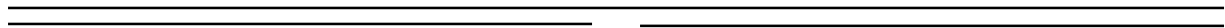*Colorado School of Mines*

2000-2001 Graduate Bulletin

To CSM Graduate Students

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

Table of Contents

Academic Calendar

Fall Semester	2000	2001
Confirmation/Registration	Aug. 21, Monday	Aug. 20, Monday
Classes start (Go to Monday classes.)	Aug. 22, Tuesday	Aug. 21, Tuesday
Grad Students - last day to register without late fee	Aug. 25, Friday	Aug. 24, Friday
Labor Day - Classes in session	Sept. 4, Monday	Sept. 3, Monday
Last day to register, add or drop courses without a "W'	Sept. 6, Wednesday	Sept. 5, Wednesday
Fall Break	Oct. 9, Monday	Oct. 8, Monday
Mid-term grades due	Oct. 16, Monday	Oct. 15, Monday
Last day to withdraw from a course Continuing students/Grad students	Oct. 31, Tuesday	Oct. 30, Tuesday
Priority Registration Spring Semester	Nov. 6-10, Mon.-Fri.	Nov. 5-9, Mon.-Fri.
Thanksgiving Recess	Nov. 23-26, Thurs.-Sun.	Nov. 22-25, Thurs.-Sun.
Last day to withdraw from a course New undergraduate students	Dec. 1, Friday	Nov. 30, Friday
Classes end	Dec. 7, Thursday	Dec. 6, Thursday
Dead Day	Dec. 8, Friday	Dec. 7, Friday
Seniors' lowest possible grades due	Dec. 12, Tuesday	Dec. 11, Tuesday
Final exams	Dec. 11-14, Mon.-Thurs.	Dec. 10-13, Mon.-Thurs.
Semester ends	Dec. 15, Friday	Dec. 14, Friday
Midyear Degree Convocation	Dec. 15, Friday	Dec. 14, Friday
Final grades due	Dec. 18, Monday	Dec. 17, Monday
Winter Recess	Dec. 16-Jan. 1	Dec. 15-Jan. 1, Sat.-Tues.

Spring Semester	2001	2002
Confirmation/Registration	Jan. 2, Tuesday	Jan. 2, Wednesday
Classes start	Jan. 3, Wednesday	Jan. 3, Thursday
Grad Students - last day to register without late fee	Jan. 5, Friday	Jan. 4, Friday
Last day to register, add or drop courses without a "W'	Jan. 17, Wednesday	Jan. 18, Friday
Mid-terms grades due	Feb. 26, Monday	Feb. 25, Monday
Spring Recess	March 10-18, Sat.-Sun.	March 9-17, Sat.-Sun.
Last day to withdraw from a course	March 20, Tuesday	March 19, Tuesday
All except new undergrads & 2nd sem freshmen		
Registration Field & Summer Terms	April 2-6, Mon.-Fri.	April 1-5, Mon.-Fri.
Priority Registration Fall Semester	April 9-13, Mon.-Fri.	April 8-12, Mon.-Fri.
Last day to withdraw from a course-new undergrads & 2nd sem freshmen	April 20, Friday	April 19, Friday
Classes end	April 26, Thursday	April 25, Thursday
Dead Day	April 27, Friday	April 26, Friday
Seniors' lower possible grades due	May 1, Tuesday	April 30, Tuesday
Final exams	Apr. 30-May 3, Mon.-Thurs.	Apr. 29-May 2
Semester ends	May 4, Friday	May 3, Friday
Commencement	May 4, Friday	May 3, Friday
Final grades due	May 7, Monday	May 6, Monday

Field/Summer Sessions	2001	2002
First Field Term, First Day of Class, Registration	May 7, Monday	May 6, Monday
Last day to register, add or drop courses without a "W" - Field Term	May 11, Friday	May 10, Friday
Memorial Day (Holiday)	May 28, Monday	May 27, Monday
Last day to withdraw from First Field Term	June 1, Friday	May 31, Friday
First Field Term ends	June 15, Friday	June 14, Friday
Field Term grades due	June 18, Monday	June 17, Monday
Summer School First Day of Class, Registration	June 18, Monday	June 17, Monday
Last day to register, add or drop courses without a W -Summer School	June 25, Monday	June 24, Monday
Independence Day (Holiday)	July 4, Wednesday	July 4, Thursday
Second Field Term begins	July 9, Monday	July 8, Monday
Last day to register, add or drop courses without a W -Second Field Term	July 12, Thursday	July 12, Friday
Last day to withdraw from Summer School	July 13, Friday	July 12, Friday
Last day to withdraw from Second Field Term	Aug. 3, Friday	Aug. 2, Friday
Summer School ends	Aug. 10, Friday	Aug. 9, Friday
Summer School grades due	Aug. 13, Monday	Aug. 12, Monday
Second Field Term ends	Aug. 17, Friday	Aug. 16, Friday
Second Field Term grades due	August 20, Monday	Aug. 19, Monday

