGN503 Integrated Exploration and Development
- GEGN504/GPGN504/PEGN504 Integrated Exploration and Development

Also 9 additional hours must consist of one course each from the 3 participating departments. The remaining 18 hours may consist of graduate courses from any of the 3 participating departments, or other courses approved by the committee. Up to 6 hours may consist of independent study, including an industry project.

### **Master of Science Degrees: Geophysics and Geophysical Engineering**

Students may obtain a Master of Science Degree in either Geophysics or Geophysical Engineering. Both degrees have the same coursework and thesis requirements, as described below. Students are normally admitted into the Master of Science in Geophysics program. If, however, a student would like to obtain the Master of Science in Geophysical Engineering, the course work and thesis topic must meet the following requirements. Note that these requirements are in addition to those associated with the Master of Science in Geophysics.

- ◆ Students must complete, either prior to their arrival at CSM or while at CSM, no fewer than 16 credits of engineering coursework. What constitutes coursework considered as engineering is determined by the Geophysics faculty at large.

- ◆ Within the opinion of the Geophysics faculty at large, the student's dissertation topic must be appropriate for inclusion as part of an Engineering degree.

For either Master of Science degree, a minimum of 26 course credits is required accompanied by a minimum of 12 credits of graduate research. While individual courses constituting the degree are determined by the student, and approved by their advisor and thesis committee, courses applied to all M.S. degrees must satisfy the following criteria:

- ◆ All course, research, transfer, residence, and thesis requirements are as described in Registration and Tuition Classification and Graduate Degrees and Requirements sections of this document.
- ◆ All credits applied to the thesis must be at the 400 (senior) level or above. Courses required to fulfill deficiencies, as described below, may be 300 level and lower, but these cannot be applied to the course credit requirements of the degree.
- ◆ The student's advisor and committee may require fulfillment of all or some program deficiencies as described below. Credits used to fulfill program deficiencies are not included in the minimum required credits needed to obtain the M.S. Degree.
- ◆ Students must include the following courses in their Master degree program
  - LICM515 – Professional Oral Communication (1 credit)
  - GPGN581 – Graduate Seminar (1 credit)
  - GPGN705 – Graduate Research – Master of Science (12 credits in addition to the required 26 course credits).

As described in the Master of Science, Thesis and Thesis Defense section of this bulletin, all M.S. candidates must successfully defend their M.S. thesis in an open oral Thesis Defense. The guidelines of the Thesis Defense enforced by the Department of Geophysics follow those outlined in the Graduate Bulletin, with one exception. The Department of Geophysics requires students submit the final draft of their written thesis to their Thesis Committee no less than two weeks prior to the thesis defense date.

### **Doctor of Philosophy Degrees:**

#### **Geophysics and Geophysical Engineering**

Students may obtain a Doctor of Philosophy Degree in either Geophysics or Geophysical Engineering. Both degrees have the same coursework and thesis requirements, as described below. Students are normally admitted into the Ph.D. in Geophysics program. If, however, a student would like to obtain the Ph.D. in Geophysical Engineering, the course work and thesis topic must meet the following requirements. Note that these requirements are in addition to those associated with the Ph.D. in Geophysics.

- ◆ Students must complete, either prior to their arrival at CSM or while at CSM, no fewer than 16 credits of engineering coursework. What constitutes coursework considered as engineering is determined by the Geophysics faculty at large.
- ◆ Within the opinion of the Geophysics faculty at large, the student's dissertation topic must be appropriate for inclusion as part of an Engineering degree.

For the Doctor of Philosophy Degree (Ph.D.), at least 72 credits beyond the Bachelors degree are required. No fewer than 24 research credits are required. At least 12 credit hours must be completed in a minor program approved by the candidate's PhD Thesis Committee. Up to 36 course credits can be awarded by the candidate's committee for completion of a thesis-based Master's Degree at another institution. While individual courses constituting the degree are determined by the student, and approved by the student's advisor and committee, courses applied to all Ph.D. degrees must satisfy the following criteria:

- ◆ All course, research, minor degree programs, transfer, residence, and thesis requirements are as described in Registration and Tuition Classification and Graduate Degrees and Requirements sections of this document.
  - ◆ All credits applied to the thesis must be at the 400 (senior) level or above. Courses required to fulfill deficiencies, as described below, may be 300 level and lower, but these cannot be applied to the course credit requirements of the degree.
  - ◆ The student's advisor and committee may require fulfillment of all or some program deficiencies as described below. Credits used to fulfill program deficiencies are not included in the minimum required credits needed to obtain the Ph.D. Degree.
  - ◆ Students must include the following courses in their Ph.D. program
    - LICM515 – Professional Oral Communication (1 credit)
    - GPGN681 – Graduate Seminar (1 credit)
    - GPGN706 – Graduate Research – Doctor of Philosophy (minimum 24 credits)
- Choose two of the following:
- SYGN501 – The Art of Science (1 credit)
  - SYGN600 – Fundamentals of College Teaching (2 credits)
  - LAIS601 – Academic Publishing (2 or 3 credits)
- ◆ Students are also required to participate in a practical teaching experience.

In the Doctoral program, students must demonstrate the potential for successful completion of independent research and enhance the breadth of their expertise by completing a Doctoral Research Qualifying Examination no later than two years from the date of enrollment in the program. An exten-

sion of one additional year may be petitioned by students through their Thesis Committees.

In the Department of Geophysics, the Doctoral Research Qualifying Examination consists of the preparation, presentation, and defense of one research project and a thesis proposal. The research project and thesis proposal used in this process must conform to the standards posted on the Department of Geophysics web site.

As described in the Doctor of Philosophy, Thesis Defense section of this bulletin, all Ph.D. candidates must successfully defend their Ph.D. thesis in an open oral Thesis Defense. The guidelines of the Thesis Defense enforced by the Department of Geophysics follow those outlined in the Graduate Bulletin, with one exception. The Department of Geophysics requires students submit the final draft of their written thesis to their Thesis Committee no less than two weeks prior to the thesis defense date. However, three weeks is preferred as discussed in the FAQ section of the Department of Geophysics website (Graduate Curriculum).

#### **Acceptable Thesis Formats**

In addition to traditional dissertations, the Department of Geophysics also accepts dissertations that are compendia of papers published or submitted to peer-reviewed journals. The following guidelines are applied by the Department in determining the suitability of a thesis submitted as a series of written papers.

- ◆ All papers included in the dissertation must have a common theme, as approved by a student's thesis committee.
- ◆ Papers should be submitted for inclusion in a dissertation in a common format and typeset.
- ◆ In addition to the individual papers, students must prepare abstract, introduction, discussion, and conclusions sections of the thesis that tie together the individual papers into a unified dissertation.
- ◆ A student's thesis committee might also require the preparation and inclusion of various appendices with the dissertation in support of the papers prepared explicitly for publication.

#### **Graduate Program Background Requirements**

All graduate programs in Geophysics require that applicants have a background that includes the equivalent of adequate undergraduate preparation in the following areas:

- ◆ Mathematics – Linear Algebra or Linear Systems, Differential Equations, Computer Programming
- ◆ Physics – Classical Physics
- ◆ Geology – Structural Geology and Stratigraphy
- ◆ Geophysics – Geophysical Field Methods and courses that include theory and application in three of the following areas: gravity/magnetics, seismic, electrical/

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electromagnetics, borehole geophysics, and physics of the earth

- ◆ In addition, candidates in the Doctoral program are expected to have no less than one year of college level or two years of high school courses in a single foreign language.

Candidates not prepared in one or more of these areas may be admitted into the program if their background and demonstrated talents give reasonable expectation that they can overcome deficiencies during their graduate career.

### *Description of Courses*

**GPGN404. DIGITAL ANALYSIS (I)** The fundamentals of one-dimensional digital signal processing as applied to geophysical investigations are studied. Students explore the mathematical background and practical consequences of the sampling theorem, convolution, deconvolution, the Z and Fourier transforms, windows, and filters. Emphasis is placed on applying the knowledge gained in lecture to exploring practical signal processing issues. This is done through homework and in-class practicum assignments requiring the programming and testing of algorithms discussed in lecture. Prerequisites: MATH213, MATH225, and PHGN311, or consent of instructor. Knowledge of a computer programming language is assumed. 2 hours lecture, 2 hours lab; 3 semester hours.

**GPGN414. GRAVITY AND MAGNETIC EXPLORATION (II)** Instrumentation for land surface, borehole, sea floor, sea surface, and airborne operations. Reduction of observed gravity and magnetic values. Theory of potential field effects of geologic distributions. Methods and limitations of interpretation. Prerequisite: GPGN303. 3 hours lecture, 3 hours lab; 4 semester hours.

**GPGN419/PEGN419. WELL LOG ANALYSIS AND FORMATION EVALUATION (I)** The basics of core analysis and the principles of all common borehole instruments are reviewed. The course shows (computer) interpretation methods that combine the measurements of various borehole instruments to determine rock properties such as porosity, permeability, hydrocarbon saturation, water salinity, ore grade, ash-content, mechanical strength, and acoustic velocity. The impact of these parameters on reserves estimates of hydrocarbon reservoirs and mineral accumulations is demonstrated. Prerequisite: MATH225, GPGN302, GPGN303, and GPGN308. 3 hours lecture, 2 hours lab; 3 semester hours.

**GPGN422. METHODS OF ELECTRICAL PROSPECTING (I)** In-depth study of the application of electrical and electromagnetic methods to crustal studies, minerals exploration, oil and gas exploration, and groundwater. Laboratory work with scale and mathematical models coupled with field work over areas of known geology. Prerequisite: GPGN308 or consent of instructor. 3 hours lecture, 3 hours lab; 4 semester hours.

**GPGN432. FORMATION EVALUATION (II)** The basics of core analysis and the principles of all common borehole instruments are reviewed. The course teaches interpretation methods that combine the measurements of various borehole instruments to determine rock properties such as porosity, permeability, hydrocarbon saturation, water salinity, ore grade and ash content. The impact of these parameters on reserve estimates of hydrocarbon reservoirs and mineral accumulations is demonstrated. Geophysical topics such as vertical seismic profiling, single well and cross-well seismic are emphasized in this course, while formation testing, and cased hole logging are covered in GPGN419/PEGN419 presented in the fall. The laboratory provides on-line course material and hands-on computer log evaluation exercises. Prerequisites: MATH225, GPGN302, GPGN303, and GPGN308. 3 hours lecture, 3 hours lab; 4 semester hours. Only one of the two courses GPGN432 and GPGN419/PEGN419 can be taken for credit.

**GPGN438. GEOPHYSICS PROJECT DESIGN (I, II)** Complementary design course for geophysics restricted elective course(s). Application of engineering design principles to geophysics through advanced work, individual in character, leading to an engineering report or senior thesis and oral presentation thereof. Choice of design project is to be arranged between student and individual faculty member who will serve as an advisor, subject to department head approval. Prerequisites: GPGN302, GPGN303, GPGN308, and completion of or concurrent enrollment in geophysics method courses in the general topic area of the project design. Credit variable, 1 to 3 hours. Course can be retaken once.

**GPGN439. GEOPHYSICS PROJECT DESIGN (II)** **GEGN439/PEGN439. MULTI-DISCIPLINARY PETROLEUM DESIGN (II)**. This is a multidisciplinary design course that integrates fundamentals and design concepts in geological, geophysical, and petroleum engineering. Students work in integrated teams consisting of students from each of the disciplines. Multiple open-end design problems in oil and gas exploration and field development, including the development of a prospect in an exploration play a detailed engineering field study, are assigned. Several detailed written and oral presentations are made throughout the semester. Project economics, including risk analysis, are an integral part of the course. Prerequisites: GP majors: GPGN302 and GPGN303; GE majors: GEOL308 or GEOL309, GEGN316, GEGN438; PE majors: PEGN316, PEGN414, PEGN422, PEGN423, PEGN424 (or concurrent). 2 hours lecture, 3 hours lab; 3 semester hours.

**GPGN452. ADVANCED SEISMIC METHODS (I)** Historical survey. Propagation of body and surface waves in elastic media; transmission and reflection at single and multiple interfaces; energy relationships; attenuation factors, data processing (including velocity interpretation, stacking, and migration) interpretation techniques including curved ray methods.



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Acquisition, processing, and interpretation of laboratory model data; seismic processing using an interactive workstation. Prerequisite: GPGN302 and concurrent enrollment in GPGN404, or consent of instructor. 3 hours lecture, 3 hours lab; 4 semester hours.

GPGN470/GEOL 470. APPLICATIONS OF SATELLITE REMOTE SENSING (II) Students are introduced to geoscience applications of satellite remote sensing. Introductory lectures provide background on satellites, sensors, methodology, and diverse applications. One or more areas of application are presented from a systems perspective. Guest lecturers from academia, industry, and government agencies present case studies focusing on applications, which vary from semester to semester. Students do independent term projects, under the supervision of a faculty member or guest lecturer, that are presented both written and orally at the end of the term. Prerequisites: PHGN200, MATH225, GEOL308 or GEOL 309, or consent of instructor. 3 hours lecture; 3 semester hours

GPGN486. GEOPHYSICS FIELD CAMP (S) Introduction to geological and geophysical field methods. The program includes exercises in geological surveying, stratigraphic section measurements, geological mapping, and interpretation of geological observations. Students conduct geophysical surveys related to the acquisition of seismic, gravity, magnetic, and electrical observations. Students participate in designing the appropriate geophysical surveys, acquiring the observations, reducing the observations, and interpreting these observations in the context of the geological model defined from the geological surveys. Prerequisites: GEOL308 or GEOL309, GEOL314, GPGN302, GPGN303, GPGN308, GPGN315 or consent of instructor. Up to 6 weeks field; up to 6 semester hours, minimum 4 hours.

GPGN494. PHYSICS OF THE EARTH (II) Students will explore the fundamental observations from which physical and mathematical inferences can be made regarding the Earth's origin, structure, and evolution. These observations include traditional geophysical observations (e.g., seismic, gravity, magnetic, and radioactive) in addition to geochemical, nucleonic, and extraterrestrial observations. Emphasis is placed on not only cataloging the available data sets, but also on developing and testing quantitative models to describe these disparate data sets. Prerequisites: GEOL201, GPGN302, GPGN303, GPGN308, PHGN311, and MATH225, or consent of instructor. 3 hours lecture; 3 semester hours.

GPGN498. SPECIAL TOPICS IN GEOPHYSICS (I, II) New topics in geophysics. Each member of the academic faculty is invited to submit a prospectus of the course to the department head for evaluation as a special topics course. If selected, the course can be taught only once under the 498 title before becoming a part of the regular curriculum under a new course number and title. Prerequisite: Consent of depart-

ment. Credit – variable, 1 to 6 hours. Repeatable for credit under different titles.

GPGN499. GEOPHYSICAL INVESTIGATION (I, II) Individual project; instrument design, data interpretation, problem analysis, or field survey. Prerequisite: Consent of department. "Independent Study" form must be completed and submitted to the Registrar. Credit dependent upon nature and extent of project. Variable 1 to 6 credit hours. Repeatable for credit.

#### **Graduate Courses**

500-level courses are open to qualified seniors with the permission of the department and Dean of the Graduate School. 600-level courses are open only to students enrolled in the Graduate School.

GPGN503/GEGN503/PEGN503. INTEGRATED EXPLORATION AND DEVELOPMENT (I) Students work alone and in teams to study reservoirs from fluvial-deltaic and valley fill depositional environments. This is a multidisciplinary course that shows students how to characterize and model subsurface reservoir performance by integrating data, methods and concepts from geology, geophysics and petroleum engineering. Activities include field trips, computer modeling, written exercises and oral team presentations. Prerequisite: GEOL501 or consent of instructors. 2 hours lecture, 3 hours lab; 3 semester hours. Offered fall semester, odd years.

GPGN504/GEGN504/PEGN504. INTEGRATED EXPLORATION AND DEVELOPMENT (I) Students work in multidisciplinary teams to study practical problems and case studies in integrated subsurface exploration and development. Students will learn and apply methods and concepts from geology, geophysics and petroleum engineering to timely design problems in oil and gas exploration and field development. Activities include field trips, computer modeling, written exercises and oral team presentations. Prerequisite: GPGN/GEGN/PEGN503 or consent of instructors. 3 hours lecture and seminar; 3 semester hours. Offered fall semester, even years.

GPGN507. NEAR-SURFACE FIELD METHODS (I) Students design and implement data acquisition programs for all forms of near-surface geophysical surveys. The result of each survey is then modeled and discussed in the context of field design methods. Prerequisite: Consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours. Offered fall semester, even years.

GPGN509. PHYSICAL AND CHEMICAL PROPERTIES AND PROCESSES IN ROCK, SOILS, AND FLUIDS (I) Physical and chemical properties and processes that are measurable with geophysical instruments are studied, including methods of measurement, interrelationships between properties, coupled processes, and processes which modify properties in pure phase minerals and fluids, and in mineral mixtures (rocks and soils). Investigation of implications for

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petroleum development, minerals extraction, groundwater exploration, and environmental remediation. Prerequisite: Consent of instructor. 3 hours lecture, 3 semester hours.

GPGN510. GRAVITY AND MAGNETIC EXPLORATION (II) Instrumentation for land surface, borehole, sea floor, sea surface, and airborne operations. Reduction of observed gravity and magnetic values. Theory of potential field effects of geologic distributions. Methods and limitations of interpretation. Prerequisite: GPGN303, GPGN321, or consent of instructor. 3 hours lecture, 3 hours lab; 4 semester hours.

GPGN511. ADVANCED GRAVITY AND MAGNETIC EXPLORATION (II) Field or laboratory projects of interest to class members; topics for lecture and laboratory selected from the following: new methods for acquiring, processing, and interpreting gravity and magnetic data, methods for the solution of two- and three-dimensional potential field problems, Fourier transforms as applied to gravity and magnetics, the geologic implications of filtering gravity and magnetic data, equivalent distributions, harmonic functions, inversions. Prerequisite: GPGN414 or consent of instructor. 3 hours lecture, 3 hours lab and field; 4 semester hours. Offered spring semester, even years.

GPGN519/PEGN 519. ADVANCED FORMATION EVALUATION (II) A detailed review of well logging and other formation evaluation methods will be presented, with the emphasis on the imaging and characterization of hydrocarbon reservoirs. Advanced logging tools such as array induction, dipole sonic, and imaging tools will be discussed. The second half of the course will offer in parallel sessions: for geologists and petroleum engineers on subjects such as pulsed neutron logging, nuclear magnetic resonance, production logging, and formation testing; for geophysicists on vertical seismic profiling, cross well acoustics and electro-magnetic surveys. Prerequisite: GPGN419/PEGN419 or consent of instructor. 3 hours lecture; 3 semester hours.

GPGN520. ELECTRICAL AND ELECTROMAGNETIC EXPLORATION (I) Electromagnetic theory. Instrumentation. Survey planning. Processing of data. Geologic interpretations. Methods and limitations of interpretation. Prerequisite: GPGN308 or consent of instructor. 3 hours lecture, 3 hours lab; 4 semester hours. Offered fall semester, odd years

GPGN521. ADVANCED ELECTRICAL AND ELECTROMAGNETIC EXPLORATION (II) Field or laboratory projects of interest to class members; topics for lecture and laboratory selected from the following: new methods for acquiring, processing and interpreting electrical and electromagnetic data, methods for the solution of two- and three-dimensional EM problems, physical modeling, integrated inversions. Prerequisite: GPGN422 or GPGN520, or consent of instructor. 3 hours lecture, 3 hours lab; 4 semester hours. Offered spring semester, even years

GPGN530. APPLIED GEOPHYSICS (II) Introduction to geophysical techniques used in a variety of industries (min-

ing, petroleum, environmental and engineering) in exploring for new deposits, site design, etc. The methods studied include gravity, magnetic, electrical, seismic, radiometric and borehole techniques. Emphasis on techniques and their applications are tailored to student interests. The course, intended for non-geophysics students, will emphasize the theoretical basis for each technique, the instrumentation used and data collection, processing and interpretation procedures specific to each technique so that non-specialists can more effectively evaluate the results of geophysical investigations. Prerequisites: PHGN100, PHGN200, MATH111. GEGN401 or consent of the instructor. 3 hours lecture; 3 semester hours

GPGN540. MINING GEOPHYSICS (I) Introduction to gravity, magnetic, electric, radiometric and borehole techniques used by the mining industry in exploring for new deposits. The course, intended for graduate geophysics students, will emphasize the theoretical basis for each technique, the instrumentation used and data collection, processing and interpretation procedures specific to each technique. Prerequisites: GPGN321, GPGN322, MATH111, MATH112, MATH213. 3 hours lecture; 3 semester hours.

GPGN551/MATH693. WAVE PHENOMENA SEMINAR (I, II) Students will probe a range of current methodologies and issues in seismic data processing, with emphasis on underlying assumptions, implications of these assumptions, and implications that would follow from use of alternative assumptions. Such analysis should provide seed topics for ongoing and subsequent research. Topic areas include: Statics estimation and compensation, deconvolution, multiple suppression, suppression of other noises, wavelet estimation, imaging and inversion, extraction of stratigraphic and lithologic information, and correlation of surface and borehole seismic data with well log data. Every student registers for GPGN551 in the first semester in residence and receives a grade of PRG. The grade is changed to a letter grade after the student's presentation of thesis research. Prerequisite: Consent of department. 1 hour seminar; 1 semester hour.

GPGN552. INTRODUCTION TO SEISMOLOGY (I) Introduction to basic principles of elasticity including Hooke's law, equation of motion, representation theorems, and reciprocity. Representation of seismic sources, seismic moment tensor, radiation from point sources in homogeneous isotropic media. Boundary conditions, reflection/transmission coefficients of plane waves, plane-wave propagation in stratified media. Basics of wave propagation in attenuative media, brief description of seismic modeling methods. Prerequisite: GPGN452 or consent of instructor. 3 hours lecture; 3 semester hours.

GPGN553. INTRODUCTION TO SEISMOLOGY (II) This course is focused on the physics of wave phenomena and the importance of wave-theory results in exploration and earthquake seismology. Includes reflection and transmission problems for spherical waves, methods of steepest descent and

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stationary phase, point-source radiation in layered isotropic media, surface and non-geometrical waves. Discussion of seismic modeling methods, fundamentals of wave propagation in anisotropic and attenuative media. Prerequisite: GPGN552 or consent of instructor. 3 hours lecture; 3 semester hours. Offered spring semester, even years

GPGN555. INTRODUCTION TO EARTHQUAKE SEISMOLOGY (II) Introductory course in observational, engineering, and theoretical earthquake seismology. Topics include: seismogram interpretation, elastic plane waves and surface waves, source kinematics and constraints from seismograms, seismicity and earthquake location, magnitude and intensity estimates, seismic hazard analysis, and earthquake induced ground motions. Students interpret digital data from globally distributed seismic stations. Prerequisite: GPGN452. 3 hours lecture; 3 semester hours. Offered spring semester, odd years.

GPGN558. SEISMIC DATA INTERPRETATION (II) Practical interpretation of seismic data used in exploration for hydrocarbons. Integration with other sources of geological and geophysical information. Prerequisite: GPGN452, GEOL501 or equivalent or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours.

GPGN561. SEISMIC DATA PROCESSING I (I) Introduction to basic principles underlying the processing of seismic data for suppression of various types of noise. Includes the rationale for and methods for implementing different forms of gain to data, and the use of various forms of stacking for noise suppression, such as diversity stacking of Vibroseis data, normal-moveout correction and common-midpoint stacking, optimum-weight stacking, beam steering and the stack array. Also discussed are continuous and discrete one- and two-dimensional data filtering, including Vibroseis correlation, spectral whitening, moveout filtering, data interpolation, slant stacking, and the continuous and discrete Radon transform for enhancing data resolution and suppression of multiples and other forms of coherent noise. Prerequisite: GPGN452 or consent of instructor. 3 hours lecture; 3 semester hours. Offered fall semester, even years.

GPGN562. SEISMIC DATA PROCESSING II (II) The student will gain understanding of applications of deterministic and statistical deconvolution for wavelet shaping, wavelet compression, and multiple suppression. Both reflection-based and refraction-based statistics estimation and correction for 2-D and 3-D seismic data will be covered, with some attention to problems where subsurface structure is complex. Also for areas of complex subsurface structure, students will be introduced to analytic and interactive methods of velocity estimation. Where the near-surface is complex, poststack and prestack imaging methods, such as layer replacement are introduced to derive dynamic corrections to reflection data. Also discussed are special problems related to the processing of multi-component seismic data for enhancement of shear-wave information, and those related to processing of vertical

seismic profile data for separation of upgoing and downgoing P- and S- wave arrivals. Prerequisite: GPGN452 and GPGN561 or consent of instructor. 3 hours lecture; 3 semester hours. Offered spring semester, odd years.

GPGN570/GEOL570. APPLICATIONS OF SATELLITE REMOTE SENSING (II) Students are introduced to geoscience applications of satellite remote sensing. Introductory lectures provide background on satellites, sensors, methodology, and diverse applications. One or more areas of application are presented from a systems perspective. Guest lecturers from academia, industry, and government agencies present case studies focusing on applications, which vary from semester to semester. Students do independent term projects, under the supervision of a faculty member or guest lecturer, that are presented both written and orally at the end of the term. Prerequisites: PHGN200, MATH225, GEOL308 or consent of instructor. 3 hours lecture; 3 semester hours

GPGN574. GROUNDWATER GEOPHYSICS (II) Description of world groundwater aquifers. Effects of water saturation on the physical properties of rocks. Use of geophysical methods in the exploration, development and production of groundwater. Field demonstrations of the application of the geophysical methods in the solution of some groundwater problems. Prerequisite: Consent of instructor. 3 hours lecture, 3 hours lab; 4 semester hours.

GPGN580/GEOL580/MNGN580. INDUCED SEISMICITY (II) Earthquakes are sometimes caused by the activities of man. These activities include mining and quarrying, petroleum and geothermal energy production, building water reservoirs and dams, and underground nuclear testing. This course will help students understand the characteristics and physical causes of man-made earthquakes and seismicity induced in various situations. Students will read published reports and objectively analyze the seismological and ancillary data therein to decide if the causative agent was man or natural processes. Prerequisite: basic undergraduate geology and physics. 3 hours lecture; 3 semester hours.

GPGN581. GRADUATE SEMINAR – MS (I, II) Presentation describing results of MS thesis research. All theses must be presented in seminar before corresponding degree is granted. Every MS student registers for GPGN581 only in his/her first semester in residence and receives a grade of PRG. Thereafter, students must attend the weekly Heiland Distinguished Lecture every semester in residence. The grade of PRG is changed to a letter grade after the student's presentation of MS thesis research. 1 hour seminar, 1 semester hour.

GPGN583. THEORY OF GEOPHYSICAL METHODS I (I) This course describes the physical and mathematical principles of the gravimetric, magnetometric and electrical methods of geophysical prospecting. For each method, the following questions are discussed: 1) the physical laws and examples illustrating their application; 2) the physical properties of rocks and the influence of the medium on the field;

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3) the distribution of field generators in the medium; 4) the relevant systems of field equations; 5) methods of solution of the forward problems; 6) approximate methods of field calculation and their application in geophysics; 7) the behavior of the fields as they are applied in the main geophysical methods; 8) the relationship between the fields and the geometric and physical parameters of the medium. Prerequisite: Consent of department. 3 hours lecture; 3 semester hours.

GPGN584. THEORY OF GEOPHYSICAL METHODS II (II) This course describes the physical and mathematical principles of the electromagnetic, seismic and nuclear methods of geophysical prospecting. For each method, the following questions are discussed: 1) the physical laws and examples illustrating their application; 2) the physical properties of rocks and the influence of the medium on the field; 3) the distribution of field generators in the medium; 4) the relevant systems of field equations; 5) methods of solution of the forward problems; 6) approximate methods of field calculation and their application in geophysics; 7) the behavior of the fields as they are applied in the main geophysical methods; 8) the relationship between the fields and the geometric and physical parameters of the medium. Prerequisite: GPGN583. 3 hours lecture; 3 semester hours.

GPGN598. SPECIAL TOPICS IN GEOPHYSICS (I, II) New topics in geophysics. Each member of the academic faculty is invited to submit a prospectus of the course to the department head for evaluation as a special topics course. If selected, the course can be taught only once under the 598 title before becoming a part of the regular curriculum under a new course number and title. Prerequisite: Consent of department. Credit-variable, 1 to 6 hours. Repeatable for credit under different titles.

GPGN599. GEOPHYSICAL INVESTIGATIONS MS (I, II) Individual project; instrument design, data interpretation, problem analysis, or field survey. Prerequisite: Consent of department and "Independent Study" form must be completed and submitted to the Registrar. Credit dependent upon nature and extent of project. Variable 1 to 6 hours. Repeatable for credit.

GPGN605. INVERSION THEORY (II) Introductory course in inverting geophysical observations for inferring earth structure and processes. Techniques discussed include: Monte-Carlo procedures, Marquardt-Levenburg optimization, and generalized linear inversion. In addition, aspects of probability theory, data and model resolution, uniqueness considerations, and the use of a priori constraints are presented. Students are required to apply the inversion methods described to a problem of their choice and present the results as an oral and written report. Prerequisite: MATH225 and knowledge of a scientific programming language. 3 hours lecture; 3 semester hours.

GPGN606. SIMULATION OF GEOPHYSICAL DATA (II) Efficiency of writing and running computer programs. Re-

view of basic matrix manipulation. Utilization of existing CSM and department computer program libraries. Some basic and specialized numerical integration techniques used in geophysics. Geophysical applications of finite elements, finite differences, integral equation modeling, and summary representation. Project resulting in a term paper on the use of numerical methods in geophysical interpretation. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. Offered spring semester, odd years.

GPGN651. ADVANCED SEISMOLOGY (I) In-depth discussion of wave propagation and seismic processing for anisotropic, heterogeneous media. Topics include influence of anisotropy on plane-wave velocities and polarizations, travelt ime analysis for transversely isotropic models, anisotropic velocity-analysis and imaging methods, point-source radiation and Green's function in anisotropic media, inversion and processing of multicomponent seismic data, shear-wave splitting, and basics of seismic fracture characterization. Prerequisites: GPGN552 and GPGN553 or consent of instructor. 3 hours lecture; 3 semester hours. Offered fall semester, even years.

GPGN658. SEISMIC MIGRATION (I, II) Seismic migration is the process that converts seismograms, each recorded as a function of time, to an image of the earth's subsurface, which is a function of depth below the surface. The theoretical and practical aspects of finite-difference, Kirchhoff, Fourier transform, and other methods for migration are emphasized with numerous computer programs and exercises. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

GPGN660. MATHEMATICS OF SEISMIC IMAGING AND MIGRATION (II) During the past 40 years geophysicists have developed many techniques (known collectively as "migration") for imaging geologic structures deep within the Earth's subsurface. Beyond merely imaging strata, migration can provide information about important physical properties of rocks, necessary for the subsequent drilling and development of oil- and gas-bearing formations within the Earth. In this course the student will be introduced to the mathematical theory underlying seismic migration, in the context of "inverse scattering imaging theory." The course is heavily oriented toward problem solving. 3 hours lecture; 3 semester hours. Offered spring semester, odd years.

GPGN681. GRADUATE SEMINAR – PHD (I, II) Presentation describing results of Ph.D. thesis research. All theses must be presented in seminar before corresponding degree is granted. Every PhD student registers for GPGN681 only in his/her first semester in residence and receives a grade of PRG. Thereafter, students must attend the weekly Heiland Distinguished Lecture every semester in residence. The grade of PRG is changed to a letter grade after the student's presentation of PhD thesis research. 1 hour seminar; 1 semester hour.



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GPGN698. SPECIAL TOPICS IN GEOPHYSICS (I, II)

New topics in geophysics. Each member of the academic faculty is invited to submit a prospectus of the course to the department head for evaluation as a special topics course. If selected, the course can be taught only once under the 698 title before becoming a part of the regular curriculum under a new course number and title. Prerequisite: Consent of instructor. Credit – variable, 1 to 6 hours. Repeatable for credit under different topics.

GPGN699. GEOPHYSICAL INVESTIGATION-PHD (I, II)

Individual project; instrument design, data interpretation, problem analysis, or field survey. Prerequisite: Consent of department and “Independent Study” form must be completed and submitted to the Registrar. Credit dependent upon nature and extent of project, not to exceed 6 semester hours. Repeatable for credit.

GPGN705. GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student’s faculty advisor. Repeatable for credit.

GPGN706. GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy-thesis. Research must be carried out under direct supervision of the graduate student’s faculty advisor. Repeatable for credit.

## Hydrologic Science and Engineering

JOHN MCCRAY, Associate Professor Environmental Science & Engineering, Program Director

DAVID BENSON, Associate Professor Geology & Geological Engineering, Associate Director

HUSSEIN AMERY, Associate Professor Liberal Arts & International Studies

TZAHY CATH, Assistant Professor Environmental Science & Engineering

RONALD R.H. COHEN, Associate Professor Environmental Science & Engineering

JÖRG DREWES, Assistant Professor Environmental Science & Engineering

VAUGHN GRIFFITHS, Professor Civil Engineering

DAVID HALE, Professor Geophysics

BRUCE HONEYMAN, Professor, Environmental Science & Engineering

JOHN HUMPHREY, Associate Professor Geology & Geological Engineering

TISSA ILLANGASEKARE, Professor Environmental Science & Engineering and AMAX Chair

YAOGUO LI, Associate Professor Geophysical Engineering

NING LU, Professor Civil Engineering

DONALD MACALADY, Professor Emeritus Chemistry & Geochemistry

JUNKO MUNAKATA MARR, Assistant Professor Environmental Science & Engineering

GARY OLHOEFT, Professor Geophysics

EILEEN POETER, Professor Geology & Geological Engineering

JAMES RANVILLE, Assistant Professor Chemistry & Geochemistry

ANDRÉE REVIL, Associate Professor Geophysical Engineering

SAMUEL ROMBERGER, Professor, Geology & Geological Engineering

GEORGE SHERK, Research Associate Professor Liberal Arts & International Studies

ROBERT L. SIEGRIST, Professor Environmental Science & Engineering

JOHN SPEAR, Assistant Professor Environmental Science & Engineering

Geological Engineering

BETTINA VOELKER, Associate Professor Chemistry & Geochemistry

### *Degrees Offered:*

Master of Science (Hydrology), Thesis option

Master of Science (Hydrology), Non-thesis option

Doctor of Philosophy (Hydrology)

### *Program Description:*

The Hydrologic Science and Engineering (HSE) Program is an interdisciplinary graduate program comprised of faculty from several different CSM departments.

The program offers programs of study in fundamental hydrologic science and applied hydrology with engineering applications. Our program encompasses ground-water hydrogeology, surface-water hydrology, vadose-zone hydrology, watershed hydrology, contaminant transport and fate, con-

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taminant remediation, hydrogeophysics, and water policy/law. Students may elect to follow the Science or the Engineering Track.

HSE requires a core study of 4 formal graduate courses and a field session. However, programs of study are interdisciplinary in nature, and the remainder of the coursework is obtained from multiple departments at CSM and is approved for each student by the student's advisor and thesis Committee.

To achieve the Master of Science (M.S.) degree, students may elect the Non-Thesis option, based exclusively upon coursework and a project report, or the Thesis option. The thesis option is comprised of coursework in combination with individual laboratory, modeling and/or field research performed under the guidance of a faculty advisor and presented in a written thesis approved by the student's committee.

HSE also offers a combined baccalaureate/masters degree program in which CSM students obtain an undergraduate degree as well as a Thesis or Non-thesis M.S. in Hydrology. As many as six credit hours may be counted toward the requirements of both the B.S. and M.S. degrees. Please see the Combined Undergraduate/Graduate Programs sections in the *Graduate and Undergraduate Bulletins* for additional information.

To achieve the Doctor of Philosophy (Ph.D.) degree, students are expected to complete a combination of coursework and original research, under the guidance of a faculty advisor and Doctoral committee, which culminates in a significant scholarly contribution to a specialized field in hydrologic sciences or engineering. Full-time enrollment is expected and leads to the greatest success, although part-time enrollment may be allowed under special circumstances. All doctoral students must complete the full-time, on-campus residency requirements described in the general section of the *Graduate Bulletin*.

Currently, students will apply to the hydrology program through the Graduate School and be assigned to the HSE participating department of the student's HSE advisor. Participating departments include: Chemistry and Geochemistry, Engineering, Environmental Science and Engineering (ESE), Geology and Geological Engineering (GGE), Geophysical Engineering, Mining Engineering (ME), and Petroleum Engineering (PE). HSE is part of the Western Regional Graduate Program, a recognition that designates these programs as unique within the Western United States. An important benefit of this designation is that students from several western states are given the tuition status of Colorado residents. These states include Alaska, Arizona, Hawaii, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming.

For more information on HSE curriculum please refer to the HSE website at <http://www.mines.edu/academic/hydro/>.

### **Combined Degree Program Option**

CSM undergraduate students have the opportunity to begin work on a M.S. degree in Hydrology while completing their Bachelor's degree. The CSM Combined Degree Program provides the vehicle for students to use undergraduate coursework as part of their Graduate Degree curriculum. For more information please contact the HSE program faculty.

#### **Program Requirements:**

M.S. Non-Thesis Option: 36 total credit hours, consisting of coursework (30 h), and Independent Study (6 h) working on a research project with HSE faculty, including a written report.

M.S. Thesis Option: 30 total credit hours, consisting of coursework (24 h), and research (6 h). Students must also write and orally defend a research thesis.

Ph.D.: 72 total credit hours, consisting of coursework (at least 15 h), and research (at least 24 h). Students must also successfully complete qualifying examinations, write and defend a dissertation proposal, write and defend a doctoral dissertation, and are expected to submit the dissertation work for publication in scholarly journals.

#### **Thesis Committee Requirements**

Students must meet the general requirements listed in the graduate bulletin section *Graduate Degrees and Requirements*. In addition, the student's advisor or co-advisor must be an HSE faculty member. For M.S. thesis students, at least two committee members must be members of the HSE faculty. For doctoral students, at least 3 members must be a member of the HSE faculty.

#### **Prerequisites Science Track:**

- ◆ baccalaureate degree in a science or engineering discipline
- ◆ college calculus: two semesters required
- ◆ differential equations: one semester required
- ◆ college physics: one semester required
- ◆ college chemistry: one year required
- ◆ college statistics: one semester required

#### **Prerequisites Engineering Track:**

- ◆ baccalaureate degree in a science or engineering discipline
- ◆ college calculus: two semesters required
- ◆ differential equations: one semester required
- ◆ college physics: two semester required
- ◆ college chemistry: two years required
- ◆ college statistics: one semester required
- ◆ statics, one semester required
- ◆ mechanics of materials, one semester required

- ◆ dynamics, one semester required
- ◆ thermodynamics, one semester required
- ◆ engineering design (equivalent of a 400-level capstone design course or ESGN 451 - Hydraulic Problems)

Note that some pre-requisites may be completed in the first few semesters of the graduate program if approved by the hydrology program faculty. Graduate courses may be used to fulfill one or more of these requirements after approval by the ISE Graduate Admissions Committee and the student's Thesis Committee.

#### **Required Curriculum:**

Students will work with their academic advisors and graduate thesis committees to establish plans of study that best fit their individual interests and goals. Each student will develop and submit a plan of study to their advisor during the first semester of enrollment. Doctoral students may transfer in credits from an earned M.S. graduate program according to requirements listed in the Graduate Degrees and Requirements section of the graduate bulletin, and after approval by the student's thesis committee. Recommended pre-requisite courses may be taken for credit during the first year a student is enrolled in HSE. In some cases, graduate courses may satisfy one or more pre-requisites if approved by the hydrology program faculty.

#### **SCIENCE TRACK:**

Curriculum areas of emphasis consist of core courses, and electives. Core courses include the following:

- Ground Water Engineering (GEGN 466)
- Surface-Water Hydrology (ESGN 527)
- Environmental Chemistry (CHGC 505)
- Subsurface Contaminant Fate and Transport (ESGN522)
- Or
- Surface Water Quality Modeling (ESGN520)
- Field Hydrology as described in the following paragraph

Students are also required to complete a hydrology field session that will be offered through existing courses taught by Environmental Science and Engineering, Geology and Geological Engineering, or Geophysical Engineering. HSE seminar is also required and will typically have a 598 course number. These are one-credit reading and discussion seminars. PhD students are required to complete at least two, and M.S. students must complete one seminar. The seminar courses are taught nearly every semester, with different topics depending on the instructor. Students who plan to incorporate hydrochemistry into their research may elect to replace CHGC 505 with a two-course combination that includes an aqueous inorganic chemistry course (e.g., GEGN 509 or ESGN 500) and an environmental organic chemistry course (e.g., CHGC/ESGN 555).

Elective courses may be chosen from a list approved by the HSE program faculty with one free elective that may be

chosen from any of the graduate courses offered at CSM and other local universities.

#### **ENGINEERING TRACK**

Curriculum areas of emphasis consist of core courses, and electives. Core courses include all core courses in the Science Track and a relevant Capstone Design Course (e.g. Ground Water Engineering GEGN 470)

Elective courses may be chosen from a list approved by the HSE program faculty with one free elective that may be chosen from any of the graduate courses offered at CSM and other local universities. At least half of the elective credits must come from the following list:

GEGN 598	Quantitative Hydrology
GEGN 683	Advanced Groundwater Modeling
ESGN 622	Multiphase Fluids Transport
GEGN 681	Vadose-Zone Hydrology
GEGN 581	Advanced Hydrogeology
GEGN 682	Flow And Transport In Fractured Rock
ESGN 503	Environmental Pollution, Fate, Sources
ESGN 575	Hazardous Waste Site Remediation
GEGN 585	Hydrochemical Modeling
GEGN 684	Chemical Modeling of Aqueous Systems
EGGN 454	Water Supply Engineering
ESGN 603	Water Reuse and Treatment
EGES 533	Unsaturated Soil Mechanics
EGES 534	Soil Behavior
EGES 553	Engineering Hydrology
EGES 554	Open Channel Flow
GEGN 532	Geological Data Analysis
GEGN 575	Applications of GIS
GEGN 542	Advanced Engineering Geomorphology
GEGN 573	Site Investigation
ESGN 601	Risk Assessment
ESGN 598	Numerical Methods for Modeling of Water and Environmental Systems

#### **Description of Courses**

The hydrology program courses are taken from existing courses at CSM. In addition to the core courses listed above, the elective courses currently approved by HSE faculty can be viewed at <http://www.mines.edu/Academic/hydro/>.

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## Liberal Arts and International Studies

LAURA J. PANG, Associate Professor and Division Director  
CARL MITCHAM, Professor  
BARBARA M. OLDS, Professor and Associate Vice President for Educational Innovation  
EUL-SOO PANG, Professor  
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TINA L. GIANQUITTO, Assistant Professor  
JOHN R. HEILBRUNN, Assistant Professor  
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DAVID J. MESKILL, Lecturer  
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WILTON ECKLEY, Emeritus Professor  
PETER HARTLEY, Emeritus Associate Professor  
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KATHLEEN H. OCHS, Emeritus Associate Professor  
ANTON G. PEGIS, Emeritus Professor  
THOMAS PHILIPOSE, University Emeritus Professor  
JOSEPH D. SNEED, Emeritus Professor  
RONALD V. WIEDENHOEFT, Emeritus Professor  
KAREN B. WILEY, Emeritus Associate Professor

### *Degrees Offered:*

Master of International Political Economy of Resources (Non-Thesis)

### *Non-Degree Certificates Offered:*

International Political Economy Graduate Certificate 1

International Political Economy Graduate Certificate 2

Graduate Certificate in Science and Technology Policy

Non-Degree Minor Offered:

Graduate Individual Minor

### *Program Description:*

The Division of Liberal Arts & International Studies offers one non-thesis professional graduate degree, the Master of International Political Economy of Resources (MIPER); two graduate certificates in International Political Economy (IPE); a graduate certificate in Science and Technology Policy; and a graduate individual minor.

## Master of International Political Economy of Resources (MIPER).

The Division of Liberal Arts and International Studies offers a 36 semester-hour non-thesis Master of International Political Economy of Resources (MIPER) degree. The master's degree program is part of CSM's Combined Undergraduate/Graduate programs. Students participating in the combined degree program may double count up to 6 semester hours of 400-level course work from their undergraduate IPE minor or undergraduate course work (excluding foreign languages) to the MIPER. An additional 3 credit-hours may be transferred upon the recommendation of the IPE Program Director and the approval of the Dean of Graduate Studies.

The MIPER program is ideal for global resources industry leaders and public sector policy makers dealing with developing non-renewable resources on a global scale. The program's philosophical foundations are built on the twin pillars of applying key methods and theories of international political economy (IPE) and comparative political economy (CPE) to understanding the role of the world's resources in the context of human and natural environment. The concept of "resources" is understood in the context of the environment in which resources are found and developed, as well as both state and non-state actors who play a role in developing, marketing, and consuming them on a global scale.

The objective of the MIPER program is to develop professional analytical skills in (1) resources development and management strategies embedded in the inter-state and supra-national relationships between the state and the market; (2) analysis of regional and global security and risk issues affecting resources industry; and (3) transnational trade and investment flows as well as resources production and consumption.

### **IPE Graduate Certificates**

The IPE Graduate Certificate program is divided into two parts: (1) the first 15-credit hour certificate focuses on the IPE theories, methods, and models; and (2) the second 15-credit hour certificate focuses on specialization, such as regional development (Asia-Pacific, Latin America/the Americas, Africa, and the Middle East), international or comparative political economy issues, and project-specific themes like trade, finance, the environment, gender, ethnicity, and so forth.

Upon completion of 15 credit hours (or 5 courses), the student will be issued a certificate. The program is designed in a flexible format so that the student can take time to complete the course requirements. The graduate certificate program is part of CSM's combined undergraduate/graduate degree program. As such, students participating in the combined degree program may double count up to 6 credit hours of 400 level course work toward each certificate. If the student completes all 30 credit hours, he/she may petition for admission into the Master of International Political Economy



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of Resources degree program, which requires the completion of an additional 6 credit-hours.

### **Science and Technology Graduate Certificate (STP)**

The Science and Technology Policy (STP) graduate certificate is offered by the Division of Liberal Arts & International Studies in collaboration with the Center for Science and Technology Policy, Cooperative Institute for Research in Environmental Science (CIRES), at the University of Colorado at Boulder. The aim is to provide a broad, practical understanding of science-society relations that will benefit practicing scientists and engineers, especially in the fields of science and engineering that are the traditional mission of the Colorado School of Mines.

### **Graduate Individual Minor**

Graduate students in departments and divisions other than LAIS may earn a minor in the Division if they complete 12 hours of course work from the LAIS course offerings, including Special Topics (LAIS 498 or 598 courses) or Independent Study (LAIS 499 or 599) chosen in consultation with an LAIS advisor. Note: The Graduate Individual Minor must be approved by the student's graduate committee and by the LAIS Division.

### *Program Requirements:*

### **Master of International Political Economy of Resources (MIPER)**

The Master of International Political Economy of Resources non-thesis professional degree requires 36 semester hours of course work. It may be completed as part of a Combined Undergraduate/Graduate program by students already matriculated as undergraduate students at Colorado School of Mines, or by individuals already holding undergraduate or advanced degrees who are interested in a non-thesis graduate program of study. CSM students interested in pursuing the MIPER as part of a Combined Undergraduate/Graduate program are encouraged to make an initial contact with the director of the MIPER program after completion of the first semester of their Sophomore year for counseling on degree application procedures, admissions standards, and degree completion requirements. See "Combined Undergraduate/Graduate Degree Programs" elsewhere in this bulletin for further details.

The MIPER program has two parts: (1) 18 credit-hours (six core courses) drawn from six core thematic areas; and (2) 18 credit-hours (six courses) of electives. See Program Director for specific courses associated with each of these two areas.

MIPER-related courses are designated in the Description of Courses below by the code [IPE].

### **Core Thematic Areas**

1. International Political Economy: Theories and Methods

2. International Political Economy of Regions (Latin America, Asia Pacific, the Middle East, and Sub-Saharan Africa)
3. Global Resources Security
4. Global Resources Development
5. International Political Risk Assessment and Mitigation
6. Quantitative Methods for IPE

### **Elective Courses**

The student is required to choose two of the following three areas:

1. Area Studies and Comparative Political Economy (CPE) Themes: Development, institutions, regimes, state-building vs. nation-building, social stratification, ethnicity, gender, religion, and culture provide fertile fields of CPE investigations in such regions of interest to the MIPER program as Asia Pacific, Latin America/the Americas, the Middle East and the Islamic World, Sub-Saharan Africa, and the European Union and FSU states.
2. IPE Themes: IPE themes include trade, finance, regionalism, cross-regionalism, globalization, international organizations, inter-state relations, security, non-traditional security, country political risk assessment and mitigation, corruption and development, ethnic conflicts, cultural clashes, environmental politics and policies, technology and social transformation, and the like.
3. IPE Theories and Methods: Study based in theories, methods, and models associated with the disciplines of International Political Economy, Comparative Political Economy, and/or International Relations.

### **Outside Field**

In some cases, the student will be encouraged to take courses outside LAIS as a minor. Courses in engineering, science, economics, business, and law can be highly useful to developing additional IPE skills in resources industry and policy making arena. The student must receive permission from the Program Director and his/her adviser before undertaking non-LAIS course work.

### **Admission Requirements**

The requirements for admission into the MIPER Program are as follows:

1. BS or BA with a cumulative grade point average (GPA) at or above 3.0 (4.0 scale). CSM undergraduates who do not meet the overall GPA of 3.0 but who are pursuing the undergraduate IPE Minor or who have taken three or more IPE courses with a minimum GPA of 3.0 in IPE course work will also be considered for admission.
2. The GRE is required. Under certain circumstances, the GRE requirements can be waived by the permission of

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the Program Director. Contact the MIPER Program Director for details.

3. A TOEFL score of 580 (paper test), 237 (computer test), or 92-93 (Internet test) or higher is required for students who are non-native English speakers.
4. A two-page essay is required and must discuss why the candidate is interested in pursuing the MIPER and how he/she intends to utilize IPE knowledge and skills.
5. No foreign language is required at the time of admission. However, those intending to spend an optional overseas semester must have appropriate language skills.

### **Transfer Credit**

Up to 15 semester hours of a MIPER degree may be transfer credit from another university. Requests for transfer credit must be approved by the Director of the MIPER Program who will review course syllabi and evidence of work completion as provided by the student. Transfer credits must not have been used as credit toward a Bachelor's degree. The transfer limit includes CSM distance learning courses.

### **Overseas Semester**

In exceptional cases, the student will be encouraged to spend one semester at an overseas institution in East Asia, Latin America, Europe, the Middle East, Africa, or Australasia. The MIPER Program Director and the student's adviser will assist in finding an appropriate university overseas.

### **International Political Economy Graduate Certificates**

The IPE Graduate Certificates require 15 credit-hours each. Either one or both of the certificates may be completed as part of a Combined Undergraduate/Graduate program by students already matriculated as undergraduate students at Colorado School of Mines, or by individuals already holding undergraduate or advanced degrees who are interested in a briefer amount of study in International Political Economy at the graduate level. CSM students interested in pursuing the MIPER as part of a Combined Undergraduate/Graduate program are encouraged to make an initial contact with the director of the MIPER program after completion of the first semester of their Sophomore year for counseling on application procedures, admissions standards, and completion requirements. See "Combined Undergraduate/Graduate Degree Programs" elsewhere in this bulletin for further details.

IPE Graduate Certificate-related courses are designated in the Description of Courses below by the code [IPE].

**Certificate I** (15 credit-hours). For the first graduate certificate, students must take courses from five of the six core thematic areas associated with the MIPER.

**Certificate II** (15 credit-hours). For the second graduate certificate, students must choose an area of specialization in consultation with the Program Director. Nine of the 15

credit-hours (three courses) in the second certificate must come from Region studies, or IPE- or CPE-driven thematic courses. Six credit hours can be minor courses taken outside of LAIS but relevant to the core content and approaches of IPE and CPE. The student must consult the Program Director before embarking on the non-LAIS minor program of study.

### **Admission Requirements**

The requirements for admission into the IPE Graduate Certificates Program are as follows:

1. BS or BA with a cumulative grade point average (GPA) at or above 3.0 (4.0 scale). CSM undergraduates who do not meet the overall GPA of 3.0 but who are pursuing the undergraduate IPE Minor or who have taken three or more IPE courses with a minimum GPA of 3.0 in IPE course work will also be considered for admission.
2. The GRE is not required.
3. A TOEFL score of 580 (paper test), 237 (computer test), or 92-93 (Internet test) or higher is required for students who are non-native English speakers.
4. A two-page essay is required and must discuss why the candidate is interested in pursuing one or both IPE Graduate Certificates and how he/she intends to utilize IPE acquired knowledge and skills.
5. No foreign language is required at the time of admission. However, demonstrated commitment to learning a second and/or third language during residency in the program is strongly encouraged.

### **Transfer Credits**

Students may not, on an individual basis, request that transfer credits from other institutions be applied to an IPE Graduate Certificate. The transfer limit includes CSM distance learning courses.

### **Double-Counting CSM Undergraduate Course Work for MIPER or IPE Graduate Certificates**

As noted above, students coming from within CSM can transfer up to 6 credit-hours of 400-level course work automatically from their undergraduate IPE minor or undergraduate International Studies Cluster (excluding foreign languages). An additional 3 credit-hours may be transferred upon the recommendation of the IPE Program Director and the approval of the Dean of the Graduate School.

### **Science and Technology Policy Graduate Certificate**

The STP certificate requires a total of 15 semester hours of graduate-level courses. Two of these courses should be science and technology policy courses that emphasize, in one instance, humanities perspectives, and in another, social science perspectives. The other three courses may be selected, at student discretion and with adviser approval, from among the suite of courses offered at CSM and CU-Boulder. Existing LAIS courses included in this suite are:

LAIS 447/547 Global Corporations

LAIS 448	Global Environmental Issues
LAIS 450/550	Political Risk Assessment
LAIS 487/587	Environmental Politics and Policy
LAIS 488/588	Water Politics and Policy
LAIS 545	International Political Economy
LAIS 548	Global Environmental Politics and Policy
LAIS 586	Science and Technology Policy

Students may also incorporate courses from the Economics and Business core M.S. curriculum in Mineral Economics in the Economics and Public Policy area of specialization.

**Finally, it is recommend that STP certificate students do either a focused study of science and technology policy in the United States or some other country, including the possibility of taking one IPE regional studies course in which student research will be allowed to focus on science and technology policy issues related to that region.**

#### *Description of Courses:*

Note: Many but not all LAIS graduate courses are listed below as 400/500 combinations.

#### *Humanities and Social Sciences (LAIS)*

LAIS401. CREATIVE WRITING: POETRY II This course is a continuation of LAIS301 for those interested in developing their poetry writing further. It focuses on reading and writing poetry. Students will learn many different poetic forms to compliment prosody, craft, and technique. Aesthetic preferences will be developed as the class reads, discusses, and models some of the great American poets. Weekly exercises reflect specific poetic tools, encourage the writing of literary poetry, and simulate the development of the student's craft. The purpose of the course is to experience the literature and its place in a multicultural society, while students "try on" various styles and contexts in order to develop their own voice. The course enrollment is split between the 300 and 400 levels to allow returning students the opportunity for continued development. An additional book review and presentation, as well as leading the small groups will be expected of returning students. Prerequisite: LAIS301. Prerequisite or corequisite: SYGN200. 3 hours seminar. 3 semester hours.

LAIS402. WRITING PROPOSALS FOR A BETTER WORLD This course develops the student's writing and higher-order thinking skills and helps meet the needs of underserved populations, particularly via funding proposals written for nonprofit organizations. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LAIS405. BECOMING AMERICAN: LITERARY PERSPECTIVES This course will explore the increasing heterogeneity of U.S. society by examining the immigration and assimilation experience of Americans from Europe, Africa, Latin America, and Asia as well as Native Americans. Pri-

mary sources and works of literature will provide the media for examining these phenomena. In addition, Arthur Schlesinger, Jr.'s thesis about the "unifying ideals and common culture" that have allowed the United States to absorb immigrants from every corner of the globe under the umbrella of individual freedom, and the various ways in which Americans have attempted to live up to the motto "e pluribus unum" will also be explored. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LAIS406. THE AMERICAN DREAM: ILLUSION OR REALITY? This seminar will examine "that elusive phrase, the American dream," and ask what it meant to the pioneers in the New World, how it withered, and whether it has been revived. The concept will be critically scrutinized within cultural contexts. The study will rely on the major genres of fiction, drama, and poetry, but will venture into biography and autobiography, and will range from Thoreau's *Walden* to Kerouac's *On the Road* and Boyle's *Budding Prospects*. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LAIS409. SHAKESPEAREAN DRAMA Shakespeare, the most well known writer in English and perhaps the world, deals with universal themes and the ultimate nature of what it is to be a human being. His plays are staged, filmed, and read around the globe, even after 400 years. This seminar will explore why Shakespeare's plays and characters have such lasting power and meaning to humanity. The seminar will combine class discussion, lecture, and video. Grades will be based on participation, response essays, and a final essay. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar. 3 semester hours.

LAIS414. HEROES AND ANTIHEROES: A TRAGIC VIEW This course features heroes and antiheroes (average folks, like most of us), but because it is difficult to be heroic unless there are one or more villains lurking in the shadows, there will have to be an Iago or Caesar or a politician or a member of the bureaucracy to overcome. Webster's defines heroic as "exhibiting or marked by courage and daring." Courage and daring are not confined to the battlefield, of course. One can find them in surprising places in the community (Ibsen's *Enemy of the People*), in the psychiatric ward (Kesey's *One Flew Over the Cuckoo's Nest*), in the military (Heller's *Catch-22*), on the river (Twain's *The Adventures of Huckleberry Finn* or in a "bachelor pad" (Simon's *Last of the Red Hot Lovers*). Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LAIS420/520. BUSINESS, ENGINEERING AND LEADERSHIP ETHICS A critical exploration of business, management, engineering, and leadership ethics, with an emphasis on relations among these fields of practice. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar/discussion; 3 semester hours.

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LAIS435/535. LATIN AMERICAN DEVELOPMENT [IPE] A senior seminar designed to explore the political economy of current and recent past development strategies, models, efforts, and issues in Latin America, one of the most dynamic regions of the world today. Development is understood to be a nonlinear, complex set of processes involving political, economic, social, cultural, and environmental factors whose ultimate goal is to improve the quality of life for individuals. The role of both the state and the market in development processes will be examined. Topics to be covered will vary as changing realities dictate but will be drawn from such subjects as inequality of income distribution; the role of education and health care; region-markets; the impact of globalization; institution-building; corporate-community-state interfaces; neoliberalism; privatization; democracy; and public policy formulation as it relates to development goals. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LAIS436/536. HEMISPHERIC INTEGRATION IN THE AMERICAS [IPE] This international political economy seminar is designed to accompany the endeavor now under way in the Americas to create a free trade area for the entire Western Hemisphere. Integrating this hemisphere, however, is not just restricted to the mechanics of facilitating trade but also engages a host of other economic, political, social, cultural, and environmental issues, which will also be treated in this course. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LAIS437/537. ASIAN DEVELOPMENT [IPE] This international political economy seminar deals with the historical development of Asia Pacific from agrarian to post-industrial eras; its economic, political, and cultural transformation since World War II, contemporary security issues that both divide and unite the region; and globalization processes that encourage Asia Pacific to forge a single trading bloc. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LAIS441. AFRICAN DEVELOPMENT (IPE) This course provides a broad overview of the political economy of Africa. Its goal is to give students an understanding of the possibilities of African development and the impediments that currently block its economic growth. Despite substantial natural resources, mineral reserves, and human capital, most African countries remain mired in poverty. The struggles that have arisen on the continent have fostered thinking about the curse of natural resources where countries with oil or diamonds are beset with political instability and warfare. Readings give first an introduction to the continent followed by a focus on the specific issues that confront African development today. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar. 3 semester hours. See list below for LAIS541 course description.

LAIS442. NATURAL RESOURCES AND WAR IN AFRICA [IPE] Africa possesses abundant natural resources yet suffers civil wars and international-conflicts based on access to resource revenues. The course examines the distinctive history of Africa, the impact of the resource curse, mismanagement of government and corruption, and specific cases of unrest and war in Africa. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar. 3 semester hours. See list below for LAIS542 course description.

LAIS446/546. GLOBALIZATION [IPE] This international political economy seminar is an historical and contemporary analysis of globalization processes examined through selected issues of world affairs of political, economic, military, and diplomatic significance. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LAIS447/547. GLOBAL CORPORATIONS [IPE] This international political economy seminar seeks to (1) understand the history of the making of global corporations and their relationship to the state, region-markets, and region-states; and (2) analyze the on-going changes in global, regional, and national political economies due to the presence of global corporations. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN 200. 3 hours seminar. 3 semester hours.

LAIS448. GLOBAL ENVIRONMENTAL ISSUES [IPE] Critical examination of interactions between development and the environment and the human dimensions of global change; social, political, economic, and cultural responses to the management and preservation of natural resources and ecosystems on a global scale. Exploration of the meaning and implications of “stewardship of the Earth” and “sustainable development.” Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LAIS449. CULTURAL DYNAMICS OF GLOBAL DEVELOPMENT [IPE] Role of cultures and nuances in world development; cultural relationship between the developed North and the developing South, specifically between the U.S. and the Third World. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LAIS450/550. POLITICAL RISK ASSESSMENT [IPE] This course will review the existing methodologies and techniques of risk assessment in both country-specific and global environments. It will also seek to design better ways of assessing and evaluating risk factors for business and public diplomacy in the increasingly globalized context of economy and politics wherein the role of the state is being challenged and redefined. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. Prerequisite: At least one IPE 300- or 400-level course and permission of instructor. 3 hours seminar; 3 semester hours.



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LAIS451/551. POLITICAL RISK ASSESSMENT RESEARCH SEMINAR [IPE] When offered, this international political economy seminar must be taken concurrently with LAIS 450/550, Political Risk Assessment. Its purpose is to acquaint the student with empirical research methods and sources appropriate to conducting a political risk assessment study, and to hone the students analytical abilities. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. Concurrent enrollment in LAIS 450/550. 1 hour seminar; 1 semester hour.

LAIS452/552. CORRUPTION AND DEVELOPMENT [IPE] This course addresses the problem of corruption and its impact on development. Readings are multidisciplinary and include policy studies, economics, and political science. Students will acquire an understanding of what constitutes corruption, how it negatively affects development, and what they, as engineers in a variety of professional circumstances, might do in circumstances in which bribe paying or taking might occur. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LAIS459. INTERNATIONAL FIELD PRACTICUM [IPE] For students who go abroad for an on-site practicum involving their technical field as practiced in another country and culture; required course for students pursuing a certificate in International Political Economy; all arrangements for this course are to be supervised and approved by the advisor of the International Political Economy minor program. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LAIS465. THE AMERICAN MILITARY EXPERIENCE A survey of military history, with primary focus on the American military experience from 1775 to present. Emphasis is placed not only on military strategy and technology, but also on relevant political, social, and economic questions. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours. Open to ROTC students or by permission of the LAIS Division.

LAIS470. TECHNOLOGY AND GENDER: ISSUES This course focuses on how women and men relate to technology. Several traditional disciplines will be used: philosophy, history, sociology, literature, and a brief look at theory. The class will begin discussing some basic concepts such as gender and sex and the essential and/or social construction of gender, for example. We will then focus on topical and historical issues. We will look at modern engineering using sociological studies that focus on women in engineering. We will look at some specific topics including military technologies, ecology, and reproductive technologies. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LAIS475. ENGINEERING CULTURES IN THE DEVELOPING WORLD An investigation and assessment of engineering problem solving in the developing world using

historical and cultural cases. Countries to be included range across Africa, Asia, and Latin America. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LAIS476. TECHNOLOGY AND INTERNATIONAL DEVELOPMENT [IPE] An historical examination of the role of technology in humanitarian and social improvement projects. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LAIS486/586. SCIENCE AND TECHNOLOGY POLICY An examination of current issues relating to science and technology policy in the United States and, as appropriate, in other countries. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LAIS487/587. ENVIRONMENTAL POLITICS AND POLICY Seminar on environmental policies and the political and governmental processes that produce them. Group discussion and independent research on specific environmental issues. Primary but not exclusive focus on the U.S. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LAIS488/588. WATER POLITICS AND POLICY Seminar on water policies and the political and governmental processes that produce them, as an example of natural resource politics and policy in general. Group discussion and independent research on specific politics and policy issues. Primary but not exclusive focus on the U.S. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LAIS498. SPECIAL TOPICS Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. Variable credit: 1 to 6 semester hours. Repeatable for credit under different topics.

LAIS499. INDEPENDENT STUDY Individual research or special problem projects supervised by a faculty member. Primarily for students who have completed their Humanities and Social Science requirements. Instructor consent required. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Prerequisite: LAIS100. Prerequisite or corequisite: SYGN200. Variable credit: 1 to 6 semester hours. Repeatable for credit.

LAIS541. AFRICAN DEVELOPMENT [IPE] Africa possesses abundant natural resources yet suffers low levels of economic growth. This IPE course examines the distinctive history of Africa, the impact of the putative resource curse, endemic unrest and civil war, mismanagement of government, and corruption, among other topics. Readings are multidisciplinary and draw from policy studies, economics, and political science. Students will acquire an understanding of different theoretical approaches from the social sciences to explain how

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natural resources affect development in Africa. The course helps students learn to apply different theories to specific cases and productive sectors. 3 hours seminar; 3 semester hours.

LAIS542. NATURAL RESOURCES AND WAR IN AFRICA [IPE] This course examines the relationship between natural resources and wars in Africa. It begins by discussing the complexity of Africa with its several many languages, peoples, and geographic distinctions. Among the most vexing challenges for Africa is the fact that the continent possesses such wealth and yet still struggles with endemic warfare, which is hypothetically caused by greed and competition over resource rents. Readings are multidisciplinary and draw from policy studies, economics, and political science. Students will acquire an understanding of different theoretical approaches from the social sciences to explain the relationship between abundant natural resources and war in Africa. The course helps students apply the different theories to specific cases and productive sectors. 3 hours seminar; 3 semester hours.

LAIS545. INTERNATIONAL POLITICAL ECONOMY [IPE] This course will combine the historical and theoretical foundations of international political economy and empirical case studies of the world's various regions. The student will be required to be familiar with key IPE schools of thought, history of development and underdevelopment of key regions, and a series of contemporary issues and themes that drives globalization. Prerequisites: any two IPE courses at the 300-level, or one IPE course at the 400 level. 3 hours seminar; 3 semester hours.

LAIS546. GLOBALIZATION [IPE] This seminar deals with the historical development of international political economy as a discipline. (Originally studied as the harbinger of today's political science, economics, sociology, anthropology, and history, International Political Economy is the multidisciplinary study of the relationship between the states and the markets.) A fuller understanding will be achieved through research and data analysis as well as interpretation of case studies. Prerequisites: LAIS345 and any 400-level IPE course, or two equivalent courses. 3 hours seminar; 3 semester hours.

LAIS548. GLOBAL ENVIRONMENTAL POLITICS AND POLICY [IPE] This seminar examines the increasing importance of environmental policy and politics in international political economy and global international relations. Using both historical analysis and interdisciplinary environmental studies perspectives, this course explores global environmental problems that have prompted an array of international and global regimes and other approaches to deal with them. It looks at the impact of environmental policy and politics on development, and the role that state and non-state actors play, especially in North-South relations and in the pursuit of sustainability. Prerequisites: any two IPE courses at the 300-level; or one IPE course at the 400 level; or one IPE course at the 300 level and one environmental policy/issues course at the 400 level. 3 hours seminar; 3 semester hours.

LAIS554. REGION-MARKETS AND REGION-STATES [IPE] This research seminar will deal with the international political economy dimensions of the origin, the structure, and the function of the world's major region-markets and region states. Special emphasis will be given to the changing roles of nation-states, globalization of trade and finance, and the future world polity. Prerequisites: any two IPE courses at the 300-level, or one IPE course at the 400 level. 3 hours seminar; 3 semester hours.

LAIS559. INTERNATIONAL INDUSTRIAL PSYCHOLOGY [IPE] This course has, as its primary aim, the equipping of a future consultant to deal with the cultural, socioeconomic, behavioral, psychological, ethical, and political problems in the international workplace. Specific materials covered are: Early experimentation with small group dynamics relative to economic incentive; Hawthorne experiments; experiments of Asch on perception, Analysis of case studies of work productivity in service and technological industries. Review of work of F.W. Taylor, Douglas McGregor, Blake & Mouton, and others in terms of optimum working conditions relative to wage and fringe benefits. Review of Niccolò Machiavelli's *The Prince and the Discourses*, and *The Art of War* by Sun Tzu with application to present times and international cultural norms. The intent of this course is to teach the survival, report writing, and presentation skills, and cultural awareness needed for success in the real international business world. The students are organized into small groups and do a case each week requiring a presentation of their case study results, and a written report of the results as well. (Textbooks: *Human Side of Enterprise* by Douglas McGregor, *Principles of Scientific Management* by F.W. Taylor, *The Art of War* by Sun Tzu, *Up The Organization* by Robert Townsend, *The Prince and the Discourses* of Niccolò Machiavelli, and *The Managerial Grid* by Blake & Mouton.) 3 hours seminar; 3 semester hours

LAIS560. GLOBAL GEOPOLITICS [IPE] This seminar deals with geopolitical theories and how they help us explain and understand contemporary developments in the world. Empirical evidence from case studies help students develop a deeper understanding of the interconnections between the political, economic, social, cultural and geographic dimensions of governmental policies and corporate decisions. Prerequisites: any two IPE courses at the 300-level, or one IPE course at the 400 level. 3 hours seminar; 3 semester hours.

LAIS561. URBANIZATION AND DEVELOPMENT [IPE] This seminar course discusses the effects of colonization, uneven regional development, industrialization and globalization on urban systems. The urban models that will be studied include the pre-industrial, colonial, global, Latin American and Islamic cities. Approaches to urban development and how they affect settlement planning, as well as urban-rural interface, urban labor markets, housing and shelter, migration will be considered. Sustainable cities and world cities will be discussed. Prerequisites: any two IPE courses at the 300-

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level, or one IPE course at the 400 level. 3 hours seminar; 3 semester hours.

LAIS586. SCIENCE AND TECHNOLOGY POLICY An examination of current issues relating to science and technology policy in the United States and, as appropriate, in other countries. 3 hours seminar; 3 semester hours.

LAIS598. SPECIAL TOPICS Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Variable credit: 1 to 6 semester hours. Repeatable for credit under different titles.

LAIS599. INDEPENDENT STUDY Individual research or special problem projects supervised by a faculty member. Variable credit: 1 to 6 hours. Repeatable for credit.

LAIS601. ACADEMIC PUBLISHING Students will finish this course with increased knowledge of general and discipline-specific writing conversations as well as the ability to use that knowledge in publishing portions of theses or dissertations. Beyond the research article, students will also have the opportunity to learn more about genres such as conference abstracts, conference presentations, literature reviews, and research funding proposals. Prerequisite: Must have completed one full year (or equivalent) of graduate school course work. 3 hours seminar. Variable credit: 2 or 3 semester hours.

### **Communication (LICM)**

LICM501. PROFESSIONAL ORAL COMMUNICATION A five-week course which teaches the fundamentals of effectively preparing and presenting messages. "Hands-on" course emphasizing short (5- and 10-minute) weekly presentations made in small groups to simulate professional and corporate communications. Students are encouraged to make formal presentations which relate to their academic or professional fields. Extensive instruction in the use of visuals. Presentations are rehearsed in class two days prior to the formal presentations, all of which are video-taped and carefully evaluated. 1 hour lecture/lab; 1 semester hour.

### **Foreign Languages (LIFL)**

A variety of foreign languages is available through the LAIS Division. Students interested in a particular language should check with the LAIS Division Office to determine when these languages might be scheduled. In order to gain basic proficiency from their foreign language study, students are encouraged to enroll for at least two semesters in whatever language(s) they elect to take. If there is sufficient demand, the Division can provide third- and fourth-semester courses in a given foreign language. No student is permitted to take a foreign language that is either his/her native language or second language. Proficiency tests may be used to determine at what level a student should be enrolled, but a student cannot receive course credit by taking these tests.

#### **Foreign Language Policy**

Students will not receive credit for taking a foreign language in which they have had previous courses as per the following formula:

If a student has taken one year in high school or one semester in college, he/she will not receive graduation credit for the first semester in a CSM foreign language course. Likewise, if a student has taken two years in high school or two semesters in college, he/she will not receive graduation credit for the second semester, and if a student has taken three years in high school or three semesters in college, he/she will not receive graduation credit for the third semester.

LIFL498. SPECIAL TOPICS IN A FOREIGN LANGUAGE Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit: 1 to 6 semester hours. Repeatable for credit under different titles.

LIFL499. INDEPENDENT STUDY Individual research or special problem projects supervised by a faculty member. Instructor consent required. Prerequisite: "Independent Study" form must be completed and submitted to the registrar. Variable credit: 1 to 6 hours. Repeatable for credit.

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## Materials Science

JOHN J. MOORE, Trustees Professor, Director, and Department Head of Metallurgical and Materials Engineering

DAVID L. OLSON, Lead Scientist, John Henry Moore Distinguished Professor of Physical Metallurgy

### Department of Chemistry and Geochemistry

DANIEL M. KNAUSS, Professor and Interim Head of Department

PAUL JAGODZINSKI, Professor

KENT J. VOORHEES, Professor

SCOTT W. COWLEY, Associate Professor

MARK EBERHART, Associate Professor

KIM R. WILLIAMS, Associate Professor

STEPHEN G. BOYES, Assistant Professor

STEVEN R. DEC, Lecturer

### Department of Chemical Engineering

JAMES ELY, Professor and Head of Department

JOHN R. DORGAN, Professor

DAVID W.M. MARR, Professor

COLIN WOLDEN, Associate Professor

DAVID T. WU, Associate Professor

SUMIT AGARWAL, Assistant Professor

MATTHEW LIBERATORE, Assistant Professor

### Division of Engineering

TERRY PARKER, Professor and Director of Engineering Division

ROBERT J. KEE, George R. Brown Distinguished Professor of Engineering

MARK LUSK, Professor

GRAHAM MUSTOE, Professor

PANOS KIOUSIS, Associate Professor

DAVID R. MUNOZ, Associate Professor

JOHN P.H. STEELE, Associate Professor

TYRONE VINCENT, Associate Professor

CHRISTIAN CIOBANU, Assistant Professor

NEAL SULLIVAN, Assistant Professor

MONESH UP MANYU, Assistant Professor

### Department of Environmental Science & Engineering

RONALD R. COHAN, Professor

JOHN R. SPEAR, Assistant Professor

### Department of Metallurgical and Materials Engineering

JOHN J. MOORE, Trustee Professor and Head of Department, and Director, Advanced Coatings and Surface Engineering Laboratory

DAVID L. OLSON, John Henry Moore Distinguished Professor, Lead Scientist Materials Science Program

MICHAEL J. KAUFMAN, Professor

STEPHEN LIU, Professor and Director of the Center for Welding, Joining and Coating Research

GERARD P. MARTINS, Professor

DAVID K. MATLOCK, ARMCO Foundation Fogarty Professor;

Director, Advanced Steel Processing and Products Research Center

BRAJENDRA MISHRA, Professor

IVAR E. REIMANIS, Professor

NIGEL SAMMES, Herman F. Coors Distinguished Professor of Ceramic Engineering

JOHN G. SPEER, Professor

PATRICK R. TAYLOR, George S. Ansell Distinguished Professor in Chemical Metallurgy, Director, Kroll Institute for Extractive Metallurgy

CHESTER J. VAN TYNE, FIERF Professor

STEVEN W. THOMPSON, Associate Professor

REED AYERS, Assistant Professor

RYAN O'HAYRE, Assistant Professor

PATRICIO MENDEZ, Assistant Professor

EDGAR E. VIDAL, Assistant Professor

ARUN MADAN, Research Professor

JOHN CHANDLER, Lecturer

MARTIN MATAYA, Lecturer

### Department of Physics

JAMES A. McNEIL, Professor and Head of Department

REUBEN T. COLLINS, Professor and Director, Center of Solar and Electronic Materials

THOMAS E. FURTAK, Professor

P. CRAIG TAYLOR, Professor and Associate Director of Colorado Energy Research Institute

TIMOTHY R. OHNO, Associate Professor

DAVID M. WOOD, Associate Professor

LINCOLN CARR, Assistant Professor

JAMES E. BERNARD, Research Associate Professor

DON L. WILLIAMSON, Emeritus Professor

### Department of Mining Engineering

HUGH MILLER, Associate Professor

VILEM PETR, Research Assistant Professor

### Degrees Offered:

Master of Science (Materials Science; thesis option or non-thesis option)

Doctor of Philosophy (Materials Science)

### Program Description:

The interdisciplinary materials science program is administered jointly by the Departments of Chemical Engineering, Chemistry and Geochemistry, Metallurgical and Materials Engineering, Physics and the Division of Engineering. Each department is represented on both the Governing Board and the Graduate Affairs Committee, which are responsible for the operation of the program. The variety of disciplines provides for programs of study ranging from the traditional materials science program to a custom-designed program.

### Program Requirements:

#### Master of Science (thesis option):

The Master of Science degree requires a minimum of 30 semester hours of acceptable course work and case study credit including:

- ◆ Minimum of 18 hours of Materials Science courses (must have completed the core courses).
- ◆ 6 to 18 hours of thesis research credits depending upon focus area requirements.
- ◆ Submit a thesis and pass the Defense of Thesis examination before the Thesis Committee.



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**Master of Science (non-thesis option with a case study):**

The Master of Science degree requires a minimum of 30 semester hours of acceptable course work and research credit including:

- ◆ 18 hours of Materials Sciences courses from a list of required courses and 12 hours of other materials-related courses selected by the student with guidance from the student's advisor and the mentor of the specialty area group that the student has selected. The specialty materials-related courses can be courses that are taken in preparation for the student's PhD qualifying process examination, usually taken in the second year of graduate school. Total of at least 30 credit hours.
- ◆ 6 hours of case study credits. (Sign up for MLGN599, Case Study Materials Science, using a paper form at the Registrar's Office.) The student must successfully prepare and defend a case study report on a topic that is most likely supporting materials for the student's PhD thesis.

The decision of which type of Master degree you should pursue needs to be decided with council of your advisor. The decision will affect the number of course hours required for the Master degree and whether a thesis or a case study report is to be written and defended.

**Required Curriculum:**

Listed below are the required six Materials Science core courses:

- MLGN500 Processing, Microstructure, and Properties of Materials
- MLGN512/MTGN412 Ceramic Engineering
- MLGN530/CRGN415/CHGN430 Introduction to Polymer Science
- MLGN501/CHGN580 Structure of Materials
- MLGN504/MTGN555 Solid State Thermodynamics or CHEN509 Advanced Chemical Engineering Thermodynamics
- MLGN511 Kinetic Concerns in Materials Processing

Students who have taken the equivalent of any of the core courses listed above, and have not used the courses to fulfill requirements towards their B.S. degree, may petition the Materials Science Graduate Committee for transfer credit.

**Doctor of Philosophy:**

The prerequisite for acceptance into the Materials Science PhD Program is completion of a science or engineering Master degree (with or without thesis) and completion of the Materials Science Core courses with a grade of B or better (or evidence that the course content of these courses had been taken in previous courses).

The Doctor of Philosophy degree requires a minimum of 72 hours of course and research credit including:

- ◆ The fulfillment of the Materials Science core course requirements plus additional courses as required by the focus area and a minimum of 30 hours of research credit.
- ◆ A written and/or oral qualifying examination in the specialty area (depending upon focus area requirements). See the Material Science Program Guidelines for Graduate Students at <http://www.mines.edu/academic/matsci/>.
- ◆ Prepare and submit a thesis and pass a Defense of Thesis examination before the Thesis Committee.

**Prerequisites:**

The primary admission requirement for this interdisciplinary program is a Bachelor of Science or Master of Engineering degree in biological sciences, physical science, or engineering. Courses must be equivalent to the degree programs offered at CSM in the following departments: Chemistry and Geochemistry, Engineering (mechanical, electrical, or civil), Chemical Engineering, Metallurgical and Materials Engineering, or Physics.

**Deficiency Courses:**

A student admitted to this graduate program who has not taken one or all of the following courses (or equivalent) will be required (depending on their focus area) to satisfy any such deficiency early in their program of study: Mechanics, Differential Equations, Modern Physics, and Physical Chemistry/Chemical Thermodynamics.

**Focus Areas:**

Advanced Polymeric Materials; Ceramics; Composites; Electronic Materials; Joining Science; Mechanics of Materials; Computational Materials Science; Surfaces & Interfaces/Films & Coatings; Biomaterials; Nuclear Materials, Mining-Materials Science, and Enviro-Materials Science.

**Thesis Committee Structure:**

The M.S. student will invite at least 3 members (one of whom is the advisor) to serve on a graduate committee. At least one of these members must be from a department other than that of the advisor.

The Ph.D. student will invite 5 members (one of whom is the advisor) to serve on a graduate committee. At least one of these members must be in a department other than that of the advisor. External members may be invited to participate.

For administrative purposes, the student will be resident in the advisor's department.

The student's graduate committee will have final approval of the course of study.

**Fields of Research:**

Advanced polymeric materials  
Alloy theory, concurrent design, theory-assisted materials engineering, electronic structure theory  
Applications of artificial intelligence techniques to materials processing and manufacturing, neural networks for process

modeling and sensor data processing, manufacturing process control  
 Archaeometallurgy, industry and university partnerships  
 Bio materials  
 Ceramic processing, modeling of ceramic processing  
 Characterization, thermal stability, and thermal degradation mechanisms of polymers  
 Chemical and physical processing of materials, engineered materials, materials synthesis  
 Chemical processing of materials  
 Chemical vapor deposition  
 Coating materials and applications  
 Computational condensed-matter physics, semiconductor alloys, first-principles phonon calculations  
 Computer modeling and simulation  
 Control systems engineering, artificial neural systems for sensor data processing, polymer cure monitoring sensors, process monitoring and control for composites manufacturing  
 Crystal and molecular structure determination by X-ray crystallography  
 Electro deposition  
 Experimental condensed-matter physics, thermal and electrical properties of materials, superconductivity, photo-voltaics  
 Extractive and process metallurgy, electrochemical corrosion, synthesis of ceramic precursor powders and metal powders  
 Forging, deformation modeling, high-temperature material behavior  
 Fuel cell materials  
 Fullerene synthesis, combustion chemistry  
 Heat and mass transfer, materials processing  
 Heterogeneous catalysis, reformulated and alcohol fuels, surface analysis, electrophotography  
 Intelligent automated systems, intelligent process control, robotics, artificial neural systems  
 Materials synthesis, interfaces, flocculation, fine particles  
 Mathematical modeling of material processes  
 Mechanical metallurgy, failure analysis, deformation of materials, advanced steel coatings  
 Molten salt processing  
 Mössbauer spectroscopy, ion implantation, small-angle X-ray scattering, semiconductor defects  
 Nano materials  
 Non destructive evaluation  
 Novel separation processes: membranes, catalytical membrane reactors, biopolymer adsorbents for heavy metal remediation of ground surface water  
 Numerical modeling of particulate media, thermomechanical analysis  
 Optical properties of materials and interfaces  
 Phase transformations and mechanisms of microstructural change, electron microscopy, structure-property relationships

Physical metallurgy, ferrous and nonferrous alloy systems  
 Physical vapor deposition, thin films, coatings  
 Power electronics, plasma physics, pulsed power, plasma material processing  
 Processing and characterization of electroceramics (ferroelectrics, piezoelectrics, pyroelectrics, and dielectrics), glass-ceramics for electronic and structural applications, thermodynamic modeling of ferroelectrics  
 Pyrometallurgy, corrosion, materials synthesis, coatings  
 Reactive metals properties and processing of ceramics and ceramic-metal composites, dielectrics and ferrimagnetics  
 Solidification and near net shape processing  
 Surface physics, epitaxial growth, interfacial science, adsorption  
 Transformations, microstructure, deformation, fracture  
 Transport phenomena, mathematical modeling, kinetic properties of colloidal suspensions, diffusion with chemical reaction  
 Weld metallurgy, materials joining processes  
 Welding and joining science

### *Description of Courses (Interdisciplinary Program)*

The following courses are considered to be part of the Materials Science Program. Some have been cross-listed between Materials Science and the participating departments/division. Other courses not included may be suitable for inclusion in a graduate program. See the participating department listings. It should be noted that the course requirement for graduate-level registration for a MLGN 500-level course which is cross-listed with a 400-level course-number will include an additional course-component above that required for 400-level credit.

MLGN500. PROCESSING, MICROSTRUCTURE, AND PROPERTIES OF MATERIALS (I) A summary of the important relationships between the processing, microstructure, and properties of materials. Topics include electronic structure and bonding, crystal structures, lattice defects and mass transport, glasses, phase transformation, important materials processes, and properties including: mechanical and rheological, electrical conductivity, magnetic, dielectric, optical, thermal, and chemical. In a given year, one of these topics will be given special emphasis. Another area of emphasis is phase equilibria. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours.

MLGN501/CHGN580. STRUCTURE OF MATERIALS (II) Principles of crystallography and diffraction from materials. Properties of radiation useful for studying the structure of materials. Structure determination methods. Prerequisite: Any Physics III course. 3 hours lecture; 3 semester hours.

MLGN502/PHGN440. INTRODUCTORY SOLID STATE PHYSICS (II) Introduction to the physics of condensed matter with an emphasis on periodic crystals, including geometrical, dynamical, thermal, and electronic properties.

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Discussion of experimental methods including photon and neutron scattering, charge and heat transport, action of simple solid state devices. Prerequisite: Physics III and MATH225. 3 hours lecture; 3 semester hours. MLGN502 requires a term project. PHGN440 ABET classification: 3 hrs. engineering science.

MLGN503/CHGN515. CHEMICAL BONDING IN MATERIALS (I) Introduction to chemical bonding theories and calculations and their applications to solids of interest to materials science. The relationship between a material's properties and the bonding of its atoms will be examined for a variety of materials. Includes an introduction to organic polymers. Computer programs will be used for calculating bonding parameters. Prerequisite: Consent of department. 3 hours lecture; 3 semester hours.

MLGN504/MTGN555. SOLID STATE THERMODYNAMICS (I) A second course in thermodynamics which applies chemical thermodynamic principles to phase equilibria, point defects, surfaces and electrochemistry. The application of thermodynamic principles through Maxwell's principles will be extended to a broad range of material properties. Prerequisite: Solid State Thermodynamics I or equivalent. 3 hours lecture; 3 semester hours.

MLGN505\*/MTGN445. MECHANICAL PROPERTIES OF MATERIALS (I) Mechanical properties and relationships. Plastic deformation of crystalline materials. Relationships of microstructures to mechanical strength. Fracture, creep, and fatigue. Prerequisite: MTGN348. 3 hours lecture; 3 hours lab; 3\*<sup>3</sup>/<sub>4</sub> semester hours. \* This is a 3 credit-hour graduate-course in the Materials Science Program and a 4 credit-hour undergraduate-course in the MTGN program.

MLGN506/MTGN556. TRANSPORT IN SOLIDS (II) Thermal and electrical conductivity. Solid state diffusion in metals and metal systems. Kinetics of metallurgical reactions in the solid state. Prerequisite: Consent of department. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MLGN507/PHGN540. CONDENSED MATTER I (I) Principles and applications of the quantum theory of electrons and phonons in solids: structure, symmetry, and bonding; electron states and excitations in metals and alloys; transport properties; surfaces. Prerequisite: PHGN420 and PHGN440 or their equivalent. 3 hours lecture; 3 semester hours.

MLGN508/PHGN541. CONDENSED MATTER II (II) Principles and applications of the quantum theory of electrons and phonons in solids: phonon states in solids; transport properties; electron states and excitations in semiconductors and insulators; defects and impurities; amorphous materials; magnetism; superconductivity. Prerequisite: MLGN507/PHGN540. 3 hours lecture; 3 semester hours.

MLGN509/CHGN523. SOLID STATE CHEMISTRY (I) Dependence on properties of solids on chemical bonding and structure; principles of crystal growth, crystal imperfections,

reactions and diffusion in solids, and the theory of conductors and semiconductors. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

MLGN510/CHGN410 SURFACE CHEMISTRY (I) Introduction to colloid systems, capillarity, surface tension and contact angle, adsorption from solution, micelles and micro-emulsions, the solid/gas interface, surface analytical techniques, Van Der Waal forces, electrical properties and colloid stability, some specific colloid systems (clays, foams and emulsions). Students enrolled for graduate credit in MLGN510 must complete a special project. Prerequisite: DCGN209 or consent of instructor. 3 hours lecture; 3 semester hours.

MLGN511. KINETIC CONCERNS IN MATERIALS PROCESSING I (I) Introduction to the kinetics of materials processing, with emphasis on the momentum, heat and mass transport. Discussion of the basic mechanism of transport in gases, liquids and solids. Prerequisite: MTGN352, MTGN361, MATH225 or equivalent. 3 hours lecture; 3 semester hours.

MLGN512/MTGN412. CERAMIC ENGINEERING (II) Application of engineering principles to nonmetallic and ceramic materials. Processing of raw materials and production of ceramic bodies, glazes, glasses, enamels, and cements. Firing processes and reactions in glass bonded as well as mechanically bonded systems. Prerequisite: MTGN348. 3 hours lecture; 3 semester hours.

MLGN513. PROBLEM SOLVING IN MATERIALS SCIENCE (I) Review the theoretical aspects of various physical phenomena of major importance to materials scientists. Develop mathematical models from these theories, and construct quantitative solution procedures based on analytical and numerical techniques. Prerequisite: MATH225. 3 hours lecture; 3 semester hours.

MLGN514. EXPERIMENTAL METHODS AND INSTRUMENTATION (S) This course consists of two parts, (i) a series of classes that describe theory of measurements and experimental principles and (ii) a series of laboratory visits to either perform experimental measurements or to see actual procedures demonstrated. Prerequisite: Consent of instructor. 1 hour lecture; 2 hours lab; 2 semester hours.