University Administration / Useful Contacts

Office of Graduate Studies

Mailing address
1500 Illinois Street
Golden, CO 80401-1887

Telephone   *FAX*
303 273-3247   303 273-3244

Phillip R. Romig, Jr.   303-273-3247
    Dean of Graduate Studies and Research

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    jkelley@mines.edu

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    jtoussai@mines.edu

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    lpowell@mines.edu

Brenda Neely   303-273-3412
    Student Services
    bneely@mines.edu

Student Housing

Bob Francisco   303-273-3353
    Director of Student Life

Off-Campus Housing Information (OCHI) 303 273-3827

Financial Aid

Roger Koester   303-273-3207
    Director of Financial Aid

Dixie Cirillo   303-273-3206
    Graduate Student Financial Aid Advisor

International Student Services

Leslie Olsen   303-273-3210
    International Student Advisor

Interlink Language Center

Daniel Niles   303-273-3558
    Interlink@mines.edu

Registrar's Office

Susan Smith   303-273-3200
    Registrar

Graduate Student Association

Michelle Crimi   303 273-3558
    President

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 and Petroleum Refining
.... 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

Petroleum Engineering
.... 303 273-3740

Physics
.... 303 273-3830

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 126 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)

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 1882.

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.

For many years the student body was predominantly white male, reflecting the industries CSM served. It gave one of the early engineering degrees for women to Florence Caldwell in 1897, but in many subsequent years there were no female students. Strong recruiting efforts and the opening up of traditionally white male industries have changed the demographics, so that today approximately 23% of the overall student body are women and 13% of the undergraduates are underrepresented minorities.

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.

Unique Programs

Colorado School of Mines is an institution of engineering and applied science that long has had a special focus on natural resources, so it 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.

A model for such programs is the Engineering Division, which combines civil, electrical, and mechanical engineering in a nontraditional curriculum and offers graduate degrees in engineering systems. Similarly, graduate degree programs in economics and business, environmental science and engineering, and materials science make the interdisciplinary connections between traditional engineering and science fields, emphasizing a broad exposure to fundamental principles while, at the same time, cross-linking information from the traditional fields to generate the insight needed for technological breakthroughs in research and development.

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 the 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.

Professional Degrees offered are in Geological Engineering, Engineering Geology, Hydrogeology, Exploration Geosciences, Geophysics, and Geophysical Engineer.

The Division of Liberal Arts and International Studies offers two graduate certificate programs with specialization in International Political Economy (IPE) and International Political Economy of Resources (IPER).

Accreditation

Colorado School of Mines is accredited through the level of the doctoral degree by the Commission on Institutions of Higher Education of the North Central Association of Colleges and Schools. The Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology accredits undergraduate degree programs in chemical and petroleum-refining 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.

Discipline	M.S.	M.E.	Ph.D.
Chemical & Petroleum Refining Engineering	✓	✓	✓
Chemistry	✓		
Applied Chemistry			✓
Engineering Systems	✓	✓	✓
Environmental Science & Engineering	✓		✓
Geochemistry	✓		✓
Geological Engineer		✓	
Geology	✓		✓
Geological Engineering	✓		✓
Geophysical Engineering	✓	✓	✓
Geophysics	✓		✓
Materials Science	✓		✓
Mathematical & Computer Science	✓		✓
Metallurgical & Materials Engineering	✓	✓	✓
Mineral Economics	✓		✓
Engineer of Mines		✓	
Mining & Earth Systems Engineering	✓		✓
Petroleum Engineer		✓	
Petroleum Engineering	✓		✓
Physics	✓		
Applied Physics			✓

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 M.E./M.S., and Ph.D. programs is competitive, based on an evaluation of undergraduate performance, test scores and references. The undergraduate background of each applicant is evaluated according to the requirements of each department outlined later in this section of the Bulletin. Except in the case of approved combined B.S./M.S. programs, a student may not be a candidate for a graduate and an undergraduate degree at the same time.