MLGN515/MTGN415. ELECTRICAL PROPERTIES AND APPLICATIONS OF MATERIALS (II) Survey of the electrical properties of materials, and the applications of materials as electrical circuit components. The effects of chemistry, processing, and microstructure on the electrical properties will be discussed, along with functions, performance requirements, and testing methods of materials for each type of circuit component. The general topics covered are conductors, resistors, insulators, capacitors, energy convertors, magnetic materials, and integrated circuits. Prerequisites: PHGN200; MTGN311 or MLGN501; MTGN412/MLGN512, or consent of instructor. 3 hours lecture; 3 semester hours.

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MLGN516/MTGN416. PROPERTIES OF CERAMICS (II) A survey of the properties of ceramic materials and how these properties are determined by the chemical structure (composition), crystal structure, and the microstructure of crystalline ceramics and glasses. Thermal, optical, and mechanical properties of single-phase and multi-phase ceramics, including composites, are covered. Prerequisites: PHGN200, MTGN311 or MLGN501, MTGN412 or consent of instructor. 3 semester hours; 3 hours lecture

MLGN517/EGGN422. SOLID MECHANICS OF MATERIALS (I) Review mechanics of materials. Introduction to elastic and non-linear continua. Cartesian tensors and stresses and strains. Analytical solution of elasticity problems. Develop basic concepts of fracture mechanics. Prerequisite: EGGN320 or equivalent, MATH225 or equivalent. 3 hours lecture; 3 semester hours.

MLGN518/MTGN518. PHASE EQUILIBRIA IN CERAMICS SYSTEMS (II) Application of one of four component oxide diagrams to ceramic engineering problems. Emphasis on refractories and glasses and their interaction with metallic systems. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

MLGN519/MTGN419. NON-CRYSTALLINE MATERIALS (I) An introduction to the principles of glass science and engineering and non-crystalline materials in general. Glass formation, structure, crystallization and properties will be covered, along with a survey of commercial glass compositions, manufacturing processes and applications. Prerequisites: MTGN311 or MLGN501; MLGN512/MTGN412, or consent of instructor. 3 hours lecture; 3 semester hours.

MLGN521. KINETIC CONCERNS IN MATERIAL PROCESSING II (I, II) Advanced course to address the kinetics of materials processing, with emphasis in those processes that promote phase and structural transformations. Processes that involve precipitation, sintering, oxidation, sol-gel, coating, etc., will be discussed in detail. Prerequisite: MLGN511. 3 hours lecture; 3 semester hours.

MLGN522/PHGN441. SOLID STATE PHYSICS APPLICATIONS AND PHENOMENA Continuation of MLGN502/PHGN440 with an emphasis on applications of the principles of solid state physics to practical properties of materials including: optical properties, superconductivity, dielectric properties, magnetism, noncrystalline structure, and interfaces. Graduate students in physics cannot receive credit for MLGN522, only PHGN441. Prerequisite: MLGN502/PHGN440. 3 hours lecture, 3 semester hours. \*Those receiving graduate credit will be required to submit a term paper, in addition to satisfying all of the other requirements of the course.

MLGN523/MTGN523. APPLIED SURFACE AND SOLUTION CHEMISTRY (I) Solution and surface chemistry of importance in mineral and metallurgical operations. Prerequisite: Consent of department. 3 semester hours. (Fall of even years only.)

MLGN525/PHGN525. SURFACE PHYSICS (I) Solid state physics focusing on the structural and electronic nature of the outer few atomic layers and the gas-surface interactions. Detailed explanations of many surface analysis techniques are provided, highlighting the application of these techniques to current problems, particularly electronic materials. Prerequisite: MLGN502 or equivalent, or consent of instructor. 3 hours lecture; 3 semester hours (Fall of even years only)

MLGN526/MTGN526. GEL SCIENCE AND TECHNOLOGY An introduction to the science and technology of particulate and polymeric gels, emphasizing inorganic systems. Interparticle forces. Aggregation, network formation, percolation, and the gel transition. Gel structure, rheology, and mechanical properties. Application to solid-liquid separation operations (filtration, centrifugation, sedimentation) and to ceramics processing. Prerequisite: Graduate level status or consent of instructor. 3 hours lecture; 3 semester hours. Spring of odd years only.

MLGN530/CHGN430/CRGN415. INTRODUCTION TO POLYMER SCIENCE (I) An introduction to the chemistry and physics of macromolecules. Topics include the properties and statistics of polymer solutions, measurements of molecular weights, molecular weight distributions, properties of bulk polymers, mechanisms of polymer formation, and properties of thermosets and thermoplasts including elastomers. Prerequisite: CHGN327 or consent of instructor. 3 hours lecture; 3 semester hours.

MLGN531/CRGN416. INTRODUCTION TO POLYMER ENGINEERING (II) This class provides a background in polymer fluid mechanics, polymer rheological response and polymer shape forming. The class begins with a discussion of the definition and measurement of material properties. Interrelationships among the material response functions are elucidated and relevant correlations between experimental data and material response in real flow situations are given. Processing operations for polymeric materials will then be addressed. These include the flow of polymers through circular, slit, and complex dies. Fiber spinning, film blowing, extrusion and coextrusion will be covered as will injection molding. Graduate students are required to write a term paper and take separate examinations which are at a more advanced level. Prerequisite: CRGN307, EGGN351 or equivalent. 3 hours lecture; 3 semester hours.

MLGN535, PHGN435/535, and ChEN435/535. INTERDISCIPLINARY MICROELECTRONICS PROCESSING LABORATORY (II) Application of science and engineering principles to the design, fabrication, and testing of microelectronic devices. Emphasis on specific unit operations and the interrelation among processing steps. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

MLGN536/CHGN536. ADVANCED POLYMER SYNTHESIS (II) An advanced course in the synthesis of macromolecules. Various methods of polymerization will be discussed



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with an emphasis on the specifics concerning the syntheses of different classes of organic and inorganic polymers. Prerequisite: CHGN430, ChEN415, MLGN530 or consent of instructor. 3 hours lecture, 3 semester hours.

MLGN544/MTGN414. **PROCESSING OF CERAMICS (II)** A description of the principles of ceramic processing and the relationship between processing and microstructure. Raw materials and raw material preparation, forming and fabrication, thermal processing, and finishing of ceramic materials will be covered. Principles will be illustrated by case studies on specific ceramic materials. A project to design a ceramic fabrication process is required. Field trips to local ceramic manufacturing operations are included. Prerequisites: MTGN311, MTGN331, and MTGN412/MLGN512 or consent of instructor. 3 hours lecture; 3 semester hours.

MLGN550/MTGN450. **STATISTICAL PROCESS CONTROL AND DESIGN OF EXPERIMENTS (I)** An introduction to statistical process control, process capability analysis and experimental design techniques. Statistical process control theory and techniques will be developed and applied to control charts for variables and attributes involved in process control and evaluation. Process capability concepts will be developed and applied for the evaluation of manufacturing processes. The theory and application of designed experiments will be developed and applied for full factorial experiments, fractional factorial experiments, screening experiments, multilevel experiments and mixture experiments. Analysis of designed experiments will be carried out by graphical and statistical techniques. Computer software will be utilized for statistical process control and for the design and analysis of experiments. Prerequisite: Consent of Instructor. 3 hours lecture, 3 semester hours.

MLGN552/MTGN552. **INORGANIC MATRIX COMPOSITES (I)** An introduction to the processing, structure, properties and applications of metal matrix and ceramic matrix composites. Importance of structure and properties of both the matrix and the reinforcement and the types of reinforcement utilized, e.g., particulate, short fiber, continuous fiber, and laminates. Special emphasis will be placed on the development of properties such as electrical and thermal will also be examined. Prerequisite/Corequisite: MTGN311, MTGN348, MTGN351, MTGN352, MTGN445/MLGN505 or consent of instructor. 3 hours lecture; 3 semester hours (Fall of odd years only)

MLGN561 **TRANSPORT PHENOMENA IN MATERIALS PROCESSING (II)** Fluid flow, heat and mass transfer applied to processing of materials. Rheology of polymers, liquid metal/particles slurries, and particulate solids. Transient flow behavior of these materials in various geometries, including infiltration of liquids in porous media. Mixing and blending. Flow behavior of jets, drainage of films and particle fluidization. Surface-tension-, electromagnetic-, and bubble-driven flows. Heat-transfer behavior in porous bodies applied to sintering and solidification of composites. Simultaneous

heat-and-mass-transfer applied to spray drying and drying porous bodies. Prerequisites: ChEN307 or ChEN308 or MTGN461 or consent of instructor. 3 hours lecture; 3 semester hours

MLGN563/MTGN463. **POLYMER ENGINEERING: STRUCTURE, PROPERTIES AND PROCESSING** An introduction to the structure and properties of polymeric materials, their deformation and failure mechanisms, and the design and fabrication of polymeric end items. The molecular and crystallographic structures of polymers will be developed and related to the elastic, viscoelastic, yield and fracture properties of polymeric solids and reinforced polymer composites. Emphasis will be placed on forming techniques for end item fabrication including: extrusion, injection molding, reaction injection molding, thermoforming, and blow molding. The design of end items will be considered in relation to: materials selection, manufacturing engineering, properties, and applications. Prerequisite: MTGN311 or equivalent or consent of instructor. 3 hours lecture; 3 semester hours.

MLGN565/MTGN565 **MECHANICAL PROPERTIES OF CERAMICS AND COMPOSITES (I)** Mechanical properties of ceramics and ceramic-based composites; brittle fracture of solids; toughening mechanisms in composites; fatigue, high temperature mechanical behavior, including fracture, creep deformation. Prerequisites: MTGN445 or MLGN505, or consent of instructor. 3 hours lecture; 3 semester hours. (Fall of even years only.)

MLGN569/MTGN569/MTGN469/EGGN469/EGES569/ChEN469/ChEN569 **FUEL CELL SCIENCE AND TECHNOLOGY (II)** Investigate fundamentals of fuel-cell operation and electrochemistry from a chemical thermodynamics and materials-science perspective. Review types of fuel cells, fuel-processing requirements and approaches, and fuel-cell system integration. Examine current topics in fuel-cell science and technology. Fabricate and test operational fuel cells in the Colorado Fuel Cell Center. 3 credit hours. Prerequisites: EGGN371 or ChEN357 or MTGN351; Thermodynamics I, MATH225 Differential Equations, or consent of instructor.

MLGN570/MTGN570 **BIOCOMPATIBILITY OF MATERIALS** Introduction to the diversity of biomaterials and applications through examination of the physiologic environment in conjunction with compositional and structural requirements of tissues and organs. Appropriate domains and applications of metals, ceramics and polymers, including implants, sensors, drug delivery, laboratory automation, and tissue engineering are presented. Prerequisites: ESGN 301 or equivalent, or instructor consent. 3 hours lecture; 3 semester hours.

MLGN583/CHGN583. **PRINCIPLES AND APPLICATIONS OF SURFACE ANALYSIS TECHNIQUES (II)** Instrumental techniques for the characterization of surfaces of solid materials. Applications of such techniques to polymers, corrosion,

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metallurgy, adhesion science, micro-electronics. Methods of analysis discussed: X-ray photoelectron spectroscopy (XPS), auger electron spectroscopy (AES), ion scattering spectroscopy (ISS), secondary ion mass spectroscopy (SIMS), Rutherford backscattering (RBS), scanning and transmission electron microscopy (SEM, TEM), energy and wavelength dispersive X-ray analysis; principles of these methods, quantification, instrumentation, sample preparation. Prerequisite: B.S. in metallurgy, chemistry, chemical engineering, physics, or consent of instructor. 3 hours lecture; 3 semester hours.

MLGN598. SPECIAL TOPICS Special topic course on a specific subject defined by instructor. Prerequisite: consent of instructor 1 to 3 hours. Repeatable for credit under different titles.

MLGN599. CASE STUDY MATERIALS SCIENCE (I, II) An independent study of a selected materials processing or material characterization problem involving a thorough analysis of the various solutions reported in the technical literature and/or a thorough industrial survey. The case study will prepare a case study report of technical merit. Prerequisite/co-requisite: MLGN501, MLGN502, MLGN503, MLGN504, and MLGN511, and MLGN517 or consent of advisor. 3 semester hours. Repeatable for credit.

MLGN625/CHEN625/CHGN625 MOLECULAR SIMULATION METHODS (I Even Years), Principles and practice of modern computer simulation techniques used to understand solids, liquids, and gases. Review of the statistical foundation of thermodynamics followed by in-depth discussion of Monte Carlo and Molecular Dynamics techniques. Discussion of intermolecular potentials, extended ensembles, and mathematical algorithms used in molecular simulations. Prerequisites: graduate level thermodynamics (required), statistical mechanics (recommended). 3 semester hours.

MLGN634. POLYMER SOLUTIONS AND THERMODYNAMICS/CRGN609. ADVANCED TOPICS IN THERMODYNAMICS The phase behavior of polymer solutions is dramatically different from their low molecular weight analogs due to the small entropy of mixing associated with large polymer molecules. This course begins with a discussion of classical thermodynamics and the stability of phases. Statistical mechanics and the partition function for an ideal mixture are reviewed. Next, the solution properties of an isolated polymer coil in solution are elucidated. This discussion leads naturally to the description of dilute solution behavior and its applications. The thermodynamics of concentrated solutions are then undertaken using Flory-Huggins theory. Brownian motion of polymer molecules and the thermodynamics of polymers at interfaces are also covered. Prerequisite: MLGN530, MLGN504, or CRGN520 or equivalent. 3 hours lecture; 3 semester hours

MLGN635. POLYMER REACTION ENGINEERING/CRGN618. ADVANCED TOPICS IN REACTION KINETICS This class is aimed at engineers with a firm technical back-

ground who wish to apply that background to polymerization production techniques. The class begins with a review of the fundamental concepts of reaction engineering, introduces the needed terminology and describes different reactor types.

The applied kinetic models relevant to polymerization reaction engineering are then developed. Next, mixing effects are introduced; goodness of mixing and effects on reactor performance are discussed. Thermal effects are then introduced and the subjects of thermal runaway, thermal instabilities, and multiple steady states are included. Reactive processing, change in viscosity with the extent of reaction and continuous drag flow reactors are described. Polymer devolatilization constitutes the final subject of the class. Prerequisites: CRGN518 or equivalent. 3 hours lecture; 3 semester hours.

MLGN673. STRUCTURE AND PROPERTIES OF POLYMERS This course will provide an understanding of structure - properties relations in polymeric materials. The topics include: phase separation, amorphous structures, crystalline structures, liquid crystals, glass-rubber transition behavior, rubber elasticity, viscoelasticity, mechanical properties of polymers, polymer forming processes, and electrical properties of polymers. Prerequisite: MLGN563 or consent of instructor. 3 hours lecture; 3 semester hours

MLGN696/MTGN696. VAPOR DEPOSITION PROCESSES (II) Introduction to the fundamental physics and chemistry underlying the control of vapor deposition processes for the deposition of thin films for a variety of applications, e.g., corrosion/oxidation resistance, decorative coatings, electronic and magnetic thin films. Emphasis on the vapor deposition processes and the control of process variables rather than the structure and properties of the thin films. Prerequisites: MTGN351, MTGN461, or equivalent courses, or consent of instructor. 3 hours lecture; 3 semester hours.

MLGN698. ADVANCED TOPICS Advanced study of materials science theory and application of materials science principles in a specialty area of the instructor's choosing. Not part of thesis. Prerequisite: Consent of instructor. 1 to 3 semester hours. Repeatable for credit under different titles.

MLGN699. INDEPENDENT STUDY Independent study of a materials science topic with guidance of an instructor. Not part of thesis. Prerequisite: Consent of Instructor. 1 to 3 hours. Repeatable for credit.

MLGN705. GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

MLGN706. GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty advisor. Repeatable for credit.

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## Mathematical and Computer Sciences

GRAEME FAIRWEATHER, Professor and Department Head  
BERNARD BIALECKI, Professor  
TRACY CAMP, Professor  
MAHADEVAN GANESH, Professor  
WILLY HEREMAN, Professor  
PAUL A. MARTIN, Professor  
DINESH MEHTA, Professor  
WILLIAM NAVIDI, Professor  
BARBARA M. MOSKAL, Associate Professor  
LUIS TENORIO, Associate Professor  
MICHAEL COLAGROSSO, Assistant Professor  
REINHARD FURRER, Assistant Professor  
QI HAN, Assistant Professor  
JAE YOUNG LEE, Assistant Professor  
ANDRZEJ SZYMCZAK, Assistant Professor  
CYNDI RADER, Senior Lecturer  
TERRY BRIDGMAN, Lecturer  
G. GUSTAVE GREIVEL, Lecturer  
NATHAN PALMER, Lecturer  
ROMAN TANKELEVICH, Lecturer  
SCOTT STRONG, Instructor  
WILLIAM R. ASTLE, Professor Emeritus  
NORMAN BLEISTEIN, Professor Emeritus  
ARDEL J. BOES, Professor Emeritus  
AUSTIN R. BROWN, Professor Emeritus  
JOHN DeSANTO, Professor Emeritus  
RAYMOND R. GUTZMAN, Professor Emeritus  
FRANK G. HAGIN, Professor Emeritus  
DONALD C.B. MARSH, Professor Emeritus  
STEVEN PRUESS, Professor Emeritus  
ROBERT E. D. WOOLSEY, Professor Emeritus  
BARBARA B. BATH, Associate Professor Emerita  
RUTH MAURER, Associate Professor Emerita  
ROBERT G. UNDERWOOD, Associate Professor Emeritus

### *Degrees Offered:*

Master of Science (Mathematical and Computer Sciences)  
Doctor of Philosophy (Mathematical and Computer Sciences)

### *Program Description:*

There are three areas of concentration within the department: applied mathematics, statistics, and computer science. Since the requirements for these areas vary somewhat, they are often considered separately in this catalog. However, labeling these as distinct areas is not meant to discourage any student from pursuing research involving more than one. Work in any of these areas can lead to the degree of Master of Science or Doctor of Philosophy. Applicants to the graduate program need these four items: 1. A statement of purpose (short essay) from the applicant briefly describing background, interests, goals at CSM, career intentions, etc. 2. The general Graduate Record Examination. 3. B or better average in courses in the major field. 4. B or better overall undergraduate grade point average.

### *Program Requirements:*

The Master of Science degree (thesis option) requires 36 credit hours of acceptable course work and research, completion of a satisfactory thesis, and successful oral defense of this thesis. The course work includes the required core curriculum. 12 of the 36 credit hours must be designated for supervised research.

The Master of Science degree (non-thesis option) requires 36 credit hours of course work. The course work includes the required core curriculum.

The Doctor of Philosophy requires 72 credit hours beyond the bachelor's degree. At least 24 of these hours are thesis hours. Doctoral students must pass the comprehensive examination (a qualifying examination and thesis proposal), complete a satisfactory thesis, and successfully defend their thesis.

The specific core curriculum requirements can be found in the Mathematical and Computer Sciences Department Graduate Student Handbook: Call 303 273-3860; FAX 303 273-3875, or look on the Web at [http://www.mines.edu/Academic/mac/ Academic\\_Programs/grad.htm](http://www.mines.edu/Academic/mac/ Academic_Programs/grad.htm). This handbook also provides an overview of the programs, requirements and policies of the department.

### *Prerequisites:*

#### **Applied Mathematics:**

Linear algebra  
Vector calculus  
Ordinary differential equations  
Advanced calculus (Introduction to real analysis)

#### **Statistics:**

Linear algebra  
Introduction to probability & statistics  
Advanced calculus (Introduction to real analysis)

#### **Computer Science:**

Science - two semesters  
Mathematics - two semesters of calculus, at least two courses from ordinary differential equations, linear algebra, statistics, discrete mathematics  
Data structures  
A programming language  
Upper level courses in at least three of software engineering, numerical analysis, machine architecture/assembly language, comparative languages, analysis of algorithms, operating systems

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### *Fields of Research:*

#### **Applied Mathematics:**

Computational Methods and Analysis for Wave Phenomena  
Classical Scattering Theory  
Classical Wave Propagation  
Mathematical Methods for Wave Phenomena  
Micro-local Analysis  
Nonlinear Partial Differential Equations  
Numerical Analysis  
Optimal Control  
Optimization Software  
Seismic Inverse Methods  
Symbolic Computing

#### **Statistics:**

Inverse Problems in Statistics  
Multivariate Statistics  
Spatial Statistics  
Stochastic Modeling  
Survival Analysis

#### **Computer Science:**

Applied Algorithms and Data Structures  
Cognitive Modeling  
Computer Aided Geometric Design  
Computer Graphics  
Computer Networks  
Computer Vision  
Data Mining  
Image Processing  
Machine Learning  
Mathematical Software  
Mobile Computing and Networking  
Parallel Computing  
Scientific Visualization  
Sensor Networks  
Simulation  
VLSI Design Automation

### *Description of Courses*

#### **Senior Year**

CSCI400. PRINCIPLES OF PROGRAMMING LANGUAGES (I, II) Study of the principles relating to design, evaluation and implementation of programming languages of historical and technical interest, considered as individual entities and with respect to their relationships to other languages. Topics discussed for each language include: history, design, structural organization, data structures, name structures, control structures, syntactic structures, and implementation of issues. The primary languages discussed are FORTRAN, PASCAL, LISP, ADA, C/C++, JAVA, PROLOG, PERL. Prerequisite: CSCI262. 3 hours lecture; 3 semester hours.

MATH401 INTRODUCTION TO ANALYSIS (I) This course is a first course in real analysis that lays out the context and motivation of analysis in terms of the transition from

power series to those less predictable series. The course is taught from a historical perspective. It covers an introduction to the real numbers, sequences and series and their convergence, real-valued functions and their continuity and differentiability, sequences of functions and their pointwise and uniform convergence, and Riemann-Stieltjes integration theory. Prerequisite: MATH213, MATH223 or MATH224, and MATH332. 3 hours lecture; 3 semester hours.

CSCI403. DATA BASE MANAGEMENT (I) Design and evaluation of information storage and retrieval systems, including defining and building a data base and producing the necessary queries for access to the stored information. Generalized data base management systems, query languages, and data storage facilities. General organization of files including lists, inverted lists and trees. System security and system recovery, and system definition. Interfacing host language to data base systems. Prerequisite: CSCI262. 3 hours lecture; 3 semester hours.

CSCI404. ARTIFICIAL INTELLIGENCE (I) General investigation of the Artificial Intelligence field. During the first part of the course a working knowledge of the LISP programming language is developed. Several methods used in artificial intelligence such as search strategies, knowledge representation, logic and probabilistic reasoning are developed and applied to problems. Learning is discussed and selected applications presented. Prerequisite: CSCI262, MATH/CSCI358. 3 hours lecture; 3 semester hours.

MATH/CSCI406. ALGORITHMS (I, II) Divide-and-conquer: splitting problems into subproblems of a finite number. Greedy: considering each problem piece one at a time for optimality. Dynamic programming: considering a sequence of decisions in problem solution. Searches and traversals: determination of the vertex in the given data set that satisfies a given property. Techniques of backtracking, branch-and-bound techniques, techniques in lower bound theory. Prerequisite: CSCI262, MATH213, MATH223 or MATH224, MATH/CSCI358. 3 hours lecture; 3 semester hours.

MATH/CSCI407. INTRODUCTION TO SCIENTIFIC COMPUTING (I, II) Round-off error in floating point arithmetic, conditioning and stability, solution techniques (Gaussian elimination, LU factorization, iterative methods) of linear algebraic systems, curve and surface fitting by the method of least-squares, zeros of nonlinear equations and systems by iterative methods, polynomial interpolation and cubic splines, numerical integration by adaptive quadrature and multivariate quadrature, numerical methods for initial value problems in ordinary differential equations. Emphasis is on problem solving using efficient numerical methods in scientific computing. Prerequisite: MATH315 or MATH325 and knowledge of computer programming. 3 hours lecture; 3 semester hours.

CSCI411. INTRODUCTION TO EXPERT SYSTEMS (II) General investigation of the field of expert systems. The first



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part of the course is devoted to designing expert systems. The last half of the course is implementation of the design and construction of demonstration prototypes of expert systems. Prerequisite: CSCI262, MATH/CSCI358. 3 hours lecture; 3 semester hours.

CSCI422. USER INTERFACES (I) User Interface Design is a course for programmers who want to learn how to create more effective software. This objective will be achieved by studying principles and patterns of interaction design, critiquing existing software using criteria presented in the textbook, and researching and analyzing the capabilities of various software development tools. Students will also learn a variety of techniques to guide the software design process, including Goal-Directed Design, Cognitive Walkthrough, Talk-aloud and others. Prerequisite: CSCI262. 3 hours lecture; 3 semester hours.

MATH424. INTRODUCTION TO APPLIED STATISTICS (I) Linear regression, analysis of variance, and design of experiments, focusing on the construction of models and evaluation of their fit. Techniques covered will include stepwise and best subsets regression, variable transformations, and residual analysis. Emphasis will be placed on the analysis of data with statistical software. Prerequisites: MATH323 or MATH335. 3 hours lecture; 3 semester hours.

MATH433/BELS433 MATHEMATICAL BIOLOGY (I) This course will discuss methods for building and solving both continuous and discrete mathematical models. These methods will be applied to population dynamics, epidemic spread, pharmacokinetics and modeling of physiologic systems. Modern Control Theory will be introduced and used to model living systems. Some concepts related to self-organizing systems will be introduced. Prerequisite: MATH315 or MATH325. 3 hours lecture, 3 semester hours.

MATH436. ADVANCED STATISTICAL MODELING (II) Modern methods for constructing and evaluating statistical models. Topics include generalized linear models, generalized additive models, hierarchical Bayes methods, and resampling methods. Prerequisites: MATH335 and MATH424. 3 hours lecture; 3 semester hours.

MATH437. MULTIVARIATE ANALYSIS (II) Introduction to applied multivariate techniques for data analysis. Topics include principal components, cluster analysis, MANOVA and other methods based on the multivariate Gaussian distribution, discriminant analysis, classification with nearest neighbors. Prerequisites: MATH335 or MATH323. 3 hours lecture; 3 semester hours.

MATH438. STOCHASTIC MODELS (II) An introduction to stochastic models applicable to problems in engineering, physical science, economics, and operations research. Markov chains in discrete and continuous time, Poisson processes, and topics in queuing, reliability, and renewal theory. Prerequisite: MATH434. 3 hours lecture, 3 semester hours.

MATH/CSCI440. PARALLEL COMPUTING FOR SCIENTISTS AND ENGINEERS (I) This course is designed to introduce the field of parallel computing to all scientists and engineers. The students will be taught how to solve scientific problems. They will be introduced to various software and hardware issues related to high performance computing. Prerequisite: Programming experience in C++, consent of instructor. 3 hours lecture; 3 semester hours.

MATH/CSCI441. COMPUTER GRAPHICS (I) Data structures suitable for the representation of structures, maps, three-dimensional plots. Algorithms required for windowing, color plots, hidden surface and line, perspective drawings. Survey of graphics software and hardware systems. Prerequisite: CSCI262. 3 hours lecture, 3 semester hours.

CSCI442. OPERATING SYSTEMS (I, II) Covers the basic concepts and functionality of batch, timesharing and single-user operating system components, file systems, processes, protection and scheduling. Representative operating systems are studied in detail. Actual operating system components are programmed on a representative processor. This course provides insight into the internal structure of operating systems; emphasis is on concepts and techniques which are valid for all computers. Prerequisite: CSCI262, CSCI. 3 hours lecture; 3 semester hours.

CSCI443. ADVANCED PROGRAMMING CONCEPTS USING JAVA. (I, II) This course will quickly review programming constructs using the syntax and semantics of the Java programming language. It will compare the constructs of Java with other languages and discuss program design and implementation. Object oriented programming concepts will be reviewed and applications, applets, servlets, graphical user interfaces, threading, exception handling, JDBC, and networking as implemented in Java will be discussed. The basics of the Java Virtual Machine will be presented. Prerequisites: CSCI261, CSCI262. 3 hours lecture, 3 semester hours

CSCI445. WEB PROGRAMMING (II) Web Programming is a course for programmers who want to develop Web-based applications. It covers basic web site design extended by client-side and server-side programming. Students should know the elements of HTML and Web architecture and be able to program in a high level language such as C++ or Java. The course builds on this knowledge by presenting topics such as Cascading Style Sheets, JavaScript, PERL and database connectivity that will allow the students to develop dynamic Web applications. Prerequisites: Fluency in a high level computer language/consent of instructor. 3 hours lecture, 3 semester hours.

MATH454. COMPLEX ANALYSIS (II) The complex plane. Analytic functions, harmonic functions. Mapping by elementary functions. Complex integration, power series, calculus of residues. Conformal mapping. Prerequisite: MATH315 or MATH325. 3 hours lecture, 3 semester hours.

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MATH455. PARTIAL DIFFERENTIAL EQUATIONS (I) Linear partial differential equations, with emphasis on the classical second-order equations: wave equation, heat equation, Laplace's equation. Separation of variables, Fourier methods, Sturm-Liouville problems. Prerequisite: MATH315 or MATH325. 3 hours lecture; 3 semester hours.

MATH458. ABSTRACT ALGEBRA (II) This course is an introduction to the concepts of contemporary abstract algebra and applications of those concepts in areas such as physics and chemistry. Topics include groups, subgroups, isomorphisms and homomorphisms, rings integral domains and fields. Prerequisites: MATH213 and MATH223 or MATH224, and MATH300 or consent of the instructor. 3 hours lecture; 3 semester hours.

CSCI471. COMPUTER NETWORKS I (I) This introduction to computer networks covers the fundamentals of computer communications, using TCP/IP standardized protocols as the main case study. The application layer and transport layer of communication protocols will be covered in depth. Detailed topics include application layer protocols (HTTP, FTP, SMTP, and DNS), reliable data transfer, connection management, and congestion control. In addition, students will build a computer network from scratch and program client/server network applications. Prerequisite: CSCI442 or consent of instructor. 3 hours lecture, 3 semester hours.

MATH 482 STATISTICS PRACTICUM (II) This is the capstone course in the Statistics Option. Students will apply statistical principles to data analysis through advanced work, leading to a written report and an oral presentation. Choice of project is arranged between the student and the individual faculty member who will serve as advisor. Prerequisites: MATH335 and MATH424. 3 hours lecture; 3 semester hours.

MATH/CSCI491. UNDERGRADUATE RESEARCH (I) (WI) Individual investigation under the direction of a department faculty member. Written report required for credit. Prerequisite: Consent of Department Head. 1 to 3 semester hours, no more than 6 in a degree program.

MATH/CSCI492. UNDERGRADUATE RESEARCH (II) (WI) Individual investigation under the direction of a department faculty member. Written report required for credit. Prerequisite: Consent of Department Head. 1 to 3 semester hours, no more than 6 in a degree program.

MATH/CSCI498. SPECIAL TOPICS (I, II, S) Selected topics chosen from special interests of instructor and students. Prerequisite: Consent of Department Head. Variable: 1 to 3 semester hours. Repeatable for credit under different titles.

MATH/CSCI499. INDEPENDENT STUDY (I, II, S) Individual research or special problem projects supervised by a faculty member; also, given agreement on a subject matter, content, and credit hours. Prerequisite: Independent Study form must be completed and submitted to the Registrar. Variable Credit: 1 to 6 credit hours. Repeatable for credit.

### Graduate Courses

500-level and 700-level courses are open to qualified seniors with the permission of the department and Dean of Graduate School.

MATH500. LINEAR VECTOR SPACES (I) Finite dimensional vector spaces and subspaces: dimension, dual bases, annihilators. Linear transformations, matrices, projections, change of basis, similarity. Determinants, eigenvalues, multiplicity. Jordan form. Inner products and inner product spaces with orthogonality and completeness. Prerequisite: MATH401. 3 hours lecture; 3 semester hours.

MATH502. REAL AND ABSTRACT ANALYSIS (I) Introduction to metric and topological spaces. Lebesgue measure and measurable functions and sets. Types of convergence, Lebesgue integration and its relation to other integrals. Integral convergence theorems. Absolute continuity and related concepts. Prerequisite: MATH401. 3 hours lecture; 3 semester hours.

MATH503. FUNCTIONAL ANALYSIS (I) Normed linear spaces, linear operators on normed linear spaces, Banach spaces, inner product and Hilbert spaces, orthonormal bases, duality, orthogonality, adjoint of a linear operator, spectral analysis of linear operators. Prerequisite: MATH502. 3 hours lecture; 3 semester hours.

MATH506. COMPLEX ANALYSIS II (II) Analytic functions. Conformal mapping and applications. Analytic continuation. Schlicht functions. Approximation theorems in the complex domain. Prerequisite: MATH454. 3 hours lecture; 3 semester hours.

MATH510. ORDINARY DIFFERENTIAL EQUATIONS AND DYNAMICAL SYSTEMS (I) Topics to be covered: basic existence and uniqueness theory, systems of equations, stability, differential inequalities, Poincare-Bendixon theory, linearization. Other topics from: Hamiltonian systems, periodic and almost periodic systems, integral manifolds, Lyapunov functions, bifurcations, homoclinic points and chaos theory. Prerequisite: MATH315 and MATH332 or equivalent. 3 hours lecture; 3 semester hours.

MATH514. APPLIED MATHEMATICS I (I) The major theme in this course is various non-numerical techniques for dealing with partial differential equations which arise in science and engineering problems. Topics include transform techniques, Green's functions and partial differential equations. Stress is on applications to boundary value problems and wave theory. Prerequisite: MATH455 or equivalent. 3 hours lecture; 3 semester hours.

MATH515. APPLIED MATHEMATICS II (II) Topics include integral equations, applied complex variables, an introduction to asymptotics, linear spaces and the calculus of variations. Stress is on applications to boundary value problems and wave theory, with additional applications to engineering and physical problems. Prerequisite: MATH514. 3 hours lecture; 3 semester hours.

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CSCI522. USER INTERFACE DESIGN (I) An introduction to the field of Human-Computer Interaction (HCI). Students will review current literature from prominent researchers in HCI and will discuss how the researchers' results may be applied to the students' own software design efforts. The course textbook and supplementary materials will provide a number of practical techniques and guidelines for developing software to better meet users' needs, such as Goal-Directed Design, Cognitive Walk Through and Talk-aloud testing methodologies, and interaction design patterns. Prerequisite: CSCI261 or equivalent. 3 hours lecture, 3 semester hours.

MATH530. STATISTICAL METHODS I (I) Introduction to probability, random variables, and discrete and continuous probability models. Elementary simulation. Data summarization and analysis. Confidence intervals and hypothesis testing for means and variances. Chi square tests. Distribution-free techniques and regression analysis. Prerequisite: MATH213 or equivalent. 3 hours lecture; 3 semester hours.

MATH531. STATISTICAL METHODS II (II) Continuation of MATH530. Multiple regression and trend surface analysis. Analysis of variance. Experimental design (Latin squares, factorial designs, confounding, fractional replication, etc.) Nonparametric analysis of variance. Topics selected from multivariate analysis, sequential analysis or time series analysis. Prerequisite: MATH323 or MATH530 or MATH535. 3 hours lecture; 3 semester hours.

MATH534. MATHEMATICAL STATISTICS I (I) The basics of probability, discrete and continuous probability distributions, sampling distributions, order statistics, convergence in probability and in distribution, and basic limit theorems, including the central limit theorem, are covered. Prerequisite: Consent of department. 3 hours lecture; 3 semester hours.

MATH535. MATHEMATICAL STATISTICS II (II) The basics of hypothesis testing using likelihood ratios, point and interval estimation, consistency, efficiency, sufficient statistics, and some nonparametric methods are presented. Prerequisite: MATH534 or equivalent. 3 hours lecture; 3 semester hours.

MATH/CSCI542. SIMULATION (I) Advanced study of simulation techniques, random number, and variate generation. Monte Carlo techniques, simulation languages, simulation experimental design, variance reduction, and other methods of increasing efficiency, practice on actual problems. Offered every other year. Prerequisite: CSCI262 (or equivalent), CSCI323 (or CSCI530 or equivalent), or permission of instructor. 3 hours lecture; 3 semester hours.

MATH550. NUMERICAL SOLUTION OF PARTIAL DIFFERENTIAL EQUATIONS (II) Numerical methods for solving partial differential equations. Explicit and implicit finite difference methods; stability, convergence, and consistency. Alternating direction implicit (ADI) methods.

Weighted residual and finite element methods. Prerequisite: MATH315, MATH332, or consent of instructor. 3 hours lecture; 3 semester hours.

MATH551. COMPUTATIONAL LINEAR ALGEBRA (II) Numerical analysis of algorithms for solving linear systems of equations, least squares methods, the symmetric eigenproblem, singular value decomposition, conjugate gradient iteration. Modification of algorithms to fit the architecture. Error analysis, existing software packages. Prerequisites: MATH332, MATH/CSCI407, or consent of instructor. 3 hours lecture; 3 semester hours.

MATH556. MODELING WITH SYMBOLIC SOFTWARE (I) Case studies of various models from mathematics, the sciences and engineering through the use of the symbolic software package MATHEMATICA. Based on hands-on projects dealing with contemporary topics such as number theory, discrete mathematics, complex analysis, special functions, classical and quantum mechanics, relativity, dynamical systems, chaos and fractals, solitons, wavelets, chemical reactions, population dynamics, pollution models, electrical circuits, signal processing, optimization, control theory, and industrial mathematics. The course is designed for graduate students and scientists interested in modeling and using symbolic software as a programming language and a research tool. It is taught in a computer laboratory. Prerequisites: Senior undergraduates need consent of instructor. 3 hours lecture; 3 semester hours.

CSCI561. THEORETICAL FOUNDATIONS OF COMPUTER SCIENCE (I) Mathematical foundations of computer science. Models of computation, including automata, pushdown automata and Turing machines. Language models, including alphabets, strings, regular expressions, grammars, and formal languages. Predicate logic. Complexity analysis. Prerequisite: CSCI262, MATH/CSCI358. 3 hours lecture; 3 semester hours.

CSCI562 APPLIED ALGORITHMS AND DATA STRUCTURES (II) Industry competitiveness in certain areas is often based on the use of better algorithms and data structures. The objective of this class is to survey some interesting application areas and to understand the core algorithms and data structures that support these applications. Application areas could change with each offering of the class, but would include some of the following: VLSI design automation, computational biology, mobile computing, computer security, data compression, web search engines, geographical information systems. Prerequisite: MATH/CSCI406, or consent of instructor. 3 hours lecture; 3 semester hours.

CSCI563. PARALLEL COMPUTING FOR SCIENTISTS AND ENGINEERS (I) Students are taught how to use parallel computing to solve complex scientific problems. They learn how to develop parallel programs, how to analyze their performance, and how to optimize program performance. The course covers the classification of parallel computers, shared memory versus distributed memory machines, soft-

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ware issues, and hardware issues in parallel computing. Students write programs for state of the art high performance supercomputers, which are accessed over the network.

Prerequisite: Programming experience in C, consent of instructor. 3 hours lecture; 3 semester hours

#### CSCI564 ADVANCED COMPUTER ARCHITECTURE (I)

The objective of this class is to gain a detailed understanding about the options available to a computer architect when designing a computer system along with quantitative justifications for the options. All aspects of modern computer architectures including instruction sets, processor design, memory system design, storage system design, multiprocessors, and software approaches will be discussed. Prerequisite: CSCI341, or consent of instructor. 3 hours lecture; 3 semester hours.

#### CSCI565. DISTRIBUTED COMPUTING SYSTEMS (II)

Introduction to the design and use of distributed computer systems based on networks of workstations and server computers. Topics include theory, applications, systems and case studies describing current approaches. Prerequisites: Undergraduate machine architecture or consent of instructor. 3 hours lecture; 3 semester hours.

#### CSCI566. ADVANCED DATABASE MANAGEMENT (II)

Advanced issues in database management, with emphasis on their application to scientific data. Topics to be covered include: object-oriented database management, database rules, distributed databases, database design, transaction management, query optimization, concurrency control, and management of scientific data. Each student develops a course project, as a vehicle for exploring and applying a database research issue. Prerequisite: CSCI403 or equivalent. 3 hours lecture; 3 semester hours.

#### CSCI567. ADVANCED OBJECT ORIENTED SOFTWARE ENGINEERING (II)

Advanced software engineering concepts, with emphasis on how to develop object-oriented application programs. The entire software lifecycle is discussed: requirements analysis, program design, implementation, debugging and testing. Seamless program development is emphasized, in which the development process is an incremental refinement of a computer model of real-world objects. Examples in the course are from scientific application programs. The object-oriented use of the C++ language is taught and used in assignments. Prerequisite: Knowledge of C or C++. 3 hours lecture; 3 semester hours.

CSCI568. DATA MINING (II) This course is an introductory course in data mining. It covers fundamentals of data mining theories and techniques. We will discuss association rule mining and its applications, overview of classification and clustering, data preprocessing, and several application-specific data mining tasks. We will also discuss practical data mining using a data mining software. Project assignments include implementation of existing data mining algorithms, data mining with or without data mining software, and study

of data mining-related research issues. Prerequisite: CSCI262 or permission of instructor. 3 hours lecture; 3 semester hours.

CSCI570. NEURAL NETWORKS (I) This course explores the theory behind neural networks, and focuses on the application of this technology to real problems in areas as diverse as DNA pattern recognition, robot control, hazardous waste remediation, and forensics. For the prepared student, this course also facilitates a transition from doing coursework to producing publishable research. Skills required to understand, critique, and extend existing research are emphasized. An introductory series of lectures is followed by more in-depth study of current research topics. Depending on a student's background, the course project is either a literature survey or application or exploration of a neural network method of the student's choice. Prerequisite: CSCI404. 3 hours lecture; 3 semester hours.

CSCI571. ARTIFICIAL INTELLIGENCE (I) Artificial Intelligence (AI) is the subfield of computer science that studies how to automate tasks for which people currently exhibit superior performance over computers. Historically, AI has studied problems such as machine learning, language understanding, game playing, planning, robotics, and machine vision. AI techniques include those for uncertainty management, automated theorem proving, heuristic search, neural networks, and simulation of expert performance in specialized domains like medical diagnosis. This course provides an overview of the field of Artificial Intelligence. Particular attention will be paid to learning the LISP language for AI programming. Prerequisite: CSCI262. 3 hours lecture; 3 semester hours.

CSCI572. COMPUTER NETWORKS II (II) This introduction to computer networks covers the fundamentals of computer communications, using TCP/IP standardized protocols as the main case study. This second course on computer networks covers the network layer, data link layer, and physical layer of communication protocols in depth. Detailed topics include routing (unicast, multicast, and broadcast), one hop error detection and correction, and physical topologies. Other topics include the history of computer communications and protocols for emerging networks (e.g., ad hoc networks and sensor networks). In addition, students will program client/server network applications and simulate a network protocol in a network simulator. Prerequisite: CSCI471. 3 hours lecture; 3 semester hours.

CSCI575. MACHINE LEARNING (II) The goal of machine learning research is to build computer systems that learn from experience and that adapt to their environments. Machine learning systems do not have to be programmed by humans to solve a problem; instead, they essentially program themselves based on examples of how they should behave, or based on trial and error experience trying to solve the problem. This course will focus on the methods that have proven valuable and successful in practical applications. The course



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will also contrast the various methods, with the aim of explaining the situations in which each is most appropriate. Prerequisites: CSCI262 and MATH323, or consent of instructor. 3 hours lecture; 3 semester hours.

MATH/CSCI598. SPECIAL TOPICS (I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

MATH/CSCI599. INDEPENDENT STUDY (I, II, S) Individual research or special problem projects supervised by a faculty member, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: Independent Study form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

MATH610. ADVANCED TOPICS IN DIFFERENTIAL EQUATIONS (II) Topics from current research in ordinary and/or partial differential equations; for example, dynamical systems, advanced asymptotic analysis, nonlinear wave propagation, solitons. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

MATH614. ADVANCED TOPICS IN APPLIED MATHEMATICS (I) Topics from current literature in applied mathematics; for example, wavelets and their applications, calculus of variations, advanced applied functional analysis, control theory. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

MATH616. INTRODUCTION TO MULTI-DIMENSIONAL SEISMIC INVERSION (II) Introduction to high frequency inversion techniques. Emphasis on the application of this theory to produce a reflector map of the earth's interior and estimates of changes in earth parameters across those reflectors from data gathered in response to sources at the surface or in the interior of the earth. Extensions to elastic media are discussed, as well. Includes high frequency modeling of the propagation of acoustic and elastic waves. Prerequisites: partial differential equations, wave equation in the time or frequency domain, complex function theory, contour integration. Some knowledge of wave propagation: reflection, refraction, diffraction. 3 hours lecture; 3 semester hours.

MATH650. ADVANCED TOPICS IN NUMERICAL ANALYSIS (II) Topics from the current literature in numerical analysis and/or computational mathematics; for example, advanced finite element method, sparse matrix algorithms, applications of approximation theory, software for initial value ODE's, numerical methods for integral equations. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

CSCI660. ADVANCED TOPICS IN COMPUTER SYSTEMS (II) Topics from the current literature in hardware and software computer systems; for example, user interfaces, object oriented software engineering, database management,

computer architectures, supercomputing, parallel processing, distributed processing, and algorithms. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

MATH/CSCI691. GRADUATE SEMINAR (I) Presentation of latest research results by guest lecturers, staff, and advanced students. Prerequisite: Consent of department. 1 hour seminar; 1 semester hour. Repeatable for credit to a maximum of 12 hours.

MATH/CSCI692. GRADUATE SEMINAR (II) Presentation of latest research results by guest lecturers, staff, and advanced students. Prerequisite: Consent of department. 1 hour seminar; 1 semester hour. Repeatable for credit to a maximum of 12 hours.

MATH693/GPGN551. WAVE PHENOMENA SEMINAR (I, II) Students will probe a range of current methodologies and issues in seismic data processing, with emphasis on underlying assumptions, implications of these assumptions, and implications that would follow from use of alternative assumptions. Such analysis should provide seed topics for ongoing and subsequent research. Topic areas include: Statistics estimation and compensation, deconvolution, multiple suppression, suppression of other noises, wavelet estimation, imaging and inversion, extraction of stratigraphic and lithologic information, and correlation of surface and borehole seismic data with well log data. Prerequisite: Consent of department. 1 hour seminar; 1 semester hour.

MATH/CSCI698. SPECIAL TOPICS (I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

MATH/CSCI699. INDEPENDENT STUDY (I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

MATH/CSCI705. GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE (I, II, S) Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

MATH/CSCI706. GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY (I, II, S) Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty advisor. Repeatable for credit.

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## Metallurgical and Materials Engineering

JOHN J. MOORE, Trustees Professor and Department Head  
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STEPHEN LIU, Professor  
GERARD P. MARTINS, Professor  
DAVID K. MATLOCK, Charles S. Fogarty Professor  
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NIGEL SAMMES, Herman. F. Coors Distinguished Professor  
JOHN G. SPEER, Professor  
PATRICK R. TAYLOR, George S. Ansell Distinguished Professor of  
Chemical Metallurgy  
CHESTER J. VANTYNE, FIERF Professor  
STEVEN W. THOMPSON, Associate Professor  
PATRICIO MENDEZ, Assistant Professor  
EDGAR E. VIDAL, Assistant Professor  
GEORGE S. ANSELL, President Emeritus and Professor Emeritus  
GLEN R. EDWARDS, University Professor Emeritus  
JOHN P. HAGER, University Professor Emeritus  
GEORGE KRAUSS, University Professor Emeritus  
W. REX BULL, Professor Emeritus  
DENNIS W. READEY, University Professor Emeritus  
GERALD L. DePOORTER, Associate Professor Emeritus  
ROBERT H. FROST, Associate Professor Emeritus  
HANS-JOACHIM KLEEBE, Research Professor  
ARUN MADAN, Research Professor

### Degrees Offered:

Master of Engineering (Metallurgical and Materials Engineering)

Master of Science (Metallurgical and Materials Engineering)

Doctor of Philosophy (Metallurgical and Materials Engineering)

### Program Description:

The program of study for the Master or Doctor of Philosophy degrees in Metallurgical and Materials Engineering is selected by the student in consultation with her or his advisor, and with the approval of the Thesis Committee. The program can be tailored within the framework of the regulations of the Graduate School to match the student's interests while maintaining the main theme of materials engineering and processing. There are three Areas of Specialization within the Department: Physical and Mechanical Metallurgy; Physicochemical Processing of Materials; and, Ceramic Engineering.

The Department is home to five research centers: the Advanced Coatings and Surface Engineering Laboratory, the Advanced Steel Processing and Products Research Center; the Colorado Center for Advanced Ceramics; the Center for Welding and Joining Research; and, the Kroll Institute for Extractive Metallurgy. A Graduate Certificate is offered by each Department Center – the program requirements are: 1) Be admitted to MME Graduate Certificate Program upon the

recommendation of the MME Department. 2) A total of 12 hours of course credits of which only 3 credit hours can be at the 400 level. The specific courses to be taken are determined by the Graduate Advisor in the Department Center selected by the candidate. A cumulative grade point average of B or better must be maintained while completing these requirements.

### Degree Program Requirements:

The program requirements for the three graduate degrees offered by the Department are listed below:

**Master of Engineering** degree: Two tracks are available as follows:

- I. Undergraduate/graduate program\*: i) a minimum of 30 total semester hours of acceptable course work; ii) case independent study course work component cannot exceed 6 semester hours; and iii) submittal and presentation, and subsequent acceptance by the Graduate Advisor, of a report which presents the results of a case study or an engineering development. (\*See pp. xx-xx, Combined Undergraduate/Graduate Programs.)
- II. Graduate Program: i) a minimum of 30 total semester hours of acceptable course work; ii) case-/independent study course-work cannot exceed 6 semester hours; and iii) submittal and presentation, and subsequent acceptance by the Graduate Advisor, of a report which presents the results of a case study or an engineering development.

**Master of Science** degree: i) a minimum of 24 semester hours of acceptable course work and 6 semester hours of research credit; and, ii) submittal and successful oral-defense of a thesis, before their Thesis Committee, which presents the results of original scientific research or development.

**Doctor of Philosophy** degree: i) a minimum of 42 semester hours of acceptable course work, which may include course credits (to be approved by the Thesis Committee) presented for the Master's degree, provided that the degree was in Metallurgical and Materials Engineering or a similar field. However, at least 21 hours of acceptable course work must be taken at the Colorado School of Mines; ii) 30 semester hours of research credit; iii) 9 to 12 semester hours of course work to compliment the research program of the student as determined by the Advisor/Thesis-Committee; iv) presentation of a Proposal on their Thesis-Research Project to their Thesis Committee; v) a passing grade on written and oral Qualifying-Process (Q.P.) Examinations, for the purpose of determining that adequate preparation and the ability to conduct high-quality, independent research have been achieved; vi) presentation (usually 6 months after successfully completing their Q.P. Examinations) of a Progress Report on their Research Project to their Thesis Committee and, vii) submittal and successful defense of a thesis, which presents the results of original scientific research or development, before their Thesis Committee.

Notes: The examinations under v) are specific to the student's declared Area of Specialization (currently a total of three), and consist of a written and oral component. The written examinations consist of a general topics examination and an area-or-specialization examination. The oral examination consists of responses by the student to questions on the fundamentals related to the student's proposed research. A Q.P. Oral-Examination Document consisting of: a) an Extended Abstract of the student's Thesis-Research Proposal, and b) associated Fundamental Topics on which the student expects to be examined, is presented to the Examining Committee (different from the Thesis Committee) prior to this event. The student delivers a 10 minutes oral-presentation, reviewing the document at the start of the (oral) examination. There is a standing schedule to offer the examinations during the last four to five weeks of the Spring and Fall semesters. However, intent to take the examinations must be declared within the first month of the intended semester.

Although there is no formal seminar-course requirement, graduate students, both Master and Doctoral candidates, as part of their professional development, are required to attend the Department seminars scheduled on Thursdays during the Fall and Spring semesters.

#### **Prerequisites:**

The entering graduate-student in the Department of Metallurgical and Materials Engineering must have completed an undergraduate program equivalent to that required for the B.S. degree in: Metallurgical and Materials Engineering, Materials Science or a related field. This should have included a background in science fundamentals and engineering principles. A student, who possesses this background but has not taken specific undergraduate-courses in Metallurgical and Materials Engineering, will be allowed to rectify these course deficiencies at the beginning of their program of study.

#### **Fields of Research:**

- Synthesis, processing, and characterization of photovoltaic materials
- Optical phenomena of interfaces and composites
- High-Tc superconductors
- Dielectrics and piezoelectrics
- Glasses and crystallizable glasses for electronics
- Ferroelectrics and ferroelectric thin films
- Porous ceramics and ceramic fibers
- Combustion synthesis of advanced materials
- Welding and joining of metals and dissimilar materials including ceramics and composites
- Laser Processing of Materials
- Physical metallurgy
- Mechanical metallurgy
- Processing microstructure, and properties of advanced steels
- Oxidation and corrosion of metals and ceramics
- Interfacial phenomena
- Surface characterization of materials

- Biomaterials
- Composite materials
- Preparation of ceramic powders
- Pyro-, hydro-, and electro-metallurgy
- Processing of industrial wastes
- Plasma synthesis and processing
- Computer simulation techniques for design of new high performance materials
- Thin film/coating, processing, and characterization
- Environmentally benign materials processes
- Semiconductor materials
- Powder metallurgy
- Aerospace structural materials
- Failure analysis and fracture mechanics of materials
- Forming of metals and other materials
- Fatigue of materials

### **Description of Courses**

#### **Undergraduate Courses**

A maximum of nine hours of 400-level credits, with the approval of the Thesis Committee, may be applied towards the course-work requirement for a Master's degree.

MTGN412/MLGN512. CERAMIC ENGINEERING (II) Application of engineering principles to nonmetallic and ceramic materials. Processing of raw materials and production of ceramic bodies, glazes, glasses, enamels, and cermets. Firing processes and reactions in glass bonded as well as mechanically bonded systems. Prerequisite: MTGN348. 3 hours lecture; 3 semester hours.

MTGN414/MLGN544. PROCESSING OF CERAMICS (II) Principles of ceramic processing and the relationship between processing and microstructure. Raw materials and raw materials preparation, forming and fabrication, thermal processing, and finishing of ceramic materials will be covered. Principles will be illustrated by case studies on specific ceramic materials. A project to design a ceramic fabrication process is required. Field trips to local ceramic manufacturing operations are included. Prerequisites: MTGN272, MTGN311 or consent of the Instructor. 3 hours lecture; 3 semester hours.

MTGN415/MLGN515. ELECTRICAL PROPERTIES AND APPLICATIONS OF MATERIALS (II) Survey of the electrical properties of materials, and the applications of materials as electrical circuit components. The effects of chemistry, processing, and microstructure on the electrical properties will be discussed, along with the functions, performance requirements, and testing methods of materials for each type of circuit component. The general topics covered are conductors, resistors, insulators, capacitors, energy convertors, magnetic materials, and integrated circuits. Prerequisite: PHGN200, MTGN311 or MLGN501 or consent of Instructor. 3 hours lecture; 3 semester hours.

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MTGN416/MLGN516. **PROPERTIES OF CERAMICS (II)** Survey of the properties of ceramic materials and how these properties are determined by the chemical structure (composition), crystal structure, and the microstructure of crystalline ceramics and glasses. Thermal, optical, and mechanical properties of single-phase and multiphase ceramics, including composites, are covered. Prerequisites: PHGN200, MTGN311 or MLGN501 or consent of Instructor. 3 hours lecture, 3 semester hours.

MTGN417. **REFRACTORY MATERIALS (I)** Refractory materials in metallurgical construction. Oxide phase diagrams for analyzing the behavior of metallurgical slags in contact with materials of construction. Prerequisite: consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN419/MLGN519. **NON-CRYSTALLINE MATERIALS (I)** An introduction to the principles of glass science-and-engineering and non-crystalline materials in general. Glass formation, structure, crystallization, and properties will be covered, along with a survey of commercial glass compositions, manufacturing processes, and applications. Prerequisites: MTGN311 or MLGN501, MTGN412/MLGN512, or consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN422. **PROCESS ANALYSIS AND DEVELOPMENT (II)** Aspects of process development, plant design, and management. Prerequisite: MTGN334. Co-requisite: MTGN424 or consent of Instructor. 2 hours lecture; 2 semester hours.

MTGN424. **PROCESS ANALYSIS AND DEVELOPMENT LABORATORY (II)** Projects designed to supplement the lectures in MTGN422. Prerequisite: MTGN422 or consent of Instructor. 3 hours lab; 1 semester hour.

MTGN429. **METALLURGICAL ENVIRONMENT (I)** Examination of the interface between metallurgical process engineering and environmental engineering. Wastes, effluents and their point sources in metallurgical processes such as mineral concentration, value extraction and process metallurgy are studied in context. Fundamentals of metallurgical unit operations and unit processes with those applicable to waste and effluent control, disposal and materials recycling are covered. Engineering design and engineering cost components are also included for selected examples. Fundamentals and applications receive equal coverage. Prerequisites: MTGN334 or consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN430. **PHYSICAL CHEMISTRY OF IRON AND STEELMAKING (I)** Physical chemistry principles of blast furnace and direct reduction production of iron and refining of iron to steel. Discussion of raw materials, productivity, impurity removal, deoxidation, alloy additions, and ladle metallurgy. Prerequisite: MTGN334. 3 hours lecture; 3 semester hours.

MTGN431. **HYDRO- AND ELECTROMETALLURGY (I)** Physical and chemical principles involved in the extraction

and refining of metals by hydro- and electrometallurgical techniques. Discussion of unit processes in hydrometallurgy, electrowinning, and electrorefining. Analysis of integrated flowsheets for the recovery of nonferrous metals. Prerequisite: MTGN334, MTGN351, MTGN461. Co-requisite: MTGN433 or consent of Instructor. 2 hours lecture; 2 semester hours.

MTGN432. **PYROMETALLURGY (II)** Extraction and refining of metals including emergent practices. Modifications driven by environmental regulations and by energy minimization. Analysis and design of processes and the impact of economic considerations. Prerequisite: MTGN334. 3 hours lecture; 3 semester hours.

MTGN433. **HYDRO- AND ELECTROMETALLURGY LABORATORY (I)** Experiments designed to supplement the lectures in MTGN431. Co-requisite: MTGN431 or consent of Instructor.

MTGN434. **DESIGN AND ECONOMICS OF METALLURGICAL PLANTS (II)** Design of metallurgical processing systems. Methods for estimating process costs and profitability. Performance, selection, and design of process equipment. Integration of process units into a working plant and its economics, construction, and operation. Market research and surveys. Prerequisite: MTGN351 or consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN436. **CONTROL AND INSTRUMENTATION OF METALLURGICAL PROCESSES (II)** Analysis of processes for metal extraction and refining using classical and direct-search optimization methods and classical process control with the aid of chemical functions and thermodynamic transfer operations. Examples from physicochemical and physical metallurgy processes. Co-requisite: MTGN438 or consent of Instructor. 2 hours lecture; 2 semester hours.

MTGN438. **CONTROL AND INSTRUMENTATION OF METALLURGICAL PROCESSES LABORATORY (II)** Experiments designed to supplement the lectures in MTGN436. Co-requisite: MTGN436 or consent of Instructor. 3 hours lab; 1 semester hour.

MTGN442. **ALLOY AND PHASE STABILITY (II)** Phase equilibrium of solid solutions, primary and intermediate phases, binary and ternary phase equilibrium diagrams, multicomponent systems. Phase transformations in ferrous alloys, hardenability, heat treatment, surface modification, alloying of steel, precipitation alloys and alloy design for cast irons, stainless steels, and tool steels. Prerequisite: MTGN348 or consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN445/MLGN505\*. **MECHANICAL PROPERTIES OF MATERIALS (I)** Mechanical properties and relationships. Plastic deformation of crystalline materials. Relationships of microstructures to mechanical strength. Fracture, creep, and fatigue. Laboratory sessions devoted to advanced mechanical testing techniques to illustrate the application of the fundamentals presented in the lectures. Prerequisite: MTGN348.



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3 hours lecture, 3 hours lab; 4/3\* semester hours. \*A 3 semester-hour graduate-course in the Materials Science Program (ML) and a 4 semester-hour undergraduate-course in the MTGN program.

MTGN450/MLGN550. STATISTICAL PROCESS CONTROL AND DESIGN OF EXPERIMENTS (I) Introduction to statistical process control, process capability analysis and experimental design techniques. Statistical process control theory and techniques developed and applied to control charts for variables and attributes involved in process control and evaluation. Process capability concepts developed and applied to the evaluation of manufacturing processes. Theory of designed experiments developed and applied to full factorial experiments, fractional factorial experiments, screening experiments, multilevel experiments and mixture experiments. Analysis of designed experiments by graphical and statistical techniques. Introduction to computer software for statistical process control and for the design and analysis of experiments. Prerequisite: Consent of Instructor. 3 hours lecture, 3 semester hours

MTGN451. CORROSION ENGINEERING (II) Principles of electrochemistry. Corrosion mechanisms. Methods of corrosion protection including cathodic and anodic protection and coatings. Examples, from various industries, of corrosion problems and solutions. Prerequisite: MTGN351. 3 hours lecture; 3 semester hours

MTGN452. CERAMIC AND METAL MATRIX COMPOSITES Introduction to the synthesis, processing, structure, properties and performance of ceramic and metal matrix composites. Survey of various types of composites, and correlation between processing, structural architecture and properties. Prerequisites: MTGN272, MTGN311, MTGN348, MTGN351. 3 hours lecture; 3 semester hours

MTGN453. PRINCIPLES OF INTEGRATED CIRCUIT PROCESSING (I) Introduction to the electrical conductivity of semiconductor materials; qualitative discussion of active semiconductor devices; discussion of the steps in integrated circuit fabrication; detailed investigation of the materials science and engineering principles involved in the various steps of VLSI device fabrication; a presentation of device packaging techniques and the processes and principles involved. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN456. ELECTRON MICROSCOPY (II) Introduction to electron optics and the design and application of transmission and scanning electron microscopes. Interpretation of images produced by various contrast mechanisms. Electron diffraction analysis and the indexing of electron diffraction patterns. Prerequisite: MTGN311 or consent of instructor. Co-requisite: MTGN458. 2 hours lecture; 2 semester hours.

MTGN458. ELECTRON MICROSCOPY LABORATORY (II) Laboratory exercises to illustrate specimen preparation techniques, microscope operation, and the interpretation of images produced from a variety of specimens, and to supple-

ment the lectures in MTGN456. Co-requisite: MTGN456. 3 hours lab; 1 semester hour.

MTGN461. TRANSPORT PHENOMENA AND REACTOR DESIGN FOR METALLURGICAL-AND-MATERIALS ENGINEERS (I) Introduction to the conserved-quantities: momentum, heat, and mass transfer, and application of chemical kinetics to elementary reactor-design. Examples from materials processing and process metallurgy. Molecular transport properties: viscosity, thermal conductivity, and mass diffusivity of materials encountered during processing operations. Uni-directional transport: problem formulation based on the required balance of the conserved-quantity applied to a control-volume. Prediction of velocity, temperature and concentration profiles. Equations of change: continuity, motion, and energy. Transport with two independent variables (unsteady-state behavior). Interphase transport: dimensionless correlations - friction factor, heat, and mass transfer coefficients. Elementary concepts of radiation heat-transfer. Flow behavior in packed beds. Design equations for: Continuous-Flow/Batch Reactors with Uniform Dispersion and Plug Flow Reactors. Digital computer methods for the design of metallurgical systems. Laboratory sessions devoted to: Tutorials/Demonstrations to facilitate the understanding of concepts related to selected topics; and, Projects with the primary focus on the operating principles and use of modern electronic instrumentation for measurements on lab-scale systems in conjunction with correlation and prediction strategies for analysis of results. Prerequisites: MATH225, MTGN351 and MTGN352. 2 hours lecture, 3 hours lab; 3 semester hours.

MTGN463. POLYMER ENGINEERING (I) Introduction to the structure and properties of polymeric materials, their deformation and failure mechanisms, and the design and fabrication of polymeric end items. Molecular and crystallographic structures of polymers will be developed and related to the elastic, viscoelastic, yield and fracture properties of polymeric solids and reinforced polymer composites. Emphasis on forming and joining techniques for end item fabrication including: extrusion, injection molding, reaction injection molding, thermoforming, and blow molding. The design of end items will be considered in relation to: materials selection, manufacturing engineering, properties, and applications. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN464. FORGING AND FORMING (II) Introduction to plasticity. Survey and analysis of working operations of forging, extrusion, rolling, wire drawing and sheet metal forming. Metallurgical structure evolution during working. Prerequisites: EGGN320 and MTGN348 or EGGN390. 2 hours lecture; 3 hours lab, 3 semester hours.

MTGN466. DESIGN: SELECTION AND USE OF MATERIALS (II) Selection of alloys for specific applications, designing for corrosion resistant service, concept of passivity,

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designing for wear resistant service, designing for high temperature service and designing for high strength/weight applications. Introduction to the aluminum, copper, nickel, cobalt, stainless steel, cast irons, titanium and refractory metal alloy-systems. Coating science and selection. Prerequisite: MTGN348. 1 hour lecture, 6 hours lab; 3 semester hours.

MTGN475. METALLURGY OF WELDING (I) Introduction to welding processes thermal aspects; metallurgical evaluation of resulting microstructures; attendant phase transformations; selection of filler metals; stresses; stress relief and annealing; preheating and post heating; distortion and defects; welding ferrous and nonferrous alloys; and, welding tests. Prerequisite: MTGN348. Co-requisite: MTGN477. 2 hours lecture; 2 semester hours.

MTGN477. METALLURGY OF WELDING LABORATORY (I) Experiments designed to supplement the lectures in MTGN475. Co-requisite: MTGN475. 3 hours lab; 1 semester hour.

MTGN498. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING (I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). The course topic is generally offered only once. . Prerequisite: Consent of Instructor. 1 to 3 semester hours. Repeatable for credit under different titles.

MTGN499. INDEPENDENT STUDY (I, II) Independent advanced-work leading to a comprehensive report. This work may take the form of conferences, library, and laboratory work. Choice of problem is arranged between student and a specific Department faculty-member. Prerequisite: Selection of topic with consent of faculty supervisor; "Independent Study Form" must be completed and submitted to Registrar. 1 to 3 semester hours for each of two semesters. Repeatable for credit.

#### **Graduate Courses**

Most courses are offered once every two years. However, those courses offered for which fewer than five students have registered may be cancelled that semester. Courses at the 500-level are open to qualified seniors with approval of the Department and the Dean of the Graduate School. Courses at the 600-level are open only to graduate students in good standing. A two-year course-schedule is available in the Department office.

MTGN511. SPECIAL METALLURGICAL AND MATERIALS ENGINEERING PROBLEMS (I) Independent advanced work, not leading to a thesis. This may take the form of conferences, library, and laboratory work. Selection of assignment is arranged between student and a specific Department faculty-member. Prerequisite: Selection of topic with consent of faculty supervisor. 1 to 3 semester hours. Repeatable for credit under different titles.

MTGN512. SPECIAL METALLURGICAL AND MATERIALS ENGINEERING PROBLEMS (II) Continuation of MTGN511. Prerequisite: Selection of topic with consent of faculty supervisor. 1 to 3 semester hours. Repeatable for credit under different titles.

MTGN514. DEFECT CHEMISTRY AND TRANSPORT PROCESSES IN CERAMIC SYSTEMS (I) Ceramic materials science in the area of structural imperfections, their chemistry, and their relation to mass and charge transport; defects and diffusion, sintering, and grain growth with particular emphasis on the relation of fundamental transport phenomena to sintering and microstructure development and control. Prerequisites: DCGN209 or MTGN351; MT311 or Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of odd years only.)

MTGN516. MICROSTRUCTURE OF CERAMIC SYSTEMS (II) Analysis of the chemical and physical processes controlling microstructure development in ceramic systems. Development of the glassy phase in ceramic systems and the resulting properties. Relationship of microstructure to chemical, electrical, and mechanical properties of ceramics. Application to strengthening and toughening in ceramic composite system. Prerequisite: Graduate status or Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of even years only.)

MTGN517. REFRACTORIES (I) The manufacture, testing, and use of basic, neutral, acid, and specialty refractories are presented. Special emphasis is placed on the relationship between physical properties of the various refractories and their uses in the metallurgical industry. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN518/MLGN518. PHASE EQUILIBRIA IN CERAMIC SYSTEMS (II) Application of one to four component oxide diagrams to ceramic engineering problems. Emphasis on refractories and glasses and their interaction with metallic systems. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MTGN523/MLGN523. APPLIED SURFACE AND SOLUTION CHEMISTRY (II) Solution and surface chemistry of importance in mineral and metallurgical operations. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MTGN526/MLGN526. GEL SCIENCE AND TECHNOLOGY An introduction to the science and technology of particulate and polymeric gels, emphasizing inorganic systems. Interparticle forces. Aggregation, network formation, percolation, and the gel transition. Gel structure, rheology, and mechanical properties. Application to solid-liquid separation operations (filtration, centrifugation, sedimentation) and to ceramics processing. Prerequisite: Graduate Status or Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

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MTGN527/ESGN562. SOLID WASTE MINIMIZATION AND RECYCLING (II) Industrial case-studies, on the application of engineering principles to minimize waste formation and to meet solid waste recycling challenges. Proven and emerging solutions to solid waste environmental problems, especially those associated with metals. Prerequisites: ESGN500 and ESGN504 or Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN528. EXTRACTIVE METALLURGY OF COPPER, GOLD AND SILVER. Practical applications of fundamentals of chemical-processing-of-materials to the extraction of gold, silver and copper. Topics covered include: History; Ore deposits and mineralogy; Process Selection; Hydrometallurgy and leaching; Oxidation pretreatment; Purification and recovery; Refinement; Waste treatment; and Industrial examples. Prerequisites: Graduate or Senior in good-standing or consent of instructor. 3 hours lecture, 3 semester hours.

MTGN529. METALLURGICAL ENVIRONMENT (I) Effluents, wastes, and their point sources associated with metallurgical processes, such as mineral concentration and values extraction—providing for an interface between metallurgical process engineering and the environmental engineering areas. Fundamentals of metallurgical unit operations and unit processes, applied to waste and effluents control, recycling, and waste disposal. Examples which incorporate engineering design and cost components are included. Prerequisites: MTGN334 or Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN530. ADVANCED IRON AND STEELMAKING (I) Physicochemical principles of gas-slag-metal reactions applied to the reduction of iron ore concentrates and to the refining of liquid iron to steel. The role of these reactions in reactor design—blast furnace and direct iron smelting furnace, pneumatic steelmaking furnace, refining slags, deoxidation and degassing, ladle metallurgy, alloying, and continuous casting of steel. Prerequisite: DCGN209 or MTGN351 or Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of even years only.)

MTGN531. THERMODYNAMICS OF METALLURGICAL AND MATERIALS PROCESSING (I) Application of thermodynamics to the processing of metals and materials, with emphasis on the use of thermodynamics in the development and optimization of processing systems. Focus areas will include entropy and enthalpy, reaction equilibrium, solution thermodynamics, methods for analysis and correlation of thermodynamics data, thermodynamic analysis of phase diagrams, thermodynamics of surfaces, thermodynamics of defect structures, and irreversible thermodynamics. Attention will be given to experimental methods for the measurement of thermodynamic quantities. Prerequisite: MTGN351 or Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN 532 PARTICULATE MATERIAL PROCESSING I - COMMINUTION AND PHYSICAL SEPARATIONS. An in-

roduction to the fundamental principles and design criteria for the selection and use of standard mineral processing unit operations in comminution and physical separation. Topics covered include: crushing (jaw, cone, gyratory), grinding (ball, pebble, rod, SAG, HPGR), screening, thickening, sedimentation, filtration and hydrocyclones. Two standard mineral processing plant-design simulation software (MinOCad and JK SimMet) are used in the course. Prerequisites: Graduate or Senior in good- standing or consent of instructor.3 hours lecture, 3 semester hours.

MTGN 533 PARTICULATE MATERIAL PROCESSING II - APPLIED SEPARATIONS. An introduction to the fundamental principles and design criteria for the selection and use of standard mineral processing unit operations in applied separations. Topics covered include: photometric ore sorting, magnetic separation, dense media separation, gravity separation, electrostatic separation and flotation (surface chemistry, reagents selection, laboratory testing procedures, design and simulation). Two standard mineral processing plant-design simulation software (MinOCad and JK SimMet) are used in the course. Graduate or Senior in good- standing or consent of instructor.3 hours lecture, 3 semester hours.

MTGN534. CASE STUDIES IN PROCESS DEVELOPMENT A study of the steps required for development of a mineral recovery process. Technical, economic, and human factors involved in bringing a process concept into commercial production. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

MTGN535. PYROMETALLURGICAL PROCESSES (II) Detailed study of a selected few processes, illustrating the application of the principles of physical chemistry (both thermodynamics and kinetics) and chemical engineering (heat and mass transfer, fluid flow, plant design, fuel technology, etc.) to process development. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN536. OPTIMIZATION AND CONTROL OF METALLURGICAL SYSTEMS Application of modern optimization and control theory to the analysis of specific systems in extractive metallurgy and mineral processing. Mathematical modeling, linear control analysis, dynamic response, and indirect optimum seeking techniques applied to the process analysis of grinding, screening, filtration, leaching, precipitation of metals from solution, and blast furnace reduction of metals. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN537. ELECTROMETALLURGY (II) Electrochemical nature of metallurgical processes. Kinetics of electrode reactions. Electrochemical oxidation and reduction. Complex electrode reactions. Mixed potential systems. Cell design and optimization of electrometallurgical processes. Batteries and fuel cells. Some aspects of corrosion. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of even years only.)

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MTGN538. HYDROMETALLURGY (II) Kinetics of liquid-solid reactions. Theory of uniformly accessible surfaces. Hydrometallurgy of sulfide and oxides. Cementation and hydrogen reduction. Ion exchange and solvent extraction. Physicochemical phenomena at high pressures. Microbiological metallurgy. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MTGN539. PRINCIPLES OF MATERIALS PROCESSING REACTOR DESIGN (II) Review of reactor types and idealized design equations for isothermal conditions. Residence time functions for nonreacting and reacting species and its relevance to process control. Selection of reactor type for a given application. Reversible and irreversible reactions in CSTR's under nonisothermal conditions. Heat and mass transfer considerations and kinetics of gas-solid reactions applied to fluo-solids type reactors. Reactions in packed beds. Scale up and design of experiments. Brief introduction into drying, crystallization, and bacterial processes. Examples will be taken from current metallurgical practice. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MTGN541. INTRODUCTORY PHYSICS OF METALS (I) Electron theory of metals. Classical and quantum-mechanical free electron theory. Electrical and thermal conductivity, thermoelectric effects, theory of magnetism, specific heat, diffusion, and reaction rates. Prerequisite: MTGN445. 3 hours lecture; 3 semester hours.

MTGN542. ALLOYING THEORY, STRUCTURE, AND PHASE STABILITY (II) Empirical rules and theories relating to alloy formation. Various alloy phases and constituents which result when metals are alloyed and examined in detail. Current information on solid solutions, intermetallic compounds, eutectics, liquid immiscibility. Prerequisite: MTGN445 or Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN543. THEORY OF DISLOCATIONS (I) Stress field around dislocation, forces on dislocations, dislocation reactions, dislocation multiplication, image forces, interaction with point defects, interpretation of macroscopic behavior in light of dislocation mechanisms. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of odd years only.)

MTGN544. FORGING AND DEFORMATION MODELING (I) Examination of the forging process for the fabrication of metal components. Techniques used to model deformation processes including slab equilibrium, slip line, upper bound and finite element methods. Application of these techniques to specific aspects of forging and metal forming processes. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of odd years only.)

MTGN545. FATIGUE AND FRACTURE (I) Basic fracture mechanics as applied to engineering materials, S-N curves, the Goodman diagram, stress concentrations, residual stress effects, effect of material properties on mechanisms of crack

propagation. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of odd years only.)

MTGN546. CREEP AND HIGH TEMPERATURE MATERIALS (II) Mathematical description of creep process. Mathematical methods of extrapolation of creep data. Micro-mechanisms of creep deformation, including dislocation glide and grain boundary sliding. Study of various high temperature materials, including iron, nickel, and cobalt base alloys and refractory metals, and ceramics. Emphasis on phase transformations and microstructure-property relationships. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MTGN547. PHASE EQUILIBRIUM IN MATERIALS SYSTEMS (I) Phase equilibrium of unary, binary, ternary, and multicomponent systems, microstructure interpretation, pressure-temperature diagrams, determination of phase diagrams. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN548. TRANSFORMATIONS IN METALS (I) Surface and interfacial phenomena, order of transformation, grain growth, recovery, recrystallization, solidification, phase transformation in solids, precipitation hardening, spinoidal decomposition, martensitic transformation, gas metal reactions. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of odd years only.)

MTGN549. CURRENT DEVELOPMENTS IN FERROUS ALLOYS (I) Development and review of solid state transformations and strengthening mechanisms in ferrous alloys. Application of these principles to the development of new alloys and processes such as high strength low alloy steels, high temperature alloys, maraging steels, and case hardening processes. Prerequisite: MTGN348. 3 hours lecture; 3 semester hours.

MTGN551. ADVANCED CORROSION ENGINEERING (I) Advanced topics in corrosion engineering. Case studies and industrial application. Special forms of corrosion. Advanced measurement techniques. Prerequisite: MTGN451. 3 hours lecture; 3 semester hours. (Fall of even years only.)

MTGN552/MLGN552. INORGANIC MATRIX COMPOSITES Introduction to the processing, structure, properties and applications of metal matrix and ceramic matrix composites. Importance of structure and properties of both the matrix and the reinforcement and the types of reinforcement utilized—particulate, short fiber, continuous fiber, and laminates. Emphasis on the development of mechanical properties through control of synthesis and processing parameters. Other physical properties such as electrical and thermal will also be examined. Prerequisite/Co-requisite\*: MTGN352, MTGN445/MLGN505\*; or, Consent of Instructor. 3 hours lecture; 3 semester hours. (Summer of even years only.)

MTGN553. STRENGTHENING MECHANISMS (II) Strain hardening in polycrystalline materials, dislocation interactions, effect of grain boundaries on strength, solid



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solution hardening, martensitic transformations, precipitation hardening, point defects. Prerequisite: MTGN543 or concurrent enrollment. 3 hours lecture; 3 semester hours. (Spring of even years only.)

MTGN554. OXIDATION OF METALS (II) Kinetics of oxidation. The nature of the oxide film. Transport in oxides. Mechanisms of oxidation. The Oxidation protection of high-temperature metal systems. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of even years only.)

MTGN555/MLGN504. SOLID STATE THERMODYNAMICS (I) Thermodynamics applied to solid state reactions, binary and ternary phase diagrams, point, line and planar defects, interfaces, and electrochemical concepts. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN556/MLGN506. TRANSPORT IN SOLIDS (I) Thermal and electrical conductivity. Solid state diffusion in metals and metal systems. Kinetics of metallurgical reactions in the solid state. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of even years only.)

MTGN557. SOLIDIFICATION (I) Heat flow and fluid flow in solidification, thermodynamics of solidification, nucleation and interface kinetics, grain refining, crystal and grain growth, constitutional supercooling, eutectic growth, solidification of castings and ingots, segregation, and porosity. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of odd years only.)

MTGN558. MANAGEMENT OF MANUFACTURING PROCESSES Theory and practice of management of manufacturing operations. Topics include inventory control models; factory dynamics and flow-through manufacturing processes; application of Little's Queuing Law to relate cycle time, throughput and work-in-process; influence of variability on utilization and process flow; bottleneck planning and the influence of bottleneck constraints on cycle time, throughput and work-in-process; batching laws; application of queueing network theory for process analysis and optimization; shop-floor control and constant work-in-process control systems. Application of the principles of manufacturing management to processes such as casting and molding, forming, machining and finishing, joining, coating, electronic manufacturing, inspection and quality control, logistic processes, and service processes. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN559. SIMULATION OF MANUFACTURING AND SERVICE PROCESSES Introduction to the theory and practice of dynamic simulation of queuing systems such as those encountered in manufacturing systems and service operations. Topics include generation of random numbers and random variates, discrete and continuous statistical distributions used for simulation, simulation dynamics, queuing systems, statistical analysis of simulation output, entity transfer, conveyors, batching, statistical analysis of simulation output, and

termination of simulation models. Commercial computer-based simulation-package to provide the experience and background necessary to build and analyze models of manufacturing and service operations such as ferrous and nonferrous alloy production, ceramic materials production, casting and molding, forming, machining and finishing, joining, coating, electronic manufacturing, inspection and quality control, logistic processes, and service processes. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN560. ANALYSIS OF METALLURGICAL FAILURES (II) Applications of the principles of physical and mechanical metallurgy to the analysis of metallurgical failures. Nondestructive testing. Fractography. Case study analysis. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MTGN561. PHYSICAL METALLURGY OF ALLOYS FOR AEROSPACE (I) Review of current developments in aerospace materials with particular attention paid to titanium alloys, aluminum alloys, and metal-matrix composites. Emphasis is on phase equilibria, phase transformations, and microstructure-property relationships. Concepts of innovative processing and microstructural alloy design are included where appropriate. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of even years only.)

MTGN564 CONSTITUTIVE MODELING OF MATERIAL BEHAVIOR (I) Examination of various constitutive models which are used to characterize material behavior. Models for elastic behavior, strain hardening, strain-rate hardening, creep, viscoplastic, cyclical hardening and nonisothermal behavior will be discussed. Experimental methods and data analysis to determine various constitutive parameters will be described. Incorporation of these models in computer codes, especially finite element analysis. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of even years only.)

MTGN565 MECHANICAL PROPERTIES OF CERAMICS AND COMPOSITES (I) Mechanical properties of ceramics and ceramic-based composites; brittle fracture of solids; toughening mechanisms in composites; fatigue, high temperature mechanical behavior, including fracture, creep deformation. Prerequisites: MTGN445 or MLGN505, or Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of even years only.)

MTGN 569, MLGN 569, EGGN 569, ChEN 569 Fuel Cell Science and Technology (II) Fundamentals of fuel-cell operation and electrochemistry from chemical-thermodynamics and materials-science perspectives. Review types of fuel cells, fuel-processing requirements and approaches, and fuel-cell system integration. Examine current topics in fuel-cell science and technology. Fabricate and test operational fuel cells in the Colorado Fuel Cell Center. Prerequisites: MTGN 351 or EGGN371 or ChEN357 and MATH225; or Consent of Instructor 3 hours lecture, 3 semester hours.

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MTGN/MLGN 570 BIOCMPATIBILITY OF MATERIALS Introduction to the diversity of biomaterials and applications through examination of the physiologic environment in conjunction with compositional and structural requirements of tissues and organs. Appropriate domains and applications of metals, ceramics and polymers, including implants, sensors, drug delivery, laboratory automation, and tissue engineering are presented. Prerequisites: ESGN 301 or equivalent, or Consent of Instructor. 3 hours lecture; 3 semester hours

MTGN571. METALLURGICAL AND MATERIALS ENGINEERING LABORATORY Basic instruction in advanced equipment and techniques in the field of extraction, mechanical or physical metallurgy. Prerequisite: Selection and Consent of Instructor. 3 to 9 hours lab ; 1 to 3 semester hours.

MTGN580. ADVANCED WELDING METALLURGY (II) Weldability, defects, phase transformations, heat flow, pre-heat treatment, post-heat treatment, heat affected zone, microstructure, and properties. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of even years only.)

MTGN581. WELDING HEAT SOURCES AND INTERACTIVE CONTROLS (I) The science of welding heat sources including gas tungsten arc, gas metal arc, electron beam and laser. The interaction of the heat source with the workpiece will be explored and special emphasis will be given to using this knowledge for automatic control of the welding process. Prerequisite: Graduate Status or Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of odd years only.)

MTGN582. MECHANICAL PROPERTIES OF WELDED JOINTS (II) Mechanical metallurgy of heterogeneous systems, shrinkage, distortion, cracking, residual stresses, mechanical testing of joints, size effects, joint design, transition temperature, fracture. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MTGN583. PRINCIPLES OF NON-DESTRUCTIVE TESTING AND EVALUATION (I) Introduction to testing methods; basic physical principles of acoustics, radiography, and electromagnetism; statistical and risk analysis; fracture mechanics concepts; design decision making, limitations and applications of processes; fitness-for- service evaluations. Prerequisite: Graduate Status or Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of odd years only.)

MTGN584. NON-FUSION JOINING PROCESSES (II) Joining processes for which the base materials are not melted. Brazing, soldering, diffusion bonding, explosive bonding, and adhesive bonding processes. Theoretical aspects of these processes, as well as the influence of process parameters. Special emphasis to the joining of dissimilar materials using these processes. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MTGN586. DESIGN OF WELDED STRUCTURES AND ASSEMBLIES Introduction to the concepts and analytical practice of designing weldments. Designing for impact, fatigue, and torsional loading. Designing of weldments using overmatching and undermatching criteria. Analysis of combined stresses. Designing of compression members, column bases and splices. Designing of built-up columns, welded plate cylinders, beam-to-column connections, and trusses. Designing for tubular construction. Weld distortion and residual stresses. Joint design. Process consideration in weld design. Welding codes and specifications. Estimation of welding costs. Prerequisite/Co-requisite: MATH225 or equivalent, EGGN320 or equivalent, MTGN475 or Consent of Instructor. 3 hours lecture; 3 semester hours. (Summer of odd years only.)

MTGN587. PHYSICAL PHENOMENA OF WELDING AND JOINING PROCESSES (I) Introduction to arc physics, fluid flow in the plasma, behavior of high pressure plasma, cathodic and anodic phenomena, energy generation and temperature distribution in the plasma, arc stability, metal transfer across arc, electron beam welding processes, keyhole phenomena. Ohmic welding processes, high frequency welding, weld pool phenomena. Development of relationships between physics concepts and the behavior of specific welding and joining processes. Prerequisite/Co-requisite: PHGN300, MATH225, MTGN475, or Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of even years only.)

MTGN591. PHYSICAL PHENOMENA OF COATING PROCESSES (I) Introduction to plasma physics, behavior of low pressure plasma, cathodic and anodic phenomena, glow discharge phenomena, glow discharge sputtering, magnetron plasma deposition, ion beam deposition, cathodic arc evaporation, electron beam and laser coating processes. Development of relationships between physics concepts and the behavior of specific coating processes. Prerequisite/Co-requisite: PHGN300, MATH225, or Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of odd years only.)

MTGN598. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING (I, II) Pilot course or special topics course. Topics chosen according to special interests of instructor(s) and student(s). The course topic is generally offered only once. Prerequisite: Consent of Instructor. Variable hours lecture/lab; 1 to 6 semester hours. Repeatable for credit under different titles.

MTGN599. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member. Student and instructor to agree on subject matter, content, and credit hours. Prerequisite: "Independent Study" Form must be completed and submitted to the Registrar. 1 to 3 semester hours for each of two semesters. Repeatable for credit.

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MTGN631. TRANSPORT PHENOMENA IN METALLURGICAL AND MATERIALS SYSTEMS Physical principles of mass, momentum, and energy transport. Application to the analysis of extraction metallurgy and other physicochemical processes. Prerequisite: MATH225 and MTGN461 or equivalent, or Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN671 ADVANCED MATERIALS LABORATORY (I) Experimental and analytical research in the fields of production, mechanical, chemical, and/or physical metallurgy. Prerequisite: Consent of Instructor. 1 to 3 semester hours; 3 semester hours.

MTGN672. ADVANCED MATERIALS LABORATORY (II) Continuation of MTGN671. 1 to 3 semester hours.

MTGN696/MLGN696. VAPOR DEPOSITION PROCESSES (II) Introduction to the fundamental physics and chemistry underlying the control of deposition processes for thin films for a variety of applications—wear resistance, corrosion/oxidation resistance, decorative coatings, electronic and magnetic. Emphasis on the vapor deposition process variables rather than the structure and properties of the deposited film. Prerequisites: MTGN351, MTGN461, or equivalent courses or Consent of Instructor. 3 hours lecture; 3 semester hours. (Summer of odd years only.)

MTGN697. MICROSTRUCTURAL EVOLUTION OF COATINGS AND THIN FILMS (I) Introduction to aqueous and non-aqueous chemistry for the preparation of an effective electrolyte; for interpretation of electrochemical principles associated with electrodeposition; surface science to describe surface structure and transport; interphasial structure including space charge and double layer concepts; nucleation concepts applied to electrodeposition; electrocrystallization including growth concepts; factors affecting morphology and kinetics; co-deposition of non-Brownian particles; pulse electrodeposition; electrodeposition parameters and control; physical metallurgy of electrodeposits; and, principles associated with vacuum evaporation and sputter deposition. Factors affecting microstructural evolution of vacuum and sputtered deposits; nucleation of vapor and sputtered deposits; modeling of matter-energy interactions during co-deposition; and, Thornton's model for coating growth. Prerequisite/co-requisite: MATH225, MTGN351, MTGN352, or Consent of Instructor. 3 hours lecture; 3 semester hours. (Summer of even years only.)

MTGN698. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING (I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). The course topic is generally offered only once. Prerequisite: Consent of instructor. 1 to 3 semester hours per semester. Repeatable for credit under different titles.

MTGN699. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member. Student and instructor to agree on subject matter, content, and credit hours. Prerequisite: "Independent Study" Form must be completed and submitted to the Registrar. 1 to 3 semester hours for each of two semesters. Repeatable for credit.

MTGN705. GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science. Research under the direct supervision of the faculty advisor. Repeatable for credit.

MTGN706. GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy. Research under the direct supervision of the faculty advisor. Repeatable for credit.

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## Mining Engineering

TIBOR G. ROZGONYI, Professor and Department Head

KADRI DAGDELEN, Professor

UGUR OZBAY, Professor

LEVENT OZDEMIR, Professor and Director of Earth Mechanics Institute

MARK KUCHTA, Associate Professor

HUGH B. MILLER, Associate Professor

MASAMI NAKAGAWA, Associate Professor

MANOHAR ARORA, Senior Lecturer

MEHMET CIGLA, Research Assistant Professor

VILEM PETR, Research Assistant Professor

### *Degrees Offered:*

Master of Engineering (Engineer of Mines)

Master of Science (Mining and Earth Systems Engineering)

Doctor of Philosophy (Mining and Earth Systems Engineering)

### *Program Description:*

The program has two distinctive, but inherently interwoven specialties.