Categories of Admission

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

Special Graduate Students:

The Graduate School may admit as Special Graduate Students 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 Professional Outreach, Office of Special Programs and Continuing Education, CSM, Golden, CO 80401-0028. Phone: 303-273-3493; FAX 303-273-3314. 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. Credits earned as a nondegree student may be transferred into the regular degree program if the student's graduate committee and department head approve.

Admission Procedure

Applying for Admission

To apply for graduate studies, contact the

> Graduate School
> Colorado School of Mines
> 1500 Illinois Street
> Golden, Colorado 80401-1869

for the admission packet, or apply electronically on the World Wide Web. Our Web address is

> http://www.mines.edu

Follow the procedure outlined below.

1. Application: Either send for an application form or find one online at www.mines.edu. In the paper packet or on the Web you will find the application and instructions on how and when to apply.

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.

3. Letters of Recommendation: For the M.S. and Ph.D. programs, ask three people who know your personal qualities and scholastic or professional abilities to mail a letter of recommendation directly to the Graduate School. At least two of the letters should be from people acquainted with the scholastic abilities of the applicant. The number of letters of recommendation varies by program; applicants should see the application packet for specific instructions.

4. Graduate Record Examination: Most departments require the General test of the Graduate Record Examination for applicants seeking admission to their programs. Computerized exams are now available through the computer-based testing program. Refer to the GRE Bulletin for information on how to apply. 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.

5. English Language Requirement: Students whose native language is not English must score at least 550 on the TOEFL examination (Test of English as a Foreign Language) or 213 on the computer-based examination and have the results sent to the Graduate School. Contact local American embassies or write to TOEFL Services, P.O. Box 6151, Princeton, NJ 08541-6151, USA, (Telephone 609-771-7100) for information about the TOEFL examination. 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 financial assistance, complete the application for an assistantship included in the paper application packet or in the Financial Assistance section of the online application.

Application Review Process

When the application materials are received by Graduate Admissions, they are processed and sent to the desired program for review. The program transmits its recommendations for admission back to the Graduate Dean, who notifies the applicant.

Health Record and Additional Steps

When they first enroll at CSM, all students 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.

Student Life at CSM

Housing

CSM currently has two student housing complexes: Prospector Village and Mines Park.

Prospector Village

The Prospector Village complex on the west edge of the campus has 69 two-bedroom apartment units. All units have two levels, with the bedrooms and bathroom on the upper level and a kitchen and living area on the lower level. Residents of the complex must be enrolled for at least 10 credit hours or 6 thesis hours both fall and spring, either be married, or have custody of their children at least 50% of the time.

Monthly rents for Prospector Village units are

$520.00 for a 2-bedroom unit.

Mines Park

The Mines Park apartment complex is located west of the 6th Avenue and 19th Street intersection on 55 acres owned by CSM. Construction completed in 1998 offers 1 & 2 bedroom units in family housing and 1, 2, & 3 bedroom units in other areas. Principle residents must be full time students.

Units are complete with refrigerators, stoves, dishwashers, cable television and campus phone hook-ups, and T-1 connections to the campus network system. There is a community center which contains the laundry facility and recreational/study space.

Rates are as follows:

Family Housing

1 bedroom	$530/mo
2 bedroom	$605/mo

Apartment Housing

1 bedroom	$530/mo
2 bedroom	$710/mo
3 bedroom	$945/mo

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

Campus Residence Halls

Four 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 rented by academic year; costs range from $2,710 for a traditional double room to $3,640 for a single in Weaver Towers. All students in residence halls must also choose a dining hall meal plan. Meal plans range from $2,332 to $2,542 per year.

Off-Campus Rooms and Apartments

Golden has a number of apartment and condominium complexes, and some students live in rooms in private homes. CSM has no part in contractual obligations between students and private landlords.

A publication called The Off-Campus Housing Information (OCHI), produced by the CSM housing office, has lists, numbers, and general information about off-campus housing. Students can call 303-273-3827 or write to OCHI to get a copy of the list.