The **Mining Engineering** area or specialty is predominantly for mining engineers and it is directed towards the traditional mining engineering fields. Graduate work is normally centered around subject areas such as mine planning and development, computer aided mine design, rock mechanics, operations research applied to the mineral industry, environment and sustainability considerations, mine mechanization, mine evaluation, finance and management and similar mining engineering topics.

The **Earth Systems Engineering** area or specialty is designed to be distinctly interdisciplinary by merging the mining engineering fundamentals with civil, geotechnical, environmental or other engineering into advanced study tracks in earth systems, rock mechanics and earth structural systems, underground excavation, and construction systems. This specialty is open for engineers with different sub-disciplinary backgrounds, but interested in working and/or considering performing research in mining, tunneling, excavation and underground construction areas.

Graduate work is normally centered around subject areas such as site characterization, environmental aspects, underground construction and tunneling (including microtunneling), excavation methods and equipment, mechanization of mines and underground construction, environmental and management aspects, modeling and design in geoenvironmental engineering.

### *Program Requirements:*

The Master of Science degree in Mining and Earth Systems Engineering has two options available. Master of Science - Thesis and Master of Science - Non-Thesis. Thesis Option requires a minimum of 21 semester credit hours of course work and 9 semester credits of research, approved by student's graduate committee, plus a master's thesis. The Master of Sci-

ence - Non-Thesis option must complete a minimum of 30 credit hours of course work of which 6 credit hours may be applied towards the analytical report writing, if required.

The Master of Engineering degree (Engineer of Mines) in Mining Engineering includes all the requirements for the M.S. degree, with the sole exception that an "engineering report" is required rather than a Master's Thesis.

The Doctor of Philosophy degree in Mining and Earth Systems Engineering requires a total of 72 credit hours, beyond the bachelor's degree. A minimum of 18 credit hours of course work, and 24 hours of research credit is required. The thesis must be successfully defended before a doctoral committee.

### *Prerequisites:*

Students entering a graduate program for the master's or doctor's degree are expected to have had much the same undergraduate training as that required at Colorado School of Mines in mining, if they are interested in the traditional mining specialty. Students interested in the Earth Systems engineering specialty with different engineering sub-disciplinary background may also require special mining engineering subjects depending upon their graduate program. Deficiencies if any, will be determined by the Department of Mining Engineering on the basis of students' education, experience, and graduate study.

For specific information on prerequisites, students are encouraged to refer to a copy of the Mining Engineering Department's Departmental Guidelines and Regulations for Graduate Students, available from the Mining Engineering Department.

### *Required Curriculum:*

Graduate students, depending upon their specialty and background may be required to complete two of the three core courses listed below during their program of study at CSM.

These courses are:

MNGN508. Advanced Rock Mechanics

MNGN512 - Surface Mine Design

MNGN516 - Underground Mining

In addition, all full-time graduate students are required to register for and attend MNGN625 - Graduate Mining Seminar each semester while in residence, except in the case of scheduling conflicts with other course(s) approved by the thesis advisor.

### *Fields of Research:*

The Mining Engineering Department focuses on the following fundamental areas:

Geomechanics, Rock Mechanics and Stability of Underground and Surface Excavations

Computerized Mine Design and Related Applications (including Geostatistical Modeling)

Advanced Integrated Mining Systems Incorporating Mine Mechanization and Mechanical Mining Systems



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Underground Excavation (Tunneling) and Construction  
Site Characterization and Geotechnical Investigations,  
Modeling and Design in Geoengineering,  
Rock Fragmentation  
Mineral Processing, Communiton, Separation Technology  
Bulk Material Handling

### *Description of Courses*

MNGN404. TUNNELING (I) Modern tunneling techniques. Emphasis on evaluation of ground conditions, estimation of support requirements, methods of tunnel driving and boring, design systems and equipment, and safety. Prerequisite: none. 3 hours lecture; 3 semester hours.

MNGN405. ROCK MECHANICS IN MINING (I) The course deals with the rock mechanics aspect of design of mine layouts developed in both underground and surface. Underground mining sections include design of coal and hard rock pillars, mine layout design for tabular and massive ore bodies, assessment of caving characteristics or ore bodies, performance and application of backfill, and phenomenon of rock burst and its alleviation. Surface mining portion covers rock mass characterization, failure modes of slopes excavated in rock masses, probabilistic and deterministic approaches to design of slopes, and remedial measures for slope stability problems. Prerequisite: MN321 or equivalent. 3 hours lecture; 3 semester hours

MNGN406. DESIGN AND SUPPORT OF UNDERGROUND EXCAVATIONS Design of underground excavations and support. Analysis of stress and rock mass deformations around excavations using analytical and numerical methods. Collections, preparation, and evaluation of in situ and laboratory data for excavation design. Use of rock mass rating systems for site characterization and excavation design. Study of support types and selection of support for underground excavations. Use of numerical models for design of shafts, tunnels and large chambers. Prerequisite: Instructor's consent. 3 hours lecture; 3 semester hours. Offered in odd years.

MNGN407. ROCK FRAGMENTATION (II) Theory and application of rock drilling, rock boring, explosives, blasting, and mechanical rock breakage. Design of blasting rounds, applications to surface and underground excavation. Prerequisite: DCGN241, concurrent enrollment or Instructor's consent. 3 hours lecture; 3 semester hours. Offered in odd years.

MNGN408. UNDERGROUND DESIGN AND CONSTRUCTION Soil and rock engineering applied to underground civil works. Tunneling and the construction of underground openings for power facilities, water conveyance, transportation, and waste disposal; design, excavation and support of underground openings. Emphasis on consulting practice, case studies, geotechnical design, and construction methods. Prerequisite: EGGN361 OR MNGN321, or Instructor's consent. 2 hours of lecture; 2 semester hours.

MNGN410. EXCAVATION PROJECT MANAGEMENT. Successful implementation and management of surface and underground construction projects, preparation of contract documents, project bidding and estimating, contract awarding and notice to proceed, value engineering, risk management, construction management and dispute resolution, evaluation of differing site conditions claims. Prerequisite: MNGN 210 or Instructor's consent, 2-hour lecture, 2 semester hours.

MNGN414. MINE PLANT DESIGN Analysis of mine plant elements with emphasis on design. Materials handling, dewatering, hoisting, belt conveyor and other material handling systems for underground mines. Prerequisite: MNGN312, MNGN314 or Instructor's consent. 3 hours lecture, 3 hours lab; 3 semester hours.

MNGN418. ADVANCED ROCK MECHANICS Analytical and numerical modeling analysis of stresses and displacements induced around engineering excavations in rock. In-situ stress. Rock failure criteria. Complete load deformation behavior of rocks. Measurement and monitoring techniques in rock mechanics. Principles of design of excavation in rocks. Analytical, numerical modeling and empirical design methods. Probabilistic and deterministic approaches to rock engineering designs. Excavation design examples for shafts, tunnels, large chambers and mine pillars. Seismic loading of structures in rock. Phenomenon of rock burst and its alleviation. Prerequisite: MNGN321 or Instructor's consent. 3 hours lecture; 3 semester hours.

MNGN421. DESIGN OF UNDERGROUND EXCAVATIONS (II) Design of underground openings in competent and broken ground using rock mechanics principles. Rock bolting design and other ground support methods. Coal, evaporite, metallic and nonmetallic deposits included. Prerequisite: MNGN321, concurrent enrollment or Instructor's consent. 3 hours lecture; 3 semester hours.

MNGN422/522. FLOTATION Science and engineering governing the practice of mineral concentration by flotation. Interfacial phenomena, flotation reagents, mineral-reagent interactions, and zeta-potential are covered. Flotation circuit design and evaluation as well as tailings handling are also covered. The course also includes laboratory demonstrations of some fundamental concepts. 3 hours lecture; 3 semester hours.

MNGN423. FLOTATION LABORATORY (I) Experiments to accompany the lectures in MNGN422. Corequisite: MNGN421 or Instructor's consent. 3 hours lab; 1 semester hour

MNGN424. MINE VENTILATION (II) Fundamentals of mine ventilation, including control of gas, dust, temperature, and humidity; ventilation network analysis and design of systems. Prerequisite: EGGN351, 371 and MNGN314 or Instructor's consent. 2 hours lecture, 3 hours lab; 3 semester hours.

MNGN427. MINE VALUATION (II) Course emphasis is on the business aspects of mining. Topics include time valuation of money and interest formulas, cash flow, investment crite-

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ria, tax considerations, risk and sensitivity analysis, escalation and inflation and cost of capital. Calculation procedures are illustrated by case studies. Computer programs are used. Prerequisite: Senior in Mining, graduate status or Instructor's consent. 2 hours lecture; 2 semester hours.

MNGN428. MINING ENGINEERING EVALUATION AND DESIGN REPORT I (I) (WI) Preparation of phase I engineering report based on coordination of all previous work. Includes mineral deposit selection, geologic description, mining method selection, ore reserve determination, and permit process outline. Emphasis is on detailed mine design and cost analysis evaluation in preparation for MNGN429. 3 hours lab; 1 semester hour.

MNGN429. MINING ENGINEERING EVALUATION AND DESIGN REPORT II (II) (WI) Preparation of formal engineering report based on all course work in the mining option. Emphasis is on mine design, equipment selection, production scheduling, evaluation and cost analysis. Prerequisite: MNGN427, 428. 3 hours lab; 2 semester hours.

MNGN431. MINING AND METALLURGICAL ENVIRONMENT This course covers studies of the interface between mining and metallurgical process engineering and environmental engineering areas. Wastes, effluents and their point sources in mining and metallurgical processes such as mineral concentration, value extraction and process metallurgy are studied in context. Fundamentals of unit operations and unit processes with those applicable to waste and effluent control, disposal and materials recycling are covered. Engineering design and engineering cost components are also included for some examples chosen. The ratio of fundamentals to applications coverage is about 1:1. Prerequisite: Instructor's consent. 3 hours lecture; 3 semester hours.

MNGN433. MINE SYSTEMS ANALYSIS I (II) Application of statistics, systems analysis, and operations research techniques to mineral industry problems. Laboratory work using computer techniques to improve efficiency of mining operations. Prerequisite: senior or graduate status. 2 hours lecture, 3 hours lab; 3 semester hours.

MNGN434. PROCESS ANALYSIS Projects to accompany the lectures in MNGN422. Prerequisite: MNGN422 or Instructor's consent. 3 hours lab; 1 semester hour.

MNGN436. UNDERGROUND COAL MINE DESIGN (II) Design of an underground coal mine based on an actual coal reserve. This course shall utilize all previous course material in the actual design of an underground coal mine. Ventilation, materials handling, electrical transmission and distribution, fluid mechanics, equipment selection and application, mine plant design. Information from all basic mining survey courses will be used. Prerequisite: MNGN316, 321, 414, EGGN329 and DCGN381 or EGGN384. Concurrent enrollment with the Instructor's consent permitted. 3 hours lecture, 3 hours lab; 3 semester hours.

MNGN438. GEOSTATISTICS (I) Introduction to elementary probability theory and its applications in engineering and sciences; discrete and continuous probability distributions; parameter estimation; hypothesis testing; linear regression; spatial correlations and geostatistics with emphasis on applications in earth sciences and engineering. Prerequisites: MATH112. 2 hours of lecture and 3 hours of lab. 3 semester hours.

MNGN440. EQUIPMENT REPLACEMENT ANALYSIS (I) Introduction to the fundamentals of classical equipment replacement theory. Emphasis on new, practical approaches to equipment replacement decision making. Topics include: operating and maintenance costs, obsolescence factors, technological changes, salvage, capital investments, minimal average annual costs, optimum economic life, infinite and finite planning horizons, replacement cycles, replacement vs. expansion, maximization of returns from equipment replacement expenditures. Prerequisite: MNGN427, senior or graduate status. 2 hours lecture; 2 semester hours.

MNGN444. EXPLOSIVES ENGINEERING II This course gives students in engineering and applied sciences the opportunity to acquire the fundamental concepts of explosives engineering and science applications as they apply to industry and real life examples. Students will expand upon their MNGN 333 knowledge and develop a more advanced knowledge base including an understanding of the subject as it applies to their specific project interests. Assignments, quizzes, concept modeling and their project development and presentation will demonstrate student's progress. Prerequisite: none. 3 hours lecture, 3 semester hours.

MNGN445/545. ROCK SLOPE ENGINEERING Introduction to the analysis and design of slopes excavated in rock. Rock mass classification and strength determination, geological structural parameters, properties of fracture sets, data collection techniques, hydrological factors, methods of analysis of slope stability, wedge intersections, monitoring and maintenance of final pit slopes, classification of slides. Deterministic and probabilistic approaches in slope design. Remedial measures. Laboratory and field exercise in slope design. Collection of data and specimens in the field for determining physical properties required for slope design. Application of numerical modeling and analytical techniques to slope stability determinations for hard rock and soft rock environments. Prerequisite: Instructor's consent. 3 hours lecture. 3 hours semester hours.

MNGN460 INDUSTRIAL MINERALS PRODUCTION (II) This course describes the engineering principles and practices associated with quarry mining operations related to the cement and aggregate industries. The course will cover resource definition, quarry planning and design, extraction, and processing of minerals for cement and aggregate production. Permitting issues and reclamation, particle sizing and environmental practices, will be studied in depth. Prerequisite: MNGN312,

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MNGN318, MNGN322, MNGN323, or Instructor's consent. 3 hours lecture; 3 semester hours.

MNGN482. MINE MANAGEMENT (II) Basic principles of successful mine management, supervision, administrative policies, industrial and human engineering. Prerequisite: Senior or graduate status or Instructor's consent. 2 hours lecture; 2 semester hours. Offered in odd years.

MNGN498. SPECIAL TOPICS IN MINING ENGINEERING (I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

MNGN499. INDEPENDENT STUDY (I, II) (WI) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

#### Graduate Courses

500-level courses are open to qualified seniors with permission of the department and Dean of the Graduate School. 600-level courses are open only to students enrolled in the Graduate School.

MNGN501. REGULATORY MINING LAWS AND CONTRACTS (I) Basic fundamentals of engineering law, regulations of federal and state laws pertaining to the mineral industry and environment control. Basic concepts of mining contracts. Offered in even numbered years. Prerequisite: Senior or graduate status. 3 hours lecture; 3 semester hours. Offered in even years.

MNGN503. MINING TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT (I, II) The primary focus of this course is to provide students an understanding of the fundamental principles of sustainability and how they influence the technical components of a mine's life cycle, beginning during project feasibility and extending through operations to closure and site reclamation. Course discussions will address a wide range of traditional engineering topics that have specific relevance and impact to local and regional communities, such as mining methods and systems, mine plant design and layout, mine operations and supervision, resource utilization and cutoff grades, and labor. The course will emphasize the importance of integrating social, political, and economic considerations into technical decision-making and problem solving. 3 hours lecture; 3 semester hours

MNGN505. ROCK MECHANICS IN MINING (I) The course deals with the rock mechanics aspect of design of mine layouts developed in both underground and surface. Underground mining sections include design of coal and hard rock pillars, mine layout design for tabular and massive ore bodies, assessment of caving characteristics or ore bodies,

performance and application of backfill, and phenomenon of rock burst and its alleviation. Surface mining portion covers rock mass characterization, failure modes of slopes excavated in rock masses, probabilistic and deterministic approaches to design of slopes, and remedial measures for slope stability problems. Prerequisite: MN321 or equivalent. 3 hours lecture; 3 semester hours

MNGN506. DESIGN AND SUPPORT OF UNDERGROUND EXCAVATIONS Design of underground excavations and support. Analysis of stress and rock mass deformations around excavations using analytical and numerical methods. Collections, preparation, and evaluation of in situ and laboratory data for excavation design. Use of rock mass rating systems for site characterization and excavation design. Study of support types and selection of support for underground excavations. Use of numerical models for design of shafts, tunnels and large chambers. Prerequisite: Instructor's consent. 3 hours lecture; 3 semester hours. Offered in odd years.

MNGN507. ADVANCED DRILLING AND BLASTING (I) An advanced study of the theories of rock penetration including percussion, rotary, and rotary percussion drilling. Rock fragmentation including explosives and the theories of blasting rock. Application of theory to drilling and blasting practice at mines, pits, and quarries. Prerequisite: MNGN407. 3 hours lecture; 3 semester hours. Offered in odd years.

MNGN508. ADVANCED ROCK MECHANICS Analytical and numerical modeling analysis of stresses and displacements induced around engineering excavations in rock. In-situ stress. Rock failure criteria. Complete load deformation behavior of rocks. Measurement and monitoring techniques in rock mechanics. Principles of design of excavation in rocks. Analytical, numerical modeling and empirical design methods. Probabilistic and deterministic approaches to rock engineering designs. Excavation design examples for shafts, tunnels, large chambers and mine pillars. Seismic loading of structures in rock. Phenomenon of rock burst and its alleviation. Prerequisite: MNGN321 or professor's consent. 3 hours lecture; 3 semester hours.

MNGN511. MINING INVESTIGATIONS (I, II) Investigational problems associated with any important aspect of mining. Choice of problem is arranged between student and instructor. Prerequisite: Consent of instructor. Lecture, consultation, lab, and assigned reading; 2 to 4 semester hours.

MNGN512. SURFACE MINE DESIGN Analysis of elements of surface mine operation and design of surface mining system components with emphasis on minimization of adverse environmental impact and maximization of efficient use of mineral resources. Ore estimates, unit operations, equipment selection, final pit determinations, short- and long-range planning, road layouts, dump planning, and cost estimation. Prerequisite: MNGN210. 3 hours lecture; 3 semester hours.

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MNGN513 ADVANCED SURFACE MINE DESIGN (II)

This course introduces students to alternative open pit planning and design concepts. Course emphasis is on optimization aspects of open pit mine design. Topics include 3-D ultimate pit limit algorithms and their applications; computer aided haul road and dump designs; heuristic long- and short-term pit scheduling techniques; parametrization concepts; mathematical optimization for sequencing and scheduling; ore control and truck dispatching. Design procedures are illustrated by case studies using various computer programs. Prerequisite: MNGN308, MNGN312, or consent of instructor. 3 hours lecture; 3 semester hours.

MNGN514. MINING ROBOTICS (I) Fundamentals of robotics as applied to the mining industry. The focus is on mobile robotic vehicles. Topics covered are mining applications, introduction and history of mobile robotics, sensors, including vision, problems of sensing variations in rock properties, problems of representing human knowledge in control systems, machine condition diagnostics, kinematics, and path finding. Prerequisite: CSCI404 or consent of instructor. 3 hours lecture; 3 semester hours. Offered in odd years.

MNGN515. MINE MECHANIZATION AND AUTOMATION

This course will provide an in-depth study of the current state of the art and future trends in mine mechanization and mine automation systems for both surface and underground mining, review the infrastructure required to support mine automation, and analyze the potential economic and health and safety benefits. Prerequisite: MNGN312, MNGN314, MNGN316, or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours. Fall of odd years.

MNGN516. UNDERGROUND MINE DESIGN Selection, design, and development of most suitable underground mining methods based upon the physical and the geological properties of mineral deposits (metallics and nonmetallics), conservation considerations, and associated environmental impacts. Reserve estimates, development and production planning, engineering drawings for development and extraction, underground haulage systems, and cost estimates. Prerequisite: MNGN210. 2 hours lecture, 3 hours lab; 3 semester hours.

MNGN517. ADVANCED UNDERGROUND MINING (II)

Review and evaluation of new developments in advanced underground mining systems to achieve improved productivity and reduced costs. The major topics covered include: mechanical excavation techniques for mine development and production, new haulage and vertical conveyance systems, advanced ground support and roof control methods, mine automation and monitoring, new mining systems and future trends in automated, high productivity mining schemes. Prerequisite: Underground Mine Design (e.g., MNGN314). 3 hours lecture; 3 semester hours.

MNGN518. ADVANCED BULK UNDERGROUND MINING TECHNIQUES

This course will provide advanced knowledge and understanding of the current state-of-the-art in design, development, and production in underground hard rock mining using bulk-mining methods. Design and layout of sublevel caving, block caving, open stoping and blasthole stoping systems. Equipment selection, production scheduling, ventilation design, and mining costs. Prerequisites: MNGN314, MNGN516, or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours. Spring of odd years.

MNGN519. ADVANCED SURFACE COAL MINE DESIGN (II)

Review of current manual and computer methods of reserve estimation, mine design, equipment selection, and mine planning and scheduling. Course includes design of a surface coal mine for a given case study and comparison of manual and computer results. Prerequisite: MNGN312, 316, 427. 2 hours lecture, 3 hours lab; 3 semester hours. Offered in odd years.

MNGN520. ROCK MECHANICS IN UNDERGROUND COAL MINING (I)

Rock mechanics consideration in the design of room-and-pillar, longwall, and shortwall coal mining systems. Evaluation of bump and outburst conditions and remedial measures. Methane drainage systems. Surface subsidence evaluation. Prerequisite: MNGN321. 3 hours lecture; 3 semester hours. Offered in odd years.

MNGN422/522. FLOTATION Science and engineering governing the practice of mineral concentration by flotation.

Interfacial phenomena, flotation reagents, mineral-reagent interactions, and zeta-potential are covered. Flotation circuit design and evaluation as well as tailings handling are also covered. The course also includes laboratory demonstrations of some fundamental concepts. 3 hours lecture; 3 semester hours.

MNGN523. SELECTED TOPICS (I, II) Special topics in mining engineering, incorporating lectures, laboratory work or independent study, depending on needs. This course may be repeated for additional credit only if subject material is different. Prerequisite: Consent of instructor. 2 to 4 semester hours. Repeatable for credit under different titles.

MNGN525. INTRODUCTION TO NUMERICAL TECHNIQUES IN ROCK MECHANICS (I)

Principles of stress and infinitesimal strain analysis are summarized, linear constitutive laws and energy methods are reviewed. Continuous and laminated models of stratified rock masses are introduced. The general concepts of the boundary element and finite element methods are discussed. Emphasis is placed on the boundary element approach with displacement discontinuities, because of its relevance to the modeling of the extraction of tabular mineral bodies and to the mobilization of faults, joints, etc. Several practical problems, selected from rock mechanics and subsidence engineering practices, are treated to demonstrate applications of the techniques. Prerequisite: MNGN321, EGGN320, or equivalent courses, MATH455 or consent of instructor. 3 hours lecture; 3 semester hours. Offered in even years.



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MNGN526. MODELING AND MEASURING IN GEOMECHANICS (II) Introduction to instruments and instrumentation systems used for making field measurements (stress, convergence, deformation, load, etc.) in geomechanics. Techniques for determining rock mass strength and deformability. Design of field measurement programs. Interpretation of field data. Development of predictive models using field data. Introduction to various numerical techniques (boundary element, finite element, FLAC, etc.) for modeling the behavior of rock structures. Demonstration of concepts using various case studies. Prerequisite: Graduate standing or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours. Offered in odd years.

MNGN527. THEORY OF PLATES AND SHELLS Classical methods for the analysis of stresses in plate type structure are presented first. The stiffness matrices for plate element will be developed and used in the finite element method of analysis. Membrane and bending stresses in shells are derived. Application of the theory to tunnels, pipes, pressure vessels, and domes, etc., will be included. Prerequisites: EGGN320 or instructor's consent. 3 hours lecture; 3 credit hours.

MNGN528. MINING GEOLOGY (I) Role of geology and the geologist in the development and production stages of a mining operation. Topics addressed: mining operation sequence, mine mapping, drilling, sampling, reserve estimation, economic evaluation, permitting, support functions. Field trips, mine mapping, data evaluation, exercises and term project. Prerequisite: GEGN401 or GEGN405 or permission of instructors. 2 hours lecture/seminar, 3 hours laboratory; 3 semester hours. Offered in even years.

MNGN530. INTRODUCTION TO MICRO COMPUTERS IN MINING (I) General overview of the use of PC based micro computers and software applications in the mining industry. Topics include the use of: database, CAD, spreadsheets, computer graphics, data acquisition, and remote communications as applied in the mining industry. Prerequisite: Any course in computer programming. 2 hours lecture, 3 hours lab; 3 semester hours.

MNGN536. OPERATIONS RESEARCH TECHNIQUES IN THE MINERAL INDUSTRY Analysis of exploration, mining, and metallurgy systems using statistical analysis. Monte Carlo methods, simulation, linear programming, and computer methods. Prerequisite: MNGN433 or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours. Offered in even years.

MNGN538. GEOSTATISTICAL ORE RESERVE ESTIMATION (I) Introduction to the application and theory of geostatistics in the mining industry. Review of elementary statistics and traditional ore reserve calculation techniques. Presentation of fundamental geostatistical concepts, including: variogram, estimation variance, block variance, kriging, geostatistical simulation. Emphasis on the practical aspects

of geostatistical modeling in mining. Prerequisite: MATH323 or equivalent course in statistics; graduate or senior status. 3 hours lecture; 3 semester hours.

MNGN539. ADVANCED MINING GEOSTATISTICS (II) Advanced study of the theory and application of geostatistics in mining engineering. Presentation of state-of-the-art geostatistical concepts, including: robust estimation, nonlinear geostatistics, disjunctive kriging, geostatistical simulation, computational aspects. This course includes presentations by many guest lecturers from the mining industry. Emphasis on the development and application of advanced geostatistical techniques to difficult problems in the mining industry today. 3 hours lecture; 3 semester hours. Offered in odd years.

MNGN545/445 ROCK SLOPE ENGINEERING Introduction to the analysis and design of slopes excavated in rock. Rock mass classification and strength determinations, geological structural parameters, properties of fracture sets, data collection techniques, hydrological factors, methods of analysis of slope stability, wedge intersections, monitoring and maintenance of final pit slopes, classification of slides. Deterministic and probabilistic approaches in slope design. Remedial measures. Laboratory and field exercise in slope design. Collection of data and specimens in the field for determining physical properties required for slope design. Application of numerical modeling and analytical techniques to slope stability determinations for hard rock and soft rock environments. Prerequisite: Instructor's consent. 3 hours lecture. 3 hours semester hours.

MNGN549/EGES549. MARINE MINING SYSTEMS (I) Define interdisciplinary marine mining systems and operational requirements for the exploration survey, sea floor mining, hoisting, and transport. Describe and design components of deep-ocean, manganese-nodule mining systems and other marine mineral extraction methods. Analyze dynamics and remote control of the marine mining systems interactions and system components. Describe the current state-of-the-art technology, operational practice, trade-offs of the system design and risk. Prerequisite: EGGN351, EGGN320, GEOC408 or consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate even years.

MNGN559/EGES559. MECHANICS OF PARTICULATE MEDIA (1) This course allows students to establish fundamental knowledge of quasi-static and dynamic particle behavior that is beneficial to interdisciplinary material handling processes in the chemical, civil, materials, metallurgy, geophysics, physics, and mining engineering. Issues of interest are the definition of particle size and size distribution, particle shape, nature of packing, quasi-static behavior under different external loading, particle collisions, kinetic theoretical modeling of particulate flows, molecular dynamic simulations, and a brief introduction of solid-fluid two-phase flows. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Fall semesters, every other year.

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MNGN550. NEW TECHNIQUES IN MINING (II) Review of various experimental mining procedures, including a critical evaluation of their potential applications. Mining methods covered include deep sea nodule mining, in situ gassification of coal, in situ retorting of oil shale, solution mining of soluble minerals, in situ leaching of metals, geothermal power generation, oil mining, nuclear fragmentation, slope caving, electro-thermal rock penetration and fragmentation. Prerequisite: Graduate standing or consent of instructor. 3 hours lecture; 3 semester hours. Offered in even years.

MNGN452/MNGN552. SOLUTION MINING AND PROCESSING OF ORES Theory and application of advanced methods of extracting and processing of minerals, underground or in situ, to recover solutions and concentrates of value-materials, by minimization of the traditional surface processing and disposal of tailings to minimize environmental impacts. Prerequisites: Senior or graduate status; instructor's consent 3 hours lecture; 3 semester hours. Offered in spring.

MNGN585. MINING ECONOMICS (I) Advanced study in mine valuation with emphasis on revenue and cost aspects. Topics include price and contract consideration in coal, metal and other commodities; mine capital and operating cost estimation and indexing; and other topics of current interest. Prerequisite: MNGN427 or EBG504 or equivalent. 3 hours lecture; 3 semester hours. Offered in even years.

MNGN590. MECHANICAL EXCAVATION IN MINING (II) This course provides a comprehensive review of the existing and emerging mechanical excavation technologies for mine development and production in surface and underground mining. The major topics covered in the course include: history and development of mechanical excavators, theory and principles of mechanical rock fragmentation, design and performance of rock cutting tools, design and operational characteristics of mechanical excavators (e.g. continuous miners, roadheaders, tunnel boring machines, raise drills, shaft borers, impact miners, slotters), applications to mine development and production, performance prediction and geotechnical investigations, costs versus conventional methods, new mine designs for applying mechanical excavators, case histories, future trends and anticipated developments and novel rock fragmentation methods including water jets, lasers, microwaves, electron beams, penetrators, electrical discharge and sonic rock breakers. Prerequisite: Senior or graduate status. 3 hours lecture; 3 semester hours. Offered in odd years.

MNGN598. SPECIAL TOPICS IN MINING ENGINEERING (I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

MNGN599. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

MNGN625. GRADUATE MINING SEMINAR (I, II) Discussions presented by graduate students, staff, and visiting lecturers on research and development topics of general interest. Required of all graduate students in mining engineering every semester during residence. 1 semester hour upon completion of thesis or residence.

MNGN698. SPECIAL TOPICS IN MINING ENGINEERING (I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

MNGN699. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

MNGN700. GRADUATE ENGINEERING REPORT-MASTER OF ENGINEERING (I, II) Laboratory, field, and library work for the Master of Engineering report under supervision of the student's advisory committee. Required of candidates for the degree of Master of Engineering. Variable 1 to 6 hours. Repeatable for credit to a maximum of 6 hours.

MNGN705 GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

MNGN706 GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty advisor. Repeatable for credit.

GOGN501. SITE INVESTIGATION AND CHARACTERIZATION An applications oriented course covering: geological data collection, geophysical methods for site investigation; hydrological data collection; materials properties determination; and various engineering classification systems. Presentation of data in a format suitable for subsequent engineering design will be emphasized. Prerequisite: Introductory courses in geology, rock mechanics, and soil mechanics. 3 hours lecture; 3 semester hours.

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GOGN502. SOLID MECHANICS APPLIED TO ROCKS

An introduction to the deformation and failure of rocks and rock masses and to the flow of groundwater. Principles of displacement, strain and stress, together with the equations of equilibrium are discussed. Elastic and plastic constitutive laws, with and without time dependence, are introduced. Concepts of strain hardening and softening are summarized. Energy principles, energy changes caused by underground excavations, stable and unstable equilibria are defined. Failure criteria for intact rock and rock masses are explained. Principles of numerical techniques are discussed and illustrated. Basic laws and modeling of groundwater flows are introduced. Prerequisite: Introductory Rock Mechanics. 3 hours lecture; 3 semester hours.

GOGN503. CHARACTERIZATION AND MODELING LABORATORY An applications oriented course covering: Advanced rock testing procedures; dynamic rock properties determination; on-site measurements; and various rock mass modeling approaches. Presentation of data in a format suitable for subsequent engineering design will be emphasized. Prerequisite: Introductory courses in geology, rock mechanics, and soil mechanics. 3 hours lecture; 3 semester hours.

GOGN504. SURFACE STRUCTURES IN EARTH MATERIALS Principles involved in the design and construction of surface structures involving earth materials. Slopes and cuts. Retaining walls. Tailing dams. Leach dumps. Foundations. Piles and piers. Extensive use of case examples. Prerequisites: GOGN501, GOGN502, GOGN503. 3 hours lecture; 3 semester hours.

GOGN505. UNDERGROUND EXCAVATION IN ROCK Components of stress, stress distributions, underground excavation failure mechanisms, optimum orientation and shape of excavations, excavation stability, excavation support design, ground treatment and rock pre-reinforcement, drill and blast excavations, mechanical excavation, material haulage, ventilation and power supply, labor requirements and training, scheduling and costing of underground excavations, and case histories. Prerequisites: GOGN501, GOGN502, GOGN503. 3 hours lecture; 3 semester hours.

GOGN506. EXCAVATION PROJECT MANAGEMENT

Normal project initiation, design procedures, project financing, permitting and environmental impacts, preparation of plans and specifications, contract award, notice to proceed and legal requirements. Construction alternatives, contract types, standard contract language, bidding and estimating and contract awarding procedures. Construction inspection and control methods and completion procedures. Conflict resolution, administrative redress, arbitration and litigation. Time and tonnage based incentive programs. The role of experts. Prerequisite: College-level in Microeconomics or Engineering Economy. Degree in Engineering. 2 hours lecture; 2 semester hours.

GOGN625. GEO-ENGINEERING SEMINAR Discussions presented by graduate students, staff, and visiting lectures on research and development topics of general interest. Required of all graduate students in Geo-Engineering every semester, during residence. Prerequisite: Enrollment in Geo-Engineering Program. 1 semester hour upon completion of thesis or residence.

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## Nuclear Engineering

UWE GREIFE, Interim Academic Program Chair, Associate Professor Physics

### Department of Chemistry

JAMES F. RANVILLE, Associate Professor Chemistry and Geochemistry

### Department of Engineering

TERRY PARKER, Professor and Division Director  
MARK LUSK, Professor  
KEVIN MOORE, Gerard August Dobelman Chair and Professor  
RAY ZHANG, Associate Professor

### Department of Environmental Science and Engineering

BRUCE D. HONEYMAN, Professor  
LINDA A. FIGUEROA, Associate Professor  
JOHN R. SPEAR, Assistant Professor  
ROBERT F. HOLUB, Research Professor

### Department of Geology and Geological Engineering

JOHN D. HUMPHREY, Associate Professor and Interim Department Head  
SAMUEL B. ROMBERGER, Professor

### Department of Liberal Arts and International Studies

CARL MITCHAM, Professor

### Department of Metallurgical and Materials Engineering

JOHN J. MOORE, Trustees Professor and Department Head  
STEPHEN LIU, Professor  
DAVID K. MATLOCK, Charles S. Fogarty Professor  
BRAJENDRA MISHRA, Professor  
DAVID L. OLSON, John H. Moore Distinguished Professor  
IVAR E. REIMANIS, Professor  
JOHN G. SPEER, Professor

### Department of Mining Engineering

TIBOR G. ROZGONYI, Professor and Department Head  
LEVENT OZDEMIR, Professor and Director of Earth Mechanics Institute  
MARK KUCHTA, Associate Professor

### Department of Physics

JAMES A. McNEIL, Professor and Department Head  
F. EDWARD CECIL, Professor Emeritus  
FREDERIC SARAZIN, Assistant Professor

### Degrees Offered

- Master of Science (Nuclear Engineering), Thesis option
- Master of Science (Nuclear Engineering), Non-thesis option
- Doctor of Philosophy (Nuclear Engineering)

### Program Description:

The Nuclear Engineering program at the Colorado School of Mines is interdisciplinary in nature and drawing substantial contributions from the Division of Engineering, the Department of Geology and Geological Engineering, the

Department of Mining Engineering, the Department of Physics, the Department of Metallurgical and Materials Engineering, the Division of Environmental Science and Engineering, and the Division of Liberal Arts and International Studies. While delivering a traditional Nuclear Engineering course core, the School of Mines program for the Nuclear Engineering degree emphasizes the nuclear fuel life cycle. Faculty bring to the program expertise in all aspects of the nuclear fuel life cycle; fuel exploration and processing, nuclear power systems production, design and operation, fuel recycling, storage, waste remediation, radiation detection and radiation damage as well as the policy issues surrounding each of these activities. Related research is conducted in CSM's Nuclear Science and Engineering Center.

For both the M.S. and PhD degrees, graduates of the Nuclear Engineering program have been exposed to a broad systems overview of the complete nuclear fuel cycle as well as having detailed expertise in a particular component of the cycle. Breadth will be assured by requiring all students to complete a rigorous set of core courses. The core consists of a 6-credit-hour course sequence; initially delivered in part by a collaborating institution through distance learning. The remainder of the course and research work is obtained from the multiple participating departments, as approved for each student by the student's advisor and thesis committee.

### Combined Degree Program Option:

CSM undergraduate students have the opportunity to begin work on a M.S. degree in Nuclear Engineering while completing their Bachelor's degree. The CSM Combined Degree Program provides the vehicle for students to use up to 6 credit hours of undergraduate coursework as part of their Graduate Degree curriculum. For more information please contact the Nuclear Engineering program director.

### Program Requirements:

**M.S. Non-Thesis Option:** 36 total credit hours, consisting of core coursework (21 h), seminar in a participating department (2h), additional elective courses (9 h) and Independent Study (4 h) working on a research project with a faculty member working in nuclear science and engineering.

**M.S. Thesis Option:** 36 total credit hours, consisting of core coursework (21 h), seminar in a participating department (2h) and research (13 h). Students must write and orally defend a research thesis.

**Ph.D.:** 72 total credit hours, consisting of coursework (21 h of core and at least 12 h electives), seminar in a participating department (4h) and research (at least 24 h).

Ph.D. students must also successfully complete the program's quality control process (which includes a dissertation proposal and defense) as well as write and defend a doctoral dissertation. The quality of the research is expected to rise to the level where it can be submitted for publication in scholarly journals.



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### *Thesis Committee Requirements*

Students must meet the general requirements listed in the Graduate Bulletin section Graduate Degrees and Requirements. In addition, the student's advisor or co-advisor must be an active faculty members of CSM's Nuclear Engineering program. For M.S. thesis students, at least two, for doctoral students, at least three committee members must be a faculty member of the Nuclear Engineering program.

### *Prerequisites:*

- baccalaureate degree in a science or engineering discipline
- mathematics coursework up to and including differential equations
- physics coursework up to and including courses in modern physics and introductory nuclear physics
- engineering thermodynamics, heat transfer and fluid flow (or equivalent courses)

Note that some pre-requisites may be completed in the first semesters of the graduate program after consultation with the student's advisor.

### *Required Curriculum:*

All degree offerings within the Nuclear Engineering program are based on a set of required courses. These include the following:

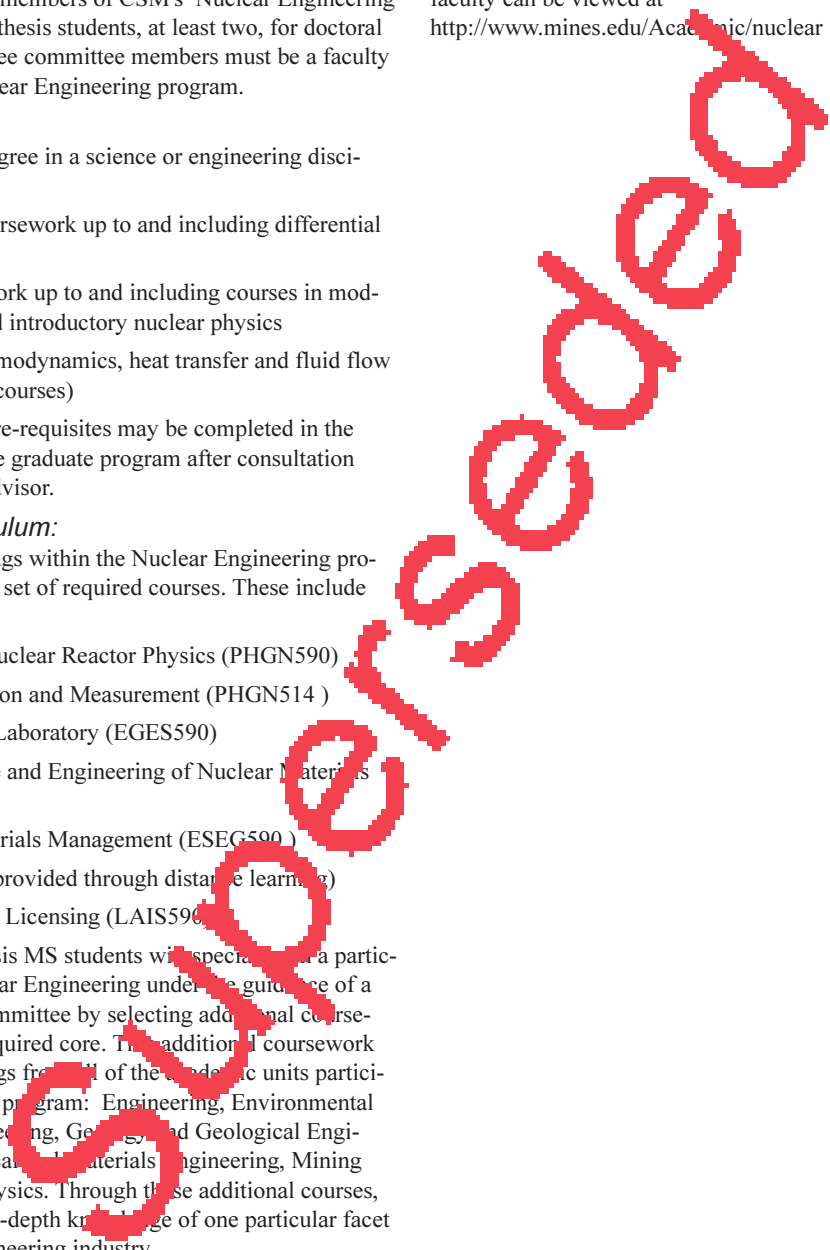
- Introduction to Nuclear Reactor Physics (PHGN590)
- Radiation Detection and Measurement (PHGN514)
- Nuclear Reactor Laboratory (EGES590)
- Materials Science and Engineering of Nuclear Materials (MTGN590)
- Radioactive Materials Management (ESEG590)
- Reactor Design (provided through distance learning)
- Public Policy and Licensing (LAIS590)

PhD and non-thesis MS students will specialize in a particular aspect of Nuclear Engineering under the guidance of a student advisory committee by selecting additional coursework beyond the required core. This additional coursework may include offerings from all of the academic units participating in the degree program: Engineering, Environmental Sciences and Engineering, Geology and Geological Engineering, Metallurgical and Materials Engineering, Mining Engineering and Physics. Through these additional courses, students will gain in-depth knowledge of one particular facet of the Nuclear Engineering industry.

Students in research-based degree programs, thesis-based MS and PhD degrees, are required to complete the minimum research credit hour requirements leading to dissertation and defense. Research is conducted under the direction of a member of CSM's Nuclear Science and Engineering program and could be tied to a research opportunity provided by industry partners.

### *Description of Courses*

Nuclear Engineering courses are taken from existing courses at CSM. In addition to the core courses listed above, the elective courses approved by the Nuclear Engineering faculty can be viewed at <http://www.mines.edu/Academic/nuclear>.



## Nuclear Science and Engineering

UWE GREIFE, Interim Academic Program Director, Associate Professor Physics

JOHN J. MOORE, Interim Research Program Director, Trustees Professor and Department Head Metallurgical and Materials Engineering

KEVIN W. MANDERNACK, Associate Professor Chemistry and Geochemistry

JAMES F. RANVILLE, Associate Professor Chemistry and Geochemistry

E. CRAIG SIMMONS, Associate Professor Chemistry and Geochemistry

TERRY PARKER, Professor and Division Director Engineering

KEVIN MOORE, Gerard August Dobelman Chair and Professor Engineering

MARK LUSK, Professor Engineering (and Physics)

RAY ZHANG, Associate Professor Engineering

BRUCE D. HONEYMAN, Professor Environmental Science and Engineering

LINDA A. FIGUEROA, Associate Professor Environmental Science and Engineering

JOHN R. SPEAR, Assistant Professor Environmental Science and Engineering

JOHN D. HUMPHREY, Associate Professor and Interim Department Head Geology and Geological Engineering

SAMUEL B. ROMBERGER, Professor Geology and Geological Engineering

CARL MITCHAM, Professor Liberal Arts and International Studies

JENNIFER SCHNEIDER, Assistant Professor Liberal Arts and International Studies

STEPHEN LIU, Professor Metallurgical and Materials Engineering

BRAJENDRA MISHRA, Professor Metallurgical and Materials Engineering

DAVID K. MATLOCK, Charles S. Fogarty Professor Metallurgical and Materials Engineering

DAVID L. OLSON, John H. Moore Distinguished Professor Metallurgical and Materials Engineering

IVAR E. REIMANIS, Professor Metallurgical and Materials Engineering

JOHN G. SPEER, Professor Metallurgical and Materials Engineering

PATRICK R. TAYLOR, George S. Ansell Distinguished Professor of Chemical Metallurgy Metallurgical and Materials Engineering

EDGAR E. VIDAL, Assistant Professor Metallurgical and Materials Engineering

Martin Mataya, Assistant Professor Metallurgical and Materials Engineering

TIBOR G. ROZGONYI, Professor and Department Head Mining Engineering

LEVENT OZDEMIR, Professor and Director of Earth Mechanics Institute Mining Engineering

MARK KUCHTA, Associate Professor Mining Engineering

JAMES A. McNEIL, Professor Physics

F. EDWARD CECIL, Professor Emeritus Physics

FREDERIC SARAZIN, Assistant Professor Physics

ROBERT F. HOLUB, Research Professor Physics

### *Degrees Offered:*

Master of Science (Nuclear Engineering), Thesis option

Master of Science (Nuclear Engineering), Non-thesis option

Doctor of Philosophy (Nuclear Engineering)

In addition, students majoring in allied fields may complete a minor degree program, consisting of 12 credit hours of coursework, through the Nuclear Science and Engineering Program. Minor programs are designed to allow students in allied fields to acquire and then indicate, in a formal way, specialization in a nuclear-related area of expertise.