> OCHI
> CSM Student Life Office
> Golden, Colorado 80401

Student Services

Ben H. Parker Student Center

The Ben H. Parker Student Center has a dining hall, meeting rooms, offices for student activities, a bookstore, a game room, and the Integral Club lounge and snack bar. Several dining hall meal plans for the cafeteria are available for all students.

The Student Center remodeling and addition was completed February 1996. The new addition houses more meeting rooms, a food court, and an outdoor recreation department.

Office for Student Development and Academic Services

Counseling: The SDAS Office at 1400 Maple Street offers personal and career counseling, a 300-volume resource library, skills development, and wellness-related materials. Students can find individual help and group presentations, presented by professional counselors on topics such as stress management, relaxation, assertiveness, time management, and alcohol/drug education.

Academic Services: Individual sessions for graduate students are available through SDAS. Topics include effective studying and preparation for qualifying or comprehensive exams, memory skills, rapid reading of technical material, and learning styles. Graduate students are welcome to avail themselves of other services offered by SDAS, such as free tutoring or weekly workshops in introductory calculus, chemistry, or physics.

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

Identification cards are made in the Student Activities Office in the Parker Student Center, and all new students must have an identification card made as soon as possible after they enroll. Students must have a valid ID to check material out of the CSM Library and may need it to attend various CSM activities.

Each semester the Student Activities Office issues validation stickers for student ID's, and students can replace lost, stolen, or damaged identification cards for a small fee.

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 $45 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 enrolled in a degree program for seven (7) credit hours or more. 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, 1306 Maple 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 Career Center helps graduate students look for engineering-related employment. Each year industry and government representatives visit the campus to interview students and explain employment opportunities. Fall is the major recruiting season for both summer and permanent positions, but interviews take place in the spring as well. In order to interview, students must register with the Career Center by submitting copies of a résumé and completing a registration and permission form.

A 'Career Manual' is available to help in résumé writing, interviewing, and off-campus job searches, and students can get individual critiques of résumés and letters and job search advice. Directories and other search materials from the Career Center library can be checked out, many workshops are offered throughout the year on job search topics, and video-taped practice interviews are available.

Each fall the Career Center sponsors a Career Day to let students explore career options with exhibiting employers.

Information on full-time, part-time, summer and CO-OP jobs is posted in the Career Center as well as on bulletin boards around campus. Registered students are often referred directly to employers. For information phone: 303-273-3235.

Orediger Student Newspaper

The Orediger 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.

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.

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 softball, 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
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 Asssociation of Drilling Engineers (AADE)

American Association of Petroleum Geologists (AAPG)

American Institute of Chemical Engineers (AIChE)

American Institute of Mining, Metallurgical & Petroleum 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)

Facilities and Academic Support

Arthur Lakes Library

Arthur Lakes Library is a regional information center for engineering, energy, minerals and materials science, and associated engineering and science fields. The library provides educational and research resources to support and enhance the academic mission of CSM. The library staff is committed to excellence in supporting the information needs of the CSM community and providing access to information for library users.

The library collections include more than 500,000 volumes; approximately 1800 serial titles; over 188,000 maps; archival materials on western mining history and mineral fields; and several special collections. The library is a selective U.S. and Colorado state depository with over 600,000 government publications, including selected NTIS publications.

Access to CSM collections is provided by an on-line public access catalog and computerized circulation system. Students and faculty also have access to nearly all of the library's electronic resources from any computer on the campus network, including those in networked CSM residential facilities. Dial-up and Internet access is also available from on and off-campus. The library's web page at http://www.mines.edu/library/ has more information and links to the electronic resources.

Reference resources include specialized printed indexes and several hundred electronic databases. Reference librarians provide instruction and personal help as needed, conduct library research sessions for classes, and provide telephone reference service and computer-aided research services.

In addition to material that can be checked out from the CSM library and other associated Colorado libraries, interlibrary loan service provides for efficient use of materials from regional and world-wide libraries.

Computing and Networking

The Computing Center, which is housed on the second floor of the Green Center, provides computing and networking services to meet instructional and research needs and to support the academic mission of the Colorado School of Mines. Computer accounts and services are available to registered students and current faculty members and staff.

Information about services including activation of new accounts and the hours during which the Computing Center is open is available in a brochure which may be picked up at the Front Desk in Room 231 (303-273-3431) and on the Computing Center's web page at http://www.mines.edu-Academic/computer/. Problem reports can be made at the Front Desk or emailed to trouble@mines.edu.

The campus network provides access to campus computing resources and to the Internet, including email and the World Wide Web. Centrally managed resources include Unix systems which are available 24 hours per day except for occasional maintenance.

Workrooms in the Computing Center contain networked PCs and workstations. Also available are printers, scanners, and digitizers. Academic departments which support specialized applications manage access to computer labs in their buildings. The Arthur Lakes Library has a computer cluster on the main floor of the building. Network access is also provided in residence halls and Mines Park for students who bring their own computers to campus and modem pools provide access to the network for off-campus residents.

It is important for all users of the Colorado School of Mines computing resources to observe the CSM Policies for Resource Usage (available on the web page or at the Front Desk) and all legal and ethical guidelines for use of those services.

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.

CSM Alumni Association

(CSMAA) The Mines Alumni Association has served the Colorado School of Mines and its alumni since 1985. Services and benefits of membership include:

Mines, a quarterly publication covering campus and alumni news; an annual directory of all Mines alumni; section activities providing a connect to campus and other Mines alumni around the world for both social and networking purposes; connections to Mines through invitations to local and annual alumni meetings, reunions, golf tournaments and other special events; customized alumni merchandise through the Miner's Pick; awards, including the opportunity to nominate fellow alumni and be nominated; CSM library privileges to Colorado residents; and e-mail forwarding services.

Benefits for the Colorado School of Mines and current students are student grants; the Student Financial Assistance Program; recognition banquets for graduating seniors/graduate students; assistance and support of School events such as Homecoming; alumni volunteer assistance in student recruiting; and programs enabling alumni input in school programming.

For further information, call 303 273-3295, FAX 303 273-3583, e-mail 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. Five full-time employees in the

EHS Department provide a wide variety of services to students, staff and faculty members. Functions of the EHS Department include: hazardous waste collection and disposal; chemical procurement and distribution; assessment of air and water quality; fire safety; general industrial safety; industrial hygiene; health physics; and recycling. The staff of the EHS Department is ready to respond to requests for information and services from parents and students. Please call 303 273-3316.

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 700 persons can be accommodated at tables for banquets or dinners. Auditorium seating can be arranged for up to 550 people.

Petroleum Hall and Metals Hall are lecture rooms seating 130 and 330, respectively. Each room has audio visual equipment. In addition, the Green Center houses the modern Computing Center, the Department of Geophysics and the Center for Geoscience Computing.

INTERLINK Language Center

The INTERLINK Language program at CSM combines intensive English language instruction with training in skills necessary for successful academic and social life at an American engineering university. Designed to address the special linguistic needs of science and technology students, its curriculum focuses on reading, writing, grammar, listening, conversation, pronunciation, and study skills. Instruction is offered in nine-week sessions at six levels of proficiency. At the successful completion of the fifth level, a qualified student can understand, take notes on academic lectures, make oral presentations, read scholarly books and journals, conduct library research, and write essays and research papers.

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 write INTERLINK Language Center at

> Colorado School of Mines,
> 1500 Illinois Street,
> Golden, CO 80401

Call 303-273-3516 or FAX 303-273-3529.

LAIS Writing Center

The LAIS Writing Center, located in room 263 of the Green Center (phone: 303 273-3085), 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 writers and professional writing instructors. The Center assists students with all their writing needs, from course assignments to scholarship applications, proposals, letters and resumes. This service is free to CSM students, faculty, and staff and includes one-to-one tutoring and online resources provided in a computerized, electronic classroom.

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.

The office works with the departments and divisions of the School to: (1) help develop and facilitate study abroad opportunities for CSM graduate and undergraduate 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.

OIP is located in 109 Stratton Hall. For more specific information about study abroad and other international programs, contact OIP at 384-2121.

Office of Women in Science, Engineering and Mathematics (WISEM)

The WISEM office is located in 300 Guggenheim Hall. 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 for women students and faculty and produces the Chevron Lecture Series. For further information, contact: Debra K. Lasich, Executive Director of Women in Science, Engineering and Mathematics, Colorado School of Mines, 1500 Illinois, Golden, CO 80401-1869, or call (303) 273-3097.

Ombuds Program

Graduate students have access to an informal campus Ombuds Program. The Ombuds Program acts as a neutral party and assists students in resolving complaints and disputes within the College. The Ombuds Program does not provide legal advice or represent students on legal matters, but can help provide clearer perspectives on issues of concern and options for effective dispute resolution. Campus Ombudspersons can be reached via email at ombuds@mines,edu.