### *Program Description:*

The Nuclear Science and Engineering program at the Colorado School of Mines is interdisciplinary in nature and drawing substantial contributions from the Department of Chemistry, Division of Engineering, the Division of Environmental Science and Engineering, the Department of Geology and Geological Engineering, the Division of Liberal Arts and International Studies, the Department of Metallurgical and Materials Engineering, the Department of Mining Engineering, and the Department of Physics. While delivering a traditional Nuclear Engineering course core, the School of Mines program in Nuclear Science and Engineering emphasizes the nuclear fuel life cycle. Faculty bring to the program expertise in all aspects of the nuclear fuel life cycle; fuel exploration and processing, nuclear power systems production, design and operation, fuel recycling, storage and waste remediation, radiation detection and radiation damage as well as the policy issues surrounding each of these activities. Related research is conducted in CSM's Nuclear Science and Engineering Center.

### *Nuclear Engineering Degree Options and Requirements*

For both the MS and PhD degrees, graduates in Nuclear Engineering are exposed to a broad systems overview of the complete nuclear fuel cycle as well as having detailed expertise in a particular component of the cycle. Breadth is assured by requiring all students to complete a rigorous set of core courses. The core consists of a 21 credit-hour course sequence. The remainder of the course and research work is obtained from the multiple participating departments, as approved for each student by the student's advisor and thesis committee.

### *Combined Degree Program Option*

CSM undergraduate students have the opportunity to begin work on a M.S. degree in Nuclear Engineering while completing their Bachelor's degree. The CSM Combined Degree Program provides the vehicle for students to use up to 6 credit hours of undergraduate coursework as part of their Graduate Degree curriculum. For more information please contact the Nuclear Engineering program director.

### *Program Requirements*

M.S. Non-Thesis Option: 36 total credit hours, consisting of core coursework (21 h), seminar in a participating department (2h), additional elective courses (9 h) and Independent Study (4 h) working on a research project with a faculty member working in nuclear science and engineering.

M.S. Thesis Option: 36 total credit hours, consisting of core coursework (21 h), seminar in a participating department (2h) and research (13 h). Students must write and orally defend a research thesis.

Ph.D.: 72 total credit hours, consisting of coursework (21 h of core and at least 12 h electives), seminar in a participating department (4h) and research (at least 24 h).

Ph.D. students must also successfully complete the program's quality control process (which includes a dissertation proposal and defense) as well as write and defend a doctoral dissertation. The quality of the research is expected to rise to the level where it can be submitted for publication in scholarly journals.

### *Thesis Committee Requirements*

Students must meet the general requirements listed in the Graduate Bulletin section *Graduate Degrees and Requirements*. In addition, the student's advisor or co-advisor must be an active faculty member of CSM's Nuclear Science and Engineering program. For M.S. thesis students, at least two, for doctoral students, at least three committee members must be faculty members of the Nuclear Science and Engineering program.

### *Prerequisites*

- baccalaureate degree in a science or engineering discipline
- mathematics coursework up to and including differential equations
- physics coursework up to and including courses in modern physics and introductory nuclear physics
- engineering thermodynamics, heat transfer and fluid flow or equivalent

Note that some pre-requisites may be completed in the first semesters of the graduate program after consultation with the student's advisor.

### *Required Curriculum*

All degree offerings within the Nuclear Engineering program are based on a set of required core courses. These include the following:

- Introduction to Nuclear Reactor Physics (PHGN590)
- Radiation Detection and Measurement (PGHN504 )
- Nuclear Reactor Laboratory (EGES590 – taught in collaboration with the USGS)
- Materials Science and Engineering of Nuclear Materials (MTGN590)
- Radioactive Materials Management (ESGN590 )

- Reactor Design
- Public Policy and Licensing (LAIS590)

As part of the Program's quality control process, PhD students need to achieve a 3.0 grade point average in the seven core courses or pass oral examinations in areas of weakness identified by the student's Thesis Committee.

PhD and non-thesis MS students will specialize in a particular aspect of Nuclear Engineering under the guidance of a student advisory committee by selecting additional coursework beyond the required core. This additional coursework may include offerings from all of the academic units participating in the degree program: Engineering, Environmental Sciences and Engineering, Geology and Geological Engineering, Liberal Arts and International Studies, Metallurgical and Materials Engineering, Mining Engineering and Physics. Through these additional courses, students gain in-depth knowledge of one particular facet of the Nuclear Engineering industry.

Students in research-based degree programs, thesis-based MS and PhD degrees, are required to complete the minimum research credit hour requirements leading to dissertation and defense. Research is conducted under the direction of a member of CSM's Nuclear Science and Engineering program and could be tied to a research opportunity provided by industry partners.

### *Minor Degree Programs*

Students majoring in allied fields may choose to complete minor degree programs through the Nuclear Science and Engineering Program indicating specialization in a nuclear-related area of expertise. Minor programs require completion of 12 credit hours of approved coursework. Existing minors and their requirements are as follows;

#### Nuclear Engineering

- Introduction to Nuclear Reactor Physics (PHGN590)
- Nuclear Reactor Laboratory (EGES590 – taught in collaboration with the USGS)
- Reactor Design
- Either Public Policy and Licensing (LAIS590) or Radioactive Materials Management (ESEG590)

#### Nuclear Materials Processing

- Introduction to Nuclear Reactor Physics (PHGN590)
- Materials Science and Engineering of Nuclear Materials (MTGN590)
- Chemical Processing of Nuclear Materials (MTGN591 )
- Radioactive Materials Management (ESEG590 )

#### Nuclear Detection

- Nuclear Physics (PHGN422)
- Introduction to Nuclear Reactor Physics (PHGN590)
- Radiation Detection and Measurement (PHGN504)

- Nuclear Reactor Laboratory (EGES590 – taught in collaboration with the USGS)

Nuclear Geoscience and Geoengineering

- Nuclear Physics (PHGN422), plus three of the following five courses
- Nuclear and Isotope Geochemistry
- In-situ Mining
- Uranium Mining
- Uranium Geology and Geochemistry (GEGN520)
- Design of Geologic Radioactive Waste Repositories (MNGN543)

*Description of Courses*

Nuclear Science and Engineering courses are taken from existing courses at CSM. In addition to the core courses listed above, the elective courses approved by the Nuclear Science and Engineering faculty can be viewed at

<http://www.mines.edu/Academic/nuclear> .



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## Petroleum Engineering

RAMONA M. GRAVES, Professor and Interim Department Head  
HOSSEIN KAZEMI, Chesebro Distinguished Professor  
ERDAL OZKAN, Professor  
CRAIG W. VAN KIRK, Professor  
ALFRED W. EUSTES III, Associate Professor  
TURHAN YILDIZ, Associate Professor  
JENNIFER L. MISKIMINS, Assistant Professor  
LINDA BATTALORA, Lecturer  
MARK G. MILLER, Lecturer  
BILLY J. MITCHELL, Professor Emeritus  
RICHARD CHRISTIANSON, Associate Professor Emeritus

### *Degrees Offered:*

- Professional Masters in Petroleum Reservoir Systems
- Master of Engineering (Petroleum Engineering)
- Master of Science (Petroleum Engineering)
- Doctor of Philosophy (Petroleum Engineering)

### *Program Description:*

The Petroleum Engineering Department offers students a choice of a Master of Science (MS) degree or a Master of Engineering (ME) degree. For the MS degree, a thesis is required in addition to course work. For the ME degree, no thesis is required, but the course work requirement is greater than that for the MS degree. After admission to the graduate program, students may change from ME to MS, or vice versa, according to their needs and interests with the approval of the student's advisor. The Petroleum Engineering Department also offers CSM undergraduate students the option of a Combined Undergraduate/Graduate Program. This is an accelerated program that provides the opportunity to the CSM students to have a head start on graduate education.

Applications from students having an ME or MS in Petroleum Engineering, or in another discipline, will be considered for admission to the Doctor of Philosophy (Ph.D.) program. To obtain the Ph.D. degree, a student must demonstrate unusual competence, creativity, and dedication in the degree field. In addition to extensive course work, a dissertation is required for the Ph.D. degree.

### *Program Requirements:*

#### **Professional Masters in Petroleum Reservoir Systems**

Minimum 36 hours of course credit

#### **Master of Engineering**

Minimum 36 hours of course credit

#### **Master of Science**

Minimum 36 hours, of which no less than 12 credit hours earned by research and 24 credit hours by course work

#### **Combined Undergraduate/Graduate Program**

The same requirements as Master of Engineering after the student is granted full graduate status. Students in the Combined Undergraduate/Graduate Program may fulfill part of the requirements of their graduate degree by including up to

6 credit hours of undergraduate course credits upon approval of the department.

### **Doctor of Philosophy**

Minimum 90 credit hours beyond the bachelor's degree of which no less than 30 credit hours earned by research, or minimum 54 credit hours beyond the Master's degree of which no less than 30 credit hours earned by research.

Petroleum Engineering, Geology and Geological Engineering, and the Geophysics Departments share oversight for the **Professional Masters in Petroleum Reservoir Systems** program through a committee consisting of one faculty member from each department. Students gain admission to the program by application to any of the three sponsoring departments. Students are administered by that department into which they first matriculate. A minimum of 36 credit hours of course credit is required to complete the Professional Masters in Petroleum Reservoir Systems program. Up to 9 credits may be earned by 400 level courses. All other credits toward the degree must be 500 level or above. At least 9 hours must consist of:

1 course selected from the following:

GEGN439/GPGN439/PEGN439 Multidisciplinary  
Petroleum Design

1 course selected from the following:

GPGN419/ PEGN419 Well Log Analysis and Formation  
Evaluation or  
GPGN519/PEGN519 Advanced Formation Evaluation

1 courses selected from the following:

GEGN503/GPGN503/PEGN503 Integrated Exploration  
and Development or  
GEGN504/GPGN504/PEGN504 Integrated Exploration  
and Development

Also 9 additional hours must consist of one course each from the 3 participating departments. The remaining 18 hours may consist of graduate courses from any of the 3 participating departments, or other courses approved by the committee. Up to 6 hours may consist of independent study, including an industry project.

Candidates for the non-thesis **Master of Engineering** degree must complete a minimum of 36 hours of graduate course credit. At least 18 of the credit hours must be from the Petroleum Engineering Department. Up to 12 graduate credit hours can be transferred from another institution, and up to 9 credit hours of senior-level courses may be applied to the degree. All courses must be approved by the student's advisor. No graduate committee is required. No more than six credit hours can be earned through independent study.

Candidates for the **Master of Science** degree must complete at least 24 graduate credit hours of course work, approved by the candidate's graduate committee, and a minimum of 12 hours of research credit. At least 12 of the course credit hours must be from the Petroleum Engineering Department. Up to

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9 credit hours may be transferred from another institution. Up to 9 credit hours of senior-level courses may be applied to the degree. For the MS degree, the student must demonstrate ability to observe, analyze, and report original scientific research. For other requirements, refer to the general instructions of the Graduate School in this bulletin.

The requirements for the **Combined Undergraduate/Graduate Program** are defined in the section of this Bulletin titled "Graduate Degrees and Requirements—V. Combined Undergraduate/Graduate Programs." After the student is granted full graduate status, the requirements are the same as those for the non-thesis Master of Engineering degree. The Combined Undergraduate/Graduate Program allows students to fulfill part of the requirements of their graduate degree by including up to 6 credit hours of their undergraduate course credits upon approval of the department. For other requirements, refer to the general directions of the Graduate School in this bulletin.

A candidate for the **Ph.D.** must complete at least 60 hours of course credit and a minimum of 30 credit hours of research beyond the Bachelor's degree or at least 24 hours of course credit and a minimum of 30 credit hours of research beyond the Master's degree. The credit hours to be counted toward a Ph.D. are dependent upon approval of the student's thesis committee. Students who enter the Ph.D. program with a Bachelor's degree may transfer up to 33 graduate credit hours from another institution with the approval of the graduate advisor. Students who enter the Ph.D. program with a master's degree may transfer up to 45 credit hours of course and research work from another institution upon approval by the graduate advisor. Ph.D. students must complete a minimum of 12 credit hours of their required course credit in a minor program of study. The student's faculty advisor, thesis committee, and the department head must approve the course selection. The Ph.D. students are also required to demonstrate proficiency in a second language other than English. Full-time Ph.D. students must satisfy the following requirements for admission to candidacy within the first two calendar years after enrolling in the program:

- i) have a thesis committee appointment form on file,
- ii) complete all prerequisite and core courses successfully,
- iii) demonstrate adequate preparation for and satisfactory ability to conduct doctoral research by successfully completing a series of written and/or oral examinations and fulfilling the other requirements of their graduate committees.

Failure to fulfill these requirements within the time limits specified above may result in immediate mandatory dismissal from the Ph.D. program according to the procedure outlined in the section of this Bulletin titled "General Regulations—Unsatisfactory Academic Performance—Unsatisfactory Academic Progress Resulting in Probation or Discretionary

Dismissal." For other requirements, refer to the general directions of the Graduate School in this bulletin.

#### *Applying for Admission:*

To apply for admission, follow the procedure outlined in the general section of this bulletin. Three letters of recommendation must accompany the application. The Petroleum Engineering Department requires the General test of the Graduate Record Examination (GRE). The applicants for the Master of Science and Master of Engineering programs are required to have 700 or better and applicants for the Ph.D. program are expected to have 750 or better on the quantitative part of the GRE exam. The applicants whose native language is not English are also expected to provide satisfactory scores on the TOEFL (Test of English as a Foreign Language) exam as specified in the general section of this bulletin.

#### *Required Curriculum:*

A student in the graduate program selects course work by consultation with the Faculty Advisor and with the approval of the graduate committee. Course work is tailored to the needs and interests of the student.

All PE graduate students are required to complete 3 credit hours of course work in writing, research, or presentation intensive classes, such as LICM501, LICM598, SYGN501, and SYGN600, as agreed by their graduate advisor. Also, students who do not have a BS degree in PE must take the deficiency courses as required by the department as soon as possible in their graduate programs.

#### *Fields of Research:*

Current research topics include

- Rock and fluid properties, phase behavior, and rock mechanics
- Analytical and numerical modeling of fluid flow in porous media
- Formation evaluation, well test analysis, and reservoir characterization
- Oil recovery processes
- Natural gas engineering, coalbed methane, and geothermal energy
- Completion and stimulation of wells
- Horizontal and multilateral wells
- Fluid flow in wellbores, and artificial lift
- Drilling mechanics, directional drilling, extraterrestrial drilling, ice coring and drilling
- Bit vibration analysis, tubular buckling and stability, wave propagation in drilling tubulars
- Laser technology in penetrating rocks
- Remediation of contaminated soils and aquifers
- Economics and management

Research projects may involve professors and graduate students from other disciplines. Projects often include off-campus laboratories, institutes, and other resources.

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The Petroleum Engineering Department houses two research centers and two consortia.

#### Research Centers

Marathon Center of Excellence for Reservoir Studies (MCERS)

Center for Earth Mechanics, Materials, and Characterization (EM<sup>2</sup>C).

#### Research Consortia

Fracturing, Acidizing, Stimulation Technology (FAST) Consortium.

Marathon Center of Excellence for Reservoir Studies, Multi-Scale Simulation Consortium

### *Special Features:*

In the exchange programs with the Petroleum Engineering Departments of the Mining University of Leoben, Austria, Technical University in Delft, Holland, and the University of Adelaide, Australia, a student may spend one semester abroad during graduate studies and receive full transfer of credit back to CSM with prior approval of the Petroleum Engineering Department at CSM.

The Petroleum Engineering Department is located in a recently renovated structure in the foothills west of Denver. The laboratory wing, completed in late 1993, has 20,000 square feet of space, with about \$2 million of equipment acquired in recent years.

The Petroleum Engineering Department enjoys strong association with the Geology and Geophysics Departments at CSM. Courses that integrate the faculty and interests of the three departments are taught at the undergraduate and graduate levels.

The department is close to oil and gas field operations, oil companies and laboratories, and geologic outcrops of producing formations. There are many opportunities for summer and part-time employment in the oil and gas industry in the Denver metropolitan region.

Each summer, some graduate students assist with the field sessions for undergraduate students. In the past, the field session students have visited oil and gas operations in Europe, Alaska, Canada, Southern California, the Gulf Coast, and western Colorado.

The Petroleum Engineering Department encourages student involvement with the Society of Petroleum Engineers and the American Association of Drilling Engineers. The department provides financial support for students attending the SPE Annual Technical Conference and Exhibition.

### *Description of Courses*

#### **Undergraduate Courses**

Students in Professional Masters in Petroleum Reservoir Systems, Master of Engineering, Master of Science, and Combined Undergraduate/Graduate Degree programs may

take up to 9 credit hours of 400-level courses provided that these courses are not required for the BS PE program at CSM. The department should approve all such courses. The following 400-level courses in the Petroleum Engineering Department are not required for BS PE degree and may be considered for graduate degree credit. Other 400-level courses may be available in the other departments.

PEGN428. ADVANCED DRILLING ENGINEERING (II) Rotary drilling systems with emphasis on design of drilling programs, directional and horizontal well planning, bit selection, bottom hole assembly and drillstring design. This **elective** course is **recommended** for petroleum engineering majors interested in drilling. Prerequisite: PEGN311, PEGN361. 3 hours lecture; 3 semester hours.

PEGN450. ENERGY ENGINEERING (I or II) Energy Engineering is an overview of energy sources that will be available for use in the 21st century. After discussing the history of energy and its contribution to society, we survey the science and technology of energy, including geothermal energy, fossil energy, solar energy, nuclear energy, wind energy, hydro energy, bio energy, energy and the environment, energy and economics, the hydrogen economy, and energy forecasts. This broad background will give you additional flexibility during your career and help you thrive in an energy industry that is evolving from an industry dominated by fossil fuels to an industry working with many energy sources. Prerequisite: MATH213, PHGN200. 3 hours lecture; 3 semester hours.

PEGN498. SPECIAL TOPICS (I, II) Group or individual study of any topic in the field of, or closely related to petroleum engineering. By consent of instructor. Hours per week and credit to be determined at time of registration.

#### **Graduate Courses**

The 500-level courses are open to qualified seniors with permission of the department and the Dean of the Graduate School. The 600-level courses are open only to students enrolled in Graduate School. Certain courses may vary from year to year, depending upon the number of students and their particular needs.

PEGN501. APPLICATIONS OF NUMERICAL METHODS TO PETROLEUM ENGINEERING The course will solve problems of interest in Petroleum Engineering through the use of spreadsheets on personal computers and structured FORTRAN programming on PCs or mainframes. Numerical techniques will include methods for numerical quadrature, differentiation, interpolation, solution of linear and non-linear ordinary differential equations, curve fitting and direct or iterative methods for solving simultaneous equations. Prerequisites: PEGN414 and PEGN424 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN502. ADVANCED DRILLING FLUIDS The physical properties and purpose of drilling fluids are investigated. Emphasis is placed on drilling fluid design, clay chemistry,

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design, and testing; and solids control. Prerequisite: PEGN311 or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours.

PEGN503/GEGN503/GPGN503. INTEGRATED EXPLORATION AND DEVELOPMENT Students work alone and in teams to study reservoirs from fluvial-deltaic and valley fill depositional environments. This is a multidisciplinary course that shows students how to characterize and model subsurface reservoir performance by integrating data, methods and concepts from geology, geophysics and petroleum engineering. Activities and topics include field trips to surface outcrops, well logs, borehole cores, seismograms, reservoir modeling of field performance, written exercises and oral team presentations. Prerequisite: Consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours.

PEGN504/GEGN504/GPGN504. INTEGRATED EXPLORATION AND DEVELOPMENT Students work in multidisciplinary teams to study practical problems and case studies in integrated subsurface exploration and development. The course addresses emerging technologies and timely topics. Activities include field trips, 3D computer modeling, written exercises and oral team presentations. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

PEGN505. HORIZONTAL WELLS: RESERVOIR AND PRODUCTION ASPECTS This course covers the fundamental concepts of horizontal well reservoir and production engineering with special emphasis on the new developments. Each topic covered highlights the concepts that are generic to horizontal wells and draws attention to the pitfalls of applying conventional concepts to horizontal wells without critical evaluation. There is no set prerequisite for the course but basic knowledge on general reservoir engineering concepts is useful. 3 hours lecture; 3 semester hours.

PEGN506. ENHANCED OIL RECOVERY METHODS Enhanced oil recovery (EOR) methods are reviewed from both the qualitative and quantitative standpoint. Recovery mechanisms and design procedures for the various EOR processes are discussed. In addition to lectures, problems on actual field design procedures will be covered. Field case histories will be reviewed. Prerequisite: PEGN424 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN507. INTEGRATED FIELD PROCESSING Integrated design of production facilities covering multistage separation of oil, gas, and water, multiphase flow, oil skimmers, natural gas dehydration, compression, crude stabilization, petroleum fluid storage, and vapor recovery. Prerequisite: PEGN411 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN508. ADVANCED ROCK PROPERTIES Application of rock mechanics and rock properties to reservoir engineering, well logging, well completion and well stimulation. Topics covered include: capillary pressure, relative permeability, velocity effects on Darcy's Law, elastic/mechanical

rock properties, subsidence, reservoir compaction, and sand control. Prerequisite: PEGN423 and PEGN426 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN511. PHASE BEHAVIOR IN THE OIL AND GAS INDUSTRY Essentials of thermodynamics for understanding phase behavior. Modeling of phase behavior of single and multi-component systems with equations of state and other appropriate solution models in spreadsheets and commercial PVT software. Special focus on paraffins, asphaltenes, natural gas hydrates, and mineral deposition. Prerequisite: CHEN357 or equivalent, or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN512. ADVANCED GAS ENGINEERING The physical properties and phase behavior of gas and gas condensates will be discussed. Flow through tubing and pipelines as well as through porous media is covered. Reserve calculations for normally pressured, abnormally pressured and water drive reservoirs are presented. Both stabilized and isochronal deliverability testing of gas wells will be illustrated. Prerequisite: PEGN423 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN513 - RESERVOIR SIMULATION I The course provides the rudiments of reservoir simulation, which include flow equations, solution methods, and data requirement. Specifically, the course covers: equations of conservation of mass, conservation of momentum, and energy balance; numerical solution of flow in petroleum reservoirs by finite difference (FD) and control volume FD; permeability tensor and directional permeability; non-Darcy flow; convective flow and numerical dispersion; grid orientation problems; introduction to finite element and mixed finite-element methods; introduction to hybrid analytical/numerical solutions; introduction to multi-phase flow models; relative permeability, capillary pressure and wettability issues; linear equation solvers; streamline simulation; and multi-scale simulation concept. Prerequisite: PEGN424 or equivalent, strong reservoir engineering background, and basic computer programming knowledge. 3 credit hours. 3 hours of lecture per week.

PEGN514. PETROLEUM TESTING TECHNIQUES Investigation of basic physical properties of petroleum reservoir rocks and fluids. Review of recommended practices for testing drilling fluids and oil well cements. Emphasis is placed on the accuracy and calibration of test equipment. Quality report writing is stressed. Prerequisite: Graduate status. 2 hours lecture, 1 hour lab; 3 semester hours. Required for students who do not have a BS in PE.

PEGN515. RESERVOIR ENGINEERING PRINCIPLES Reservoir Engineering overview. Predicting hydrocarbon in place; volumetric method, deterministic and probabilistic approaches, material balance, water influx, graphical techniques. Fluid flow in porous media; continuity and diffusivity equations. Well performance; productivity index for vertical,



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perforated, fractured, restricted, slanted, and horizontal wells, inflow performance relationship under multiphase flow conditions. Combining material balance and well performance equations. Future reservoir performance prediction; Muskat, Turner, Carter and Tracy methods. Fetkovich decline curves. Reservoir simulation; fundamentals and formulation, streamline simulation, integrated reservoir studies. 3 hours lecture, 3 semester hours.

PEGN516. PRODUCTION ENGINEERING PRINCIPLES Production Engineering Overview. Course provides a broad introduction to the practice of production engineering. Covers petroleum system analysis, well stimulation (fracturing and acidizing), artificial lift (gas lift, sucker rod, ESP, and others), and surface facilities. 3 hours lecture, 3 semester hours.

PEGN 517. DRILLING ENGINEERING PRINCIPLES Drilling Engineering overview. Subjects to be covered include overall drilling organization, contracting, and reporting; basic drilling engineering principles and equipment; drilling fluids, hydraulics, and cuttings transport; drillstring design; drill bits; drilling optimization; fishing operations; well control; pore pressure and fracture gradients, casing points and design; cementing; directional drilling and horizontal drilling. 3 hours lecture, 3 semester hours.

PEGN519. ADVANCED FORMATION EVALUATION A detailed review of wireline well logging and evaluation methods stressing the capability of the measurements to determine normal and special reservoir rock parameters related to reservoir and production problems. Computers for log processing of single and multiple wells. Utilization of well logs and geology in evaluating well performance before, during, and after production of hydrocarbons. The sensitivity of formation evaluation parameters in the volumetric determination of petroleum in reservoirs. Prerequisite: PEGN419 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN522. ADVANCED WELL STIMULATION Basic applications of rock mechanics to petroleum engineering problems. Hydraulic fracturing; acid fracturing, fracturing simulators; fracturing diagnostics; sandstone acidizing; sand control, and well bore stability. Different theories of formation failure, measurement of mechanical properties. Review of recent advances and research areas. Prerequisite: PEGN426 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN523. ADVANCED ECONOMIC ANALYSIS OF OIL AND GAS PROJECTS Determination of present value of oil properties. Determination of severance, ad valorem, windfall profit, and federal income taxes. Analysis of profitability indicators. Application of decision tree theory and Monte Carlo methods to oil and gas properties. Economic criteria for equipment selection. Prerequisite: PEGN422 or EBG504 or ChEN504 or MNGN427 or ChEN421 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN524. PETROLEUM ECONOMICS AND MANAGEMENT Business applications in the petroleum industry are the central focus. Topics covered are: fundamentals of accounting, oil and gas accounting, strategic planning, oil and gas taxation, oil field deals, negotiations, and the formation of secondary units. The concepts are covered by forming companies that prepare proforma financial statements, make deals, drill for oil and gas, keep accounting records, and negotiate the participation formula for a secondary unit. Prerequisite: PEGN422 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN541. APPLIED RESERVOIR SIMULATION Concepts of reservoir simulation within the context of reservoir management will be discussed. Course participants will learn how to use available flow simulators to achieve reservoir management objectives. They will apply the concepts to an open-ended engineering design problem. Prerequisites: PEGN424 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN542. INTEGRATED RESERVOIR CHARACTERIZATION The course introduces integrated reservoir characterization from a petroleum engineering perspective. Reservoir characterization helps quantify properties that influence flow characteristics. Students will learn to assess and integrate data sources into a comprehensive reservoir model. Prerequisites: PEGN424 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN550. MODERN RESERVOIR SIMULATORS Students will learn to run reservoir simulation software using a variety of reservoir engineering examples. The course will focus on the capabilities and operational features of simulators. Students will learn to use pre- and post-processors, fluid property analysis software, black oil and gas reservoir models, and compositional models. 3 hours lecture; 3 semester hours.

PEGN577. WORKOVER DESIGN AND PRACTICE Workover Engineering overview. Subjects to be covered include Workover Economics, Completion Types, Workover Design Considerations, Wellbore Cleanout (Fishing), Workover Well Control, Tubing and Workstring Design, Slickline Operations, Coiled Tubing Operations, Packer Selection, Remedial Cementing Design and Execution, Completion Fluids, Gravel Packing, and Acidizing. 3 hours lecture, 3 semester hours.

PEGN594. DIRECTIONAL AND HORIZONTAL DRILLING Application of directional control and planning to drilling. Major topics covered include: Review of procedures for the drilling of directional wells. Section and horizontal view preparation. Two and three dimensional directional planning. Collision diagrams. Surveying and trajectory calculations. Surface and down hole equipment. Common rig operating procedures, and horizontal drilling techniques. Prerequisites: PEGN311 or equivalent, or consent of instructor. 3 hours lecture; 3 semester hours.

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PEGN595. DRILLING OPERATIONS Lectures, seminars, and technical problems with emphasis on well planning, rotary rig supervision, and field practices for execution of the plan. This course makes extensive use of the drilling rig simulator. Prerequisite: PEGN311, or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN596. ADVANCED WELL CONTROL Principles and procedures of pressure control are taught with the aid of a full-scale drilling simulator. Specifications and design of blowout control equipment for onshore and offshore drilling operations, gaining control of kicks, abnormal pressure detection, well planning for wells containing abnormal pressures, and kick circulation removal methods are taught. Students receive hands-on training with the simulator and its peripheral equipment. Prerequisite: PEGN311 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN597. TUBULAR DESIGN Fundamentals of tubulars (casing, tubing, and drill pipe) design applied to drilling. Major topics covered include: Dogleg running loads. Directional hole considerations. Design criteria development. Effects of formation pressures. Stability loads after cementing. Effects of temperature, pressure, mud weights, and cement. Helical bending of tubing. Fishing loads. Micro-annulus problem. Strengths of API tubulars. Abrasive wear while rotating drill pipe. How to design for hydrogen sulfide and fatigue corrosion. Connection selection. Common rig operating procedures. Prerequisite: PEGN311, PEGN361 or equivalent, or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN598. SPECIAL TOPICS IN PETROLEUM ENGINEERING Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

PEGN599. INDEPENDENT STUDY Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

PEGN601. APPLIED MATHEMATICS OF FLUID FLOW IN POROUS MEDIA This course is intended to expose petroleum-engineering students to the special mathematical techniques used to solve transient flow problems in porous media. Bessel's equation and functions, Laplace and Fourier transformations, the method of sources and sinks, Green's functions, and boundary integral techniques are covered. Numerical evaluation of various reservoir engineering solutions, numerical Laplace transformation and inverse transformation are also discussed. 3 hours lecture; 3 semester hours.

PEGN603. DRILLING MODELS Analytical models of physical phenomena encountered in drilling. Casing and drilling failure from bending, fatigue, doglegs, temperature, stretch; mud filtration; corrosion; wellhead loads; and buoyancy of tubular goods. Bit weight and rotary speed optimization. Prerequisite: PEGN311, PEGN361, or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN604. INTEGRATED FLOW MODELING Students will study the formulation, development and application of a reservoir flow simulator that includes traditional fluid flow equations and a petrophysical model. The course will discuss properties of porous media within the context of reservoir modeling, and present the mathematics needed to understand and apply the simulator. Simulator applications will be interspersed throughout the course. 3 hours lecture; 3 semester hours.

PEGN605. WELL TESTING AND EVALUATION Various well testing procedures and interpretation techniques for individual wells or groups of wells. Application of these techniques to field development, analysis of well problems, secondary recovery, and reservoir studies. Productivity, gas well testing, pressure buildup and drawdown, well interference, fractured wells, type curve matching, and short-term testing. Prerequisite: PEGN426 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN606. ADVANCED RESERVOIR ENGINEERING A review of depletion type, gas-cap, and volatile oil reservoirs. Lectures and supervised studies on gravity segregation, moving gas-oil front, individual well performance analysis, history matching, performance prediction, and development planning. Prerequisite: PEGN423 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN607. PARTIAL WATER DRIVE RESERVOIRS The hydrodynamic factors which influence underground water movement, particularly with respect to petroleum reservoirs. Evaluation of oil and gas reservoirs in major water containing formations. Prerequisite: PEGN424 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN608. FLUID DISPLACEMENT IN POROUS MEDIA The factors involved in multiphase fluid flow in porous media. The micro- and macroscopic movement of various fluid combinations. Performance of various displacement tests on cores in the laboratory. Prerequisite: PEGN423 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN614. RESERVOIR SIMULATION II: The course reviews the rudiments of reservoir simulation and flow equations, solution methods, and data requirement. The course emphasizes multi-phase flow and solution techniques; teaches the difference between conventional reservoir simulation, compositional modeling and multi-porosity modeling; teaches how to construct three-phase relative permeability from water-oil and gas-oil relative permeability data set; the importance of capillary pressure measurements and wettabil-

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ity issues; discusses the significance of gas diffusion and interphase mass transfer. Finally, the course develops solution techniques to include time tested implicit-pressure-explicit-saturation, sequential and fully implicit methods. Prerequisite: PEGN513 or equivalent, strong reservoir engineering background, and basic computer programming knowledge. 3 credit hours. 3 hours of lecture per week.

**PEGN620. NATURALLY FRACTURED RESERVOIRS--ENGINEERING AND RESERVOIR SIMULATION** The course covers reservoir engineering, well testing, and simulation aspects of naturally fractured reservoirs. Specifics include: fracture description, connectivity and network; fracture properties; physical principles underlying reservoir engineering and modeling naturally fractured reservoirs; local and global effects of viscous, capillary, gravity and molecular diffusion flow; dual-porosity/dual-permeability models; multi-scale fracture model; dual-mesh model; streamline model; transient testing with non-Darcy flow effects; tracer injection and breakthrough analysis; geomechanics and fractures; compositional model; coal-bed gas model; oil and gas from fractured shale; improved and enhanced oil recovery in naturally fracture reservoirs. Prerequisite: PEGN513 or equivalent, strong reservoir engineering background, and basic computer programming knowledge. 3 hours lecture; 3 semester hours.

**PEGN 624. COMPOSITIONAL MODELING - APPLICATION TO ENHANCED OIL RECOVERY** Efficient production of rich and volatile oils as well as enhanced oil recovery by gas injection (lean and rich natural gas, CO<sub>2</sub>, N<sub>2</sub>, air, and steam) is of great interest in the light of greater demand for hydrocarbons and the need for CO<sub>2</sub> sequestration. This course is intended to provide technical support for engineers dealing with such issues. The course begins with a review of the primary and secondary recovery methods, and will analyze the latest worldwide enhanced oil recovery production statistics. This will be followed by presenting a simple and practical solvent flooding model to introduce the student to data preparation and code writing. Next, fundamentals of phase behavior, ternary phase diagram, and the Peng-Robinson equation of state will be presented. Finally, a detailed set of flow and thermodynamic equations for a full-fledged compositional model, using molar balance, equation of motion and the afore-mentioned equation of state, will be developed and solution strategy will be presented. Prerequisite: PEGN513 or equivalent, strong reservoir engineering background, and basic computer programming knowledge. 3 hours lecture; 3 semester hours.

**PEGN681. PETROLEUM ENGINEERING SEMINAR** Comprehensive reviews of current petroleum engineering literature, ethics, and selected topics as related to research. 2 hours seminar; 1 semester hour.

**PEGN682. PETROLEUM ENGINEERING SEMINAR** Comprehensive reviews of current petroleum engineering literature, ethics, and selected topics as related to professionalism. 2 hours seminar; 1 semester hour.

**PEGN698. SPECIAL TOPICS IN PETROLEUM ENGINEERING** Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

**PEGN699. INDEPENDENT STUDY** Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

**PEGN705. GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE** Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

**PEGN706. GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY** Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty advisor. Repeatable for credit.

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## Physics

JAMES A. McNEIL, Professor and Department Head  
REUBEN T. COLLINS, Professor  
THOMAS E. FURTAK, Professor  
FRANK V. KOWALSKI, Professor  
MARK T. LUSK, Professor (and Engineering)  
JOHN A. SCALES, Professor  
JEFF A. SQUIER, Professor  
P. CRAIG TAYLOR, Professor  
CHARLES G. DURFEE III, Associate Professor  
UWE GREIFE, Associate Professor  
TIMOTHY R. OHNO, Associate Professor  
LAWRENCE R. WIENCKE, Associate Professor  
DAVID M. WOOD, Associate Professor  
LINCOLN D. CARR, Assistant Professor  
FREDERIC SARAZIN, Assistant Professor  
TODD G. RUSKELL, Senior Lecturer  
CHARLES A. STONE, IV, Senior Lecturer  
MATTHEW M. YOUNG, Senior Lecturer  
ALEX T. FLOURNOY, Lecturer  
PATRICK B. KOHL, Lecturer  
H. VINCENT KUO, Lecturer  
SUE ANNE BERGER, Instructor  
JOHN U. TREFNY, Professor Emeritus and President Emeritus  
JAMES T. BROWN, Professor Emeritus  
F. EDWARD CECIL, Professor Emeritus  
JOHN A. DESANTO, Professor Emeritus  
FRANKLIN D. SCHOWENGERDT, Professor Emeritus  
DON L. WILLIAMSON, Professor Emeritus  
F. RICHARD YEATTS, Professor Emeritus  
WILLIAM B. LAW, Associate Professor Emeritus  
ARTHUR Y. SAKAKURA, Associate Professor Emeritus  
MARK W. COFFEY, Research Professor  
ROBERT F. HOLUB, Research Professor  
VICTOR KAYDANOV, Research Professor  
JAMES E. BERNARD, Research Associate Professor  
JOSEPH D. BEACH, Research Assistant Professor

### Degrees Offered:

Master of Science (Applied Physics)

Doctor of Philosophy (Applied Physics)

### Program Description:

The Physics Department at CSM offers a full program of instruction and research leading to the M.S. or Ph.D. in applied physics.

Graduate students are given a solid background in the fundamentals of classical and modern physics at an advanced level and are encouraged early in their studies to learn about the research interests of the faculty so that a thesis topic can be identified.

### Program Requirements:

Students entering graduate programs in Applied Physics will select an initial program in consultation with the departmental graduate student advising committee until such time as a research field has been chosen and a thesis committee appointed. The following are requirements for the M.S. and Ph.D. degrees:

Master's: 20 semester hours of course work in an approved program plus 16 semester hours of research credit, with a satisfactory thesis. Doctorate: 34 semester hours of course work in an approved program plus 38 semester hours of research credit, with a satisfactory thesis. 12 semester hours of course work will be in an approved minor. Possible minors include specialty programs in Optical Science and Engineering, Photovoltaic and Electronic Materials, and Nuclear Physics and Astrophysics in addition to minors in other degree programs on the CSM campus.

To demonstrate adequate preparation for the Ph.D. degree in Applied Physics, each student must pass the physics graduate core courses with an average grade of "B" or better. Students not achieving this standard must pass oral examinations covering the areas of weakness identified in the core courses or retake the respective course with a grade of "B" or better within one year. This process is part of the requirement for admission to candidacy, which full time Ph.D. students must complete within two calendar years of admission, as described in the campus-wide graduate degree requirements section of this bulletin. Other degree requirements, time limits, and procedures details can be found in the Physics Department Graduate Policy Manual.

### Prerequisites:

The Graduate School of the Colorado School of Mines is open to graduates from four-year programs at accredited colleges or universities. Admission to the Physics Department M.S. and Ph.D. programs is competitive and is based on an evaluation of undergraduate performance, standardized test scores, and references. The undergraduate course of study of each applicant is evaluated according to the requirements of the Physics Department.

### Required Curriculum:

#### Master of Science, Applied Physics

Core Courses

PHGN511 Mathematical Physics I

PHGN520 Quantum Mechanics I

One additional course selected from:

PHGN505 Classical Mechanics I

PHGN507 Electromagnetic Theory I

PHGN521 Quantum Mechanics II

PHGN530 Statistical Mechanics

Electives - 9 hours.

Graduate Seminar\* - 2 hours.

Master's Thesis

#### Doctor of Philosophy, Applied Physics

Core Courses

PHGN505 Classical Mechanics I

PHGN507 Electromagnetic Theory I

PHGN511 Mathematical Physics I

PHGN520 Quantum Mechanics I

PHGN521 Quantum Mechanics II



PHGN530 Statistical Mechanics  
Graduate Seminar\* - 4 hours.

12 hour minor: as specified in the general requirements for the graduate school and discussed above under program requirements.

Doctoral Thesis.

\*Graduate Seminar: Each full-time graduate student (M.S. and Ph.D.) will register for Graduate Seminar each semester for a total of 2 semester hours credit for the M.S. and 4 semester hours credit for the Ph.D.

### *Fields of Research:*

Applied Optics: lasers, ultrafast optics and x-ray generation, spectroscopy, near-field and multi-photon microscopy, non-linear optics, quasi-optics and millimeter waves.

Ultrasonics: laser ultrasonics, resonant ultrasound spectroscopy, wave propagation in random media.

Nuclear: low energy reactions, nuclear astrophysics, nuclear theory, fusion plasma diagnostics.

Electronic Materials: photovoltaics, nanostructures and quantum dots, thin film semiconductors, transparent conductors, amorphous materials.

Solid State: x-ray diffraction, Raman spectroscopy, self assembled systems, soft condensed matter, condensed matter theory, quantum chaos, quantum information and quantum many body theory.

Surface and Interfaces: x-ray photoelectron spectroscopy, Auger spectroscopy, scanning probe microscopies, second harmonic generation.

### *Description of Courses*

#### **Senior Level**

PHGN404. PHYSICS OF THE ENVIRONMENT An examination of several environmental issues in terms of fundamental underlying principles of physics including energy conservation, conversion and generation; solar energy; nuclear power and weapons, radioactivity and radiation effects; aspects of air, noise, and thermal pollution. Prerequisite: PHGN200/210 or consent of instructor. 3 hours lecture; 3 semester hours.

PHGN412. MATHEMATICAL PHYSICS Mathematical techniques applied to the equations of physics; complex variables, partial differential equations, special functions, finite and infinite-dimensional vector spaces. Green's functions. Transforms; computer algebra. Prerequisite: PHGN311. 3 hours lecture; 3 semester hours.

PHGN419. PRINCIPLES OF SOLAR ENERGY SYSTEMS Theory and techniques of insolation measurement. Absorptive and radiative properties of surfaces. Optical properties of materials and surfaces. Principles of photovoltaic devices. Optics of collector systems. Solar energy conversion techniques: heating and cooling of buildings, solar thermal (power and process heat), wind energy, ocean thermal, and

photovoltaic. Prerequisite: PHGN300/310 3 hours lecture; 3 semester hours

PHGN420. QUANTUM MECHANICS Schrodinger equation, uncertainty, change of representation, one-dimensional problems, axioms for state vectors and operators, matrix mechanics, uncertainty relations, time-independent perturbation theory, time-dependent perturbations, harmonic oscillator, angular momentum. Prerequisite: PHGN320, PHGN350, PHGN361. 3 hours lecture; 3 semester hours.

PHGN422. NUCLEAR PHYSICS Introduction to subatomic (particle and nuclear) phenomena. Characterization and systematics of particle and nuclear states; symmetries; introduction and systematics of the elect, magnetic, weak, and strong interactions; Systematics of radioactivity; liquid drop and shell models; nuclear technology. Prerequisite: PHGN320. 3 hours lecture; 3 semester hours.

PHGN423. DIRECT ENERGY CONVERSION Review of basic physical principles. Types of power generation treated include fission, fusion, magnetohydrodynamic, thermoelectric, thermionic, fuel cells, photovoltaic, electrohydrodynamic, piezoelectrics. Prerequisite: PHGN300/310. 3 hours lecture; 3 semester hours.

PHGN424. ASTROPHYSICS A survey of fundamental aspects of astrophysical phenomena, concentrating on measurement of basic stellar properties such as distance, luminosity, spectral classification, mass, and radii. Simple models of stellar structure evolution and the associated nuclear processes as sources of energy and nucleosynthesis. Introduction to cosmology and physics of standard big-bang models. Prerequisite: PHGN320. 3 hours lecture; 3 semester hours.

PHGN435/ChEN435. INTERDISCIPLINARY MICRO-ELECTRONICS PROCESSING LABORATORY Application of science and engineering principles to the design, fabrication, and testing of microelectronic devices. Emphasis on specific unit operations and the interrelation among processing steps. Prerequisites: Senior standing in PHGN, ChEN, MTGN, or EGGN; consent of instructor. 1.5 hours lecture, 4 hours lab; 3 semester hours.

PHGN440/MLGN502. SOLID STATE PHYSICS An elementary study of the properties of solids including crystalline structure and its determination, lattice vibrations, electrons in metals, and semiconductors. (Graduate students in physics may register only for PHGN440.) Prerequisite: PHGN320. 3 hours lecture; 3 semester hours.

PHGN441/MLGN522. SOLID STATE PHYSICS APPLICATION AND PHENOMENA Continuation of PHGN440/MLGN502 with an emphasis on applications of the principles of solid state physics to practical properties of materials including: optical properties, superconductivity, dielectric properties, magnetism, noncrystalline structure, and interfaces. (Graduate students in physics may register only for PHGN441.) Prerequisite: PHGN440/MLGN501 or equivalent by instructor's permission. 3 hours lecture; 3 semester hours.