Public Affairs

The Public Affairs Department encompasses three areas–media relations, community relations and publications. The

department keeps the news media and general public informed about happenings within the CSM community.

The President has delegated to Public Affairs the responsibility of speaking for the institution in the day-to-day conduct of business. Public Affairs personnel also assist faculty, staff and students in initiating and responding to media. The news and information staff produce articles on faculty, research, staff and student activities for both internal and external audiences for use in print and broadcast media. To obtain news coverage of an activity or event, call the Public Affairs office as far in advance as possible.

The department produces *Mines Today*, a magazine published quarterly for the campus community and friends of the school. *CSM Update* is also published by this department and is distributed to faculty and staff on campus.

To ensure quality and consistency, all publications are required to adhere to guidelines which can be obtained from the Office of Public Affairs. Public Affairs advises CSM departments on the selection of vendors for writing, editing, design, photography, production, printing, and distribution.

Public Affairs maintains World Wide Web pages at www.mines.edu/All_about/public/. Included on these pages are the CSM Experts Database and official CSM press releases.

Research Development

The Office of Research Development (ORD), under the direction of Phillip R. Romig, Dean of Graduate Studies and Research, nurtures and builds CSM's research effort within the continually changing internal and external environment by actively seeking, evaluating and implementing effective ways to market CSM's research expertise and experience; effectively expands and maintains the information management program; stimulates new research areas and applications; and develops and implements programs for research faculty/staff development.

The office serves individual researchers, at all levels, junior through senior; group and interdisciplinary research entities; external sponsors and collaborators including industry, government, other academic institutions and nonprofit entities; CSM's administration and its needs for information (internal and external) and assistance with special functions.

Research Services

The Office of Research Services (ORS), under the Vice President for Finance and Operations, provides administrative support in proposal preparation, contract and grant administration, both negotiation and set-up, and close out of expired agreements.

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 Professional Outreach Program provides opportunities for students to take campus courses on a non-degree basis. The Office offers a broad array of programming for K-12 teachers and students through its Teacher Enhancement Program, *the Denver Earth Science Project,* the *National Science Academy,* and *Summer Investigations for Middle/High Schoolers*. 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. The SPACE Office also offers a variety of web-based distance delivery courses for off-campus audiences through *Mines On-line*. 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; website www.mines.edu/Outreach/Cont_Ed.

Telecommunications Center

The Telecommunications Center is located at the west end of the Plant Facilities building, and provides telephone and voicemail service to the campus, residence halls, and Mines Park housing areas. The Telecommunications Center also publishes a CSM Campus Directory available anytime to staff, faculty and students on the Web: (mines.edu/directory/csm_only/).

Local telephone service is provided as part of the housing rates. The Telecommunications Center provides maintenance for telephone lines and services.

Voicemail service is provided as an optional service by subscription. The fee is $22.50 per semester, and subscription cards are available in the Housing Office or in the Telecommunications Center. The voicemail fee is non-refundable, except in the case of departure from the campus (refunded at a decreased, monthly prorated rate).

The Telecommunications Center provides long distance services for the Residence Halls and Mines Park housing areas through individual account codes. Long distance rates for domestic calling are 0.10 per minute 24 hours a day, seven days a week. International rates are available on request from the Telecommunications Center. Accounts are issued at the beginning of the fall semester, or by request at any time. Monthly long distance charges are assessed to student accounts each month and invoices are mailed directly to students at their campus address. Questions and requests for information for the above services should be directed to the Telecommunications Center (303) 273-3000 or 1-800-446-9488.

Registration and Tuition Classification

General Registration Requirements

To remain in good standing, non-thesis students must register continuously for a minimum of 3 hours of course credit each fall and spring semester. Summer registration is not required for non-thesis students to remain in good standing.

Thesis-based students register for the following components to satisfy the requirements for their degrees: course credit hours, research credit hours and thesis credit hours. During the fall and spring semesters, thesis-based students must register continuously for a minimum of 4 credit hours. Students may not register for more than 12 credit hours during these semesters, unless they are registered for course credit only. Students who continue to work on degree programs and utilize CSM facilities and resources during the summer must register for a minimum of 3 credit hours. Students may not register for more than 6 credit hours during the summer, unless they are registering for course credit only. Students registered during the summer session must pay student health center, student center and athletic fees.

Students who qualify for thesis registration as described below must register continuously for 4 hours of thesis credit during the fall and spring semesters and 3 hours of thesis credit during the summer in order to remain in good standing.

Students supported by CSM funds (Graduate Assistantships, fellowships or other) must be registered as full-time students as defined below.

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's students must complete a minimum of 12 hours of research credit, and doctoral students must complete a minimum of 24 hours of research credit after they are accepted into the Ph.D. program. 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 students' work.

Eligibility for Thesis Registration

Students enrolled in thesis-based degree programs who have completed the minimum course and research requirements for their degree will be eligible to register for thesis credit and will be considered to be pursuing their graduate program full time at a reduced registration level. In order to be considered to have completed the minimum course and research requirements, 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, including satisfying minor requirements

3. For all students, having approved Admission to Candidacy forms on file in the Graduate Office.

While fulflling this requirement, students will register for thesis credit under course numbers 700 (M.E.), 701 (M.S.) or 703 (Ph.D.) as appropriate. Faculty will assign thesis grades indicating satisfactory or unsatisfactory progress based on their evaluation of the students' work.

Graduation Requirements

Graduate students must be validly registered during the term in which they complete their program. Students must complete all graduate degree requirements before the last day of registration for the semester to avoid having to register for that particular semester. Students registered for the spring semester must complete all requirements before the last day of registration for the summer session or they will be required to register for either the summer or the following fall semester.

Full-time Status - Required Course Load

To be deemed full-time during the fall and spring semesters, students must register for 10 or more hours of course, research and thesis credit combined. 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 student has completed his or her required course work and research credits (36 hours for master's students and 72 hours for doctoral students) and has an approved Admission to Candidacy form on file in the Graduate Office, the student will be deemed full-time if he or she is registered for at least 4 credit hours of thesis 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. Any request for a leave of absence must have the prior approval of the student's faculty advisor, the department head or division

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, research or thesis credits. However, time spent on a leave of absence will count toward any time limitations for completing degrees.

Thesis-based students may not do any work related to their thesis and may not discuss their thesis with their faculty advisor while on a leave of absence.

Students who wish to return to graduate school after an unauthorized leave of absence must apply for readmission and pay a $200 readmission fee.

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.

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 a Research Assistant or Teaching Assistant contract 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, that 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 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., M.E., and Ph.D.)
Geochemistry (M.S. and Ph.D.)
Mineral Economics (M.S. and Ph.D.)
Mining and Earth Systems Engineering (M.S. and Ph.D.)
Petroleum Engineering (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 cases of withdrawal from school or for extenuating circumstances upon approval by the Registrar. Unsatisfactory academic performance does not constitute an extenuating circumstance. Students receive a grade of F in courses which are dropped after the deadline without approval.

Auditing Courses

As part of the maximum of 12 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. Grades of NC are awarded only if all conditions stipulated by course instructors are met.

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. All exceptions to the policies stated in the CSM Graduate Bulletin must be approved by the Graduate Dean. The Graduate Bulletin current when a graduate student first enrolls gives the requirements the student must meet to graduate. However, a student can change to the requirements in a later catalog published while the student is enrolled in the graduate school.

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 Dismissal Policy and the Academic Dishonesty Policy 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.

Code of Conduct

This policy proscribes student personal behavior, the reasons for dismissal or suspension from school, and student disciplinary action.

Academic Integrity

This policy defines academic integrity and academic dishonesty, and explains student responsibilities and what is expected of them.

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.

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 in graduate coursework;

◆ Receipt of an "In-Progress-Unsatisfactory" grade for research or thesis credits; 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.

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 as a result of a second indication of unsatisfactory academic progress, the Dean shall notify the student and invite him or her to submit a 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 endorsed by the department head or division director, shall be submitted to the Dean no later than 21 days from the date upon which the student received official notification from the Dean regarding his or her discretionary dismissal status. 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 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 pass the comprehensive examination after two attempts; (2) failure to successfully defend the thesis after two attempts; (3) failure by a student subject to discretionary dismissal to submit a remedial plan on or before expiration of the applicable deadline; or (4) 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.

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 30 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 30 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.

Resolution of Conflicting Bulletin Provisions

The provisions of this section of the CSM Graduate Bulletin shall govern the resolution of any conflict or inconsistency that may be found to exist between this section and any other provision of the Bulletin.