PHGN450. COMPUTATIONAL PHYSICS Introduction to numerical methods for analyzing advanced physics problems. Topics covered include finite element methods, analysis of scaling, efficiency, errors, and stability, as well as a survey of numerical algorithms and packages for analyzing algebraic, differential, and matrix systems. The numerical methods are introduced and developed in the analysis of advanced physics problems taken from classical physics, astrophysics, electromagnetism, solid state, and nuclear physics. Prerequisites: Introductory-level knowledge of C, Fortran or Basic; PHGN311. 3 hours lecture; 3 semester hours.

PHGN462. ELECTROMAGNETIC WAVES AND OPTICAL PHYSICS (I) Solutions to the electromagnetic wave equation and polarization; applications in optics: imaging, lasers, resonators and wavelengths. Prerequisite: PHGN361. 3 hours lecture; 3 semester hours.

PHGN471. SENIOR DESIGN (I) The first of a two-semester program covering the full spectrum of experimental design, drawing on the student's previous course work. At the beginning of the first semester, the student selects a research project in consultation with the course coordinator and the faculty supervisor. The objectives of the project are given to the student in broad outline form. The student then designs the entire project, including any or all of the following elements as appropriate: literature search, specialized apparatus, block-diagram electronics, computer data acquisition and/or analysis, sample materials, and measurement and/or analysis sequences. The course culminates in a senior thesis. Supplementary lectures are given on techniques of physics research and experimental design. Prerequisite: PHGN384 and PHGN326. 1 hour lecture, 6 hours lab; 3 semester hours.

PHGN472. SENIOR DESIGN (II) Continuation of PHGN471. Prerequisite: PHGN384 and PHGN326. 1 hour lecture, 6 hours lab; 3 semester hours.

PHGN498. SPECIAL TOPICS (I, II) Pilot course on special topics course. Prerequisites: Consent of instructor. Credit to be determined by instructor, maximum of 6 credit hours. Repeatable for credit under different titles.

PHGN499. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member; student and instructor agree on subject matter, content, deliverables, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit, up to 6 credit hours. Repeatable for credit.

### Graduate Courses

500-level courses are open to qualified seniors with the permission of the department and the Dean of the Graduate School.

PHGN501. GRADUATE SEMINAR (I) M.S. students and Ph.D. students who have not been admitted to candidacy will attend the weekly Physics Colloquium. Students will be

responsible for presentations during this weekly seminar. 1 hour seminar; 1 semester hour.

PHGN502. GRADUATE SEMINAR (II) M.S. students and Ph.D. students who have not been admitted to candidacy will attend the weekly Physics Colloquium. Students will be responsible for presentations during this weekly seminar. 1 hour seminar; 1 semester hour.

PHGN504. RADIATION DETECTION AND MEASUREMENT Physical principles and methodology of the instrumentation used in the detection and measurement of ionizing radiation. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

PHGN505. CLASSICAL MECHANICS I (I) Review of Lagrangian and Hamiltonian formulations in the dynamics of particles and rigid bodies, kinetic theory; coupled oscillations and continuum mechanics; fluid mechanics. Prerequisite: PHGN350 or equivalent. 3 hours lecture; 3 semester hours.

PHGN507. ELECTROMAGNETIC THEORY I (II) To provide a strong background in electromagnetic theory. Electrostatics, magnetostatics, dynamical Maxwell equations, wave phenomena. Prerequisite: PHGN462 or equivalent. 3 hours lecture; 3 semester hours.

PHGN511. MATHEMATICAL PHYSICS (I) Review of complex variable and finite and infinite-dimensional linear vector spaces. Sturm-Liouville problem, integral equations, computer algebra. Prerequisite: PHGN311 or equivalent. 3 hours lecture; 3 semester hours.

PHGN520. QUANTUM MECHANICS I (I) Schroedinger equation, uncertainty, change of representation, one-dimensional problems, axioms for state vectors and operators, matrix mechanics, uncertainty relations, time-independent perturbation theory, time-dependent perturbations, harmonic oscillator, angular momentum; semiclassical methods, variational methods, two-level system, sudden and adiabatic changes, applications. Prerequisite: PHGN420 or equivalent. 3 hours lecture; 3 semester hours.

PHGN521. QUANTUM MECHANICS II (II) Review of angular momentum, central potentials and applications. Spin; rotations in quantum mechanics. Formal scattering theory, Born series, partial wave analysis. Addition of angular momenta, Wigner-Eckart theorem, selection rules, identical particles. Prerequisite: PHGN520. 3 hours lecture; 3 semester hours.

PHGN525/MLGN525. SURFACE PHYSICS Solid state physics focusing on the structural and electronic nature of the outer few atomic layers and the gas-surface interactions. Detailed explanations of many surface analysis techniques are provided, highlighting the application of these techniques to current problems, particularly electronic materials. Prerequisite: MLGN502 or equivalent, or consent of instructor. 3 hours lecture; 3 semester hours.

PHGN530. STATISTICAL MECHANICS (II) Review of thermodynamics; equilibrium and stability; statistical operator and ensembles; ideal systems; phase transitions; non-equilibrium systems. Prerequisite: PHGN341 or equivalent and PHGN520. Co-requisite: PHGN521. 3 hours lecture; 3 semester hours.

PHGN535/ChEN535/MLGN535. INTERDISCIPLINARY SILICON PROCESSING LABORATORY Explores the application of science and engineering principles to the fabrication and testing of microelectronic devices with emphasis on specific unit operations and interrelation among processing steps. Teams work together to fabricate, test, and optimize simple devices. Prerequisite: Consent of instructor. 1 hour lecture, 4 hours lab; 3 semester hours.

PHGN542. SOLID STATE DEVICES An overview of the physical principles involved in the fabrication, characterization, and operation of solid state devices. Topics will include: p-n junction devices (e.g., LEDs, solar cells, lasers, particle detectors); junction transistor devices (e.g., FETs, thyristors, switches); surface- and interface-controlled devices (e.g., MOSFETs, CSDs, Schottky barrier devices); other devices such as infrared detectors, recording and display devices, thermoelectric devices, Josephson junctions, electroluminescent and electrochromic panels. Prerequisite: PHGN440. 3 hours lecture; 3 semester hours.

PHGN544. THEORY AND OPERATION OF PHOTOVOLTAIC DEVICES A thorough treatment of photovoltaic device operation and theory. Material and device parameters as related to the generation of photocurrents and photovoltage in solar cells. Physics of various solar cell types: homojunctions, heterojunctions, Schottky barriers, MIS, SIS, electrochemical. Environmental effects and device production. Important measurement techniques. Discussion of research topics from the current literature. Prerequisite: PHGN440 or consent of instructor. 3 hours lecture; 3 semester hours.

PHGN550 NANOSCALE PHYSICS AND TECHNOLOGY An introduction to the basic physics concepts involved in nanoscale phenomena, processing methods resulting in engineered nanostructures, and the design and operation of novel structures and devices which take advantage of nanoscale effects. Students will become familiar with interdisciplinary aspects of nanotechnology, as well as with current nanoscience developments described in the literature. Prerequisites: PHGN 320, PHGN 341 or equivalent. Prerequisite: PHGN462, or permission of instructor. 3 hours lecture; 3 semester hours.

PHGN560. FIBER OPTIC COMMUNICATION Introduction to the theory and techniques of optical communications. Topics include fiber optics, transmitters, receivers, amplifiers, multichannel system design, dispersion compensation and soliton communications. Prerequisite: PHGN462 or equivalent. 3 hours lecture; 3 semester hours.

PHGN566. MODERN OPTICAL ENGINEERING Provides students with a comprehensive working knowledge of optical

system design that is sufficient to address optical problems found in their respective disciplines. Topics include paraxial optics, imaging, aberration analysis, use of commercial ray tracing and optimization, diffraction, linear systems and optical transfer functions, detectors, and optical system examples. Prerequisite: PHGN462 or consent of instructor. 3 hours lecture; 3 semester hours.

PHGN580. QUANTUM OPTICS Theory and application of the following: Gaussian beams, optical cavities and wave guides, atomic radiation, detection of radiation, laser oscillation, nonlinear optics. Prerequisite: PHGN420 and PHGN462. 3 hours lecture; 3 semester hours.

PHGN598. SPECIAL TOPICS (II) Pilot course or special topics course. Prerequisite: Consent of department. Credit to be determined by instructor. Maximum of 6 credit hours. Repeatable for credit under different titles.

PHGN599. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member; student and instructor agree on a subject matter, content, deliverables, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

PHGN601. ADVANCED GRADUATE SEMINAR (I) Ph.D. students who have been admitted to candidacy will attend the weekly Physics Colloquium. Students will be responsible for presentations during this weekly seminar. Prerequisite: credit in PHGN501 and PHGN502. 1 hour seminar; 1 semester hour.

PHGN602. ADVANCED GRADUATE SEMINAR (II) Ph.D. students who have been admitted to candidacy will attend the weekly Physics Colloquium. Students will be responsible for presentations during this weekly seminar. Prerequisite: credit in PHGN501 and PHGN502. 1 hour seminar; 1 semester hour.

PHGN606. CLASSICAL MECHANICS II Continuation of PHGN505. Selected topics from elasticity, plasticity, and fluid mechanics including the thermal and electromagnetic interaction. Theories of interacting fields. Prerequisite: PHGN505. 3 hours lecture; 3 semester hours.

PHGN608. ELECTROMAGNETIC THEORY II Spherical, cylindrical, and guided waves; relativistic 4-dimensional formulation of electromagnetic theory. Prerequisite: PHGN507. 3 hours lecture; 3 semester hours.

PHGN612. MATHEMATICAL PHYSICS II Continuation of PHGN511. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

PHGN622. QUANTUM MECHANICS III Continuation of PHGN521. Introduction to the techniques of quantized fields with applications to quantum electrodynamics and the non-relativistic many-body problem. Prerequisite: PHGN521. 3 hours lecture; 3 semester hours.

PHGN623. NUCLEAR STRUCTURE AND REACTIONS The fundamental physics principles and quantum mechanical models and methods underlying nuclear structure, transitions, and scattering reactions. Prerequisite: PHGN521 or consent of instructor. 3 hours lecture; 3 semester hours.

PHGN624. NUCLEAR ASTROPHYSICS The physical principles and research methods used to understand nucleosynthesis and energy generation in the universe. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

PHGN631. TOPICS IN STATISTICAL MECHANICS Continuation of PHGN530. Interacting systems; disordered systems; phase transitions; Green functions for many-body systems; scaling and renormalization in critical phenomena. Prerequisite: PHGN530 and PHGN622. 3 hours lecture; 3 semester hours.

PHGN640/MLGN607. CONDENSED MATTER I (I) Principles and applications of the quantum theory of electrons in solids: structure and symmetry; electron states and excitations in metals; transport properties. Prerequisite: PHGN520 and PHGN440/MLGN502 or consent of instructor. 3 hours lecture; 3 semester hours.

PHGN641/MLGN648. CONDENSED MATTER II (II) Principles and applications of the quantum theory of electrons and phonons in solids: phonon states in solids; transport properties; electron states and excitations in semiconductors and insulators; magnetism; superconductivity. Prerequisite: PHGN640/MLGN607 or consent of instructor. 3 hours lecture; 3 semester hours.

PHGN698. SPECIAL TOPICS (I, II) Pilot course or special topics course. Prerequisites: Consent of department. Credit to be determined by instructor, maximum of 6 credit hours. Repeatable for credit under different titles.

PHGN699. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member; student and instructor agree on a subject matter, content, deliverables, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

PHGN705. GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty adviser. Repeatable for credit.

PHGN706. GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty adviser. Repeatable for credit.

## Systems

### Description of Courses

#### Graduate Courses

SYGN501. THE ART OF SCIENCE This course consists of class sessions and practical exercises. The content of the course is aimed at helping students acquire the skills needed for a career in research. The class sessions cover topics such as the choice of a research topic, making a work plan and executing that plan effectively, what to do when you are stuck, how to write a publication and choose a journal for publication, how to write proposals, the nature of research, the academic career versus a career in industry, time-management, and a variety of other topics. The course is open to students with very different backgrounds; this ensures a rich and diverse intellectual environment. Prerequisite: Consent of instructor. 1 hour lecture; 1 semester hour.

SYGN600. COLLEGE TEACHING This course is designed for graduate students planning careers in academia and focuses on principles of learning and teaching in a college setting; methods to foster and assess higher order thinking; and effective design, delivery and assessment of college courses. Prerequisite: Permission of the instructor. 2 hours lecture; 2 semester hours.



## Physics

JAMES A. McNEIL, Professor and Department Head  
REUBEN T. COLLINS, Professor  
THOMAS E. FURTAK, Professor  
FRANK V. KOWALSKI, Professor  
MARK T. LUSK, Professor (and Engineering)  
JOHN A. SCALES, Professor  
JEFF A. SQUIER, Professor  
P. CRAIG TAYLOR, Professor  
CHARLES G. DURFEE III, Associate Professor  
UWE GREIFE, Associate Professor  
TIMOTHY R. OHNO, Associate Professor  
LAWRENCE R. WIENCKE, Associate Professor  
DAVID M. WOOD, Associate Professor  
LINCOLN D. CARR, Assistant Professor  
FREDERIC SARAZIN, Assistant Professor  
TODD G. RUSKELL, Senior Lecturer  
CHARLES A. STONE, IV, Senior Lecturer  
MATTHEW M. YOUNG, Senior Lecturer  
ALEX T. FLOURNOY, Lecturer  
PATRICK B. KOHL, Lecturer  
H. VINCENT KUO, Lecturer  
SUE ANNE BERGER, Instructor  
JOHN U. TREFNY, Professor Emeritus and President Emeritus  
JAMES T. BROWN, Professor Emeritus  
F. EDWARD CECIL, Professor Emeritus  
JOHN A. DESANTO, Professor Emeritus  
FRANKLIN D. SCHOWENGERDT, Professor Emeritus  
DON L. WILLIAMSON, Professor Emeritus  
F. RICHARD YEATTS, Professor Emeritus  
WILLIAM B. LAW, Associate Professor Emeritus  
ARTHUR Y. SAKAKURA, Associate Professor Emeritus  
MARK W. COFFEY, Research Professor  
ROBERT F. HOLUB, Research Professor  
VICTOR KAYDANOV, Research Professor  
JAMES E. BERNARD, Research Associate Professor  
JOSEPH D. BEACH, Research Assistant Professor

### *Degrees Offered:*

Master of Science (Applied Physics)  
Doctor of Philosophy (Applied Physics)

### *Program Description:*

The Physics Department at CSM offers a full program of instruction and research leading to the M.S. or Ph.D. in applied physics.

Graduate students are given a solid background in the fundamentals of classical and modern physics at an advanced level and are encouraged early in their studies to learn about the research interests of the faculty so that a thesis topic can be identified.

### *Program Requirements:*

Students entering graduate programs in Applied Physics will select an initial program in consultation with the departmental graduate student advising committee until such time as a research field has been chosen and a thesis committee appointed. The following are requirements for the M.S. and Ph.D. degrees:

Master's: 20 semester hours of course work in an approved program plus 16 semester hours of research credit, with a satisfactory thesis. Doctorate: 34 semester hours of course work in an approved program plus 38 semester hours of research credit, with a satisfactory thesis. 12 semester hours of course work will be in a specialty topic area defined in consultation with the thesis advisor. Possible specialty topic areas within the physics department exist in Optical Science and Engineering, Photovoltaics and Electronic Materials, and Nuclear Physics and Astrophysics

To demonstrate adequate preparation for the Ph.D. degree in Applied Physics, each student must pass the physics graduate core courses with a grade point average of 3.0 or better. Students not achieving this standard must pass oral examinations covering the areas of weakness identified in the core courses or retake the respective course with a grade of 3.0 or better within one year. This process is part of the requirement for admission to candidacy, which full time Ph.D. students must complete within two calendar years of admission, as described in the campus-wide graduate degree requirements section of this bulletin. Other degree requirements, time limits, and procedural details can be found in the Physics Department Graduate Student Advising Brochure.

### *Prerequisites:*

The Graduate School of the Colorado School of Mines is open to graduates from four-year programs at accredited colleges or universities. Admission to the Physics Department M.S. and Ph.D. programs is competitive and is based on an evaluation of undergraduate performance, standardized test scores, and references. The undergraduate course of study of each applicant is evaluated according to the requirements of the Physics Department.

### *Required Curriculum:*

#### **Master of Science, Applied Physics**

##### Core Courses

PHGN511 Mathematical Physics I  
PHGN520 Quantum Mechanics I

##### One additional course selected from:

PHGN505 Classical Mechanics I  
PHGN507 Electromagnetic Theory I  
PHGN521 Quantum Mechanics II  
PHGN530 Statistical Mechanics

Electives - 9 hours.

Graduate Seminar\* - 2 hours.

Master's Thesis

#### **Doctor of Philosophy, Applied Physics**

##### Core Courses

PHGN505 Classical Mechanics I  
PHGN507 Electromagnetic Theory I  
PHGN511 Mathematical Physics I  
PHGN520 Quantum Mechanics I  
PHGN521 Quantum Mechanics II

PHGN530 Statistical Mechanics

Graduate Seminar\* - 4 hours.

12 hours special topic area electives.

Doctoral Thesis.

\*Graduate Seminar: Each full-time graduate student (M.S. and Ph.D.) will register for Graduate Seminar each semester for a total of 2 semester hours credit for the M.S. and 4 semester hours credit for the Ph.D.

#### **Fields of Research:**

Applied Optics: lasers, ultrafast optics and x-ray generation, spectroscopy, near-field and multi-photon microscopy, non-linear optics, quasi-optics and millimeter waves.

Ultrasonics: laser ultrasonics, resonant ultrasound spectroscopy, wave propagation in random media.

Subatomic: low energy nuclear physics, nuclear astrophysics, cosmic ray physics, nuclear theory, fusion plasma diagnostics.

Electronic Materials: photovoltaics, nanostructures and quantum dots, thin film semiconductors, transparent conductors, amorphous materials.

Solid State: x-ray diffraction, Raman spectroscopy, self assembled systems, soft condensed matter, condensed matter theory, quantum chaos, quantum information and quantum many body theory.

Surface and Interfaces: x-ray photoelectron spectroscopy, Auger spectroscopy, scanning probe microscopies, second harmonic generation.

#### **Description of Courses**

##### **Senior Level**

PHGN404. PHYSICS OF THE ENVIRONMENT An examination of several environmental issues in terms of the fundamental underlying principles of physics including energy conservation, conversion and generation; solar energy; nuclear power and weapons, radioactivity and radiation effects; aspects of air, noise, and thermal pollution.

Prerequisite: PHGN200/210 or consent of instructor. 3 hours lecture; 3 semester hours.

PHGN412. MATHEMATICAL PHYSICS Mathematical techniques applied to the equations of physics; complex variables, partial differential equations, special functions, finite and infinite-dimensional vector spaces. Green's functions. Transforms; computer algebra. Prerequisite: PHGN311. 3 hours lecture; 3 semester hours.

PHGN419. PRINCIPLES OF SOLAR ENERGY

SYSTEMS Theory and techniques of insolation measurement. Absorptive and radiative properties of surfaces. Optical properties of materials and surfaces. Principles of photovoltaic devices. Optics of collector systems. Solar energy conversion techniques: heating and cooling of buildings, solar thermal (power and process heat), wind energy, ocean thermal, and photovoltaic. Prerequisite: PHGN300/310 3 hours lecture; 3 semester hours

PHGN420. QUANTUM MECHANICS Schroedinger equation, uncertainty, change of representation, one-dimensional problems, axioms for state vectors and operators, matrix mechanics, uncertainty relations, time-independent perturbation theory, time-dependent perturbations, harmonic oscillator, angular momentum. Prerequisite: PHGN320, PHGN350, PHGN361. 3 hours lecture; 3 semester hours.

PHGN422. NUCLEAR PHYSICS Introduction to subatomic (particle and nuclear) phenomena. Characterization and systematics of particle and nuclear states; symmetries; introduction and systematics of the electromagnetic, weak, and strong interactions; systematics of radioactivity; liquid drop and shell models; nuclear technology. Prerequisite: PHGN320. 3 hours lecture; 3 semester hours.

PHGN423. DIRECT ENERGY CONVERSION Review of basic physical principles; types of power generation treated include fission, fusion, magnetohydrodynamic, thermoelectric, thermionic, fuel cells, photovoltaic, electrohydrodynamic, piezoelectrics. Prerequisite: PHGN300/310. 3 hours lecture; 3 semester hours.

PHGN424. ASTROPHYSICS A survey of fundamental aspects of astrophysical phenomena, concentrating on measurements of basic stellar properties such as distance, luminosity, spectral classification, mass, and radii. Simple models of stellar structure evolution and the associated nuclear processes as sources of energy and nucleosynthesis. Introduction to cosmology and physics of standard big-bang models. Prerequisite: PHGN320. 3 hours lecture; 3 semester hours.

PHGN435/ChEN435. INTERDISCIPLINARY MICROELECTRONICS PROCESSING LABORATORY Application of science and engineering principles to the design, fabrication, and testing of microelectronic devices. Emphasis on specific unit operations and the interrelation among processing steps. Prerequisites: Senior standing in PHGN, ChEN, MTGN, or EGGN; consent of instructor. 1.5 hours lecture, 4 hours lab; 3 semester hours.

PHGN440/MLGN502. SOLIDSTATE PHYSICS An elementary study of the properties of solids including crystalline structure and its determination, lattice vibrations, electrons in metals, and semiconductors. (Graduate students in physics may register only for PHGN440.) Prerequisite: PHGN320. 3 hours lecture; 3 semester hours.

PHGN441/MLGN522. SOLIDSTATE PHYSICS APPLICATION AND PHENOMENA Continuation of PHGN440/MLGN502 with an emphasis on applications of the principles of solid state physics to practical properties of materials including: optical properties, superconductivity, dielectric properties, magnetism, noncrystalline structure, and interfaces. (Graduate students in physics may register only for PHGN441.) Prerequisite: PHGN440/MLGN501 or equivalent by instructor's permission. 3 hours lecture; 3 semester hours.

PHGN450. COMPUTATIONAL PHYSICS Introduction to numerical methods for analyzing advanced physics problems. Topics covered include finite element methods, analysis of scaling, efficiency, errors, and stability, as well as a survey of numerical algorithms and packages for analyzing algebraic, differential, and matrix systems. The numerical methods are introduced and developed in the analysis of advanced physics problems taken from classical physics, astrophysics, electromagnetism, solid state, and nuclear physics. Prerequisites: Introductory-level knowledge of C, Fortran or Basic; PHGN311. 3 hours lecture; 3 semester hours.

PHGN462. ELECTROMAGNETIC WAVES AND OPTICAL PHYSICS (I) Solutions to the electromagnetic wave equation and polarization; applications in optics: imaging, lasers, resonators and wavelengths. Prerequisite: PHGN361. 3 hours lecture; 3 semester hours.

PHGN466 MODERN OPTICAL ENGINEERING Provides students with a comprehensive working knowledge of optical system design that is sufficient to address optical problems found in their respective disciplines. Topics include paraxial optics, imaging, aberration analysis, use of commercial raytracing and optimization, diffraction, linear systems and optical transfer functions, detectors and optical systems examples. Prerequisite: PHGN462 or consent of the instructor. 3 hours lecture; 3 semester hours.

PHGN471. SENIOR DESIGN (I) The first of a two-semester program covering the full spectrum of experimental design, drawing on the student's previous course work. At the beginning of the first semester, the student selects a research project in consultation with the course coordinator and the faculty supervisor. The objectives of the project are given to the student in broad outline form. The student then designs the entire project, including any or all of the following elements as appropriate: literature search, specialized apparatus, block-diagram electronics, computer data acquisition and/or analysis, sample materials, and measurement and/or analysis sequences. The course culminates in a senior thesis. Supplementary lectures are given on techniques of physics research and experimental design. Prerequisite: PHGN384 and PHGN326. 1 hour lecture, 6 hours lab; 3 semester hours.

PHGN472. SENIOR DESIGN (II) Continuation of PHGN471. Prerequisite: PHGN384 and PHGN326. 1 hour lecture, 6 hours lab; 3 semester hours.

PHGN498. SPECIAL TOPICS (I, II) Pilot course or special topics course. Prerequisites: Consent of instructor. Credit to be determined by instructor, maximum of 6 credit hours.

PHGN499. INDEPENDENT STUDY (I, II) Individual - research or special problem projects supervised by a faculty member; student and instructor agree on a subject matter, content, deliverables, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours.

#### Graduate Courses

500-level courses are open to qualified seniors with the permission of the department and the Dean of the Graduate School.

PHGN501. GRADUATE SEMINAR (I) M.S. students and Ph.D. students who have not been admitted to candidacy will attend the weekly Physics Colloquium. Students will be responsible for presentations during this weekly seminar. 1 hour seminar; 1 semester hour.

PHGN502. GRADUATE SEMINAR (II) M.S. students and Ph.D. students who have not been admitted to candidacy will attend the weekly Physics Colloquium. Students will be responsible for presentations during this weekly seminar. 1 hour seminar; 1 semester hour.

PHGN504. RADIATION DETECTION AND MEASUREMENT Physical principles and methodology of the instrumentation used in the detection and measurement of ionizing radiation. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

PHGN505. CLASSICAL MECHANICS I (I) Review of - Lagrangian and Hamiltonian formulations in the dynamics of particles and rigid bodies; kinetic theory; coupled oscillations and continuum mechanics; fluid mechanics. Prerequisite: PHGN350 or equivalent. 3 hours lecture; 3 semester hours.

PHGN507. ELECTROMAGNETIC THEORY I (II) To provide a strong background in electromagnetic theory. Electrostatics, magnetostatics, dynamical Maxwell equations, wave phenomena. Prerequisite: PHGN462 or equivalent. 3 hours lecture; 3 semester hours.

PHGN511. MATHEMATICAL PHYSICS (I) Review of complex variable and finite and infinite-dimensional linear vector spaces. Sturm-Liouville problem, integral equations, computer algebra. Prerequisite: PHGN311 or equivalent. 3 hours lecture; 3 semester hours.

PHGN520. QUANTUM MECHANICS I (I) Schrodinger equation, uncertainty, change of representation, one-dimensional problems, axioms for state vectors and operators, matrix mechanics, uncertainty relations, time-independent perturbation theory, time-dependent perturbations, harmonic oscillator, angular momentum; semiclassical methods, variational methods, two-level system, sudden and adiabatic changes, applications. Prerequisite: PHGN420 or equivalent. 3 hours lecture; 3 semester hours.

PHGN521. QUANTUM MECHANICS II (II) Review of - angular momentum, central potentials and applications. Spin; rotations in quantum mechanics. Formal scattering theory, Born series, partial wave analysis. Addition of angular momenta, Wigner-Eckart theorem, selection rules, identical particles. Prerequisite: PHGN520. 3 hours lecture; 3 semester hours.

PHGN525/MLGN525. SURFACE PHYSICS Solid state physics focusing on the structural and electronic nature of the outer few atomic layers and the gas-surface interactions. - Detailed explanations of many surface analysis techniques are provided, highlighting the application of these techniques to current problems, particularly electronic materials. Prerequisite: MLGN502 or equivalent, or consent of instructor. 3 hours lecture; 3 semester hours.

PHGN530. STATISTICAL MECHANICS (II) Review of thermodynamics; equilibrium and stability; statistical operator and ensembles; ideal systems; phase transitions; non-equilibrium systems. Prerequisite: PHGN341 or equivalent and PHGN520. Co-requisite: PHGN521. 3 hours lecture; 3 semester hours.

PHGN535/ChEN535/MLGN535. INTERDISCIPLINARY SILICON PROCESSING LABORATORY Explores the application of science and engineering principles to the fabrication and testing of microelectronic devices with emphasis on specific unit operations and interrelation among processing steps. Teams work together to fabricate, test, and optimize simple devices. Prerequisite: Consent of instructor. 1 hour lecture, 4 hours lab; 3 semester hours.

PHGN542. SOLID STATE DEVICES An overview of the physical principles involved in the fabrication, characterization, and operation of solid state devices. Topics will include: p-n junction devices (e.g., LEDs, solar cells, lasers, particle detectors); junction transistor devices (e.g., FETs, thyristors, switches); surface- and interface-controlled devices (e.g., MOSFETs, CSDs, Schottky barrier devices); other devices such as infrared detectors, recording and display devices, thermoelectric devices, Josephson junctions, electroluminescent and electrochromic panels. Prerequisite: PHGN440. 3 hours lecture; 3 semester hours.

PHGN544. THEORY AND OPERATION OF PHOTOVOLTAIC DEVICES A thorough treatment of photovoltaic device operation and theory. Material and device parameters as related to the generation of photocurrents and photovoltages in solar cells. Physics of various solar cell types: homojunctions, heterojunctions, Schottky barriers, MIS, SIS, electrochemical. Environmental effects and device production. Important measurement techniques. Discussion of research topics from the current literature. Prerequisite: PHGN440 or consent of instructor. 3 hours lecture; 3 semester hours.

#### PHGN550 NANOSCALE PHYSICS AND TECHNOLOGY

An introduction to the basic physics concepts involved in nanoscale phenomena, processing methods resulting in engineered nanostructures, and the design and operation of novel structures and devices which take advantage of nanoscale effects. Students will become familiar with interdisciplinary aspects of nanotechnology, as well as with current nanoscience developments described in the literature. Prerequisites: PHGN 320, PHGN 341, co-requisite: PHGN462, or permission of instructor. 3 hours lecture; 3 semester hours.

PHGN560. FIBER OPTIC COMMUNICATION Introduction to the theory and techniques of optical communications. Topics include fiber optics, transmitters, receivers, amplifiers, multichannel system design, dispersion compensation and soliton communications. Prerequisite: PHGN462 or equivalent. 3 hours lecture; 3 semester hours.

PHGN566. MODERN OPTICAL ENGINEERING Provides students with a comprehensive working knowledge of optical system design that is sufficient to address optical problems found in their respective disciplines. Topics include paraxial optics, imaging, aberration analysis, use of commercial ray tracing and optimization, diffraction, linear systems and - optical transfer functions, detectors, and optical system examples. Prerequisite: PHGN462 or consent of instructor. 3 hours lecture; 3 semester hours.

PHGN 570. FOURIER AND PHYSICAL OPTICS This course addresses the propagation of light through optical systems. Diffraction theory is developed to show how 2D Fourier transforms and linear systems theory can be applied to imaging systems. Analytic and numerical Fourier and Fresnel transform techniques are applied to systems such as microscopes, spectrometers and holographic imaging. They are also applied to temporal propagation in ultrafast optics. Prerequisite: PHGN 462 or equivalent, or permission of instructor. 3 hours lecture; 3 semester hours.

PHGN580. QUANTUM OPTICS Theory and application of the following: Gaussian beams, optical cavities and wave guides, atomic radiation, detection of radiation, laser oscillation, nonlinear optics. Prerequisite: PHGN420 and PHGN462. 3 hours lecture; 3 semester hours.

PHGN 585. NONLINEAR OPTICS An exploration of the nonlinear response of a medium (semiclassical and quantum descriptions) and nonlinear wave mixing and propagation. Analytic and numeric techniques to treat nonlinear dynamics are developed. Applications to devices and modern research areas are discussed, including harmonic and parametric wave generation and phase matching, self-focusing, self-phase modulation, phase conjugation, electro-optic modulation. Prerequisite: PHGN 462 or equivalent, PHGN 520, or by permission of instructor. 3 hours lecture; 3 semester hours.

PHGN598. SPECIAL TOPICS (I, II) Pilot course or special topics course. Prerequisites: Consent of department. Credit to be determined by instructor, maximum of 6 credit hours.



PHGN599. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member; student and instructor agree on a subject matter, content, deliverables, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours.

PHGN601. ADVANCED GRADUATE SEMINAR (I) Ph.D. students who have been admitted to candidacy will attend the weekly Physics Colloquium. Students will be responsible for presentations during this weekly seminar. Prerequisite: credit in PHGN501 and PHGN502. 1 hour seminar; 1 semester hour.

PHGN602. ADVANCED GRADUATE SEMINAR (II) Ph.D. students who have been admitted to candidacy will attend the weekly Physics Colloquium. Students will be responsible for presentations during this weekly seminar. Prerequisite: credit in PHGN501 and PHGN502. 1 hour seminar; 1 semester hour.

PHGN608. ELECTROMAGNETIC THEORY II Spherical, cylindrical, and guided waves; relativistic 4-dimensional formulation of electromagnetic theory. Prerequisite: PHGN507. 3 hours lecture; 3 semester hours.

PHGN612. MATHEMATICAL PHYSICS II Continuation of PHGN511. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

PHGN623. NUCLEAR STRUCTURE AND REACTIONS The fundamental physics principles and quantum mechanical models and methods underlying nuclear structure, transitions, and scattering reactions. Prerequisite: PHGN521 or consent of instructor. 3 hours lecture; 3 semester hours.

PHGN624. NUCLEAR ASTROPHYSICS The physical principles and research methods used to understand nucleosynthesis and energy generation in the universe. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

PHGN640/MLGN607. CONDENSED MATTER I (I) Principles and applications of the quantum theory of electrons in solids: structure and symmetry; electron states and excitations in metals; transport properties. Prerequisite: PHGN520 and PHGN440/MLGN502 or consent of instructor. 3 hours lecture; 3 semester hours.

PHGN641/MLGN648. CONDENSED MATTER II (II) Principles and applications of the quantum theory of electrons and phonons in solids: phonon states in solids; transport properties; electron states and excitations in semiconductors and insulators; magnetism; superconductivity. Prerequisite: PHGN640/MLGN607 or consent of instructor. 3 hours lecture; 3 semester hours.

PHGN698. SPECIAL TOPICS (I, II) Pilot course or special topics course. Prerequisites: Consent of department. Credit to be determined by instructor, maximum of 6 credit hours.

PHGN699. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member; student and instructor agree on a subject matter, content, deliverables, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours.

PHGN705. GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor.

PHGN706. GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty advisor.

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## Research Centers and Institutes

### Advanced Coatings and Surface Engineering Laboratory

The Advanced Coating and Surface Engineering Laboratory (ACSEL) is a multi-disciplinary laboratory that serves as a focal point for industry-driven research and education in advanced thin films and coating systems, surface engineering, tribology, electronic, optical and magnetic thin films and devices. The laboratory is supported by a combination of government funding agencies (NSF, DOE, DOD) and an industrial consortium that holds annual workshops designed to maximize interaction between participants, evaluate the research conducted by graduate students and faculty, and provide direction and guidance for future activities. ACSEL provides opportunities for CSM faculty and graduate students to visit and work in sponsor facilities, participate in technical meetings with sponsors, and for CSM graduates to gain employment with sponsors.

### Advanced Control of Energy and Power Systems

The Advanced Control of Energy and Power Systems Center (ACEPS), based in the Engineering Division, features a unique partnership consisting of industry, the Department of Energy (DOE), the Electric Power Research Institute (EPRI), Colorado School of Mines (CSM) and twelve other universities. The mission of ACEPS is to conduct fundamental and applied research supporting the technical advancement of the electric utility industry, their customers, and component suppliers in the field of electric power systems and power electronics. Special emphasis is placed on advanced/intelligent control and power quality in the generation, transmission, distribution, and utilization.

Center research projects focus on the development of an intelligent energy system that will employ advanced power electronics, enhanced computer and communications systems, renewable energy applications and distributed generation. Examples include development of intelligent substations, impact of highly varying loads, power quality, electrical equipment life assessment, and intelligent automatic generation control for transient loads.

### Advanced Steel Processing and Products Research Center

The Advanced Steel Processing and Products Research Center (ASPPRC) at Colorado School of Mines was established in 1984. The Center is a unique partnership between industry, the National Science Foundation (NSF), and Colorado School of Mines, and is devoted to building excellence in research and education in the ferrous metallurgy branch of materials science and engineering. Objectives of ASPPRC are to perform research of direct benefit to the users and producers of steels, to educate graduate students within the context of research programs of major theoretical and practical interest to the steel-using and steel-producing industries, to

stimulate undergraduate education in ferrous metallurgy, and to develop a forum to stimulate advances in the processing, quality and application of steel.

Research programs consist of several projects, each of which is a graduate student thesis. Small groups of students and faculty are involved in each of the research programs. Sponsor representatives are encouraged to participate on the graduate student committees.

The Center was established with a five-year grant of \$575,000 from the National Science Foundation, and is now self-sufficient, primarily as a result of industry support.

### Center for Automation, Robotics and Distributed Intelligence

The mission of the Center for Automation, Robotics and Distributed Intelligence (CARDI) is to engage in interdisciplinary research encompassing the fields of control systems, robotics and automation, and distributed systems and networking. Focus areas include the theory of adaptive and non-linear control, intelligent and learning control systems, system identification and fault detection, computer vision and image processing, wireless communication networks, intelligent autonomous robotic systems, machine learning and artificial intelligence, network communication protocols and simulation and modeling of computer networks. Applications of CARDI research can be found in renewable energy and power systems, materials processing, sensor and control networks, bio-engineering and medicine, data mining and activity recognition, defense and homeland security, smart structures, intelligent geo-systems, and environmental monitoring. CARDI research concentrates on problems which are not amenable to traditional solutions within a single discipline, but rather require a multi-disciplinary systems approach to integrate technologies.

Established in 1994, CARDI includes faculty from the Division of Engineering and the Department of Mathematical and Computer Science. Research is sponsored by industry, federal agencies, state agencies, and joint government-industry initiatives. Interaction with industry enables CARDI to identify technical needs that require research, to cooperatively develop solutions, and to generate innovative mechanisms for the technology transfer. Enthusiastic and motivated students are encouraged to join CARDI for education and research in the area of automation, robotics, and distributed systems.

### Center for Earth Materials, Mechanics, and Characterization

EM<sup>2</sup>C is a multidisciplinary research center intended to promote research in a variety of areas including rock mechanics, earth systems, and nontraditional characterization. The Center does not limit its focus to either “hard” or “soft” rock applications but instead fosters research in both arenas and encourages interdisciplinary communication be-

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tween the associated disciplines. The Colorado School of Mines is a world leader in multidisciplinary integration and therefore presents a unique atmosphere to promote the success of such research. Faculty and students from the Departments of Petroleum Engineering, Geophysical Engineering, Geology and Geological Engineering, Engineering, and Mining Engineering are involved in EM<sup>2</sup>C. In addition to traditional topics in these disciplines, the center cultivates research in nontraditional characterization such as arctic ice coring, extraterrestrial space boring, and laser/rock destruction for multiple applications. EM<sup>2</sup>C was established in 2003.

### **Center for Engineering Education**

The Center serves as a focal point for engineering and science education research conducted by CSM faculty. Successfully educating tomorrow's engineers and scientists requires that we look at student learning as a system. The principles of cognitive psychology and educational psychology provide the best explanation of how this learning system works. Education will be most effective when education research, informed by the principles of cognitive and educational psychology are applied to design and application of classroom teaching techniques and curricular materials.

The primary goals of the Center for Engineering Education are

- ◆ To conduct world-class research on teaching and learning in engineering and science.
- ◆ To use the results of that research by continually improving instruction at the Colorado School of Mines to better support the learning process of our students.
- ◆ To support the educational needs of science and engineering instructors at the pre-college, college, graduate and professional development levels.

### **Center for Environmental Risk Assessment**

The mission of the Center for Environmental Risk Assessment (CERA) at CSM is to unify and enhance environmental risk assessment research and educational activities at CSM. By bringing diverse, inter-disciplinary expertise to bear on problems in environmental risk assessment, CERA facilitates the development of significantly improved, scientifically based approaches for estimating human and ecological risks and for using the results of such assessments. Education and research programs within CERA integrate faculty and students from the departments of Chemical Engineering and Petroleum Refining, Environmental Sciences and Engineering, Chemistry and Geochemistry, Mathematics and Computer Science, and Geology and Geological Engineering.

### **Center for Intelligent Biomedical Devices and Musculoskeletal Systems**

The multi-institutional Center for Intelligent Biomedical Devices and Musculoskeletal systems (IBDMS) integrates programs and expertise from CSM and the University of Colorado at Denver and Health Sciences Center. Established at CSM as a National Science Foundation (NSF) Industry/University Cooperative Research Center, IBDMS is also supported by industry, State, and Federal organizations.

IBDMS has become an international center for the development of Computer Assisted Surgery, Advanced Orthopaedic Applications, Sports Medicine, Occupational Biomechanics, and Biomaterials. Through the efforts of this center, new major and minor programs in bioengineering and biotechnology have been established at both the CSM graduate and undergraduate levels.

IBDMS seeks to establish educational programs in addition to short- and long-term basic and applied research efforts that would enhance the competitive position of Colorado and U.S. bio-industry in the international markets. IBDMS focuses the work of diverse engineering, materials and medicine disciplines. Its graduates are a new generation of students with an integrated engineering and medicine systems view, with increasing opportunities available in the biosciences.

For more information about the IBDMS Center please contact Dr. Joel M. Bach at [jmbach@mines.edu](mailto:jmbach@mines.edu) or 303-384-2161.

### **Center for Research on Hydrates and Other Solids**

Since 1975, the Center for Research on Hydrates and Other Solids has performed both fundamental and applied research on natural gas hydrates, curious ice-like compounds composed of water and hydrocarbon gases. Gas hydrates, which generally form at cold temperatures and high pressures, present both a major challenge and major opportunity in energy production. Gas hydrates can plug deep sea and arctic gas and oil pipelines, and preventing hydrate formation is a major design and operational challenge. On the other hand, naturally occurring gas hydrates could potentially provide the world's largest resource of natural gas. Recently, researchers at the center have also found that hydrates can be used a hydrogen storage material, for potential use in fuel cell vehicles.

With active participation of faculty, graduate, and undergraduate students, the center provides a unique combination of expertise that has enabled CSM to achieve international prominence in gas hydrate research. CSM participants interact on an on-going basis with sponsors and other collaborators, including frequent visits to their facilities both in the US and abroad. For students, this interaction often continues beyond graduation, with opportunities for employment at sponsoring industries. More information can be found at the center website, [www.mines.edu/research/chs](http://www.mines.edu/research/chs).

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## Center for Solar and Electronic Materials

The Center for Solar and Electronic Materials (CSEM) was established in 1995 to focus, support, and extend growing activity in electronic materials for solar applications, in electronic and microelectronic technologies, and in related optical technologies. In addition to photovoltaics, CSEM supports research into advanced optics, novel optical devices, thin film materials, polymeric devices, micro fluidic devices, nanoscale science and nanofabrication, novel characterization, electronic materials processing, process simulation, and systems issues associated with electronic materials and devices. Alternative energy technologies and sustainability are also areas of interest. CSEM facilitates interdisciplinary collaborations across the CSM campus and fosters interactions with national laboratories, industries, public utilities, local state and federal government, and other universities. The center coordinates grant applications by its members to collective funding opportunities, manages a joint-use laboratory with a broad range of characterization and processing tools, purchases joint-use tools based on member needs and maintains a virtual computational lab. In fulfilling its research and educational mission, CSEM draws from expertise in the departments of Physics, Chemical Engineering, Metallurgical and Materials Engineering, Chemistry and Geochemistry, and from the Division of Engineering.

CSEM also serves to guide and strengthen the curriculum in electronic materials and related areas. CSEM members develop and teach relevant courses. CSEM also emphasizes training through research experiences for both graduate and undergraduate students. Graduate students in the above-mentioned departments as well as the materials science program can pursue research on center-related projects. Undergraduates are involved through engineering design courses and summer research experiences. Close proximity to the National Renewable Energy Lab and several local photovoltaic companies provides a unique opportunity for students to work with industry and government labs as they solve real world problems. External contacts also provide guidance in targeting the educational curriculum toward the needs of the electronic materials industry.

## Center for Space Resources (CSR)

The Center for Space Resources is dedicated to the human and robotic exploration of space and to the utilization of what we learn to the improvement of our society by developing technologies for space resource extraction, manufacturing in space, and life-support systems on spacecraft and planetary habitats. While there are several practical applications of space exploration on Earth, the greatest achievement bringing benefits to humankind would be to develop commercial applications of space technology, including space and planetary resources, in space.

These will one day form the basis for new space industries that include the harvesting of solar energy outside Earth's atmosphere, the development of an in-space reusable transportation infrastructure carrying payloads from Earth to geostationary orbits, the Moon or Mars and back, servicing of satellites to extend their useful lifetimes and reduce the costs of space operations, and processing of value-added materials in Earth orbit based on lunar material resources.

These goals are pursued by a Consortium involving faculty and students from several departments, NASA and other government agencies, and industrial partners working together on space-related projects.

## Center for Wave Phenomena

With sponsorship for its research by 24 companies in the worldwide oil exploration industry and several government agencies, this program, which includes faculty and students from the Departments of Geophysics, is engaged in a coordinated and integrated program of research in wave propagation, inverse problems and seismic data processing. Its methods have applications to seismic exploration and reservoir monitoring, global seismology, nondestructive testing and evaluation, and land-mine detection, among other areas. Extensive use is made of analytical methods as well as computational techniques. Methodology is developed through computer implementation, based on the philosophy that the ultimate test of an inverse method is its application to experimental data. Thus, the group starts from a physical problem, develops a mathematical model that adequately represents the physics, derives an approximate solution, generates a computer code to implement the method, performs tests on synthetic data, and finally, on field data.

## Center for Welding, Joining and Coatings Research

The Center for Welding, Joining and Coatings Research (CWJCR) is an interdisciplinary organization with researchers and faculty from the Metallurgical and Materials Engineering Department, the Engineering Division, and the Mining Engineering Department. The goal of CWJCR is to promote graduate-level education and research, and to advance understanding of the metallurgical and processing aspects of welding, joining and coating processes. Current center activities include: education, research, conferences, short courses, seminars, information source and transfer, and industrial consortia. The Center receives significant support from industry, national laboratories and government entities.

The Center for Welding, Joining and Coatings Research strives to provide numerous opportunities that directly contribute to the student's professional growth. Some of the opportunities include:

Direct involvement in projects that constitute the Center's research program.

Interaction with internationally renowned visiting scholars.



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Industrial collaborations that provide equipment, materials and services.

Research experience at industrial plants or national laboratories.

Professional experience and exposure before nationally recognized organizations through student presentations of university research.

Direct involvement in national welding, materials, and engineering professional societies.

## **Chevron Center of Research Excellence**

The Chevron Center of Research Excellence (CoRE) is a partnership between the Colorado School of Mines (CSM) and Chevron (CVX) to conduct research on sedimentary architecture and reservoir characterization and modeling. The center supports the development of new earth science technology while providing CVX international employees the opportunity to earn advanced degrees.

## **Colorado Center for Advanced Ceramics**

The Colorado Center for Advanced Ceramics (CCAC) is developing the fundamental knowledge that is leading to important technological developments in advanced ceramics and composite materials. Established at CSM in April 1988 as a joint effort between CSM and the Coors Ceramics Company (now CoorsTek), the Center is dedicated to excellence in research and graduate education in high technology ceramic and composite materials. The goal of the Center is to translate advances in materials science into new and improved ceramic fabrication processes and ceramic and composite materials. Current research projects cover a broad spectrum of materials and phenomena including fuel cell, solar cell and battery materials; nano-scale powder preparation and mechanics; ceramic-metal composites; interparticle forces; layered materials for ballistic applications; and mechanical properties of thin films. Current projects are supported by both industry and government and several students are performing their research through a collaboration with the National Renewable Energy Laboratory located in Golden. Each project involves research leading to a graduate thesis of a student.

## **Colorado Energy Research Institute**

Originally established in 1974 and reestablished in 2004, the Colorado Energy Research Institute (CERI) promotes research and educational activities through networking among all constituencies in Colorado, including government agencies, energy industries, and universities. CERI's mission is to serve as a state and regional resource on energy and energy-related minerals issues, provide energy status reports, sponsorship of symposia, demonstration programs, and reports on research results. CERI's activities enhance the development

and promotion of energy and energy-related minerals education programs in the areas of energy development, utilization, and conservation, and provide a basis for informed energy-related state policies and actions.

## **Colorado Institute for Energy, Materials and Computational Science**

The Colorado Institute for Energy, Materials and Computational Science (CIEMACS) is an interdisciplinary research institute involving research active faculty and students from several academic departments at the Colorado School of Mines. These faculty and students have expertise in the chemistry, physics and engineering of energy conversion processes, including solid oxide and PEMS fuel cells, clean fuels, combustion experimentation and modeling, materials synthesis in flames, atomistic materials modeling and the development of optical measurement techniques for combustion systems and reactive flows. CIEMACS is also a CSM focal point for high performance computing. It is home to the CIEMACS-CHEETAH teraflop computing laboratory and to GECO-the Golden Energy Computing Organization. GECO is a collaborative project with CSM academic departments, the National Center for Atmospheric Research (NCAR) and the National Renewable Energy Laboratory (NREL) focused on high performance computing in the energy, geological and materials sciences.

## **Colorado Institute for Macromolecular Science and Engineering**

The Colorado Institute for Macromolecular Science and Engineering (CIMSE) was established in 1999 by an interdisciplinary team of faculty from several CSM departments. It is sponsored by the National Science Foundation, the Environmental Protection Agency, and the Department of Energy.

The mission of the Institute is to enhance the training and research capabilities of CSM in the area of polymeric and other complex materials as well as to promote education in the areas of materials, energy, and the environment.

Fourteen CSM faculty members from eight departments are involved with the Institute's research. The research volume is more than \$1 million and supports around 15 full-time graduate students in polymers, colloids and complex fluids. Current research projects include plastics from renewable resources, computer simulation of polymers, novel synthetic methods, and the development of new processing strategies from polymer materials.

CIMSE works to improve the educational experience of undergraduate and graduate students in polymers and complex fluids as well as maintain state-of-the-art lab facilities. Currently CSM has the largest polymeric materials effort in the State of Colorado. Materials are a dominant theme at CSM, and CIMSE will play an important role in ensuring that our students remain competitive in the workforce.

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## Energy and Minerals Field Institute

The Energy and Minerals Field Institute is an educational activity serving Colorado School of Mines students and external audiences. The goal of the Institute is to provide better understanding of complex regional issues surrounding development of western energy and mineral resources by providing firsthand experience that cannot be duplicated in the classroom. The Institute conducts field programs for educators, the media, government officials, industry, and the financial community. The Institute also hosts conferences and seminars throughout the year dealing with issues specific to western resources development. Students involved in Institute programs are afforded a unique opportunity to learn about the technological, economic, environmental, and policy aspects of resource development.

## Excavation Engineering and Earth Mechanics Institute

The Excavation Engineering and Earth Mechanics Institute (EMI), established in 1974, combines education and research for the development of improved excavation technology. By emphasizing a joint effort among research, academic, and industrial concerns, EMI contributes to the research, development and testing of new methods and equipment, thus facilitating the rapid application of economically feasible new technologies.

Current research projects are being conducted throughout the world in the areas of tunnel, raise and shaft boring, rock mechanics, micro-seismic detection, machine instrumentation and robotics, rock fragmentation and drilling, materials handling systems, innovative mining methods, and mine design and economics analysis relating to energy and non-fuel minerals development and production. EMI has been a pioneer in the development of special applications software and hardware systems and has amassed extensive databases and specialized computer programs. Outreach activities for the Institute include the offering of short courses to the industry, and sponsorship and participation in major international conferences in tunneling, shaft drilling, raise boring and mine mechanization.

The full-time team at EMI consists of scientists, engineers, and support staff. Graduate students pursue their thesis work on Institute projects, while undergraduate students are employed in research.

## International Ground Water Modeling Center

The International Ground Water Modeling Center (IGWMC) is an information, education, and research center for ground-water modeling established at Holcomb Research Institute in 1978, and relocated to the Colorado School of Mines in 1991. Its mission is to provide an international focal point for ground-water professionals, managers, and educators in advancing

the use of computer models in ground-water resource protection and management. IGWMC operates a clearinghouse for ground-water modeling software; organizes conferences, short courses and seminars; and provides technical advice and assistance related to ground water. In support of its information and training activities, IGWMC conducts a program of applied research and development in ground-water modeling.

## Kroll Institute for Extractive Metallurgy

The Kroll Institute for Extractive Metallurgy (KIEM), a Center for Excellence in Extractive Metallurgy, was established at the Colorado School of Mines in 1974 using a bequest from William J. Kroll. Over the years, the Kroll Institute has provided support for a significant number of undergraduate and graduate students who have gone on to make important contributions to the mining, minerals and metals industries. The initial endowment has provided a great foundation for the development of a more comprehensive program to support industry needs.

The primary objectives of the Kroll Institute are to provide research expertise, well-trained engineers to industry, and research and educational opportunities to students, in the areas of minerals, metals and materials processing; extractive and chemical metallurgy; chemical processing of materials; and recycling and waste treatment and minimization.

## Marathon Center of Excellence for Reservoir Studies

Marathon Center of Excellence for Reservoir Studies conducts collaborative research on timely topics of interest to the upstream segment of the petroleum industry and provides relevant technical service support, technology transfer, and training to the Center's sponsors. Research includes sponsorship of M.S. and Ph.D. graduate students, while technology transfer and training involve one-on-one training of practicing engineers and students from the sponsoring companies. The Center is a multi-disciplinary organization housed in the Petroleum Engineering Department. The Center activities call for the collaboration of the CSM faculty and graduate students in various engineering and earth sciences disciplines together with local world-class experts. The Center was initiated with a grant from Marathon Oil Company, in 2003 and has been serving the oil industry around the world. The current research topics include: modeling and evaluation of unconventional oil and gas resources, reservoir engineering aspects of horizontal and deviated wells, Non-Darcy flow effects in hydraulic fractures and naturally fractured reservoirs, streamline modeling in dual-porosity reservoirs, multi-scale simulation methods to capture the fine-scale heterogeneity effects in displacement processes, modeling of transient flow in hydraulically fractured horizontal wells, naturally fractured reservoirs containing multiple sets of intersecting fractures, numerical modeling of reservoirs containing sparse

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naturally fractured regions, improved modeling of matrix vertical flow in dual-porosity reservoirs, steam assisted gravity drainage (SAGD) for medium gravity foamy oil reservoirs.

## **Petroleum Exploration and Production Center**

The Petroleum Exploration and Production Center (PEPC) is an interdisciplinary educational and research organization specializing in applied studies of petroleum reservoirs. The center integrates disciplines from within the Departments of Geology and Geological Engineering, Geophysics and Petroleum Engineering.

PEPC offers students and faculty the opportunity to participate in research areas including: improved techniques for exploration, drilling, completion, stimulation and reservoir evaluation techniques; characterization of stratigraphic architecture and flow behavior of petroleum reservoirs at multiple scales; evaluation of petroleum reserves and resources on a national and worldwide basis; and development and application of educational techniques to integrate the petroleum disciplines.

## **Reservoir Characterization Project**

The Reservoir Characterization Project (RCP), established in 1985 at Colorado School of Mines, is an industry-sponsored research consortium. Its mission is to develop and apply 4-D, 9-C seismology and associated technologies for enhanced reservoir recovery. Each multi-year research phase focuses on a consortium partner's unique field location, where multi-component seismic data are recorded, processed, and interpreted to define reservoir heterogeneity and architecture. Each field study has resulted in the development and advancement of new 3- and 4-D multicomponent acquisition, processing, and interpretation technology, which has led to additional hydrocarbon recovery. Research currently focuses on dynamic reservoir characterization, which enables monitoring of the reservoir production process. The Reservoir Characterization Project promotes interdisciplinary research and education among industry and students in the fields of geophysics, geology and geological engineering, and petroleum engineering.

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# Directory of the School

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# Policies and Procedures

## Affirmative Action

Colorado School of Mines has instituted an affirmative action plan, which is available for perusal in numerous CSM offices including the Library, the Dean of Students' Office, and the Office of Human Resources.

Any person feeling that a violation of the following policies has occurred should promptly refer the matter to the Office of Human Resources, located in Guggenheim Hall (2nd floor), for investigation.

## Colorado School of Mines Unlawful Discrimination Policy and Complaint Procedure

### *I. Statement of Authority and Purpose*

This policy is promulgated by the Board of Trustees pursuant to the authority conferred upon it by §23-41-104(1), C.R.S. (1998) in order to set forth a policy concerning unlawful discrimination at CSM. This policy shall supersede any previously promulgated CSM policy which is in conflict herewith.

### *II. Unlawful Discrimination Policy*

Attendance and employment at CSM are based solely on merit and fairness. Discrimination on the basis of age, gender, race, ethnicity, religion, national origin, disability, and military veteran status is prohibited. No discrimination in admission, application of academic standards, financial aid, scholastic awards, promotion, salary, benefits, transfers, reductions in force, terminations, re-employment, professional development, or conditions of employment shall be permitted. The remainder of this policy shall contain a complaint procedure outlining a method for reporting alleged violations of this policy and a review mechanism for the impartial determination of the merits of complaints alleging unlawful discrimination.

### *III. Persons Who May File an Unlawful Discrimination Complaint*

An unlawful discrimination complaint may be filed by any individual described in one of the categories below:

A. Any member of the CSM community, including classified staff, exempt employees, and students as well as any applicant for employment or admission, who believes that he or she has been discriminated against by CSM, a branch of CSM, or another member of the CSM community on account of age, gender, race, ethnicity, religion, national origin, disability, or military veteran status;

B. Any person who believes that he or she has been threatened with or subjected to duress or retaliation by CSM, a branch of CSM, or a member of the CSM community as a result of (1) opposing any unlawful discriminatory practice; (2) filing a complaint hereunder; (3) representing a Complainant hereunder; or (4) testifying, assisting, or participating

in any manner in an investigation, proceeding, hearing, or lawsuit involving unlawful discrimination; or

C. The Human Resources Director or an attorney from the Office of Legal Services, if any of these individuals deem it to be in the best interest of CSM to do so.

### *IV. Informal Complaint Resolution Process*

At the written request of an individual who has come forward with a complaint alleging unlawful discrimination, hereinafter the "Complainant," the Human Resources Director shall assist in an attempt to resolve the complaint in an informal manner. The informal unlawful discrimination complaint resolution process shall consist of an informal discussion between the Complainant and the individual or a representative of the entity accused of unlawful discrimination, hereinafter the "Respondent." The Human Resources Director shall act as a mediator during this process, which shall be calculated to bring the complaint to the attention of the Respondent and elicit the voluntary cooperation of the Respondent in settling the matter. By attempting to resolve the unlawful discrimination complaint in an informal manner pursuant to the terms of this section, the Complainant shall not waive any rights to subsequently pursue the complaint through the formal complaint procedure set forth below.

### *V. Formal Complaint Procedure*

#### **A. Purpose**

The purpose of the formal unlawful discrimination complaint procedure is to provide a formal mechanism for the prompt and fair internal resolution of complaints alleging unlawful discrimination. The procedure outlined below shall be the exclusive forum for the internal resolution of such complaints at CSM.

#### **B. Where to file a Complaint**

All complaints by non-students alleging unlawful discrimination or retaliation shall be filed in writing at the Office of Human Resources located on the second floor of Guggenheim Hall. Complaints by students alleging unlawful discrimination or retaliation may be submitted to the Human Resources Office, the Student Development Center, the Dean of Students, any faculty member, or any Resident Assistant. Any recipient of such a student complaint shall promptly forward the complaint to the Director of Human Resources for handling in accordance with the provisions set forth below.

#### **C. Time Limits**

All complaints alleging unlawful discrimination or retaliation must be filed within ninety days from the date upon which the incident, occurrence, or other action alleged to constitute unlawful discrimination or retaliation occurred. However, if the alleged discrimination or retaliation is of a continuing nature, a complaint may be filed at any time.

#### **D. Contents of Complaint**

A complaint alleging unlawful discrimination or retaliation must be signed by the Complainant and set forth specific factual matters believed to constitute unlawful discrimination or

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retaliation. The complaint shall name as Respondent the individual or entity whom the Complainant believes to have committed, participated in, or encouraged the discrimination or retaliation. The complaint shall also include a brief statement describing the relief requested by the Complainant.

#### **E. Fulfillment of Complaint Prerequisites**

As soon as practicable after receipt of a complaint, the Human Resources Director shall submit the complaint to an attorney from the Office of Legal Services, who shall examine it and determine if the prerequisites outlined above have been fulfilled. If the prerequisites have not been fulfilled, the attorney shall inform the Complainant of the specifics of such determination in writing. Unless the time limitations set forth above have lapsed prior to the initial filing of the complaint, the Complainant shall have the opportunity to correct any deficiencies and re-file the complaint. If the prerequisites have been fulfilled, the complaint will be handled as set forth below.

#### **F. Choice of Remedies**

No Complainant shall be permitted to simultaneously file an unlawful discrimination claim under the CSM Unlawful Discrimination Policy and Complaint Procedure and a sexual harassment claim under the CSM Sexual Harassment Policy and Complaint Procedure against the same individual arising out of an identical set of facts. In such a situation, a Complainant shall be entitled to file his or her claim under either, but not both, of the above-mentioned policies.

### **VI. Pre-Hearing Procedures**

#### **A. Notification to Proceed**

As soon as practicable after a determination has been made that the complaint is sufficient pursuant to subsection V.E above, the reviewing attorney shall inform the Director of Human Resources of that fact and the Director of Human Resources shall proceed with the notifications specified in subsection B below.

#### **B. Acknowledgment of Complaint and Notification of Respondent**

As soon as practicable, the Director of Human Resources shall send a letter to the Complainant acknowledging receipt of the complaint. At the same time, the Director shall provide the Respondent with a copy of the complaint and notify the Respondent in writing of the requirements set forth in subsection C below.

#### **C. Response to Complaint**

Within ten days from the date of receipt of a copy of the complaint, the Respondent shall file with the Director of Human Resources a response in which the allegations contained in the complaint are admitted or denied. The Director shall provide the Complainant with a copy of the response as soon as practicable. If the response contains a denial of one or more of the allegations contained in the complaint, the process shall proceed with the selection of a hearing panel as set forth in subsection D below. If no timely response is received, or if the response admits the allegations in their entirety, the matter

shall be submitted to the President, who shall then issue a decision in accordance with subsection IX.D below.

#### **D. Selection of Hearing Panel**

An initial hearing panel of six individuals shall be selected in a random manner from a list of full-time CSM employees. The Complainant and the Respondent shall each disqualify one of the initial panel members. The disqualifications to be exercised by the parties shall commence with the Complainant. Of the remaining initial panel members, the one chosen last shall serve as an alternate hearing panel member. The other three initial panel members shall constitute the hearing panel for the appeal. Prospective panel members may be excused on account of conflict of interest, health, or unavoidable absence from campus. An excused initial panel member shall be replaced by another initial panel member chosen in a random drawing prior to the exercise of disqualifications by either party.

#### **E. Selection of Chief Panel Member**

After a hearing panel has been chosen, the panel members shall elect a chief panel member from their number who shall preside throughout the remainder of the case.

##### **1. Authority of Chief Panel Member**

The chief panel member shall have the authority to (a) issue orders to compel discovery; (b) make rulings on evidentiary objections; and (c) issue any other orders necessary to control the conduct of the hearing and prohibit abusive treatment of witnesses, including removal of disruptive individuals from the hearing room.

##### **2. Role of Alternate Hearing Panel Member**

The alternate hearing panel member shall observe, but not actively participate in, all of the proceedings in the case and be prepared to substitute for a panel member who becomes unavailable during any stage of the case due to death, illness, or emergency.

#### **F. Setting of Hearing Date**

After a chief panel member has been chosen, a hearing date shall be set with reasonable consideration given to the schedules of the participants. The chief panel member shall set a date for the hearing, which shall occur no more than ninety days after the date upon which the formal complaint was filed with the Director of Human Resources. Once set, the hearing date may be rescheduled only with the concurrence of the Complainant, the Respondent, and the hearing panel.

#### **G. Participation of Attorneys**

Either party may engage the services of an attorney to assist in document preparation or case preparation. However, an attorney may not enter an appearance or formally participate in the case on behalf of either party.

#### **H. Legal Advice for Hearing Panel**

If the hearing panel desires legal advice at any time during the case, the chief panel member shall request such advice from the Office of Legal Services. An attorney from the

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Office of Legal Services shall provide the requested advice unless all such attorneys are actively involved in the case on behalf of one of the parties. In such event, the chief panel member shall request the desired legal advice from the Assistant Attorney General assigned to CSM, whose name and telephone number shall be provided to the chief panel member by the legal office.

### **I. Pre-Hearing Discovery**

Informal discovery, or the exchange between the parties of information relevant to the case, is encouraged. If the parties cannot resolve such issues informally, either party may request the chief panel member up to ten days prior to the hearing date to enter an order compelling discovery upon a showing of the relevance of the requested information and the necessity of such information to case preparation. The other party may oppose such request by showing that the requested information is irrelevant, unnecessary to the requesting party's case preparation, or privileged according to law.

### **VII. Pre-Hearing Statements**

#### **A. Contents of Pre-Hearing Statements**

Each party shall file a pre-hearing statement containing the following components:

1. Summary of the Argument: A concise statement summarizing the case from the position of the submitting party;
2. List of Issues: A list of the issues which the submitting party wishes the hearing panel to resolve;
3. List of Witnesses: A list of witnesses to be presented at the hearing along with a summary of the anticipated testimony of each witness; and
4. Photocopies of Exhibits: Photocopies of each exhibit to be presented at the hearing.

#### **B. Deadlines for Pre-Hearing Statements**

The Complainant shall file a pre-hearing statement with the hearing panel and provide a copy to the opposing party no later than ten days prior to the hearing date. The Respondent shall file a pre-hearing statement with the hearing panel and provide a copy to the opposing party no later than five days prior to the hearing date. If the hearing date is rescheduled, these time limits shall apply to the rescheduled hearing date.

#### **C. Limitations Imposed by Pre-Hearing Statements**

Neither party shall make an argument during the hearing which is inconsistent with the arguments set forth in the summary of the argument section of his or her pre-hearing statement. Neither party shall introduce any witnesses or exhibits at the hearing which are not listed in his or her pre-hearing statement. All exhibits listed in the pre-hearing statements shall be deemed genuine and admissible unless successfully challenged prior to the hearing.

#### **D. List of Hearing Issues**

After examining the pre-hearing statements of both parties, the hearing panel shall prepare a list of issues to be resolved through the hearing and distribute such list to the parties no

later than two days prior to the hearing date. The panel may list issues contained in the pre-hearing statement of either party or relevant issues not contained in the pre-hearing statement of either party. However, since the jurisdiction of the hearing panel is limited to hearing claims of unlawful discrimination, only issues directly related to the Complainant's claim of unlawful discrimination may be placed on the list of issues. The list of issues generated pursuant to this subparagraph shall be binding upon the subsequent hearing and shall form the standard against which all relevancy arguments shall be weighed.

#### **E. Amendments to Pre-Hearing Statements**

Up to two days prior to the hearing date, either party may request the chief panel member to permit amendments to his or her pre-hearing statement upon a showing of good cause and lack of prejudice to the opposing party. Any party filing an amended pre-hearing statement shall provide a copy thereof to the opposing party no later than the filing deadline imposed by the order granting leave to amend.

### **VIII. Hearing Procedures**

#### **A. Burden and Standard of Proof**

The Complainant shall bear the burden of proof throughout the case. The standard of proof which the Complainant must meet to sustain the burden of proof shall be the preponderance of the evidence standard. The preponderance of the evidence standard shall be deemed met if the panel believes that it is more likely than not that the facts at issue occurred. The facts at issue shall include all facts which are required to be proven by the party bearing the burden of proof in order for such party to prevail.

#### **B. Order of Presentation**

Since the Complainant bears the burden of proof, that party shall present his or her case first. After the Complainant has finished, the Respondent shall present his or her case.

#### **C. Outline of Hearing**

The hearing shall proceed according to the following general outline:

1. Complainant's Opening Statement
2. Respondent's Opening Statement (unless reserved)
3. Complainant's Case
4. Respondent's Opening Statement (if reserved)
5. Respondent's Case
6. Complainant's Rebuttal Case (unless waived)
7. Respondent's Rebuttal Case (only if Complainant presents a rebuttal case and unless waived)
8. Complainant's Closing Argument
9. Respondent's Closing Argument
10. Complainant's Rebuttal Argument (unless waived)

#### **D. Inapplicability of Strict Evidentiary Rules**

Strict legal evidentiary rules shall not apply during the hearing. The chief panel member shall rule on the admissibility of



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disputed evidence with primary consideration given to the relevance, reliability, and probative value of proffered evidence.

#### **E. Witness Examination Procedure**

Each witness shall be directly examined by the party on whose behalf the witness has appeared to testify. Upon the conclusion of the direct examination of each witness, the opposing party shall be permitted the right of cross-examination. The chief panel member may permit re-direct and re-cross examination. However, an identical examination procedure shall be utilized for all witnesses testifying in a given hearing. Hearing panel members may interject questions at any time during the direct, cross, re-direct, or re-cross examinations.

### **IX. Post-Hearing Procedure**

#### **A. Recommendation of the Hearing Panel**

Within a reasonable time after the conclusion of the hearing, the hearing panel shall confer among themselves and vote upon a recommended course of action. The panel members holding a majority point of view shall designate one of their number to write a recommendation reflecting their opinion. The panel members holding a minority point of view, if any, may issue a dissenting recommendation in a similar fashion.

#### **B. Contents of Recommendation**

The recommendation of the hearing panel shall include the following components:

1. Statement Regarding Burden of Proof: A statement regarding whether or not the hearing panel believes that the burden of proof borne by the Complainant has been sustained;
2. Findings of Fact: A list of the relevant facts found by the hearing panel upon which the recommendation is based;
3. Legal Conclusions: A list of the legal conclusions of the hearing panel upon which the determination of the issue of unlawful discrimination is based; and
4. Recommended Action: A statement regarding the relief for the Complainant, if any, that is being recommended by the hearing panel.

#### **C. Issuance of Recommendation**

The recommendation of the hearing panel shall be issued to the parties and delivered to the President along with the case file within fifteen days after the conclusion of the hearing.

#### **D. Decision of President**

The President shall examine the case file, consider the recommendation of the hearing panel, and issue a final written decision in the matter. The President shall possess the authority to affirm, reverse, or modify the recommendation of the hearing panel or to remand the matter to the panel for further proceedings or consideration. In the decision, the President may provide appropriate relief to the Complainant and may impose appropriate disciplinary action upon the Respondent. The decision of the President shall be delivered to the parties and the hearing panel within fifteen days from the date of the President's receipt of the recommendation and case file from

the hearing panel, unless the President is unavailable for a significant amount of time during this period.

#### **E. Presidential Unavailability**

The term "unavailable," as utilized in this subsection and subsection X.D above, shall be defined to mean out of town, medically incapacitated, or engaged in important CSM business to the extent that sufficient time cannot be devoted to decision making hereunder. If the President is unavailable for a significant period of time during the decision making period, a letter shall be sent to the parties advising them of that fact as well as the anticipated date of presidential availability. In such event, the decision shall be due fifteen days from the date upon which the President becomes available. The President shall be the sole judge of presidential unavailability hereunder.

#### **F. Appeal of Presidential Decision**

There shall be no internal appeal from the final decision of the President. A party aggrieved by the decision of the President may file a complaint with the appropriate equal opportunity enforcement agency or pursue other available legal remedies.

*Promulgated by the CSM Board of Trustees on March 13, 1992. Amended by the CSM Board of Trustees on June 10, 1999. Amended by the CSM Board of Trustees on June 22, 2000.*

## **Colorado School Of Mines Sexual Harassment Policy and Complaint Procedure**

### **I. Statement of Authority and Purpose**

This policy is promulgated by the Board of Trustees pursuant to the authority conferred upon it by §23-41-104(1), C.R.S. (1988 Repl. Vol.) in order to set forth a policy concerning sexual harassment at CSM. This policy shall supersede any previously promulgated CSM policy which is in conflict herewith.

### **II. Sexual Harassment Policy**

#### **A. Definition of Sexual Harassment**

Sexual harassment shall, without regard to the gender of the alleged perpetrator or victim, consist of unwelcome sexual advances, requests for sexual favors, and other verbal or physical conduct of a sexual nature when (1) submission to such conduct is made either explicitly or implicitly a term or condition of an individual's employment or scholastic endeavors; (2) submission to or rejection of such conduct by an individual is used as the basis for employment or academic decisions affecting the individual; or (3) such conduct has the purpose or effect of unreasonably interfering with an individual's work or school performance, or creating an intimidating, hostile, or offensive working or studying environment.

#### **B. Policy Statement**

CSM wishes to foster an environment for its students and employees which is free from all forms of sexual harassment,

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sexual intimidation, and sexual exploitation. Accordingly, CSM will not tolerate sexual harassment and will take all necessary measures to deter such misconduct and discipline violators of this policy with appropriate sanctions. Furthermore, retaliation in any form against an individual for reporting sexual harassment or cooperating in a sexual harassment investigation is strictly prohibited. Such retaliation shall be dealt with as a separate instance of sexual harassment. The remainder of this policy shall contain a complaint procedure outlining a method for reporting alleged violations of this policy and a review mechanism for the impartial determination of the merits of complaints alleging sexual harassment.

### **C. Sanctions for Sexual Harassment**

Appropriate sanctions may be imposed upon an employee or student who has sexually harassed another. The term Perpetrator shall be utilized herein to refer to such a person. The sanctions may include one or more of the following: verbal reprimand and warning, written reprimand and warning, student probation, suspension from registration, monetary fine, suspension without pay, expulsion, or termination. In determining appropriate sanctions for the offense, the decision maker shall consider the severity of the offense, aggravating and mitigating factors, and the Perpetrator's previous history of sexual harassment offenses. If the decision maker concludes that a lack of comprehension of the concept of sexual harassment is a factor in the offense, the Perpetrator can also be required to attend a sexual harassment seminar or workshop.

### **III. Persons Who May File a Complaint**

A sexual harassment complaint may be filed by an individual described in one of the categories below:

A. Any person who believes that he or she has been sexually harassed by a member of the CSM community, including classified staff, exempt employees, and students;

B. Any person who believes that he or she has been threatened with or subjected to duress or retaliation by a member of the CSM community as a result of (1) opposing any perceived sexual harassment; (2) filing a complaint hereunder; (3) representing a Complainant hereunder; or (4) testifying, assisting, or participating in any manner in an investigation, proceeding, hearing, or lawsuit involving sexual harassment; or

C. The Human Resources Director or an attorney from the Office of Legal Services, if any of these individuals deem it to be in the best interest of CSM to do so.

### **IV. Informal Complaint Resolution Process**

At the request of an individual who has come forward with a sexual harassment complaint, hereinafter the "Complainant," the Director of Human Resources shall assist in an attempt to resolve the complaint in an informal manner. Although verbal requests to proceed with the informal complaint resolution process will be honored, complainants are strongly encouraged to put such requests in writing. The informal sexual harassment complaint resolution process shall consist of an informal discussion between the Complainant and the indi-

vidual accused of sexual harassment, hereinafter the "Respondent." The Director of Human Resources shall act as a mediator during this process, which shall be calculated to bring the complaint to the attention of the Respondent and elicit the voluntary cooperation of the Respondent in settling the matter. By attempting to resolve the sexual harassment complaint in an informal manner pursuant to the terms of this section, the Complainant shall not waive any rights to subsequently pursue the complaint through the formal sexual harassment complaint procedure set forth below.

## **V. Formal Complaint Procedure**

### **A. Purpose**

The purpose of the formal sexual harassment complaint procedure is to provide a formal mechanism for the prompt and fair internal resolution of complaints alleging sexual harassment. The procedure outlined below shall be the exclusive forum for the internal resolution of sexual harassment complaints at CSM.

### **B. Where to file a Complaint**

All complaints by non-students alleging sexual harassment or retaliation shall be lodged with the Human Resources Office located on the second floor of Guggenheim Hall. Complaints by students alleging sexual harassment or retaliation may be submitted to the Human Resources Office, the Student Development Center, the Dean of Students, any faculty member, or any Resident Assistant. Any recipient of a student sexual harassment or retaliation complaint shall promptly forward such complaint to the Director of Human Resources for handling in accordance with the provisions set forth below.

### **C. Time Limits**

A complaint may be lodged at any time, but CSM strongly encourages individuals who feel they have been victims of sexual harassment to come forward as soon as possible after the occurrence of the incident, event, or other action alleged to constitute sexual harassment or retaliation.

### **D. Contents of Complaint**

Although a verbal sexual harassment complaint will be investigated, complainants are strongly encouraged to submit sexual harassment complaints in writing. Written complaints must be signed and must set forth specific factual matters believed to constitute sexual harassment or retaliation. The Complaint shall name as Respondent each individual whom the Complainant believes to have committed, participated in, or encouraged the sexual harassment or retaliation. The complaint shall also include a brief statement describing the relief requested by the Complainant.

### **E. Fulfillment of Complaint Prerequisites**

As soon as practicable after receipt of the complaint, the Director of Human Resources shall submit the complaint to an attorney from the Office of Legal Services, who shall determine if the prerequisites outlined above have been fulfilled. If the prerequisites have not been fulfilled, the reviewing attorney shall inform the Complainant of the specifics of

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such determination in writing. The Complainant shall have the opportunity to correct any deficiencies and re-file the complaint. If the prerequisites have been fulfilled, the complaint will be handled as set forth below.

#### **F. Choice of Remedies**

No Complainant shall be permitted to simultaneously file an unlawful discrimination claim under the CSM Unlawful Discrimination Policy and Complaint Procedure and a sexual harassment claim under the CSM Sexual Harassment Policy and Complaint Procedure against the same individual arising out of an identical set of facts. In such a situation, a Complainant shall be entitled to file his or her claim under either, but not both, of the above-mentioned policies.

#### **G. Notification of CSM Management Personnel**

As soon as practicable after a determination has been made that the complaint is sufficient pursuant to subsection V.E above, the Office of Legal Services shall notify CSM Management Personnel of the complaint and provide them with a copy thereof. For the purpose of this policy, the term CSM Management Personnel shall refer to the President, the vice president in whose area the Respondent is employed or enrolled, and, if applicable, the Respondent's immediate supervisor. However, if the President is the Respondent, the term CSM Management Personnel shall refer to the Board of Trustees, and if the Respondent is a vice president, the term "CSM Management Personnel" shall refer to the President.

#### **H. Acknowledgment of Complaint and Notification of Respondent**

As soon as practicable after being informed of the complaint pursuant to subsection V.G above, the vice president shall send a letter to the Complainant acknowledging receipt of the complaint. At the same time, the vice president shall notify the Respondent of the complaint in writing, and if the complaint has been reduced to writing, the vice president shall provide the Respondent with a copy thereof. If the President is the Respondent, the President of the Board of Trustees shall perform the above duties. If the Respondent is a vice president, the President shall perform these duties.

#### **I. Investigation Authorization Form**

Unless the complaint is initiated by an attorney from the Office of Legal Services or the Director of Human Resources pursuant to subsection III.C above, the Complainant shall be required to execute a Sexual Harassment Complaint Investigation Authorization Form prior to any investigation of the complaint.

#### **J. Investigation of Complaint**

An attorney from the Office of Legal Services and the Director of Human Resources shall jointly investigate the complaint by examining relevant documents, if any, and interviewing witnesses and other individuals designated by either party. The investigators will strive to conduct the investigation in a discrete and expeditious manner with due regard to thoroughness and fairness to both parties.

#### **K. Confidentiality of Investigative Materials**

All materials and documents prepared or compiled by the investigators during the course of investigating a sexual harassment complaint hereunder shall be kept confidential to the fullest extent of the law in order to protect interviewees and promote candor.

#### **L. Alternate Investigators**

If either an attorney from the Office of Legal Services or the Director of Human Resources is the Complainant or the Respondent hereunder, or is otherwise unavailable, the President shall appoint an alternate investigator.

#### **M. Report of Findings and Confidential Recommendation**

As soon as practicable after the conclusion of the investigation, the investigating attorney shall prepare and submit a report of findings and a confidential recommendation to CSM Management Personnel and the Director of Human Resources. The report of findings shall be provided to the Complainant and Respondent within a reasonable time following the issuance of a decision pursuant to subsection V.N below. The confidential recommendation shall not be released to the Complainant or the Respondent without written authorization from the President. The Director of Human Resources shall submit a separate recommendation to CSM Management Personnel which contains a statement of agreement or disagreement with the findings and recommendation of the investigating attorney.

#### **N. Resolution of the Complaint**

Following consultations with the President, the investigating attorney, and the Director of Human Resources, the vice president shall issue a final written decision regarding the complaint. The decision shall be addressed to the Complainant and shall contain a statement of whether or not sexual harassment was found to have occurred, the remedies to be provided to the Complainant, if any, and the sanctions to be imposed upon the Respondent, if any. At approximately the same time, the decision shall be communicated to the Respondent in writing. If sanctions are to be imposed upon the Respondent, the vice president shall also notify the Respondent of that aspect of the decision in writing. If the President is the Respondent, the President of the Board of Trustees shall perform the above duties. If the Respondent is a vice president, the President shall perform these duties.

#### **O. Appeal of Final Decision**

There shall be no internal appeal from the final decision rendered pursuant to subsection V.N above. A party aggrieved by the decision may file a complaint with the appropriate administrative agency or pursue other available legal remedies.

*Promulgated by the CSM Board of Trustees on March 13, 1992. Amended by the CSM Board of Trustees on March 26, 1998. Amended by the CSM Board of Trustees on June 10, 1999. Amended by the CSM Board of Trustees on June 22, 2000.*

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## Colorado School of Mines Personal Relationships Policy

### *I. Statement of Authority and Purpose*

This policy is promulgated by the Board of Trustees pursuant to the authority conferred upon it by §23-41-104(1), C.R.S. (1988 Repl. Vol.) in order to set forth a policy concerning certain personal relationships at CSM as addressed herein. This policy shall supersede any previously promulgated CSM policy which is in conflict herewith.

### *II. Preface*

Certain amorous, romantic, or sexual relationships in which the parties appear to have consented, but where a definite power differential exists between them, are of serious concern to CSM. Personal relationships which might be appropriate in other circumstances always pose inherent dangers when they occur between an Instructor and a Student, between a Person in a Position of Trust and a Student, and between a Supervisor and a Subordinate Employee. Although both parties to the relationship may have consented at the outset, such relationships are fundamentally asymmetric in nature. It is incumbent upon those with authority not to abuse, nor appear to abuse, the power with which they are entrusted. Accordingly, codes of ethics promulgated by most professional regulatory associations forbid professional-client amorous, romantic, or sexual relationships. The relationships prohibited by this policy shall be viewed in this context, and Instructors, Persons in Positions of Trust, and Supervisors should be aware that any violation of this policy shall result in formal disciplinary action against them.

### *III. Definitions*

For the purposes of this policy, the following definitions shall apply:

**A. Person in a Position of Trust:** Any person occupying a position of trust with respect to one or more students at CSM such that engaging in an amorous, romantic, or sexual relationship with any student would compromise the ability of the employee to perform his or her duties. Examples of Persons in Positions of Trust at CSM are those employed in the Office of the Registrar, those employed in the Student Life Office, those employed in the Student Development Office, those employed in Public Safety, resident assistants, and paper graders. The above examples are provided for illustrative purposes only and are not intended to be exhaustive listings or to limit the illustrated category in any manner.

**B. Instructor:** Any person who teaches at CSM, including academic faculty members, instructional staff, and graduate students with teaching or tutorial responsibilities.

**C. Student:** Any person who is pursuing a course of study at CSM.

**D. Subordinate Employee:** Any person employed by CSM who is supervised by another employee.

**E. Supervisor:** Any person employed by CSM who occupies a position of authority over another employee with regard to hiring, administering discipline, conducting evaluations, granting salary adjustments, or overseeing task performance.

### *IV. Policy*

A. Personal Relations Between Instructors and Students in the Instructional Context

No Instructor shall engage in an amorous, romantic, or sexual relationship, consensual or otherwise, with a Student who is enrolled in a course being taught by the Instructor, or whose academic work is being supervised by the Instructor.

B. Personal Relationships Between Instructors and Students Outside the Instructional Context

In a personal relationship between an Instructor and a Student for whom the Instructor has no current professional responsibility, the Instructor should be sensitive to the constant possibility that he or she may unexpectedly be placed in a position of responsibility for the instruction or evaluation of the Student. This could entail a request to write a letter of recommendation for the Student or to serve on an admissions or selection committee involving the Student. In addition, an awareness should be maintained that others may speculate that a specific power relationship exists even when none is present, giving rise to assumptions of inequitable academic or professional advantage of the Student. Even if potential conflict of interest issues can be resolved, charges of sexual harassment may arise. In such situations, it is the Instructor who, by virtue of his or her special responsibility, shall be held accountable for unprofessional behavior.

C. Personal Relationships Between Supervisors and Subordinate Employees

No Supervisor shall engage in an amorous, romantic, or sexual relationship, consensual or otherwise, with a Subordinate Employee who reports, either directly or indirectly, to the Supervisor or is under the Supervisor's direct or indirect authority.

D. Personal Relationships Between Persons in Positions of Trust and Students

No Person in a Position of Trust shall engage in an amorous, romantic, or sexual relationship, consensual or otherwise, with a Student.

*(Promulgated by the CSM Board of Trustees on February 14, 1992)*



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# Index

## A

Academic Calendar 4  
Academic Computing and Networking 18  
Academic Integrity 27  
Academic Services 13  
Access to Student Records 33  
Accreditation 10  
Admission Procedure 11  
Admission Requirements 11  
Admission to Candidacy 41, 43  
Affirmative Action 201  
Alcohol Use 26  
Alumni Association 19  
Apartments 13  
Application Review Process 12  
Army ROTC 15  
Arthur Lakes Library 18  
Auditing Courses 24

## B

Blaster Cards 14

## C

Campus Security 26  
Career Center 14  
Categories of Admission 11  
Chemical Engineering 5, 45  
Chemistry and Geochemistry 5, 51  
Combined Undergraduate/Graduate Programs 11, 43  
Communications 134  
Copy Center 18  
Counseling 13  
Course Grade 30  
Curriculum Changes 26

## D

Degree Students 11  
Description of Courses 45  
Directory of the School 187  
Doctor of Philosophy 40  
Doctoral Thesis Committee 40  
Dropping and Adding Courses 24  
Drug Free Schools & Communities 26  
Drug Use 26

## E

Economics and Business 5, 58  
Employment Restrictions and Agreements 36  
Encumbrances 35  
Engineer Days 16  
Engineering 5, 67  
Environmental Health and Safety 19  
Environmental Science and Engineering 5, 84

## F

Fees 35  
Fellowships 36  
Financial Aid 5, 36  
Financial Assistance 12, 35  
Financial Responsibility 35  
Foreign Languages 134  
Full-time Status 22

## G

General Registration Requirements 22  
Geochemistry 91  
Geology and Geological Engineering 5, 97  
Geophysics 5, 114  
Grade Appeal Process 30  
Grade-Point Averages 33  
Grading System 32  
Graduate Degree Programs 43  
Graduate Degrees and Requirements 37  
Graduate Degrees Offered 10  
Graduate School Bulletin 26  
Graduate Student Association 5, 15  
Graduate Thesis 29  
Graduation 31  
Graduation Requirements 22, 42  
Green Center 19  
GSA Fall & Spring Blowout 16

## H

Health Center 14  
Health Insurance 14  
Health Record 12  
History of CSM 9  
Homecoming 16  
Honor Societies 16  
Housing 5, 13  
Hydrologic Sciences and Engineering 124

## I

Identification Cards 14  
In-State Tuition Classification Status 23  
Incomplete Grade 32  
Independent Study 30  
Individualized, Interdisciplinary Graduate Degrees 42  
Institutional Values and Principles 6  
Intellectual Property 8  
Interest Organizations 16  
INTERLINK Language Center (ESL) 19  
International & Minority Organizations 16  
International Day 16  
International Programs 20  
International Student Services 5, 14  
International Students 12

## J

Job Resources 15

---

---

## L

LAIS Writing Center 19  
Late Payment 35  
Late Registration Fee 23  
Leave of Absence 23  
Liberal Arts and International Studies 5, 127

## M

Master of Science and Engineering Programs 38  
Materials Science 5, 135  
Mathematical and Computer Sciences 5, 142  
Metallurgical and Materials Engineering 5, 149  
Mines Park 13  
Mining Engineering 5, 159  
Minor Programs 38, 40, 42  
Minority Organizations 16  
Mission and Goals 6  
Motor Vehicles 14

## N

NC Grade 33  
Nondegree Students 11, 32  
Nuclear Engineering 5, 167

## O

Off Campus Study 19, 25  
Office of Graduate Studies 5  
Oredigger Student Newspaper 14

## P

Parking 14  
Payments and Refunds 35  
Personal Relationships Policy 207  
Petroleum Engineering 5, 169  
Physics 5, 176  
Policy on Violation of Academic Integrity 27  
Procedures for Addressing Academic Misconduct 27  
Professional Education 7  
Professional Programs 37  
Professional Societies 16  
Public Relations 20

## Q

Quality Hours and Quality Points 33

## R

Reciprocal Registration 23  
Recreational Organizations 17  
Reduced Registration 22  
Refunds 35  
Registrar 5, 20  
Registration 22  
Research 7  
Research Administration 21  
Research Centers and Institutes 181  
Research Fair 16  
Research Grades 30

Research Registration 22  
Residence Halls 13  
Residency 23  
Resolution of Conflicting Bulletin Provisions 28

## S

Satisfactory Progress Grades 32  
Semester Hours 33  
Services for Students with Disabilities 13  
Sexual Harassment Policy 204  
Special Events 16  
Special Programs and Continuing Education (SPACE) 21  
Spring Blowout 16  
Student Center 13  
Student Conduct 26  
Student Development and Academic Services 13  
Student Fees 35  
Student Government 15  
Student Honor Code 26  
Student Housing 5  
Student Loans 36  
Student Misconduct 27  
Student Recreation Center 13  
Systems 180

## T

Technology Transfer 20  
Telecommunications Center 21  
Thesis Committee 39, 40, 43  
Thesis Defense 39, 41, 43  
Tuition 35  
Tutoring 13

## U

Undergraduate Courses 30  
Undergraduate Deficiencies 29  
Unique Programs 10  
Unlawful Discrimination Policy 201  
Unsatisfactory Academic Performance 28

## V

Veterans' Benefits 14, 32

## W

Winter Carnival 16  
Withdrawal from School 35  
Withdrawing from School 31  
Women in Science, Engineering and Mathematics  
(WISEM) 21