Academic Dishonesty Policy

Academic Dishonesty:

Academic dishonesty means to engage in cheating or fraudulent behavior during an academic endeavor at the Colorado School of Mines. Academic dishonesty includes, but is not limited to, the following conduct: (1) submission of research or writing done by another as one's own, i.e., plagiarism; (2) falsification of research results; and (3) giving, requesting, or utilizing improper assistance on an examination.

Initial Determination:

Issues regarding plagiarism or falsification of research results shall be determined within a reasonable time by a majority vote of the graduate student's committee. Issues regarding cheating on examinations shall be determined within a reasonable time by the department head, division director, or program director of the affected department, division, or program. Individuals charged with decision making authority hereunder shall discuss the charges with all relevant witnesses and review all relevant documents, as appropriate, prior to rendering any decision.

Appeal Procedure:

All appeals hereunder shall be filed with the Dean of Graduate Studies and Research. In order to be considered, an appeal hereunder must be: (1) in writing; (2) contain a specific description of the matter being appealed; and (3) be received by the Dean no later than 30 days from the date upon which the graduate student received official notification from CSM regarding the action or matter being appealed.

Upon receipt of a timely appeal, the Dean shall appoint a committee of five tenured faculty members to review the matter and, within a reasonable time, issue a written recommendation thereon to the Dean. During the course of performing this function, the committee shall: (1) interview the student and the initial decision maker(s); (2) review all documentation related to the matter under consideration; and (3) secure any outside expertise necessary to properly consider the appeal.

The Dean has authority to issue a final decision regarding all graduate student appeals.

Any CSM student who has committed an act of academic dishonesty shall be subject to the imposition of appropriate sanctions up to, and including, dismissal from CSM.

Resolution of Conflicting Bulletin Provisions:

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

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 Graduate School 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 towards their graduate degree, or complete supervised readings, or both. Students are notified of their apparent deficiency areas in their acceptance letter 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 interdisciplinary programs which have been recommended by both departments 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.

Graduate Credit for Courses Taken as Undergraduates

Students can receive credit toward a graduate degree for graduate courses taken before they enroll in an advanced degree program as long as those courses were not applied to an undergraduate degree.

Transfer Credit

Credits from Other Universities:

Credits earned with grades of B or higher may be accepted towards a Professional, M.S., or Ph.D. degree by transfer from another recognized institution if approved by the student's committee and the Graduate Dean. Courses transferred from another university shall not be used to calculate the student's grade point average.

Credits Earned as Non-Degree Student:

If a student transfers non-degree credits to a regular graduate transcript, they all must be calculated into the student's overall GPA. Up to nine credits earned as a nondegree student may be transferred into the regular degree program if the student's graduate committee and the Graduate Dean approve.

Number of Transfer Credit Allowed

Nine hours of transfer credit are allowed for thesis programs; 15 hours are allowed for non-thesis M.S. programs.

Independent Study

For each semester credit hour awarded for independent study a student is expected to invest approximately 25 hours of effort in educational activity involved. 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 Thesis Grades

Requirements

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, including both graduate and undergraduate courses. A grade of D is not acceptable for graduate students in any course and will be considered the equivalent of an F (failure) for all purposes except calculation of the grade point average.

For research and thesis credits, students receive either an "In Progress-Satisfactory" or an "In Progress-Unsatisfactory" grade based on their faculty advisor's evaluation of their work. When the thesis is satisfactorily completed, the student receives a grade of M-Completed on his or her final semester transcript. Research and thesis 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 or thesis grade are placed on academic probation by the Graduate Dean. If a student becomes eligible for probation a second time, he or she must submit a plan for completing the degree program successfully in order to avoid dismissal. (See the Unsatisfactory Academic Performance policy elsewhere in this section.)

Grade Appeal Process

Student appeals on grades are to be heard by the Faculty Affairs Committee of the CSM Faculty Senate if they cannot be resolved at a lower level. The appeal process is as follows:

1. The student should attempt to work out the dispute with the faculty member responsible for the course.

2. If the student is not satisfied with the results of Step 1, she or he must appeal in writing to the Department Head/ Division Director, who will appoint a faculty member who is familiar with the course material to serve as adjudicator.

3. If the student is not satisfied with the results of Step 2, she or he must notify the Department Head/Division Director in writing, and the Department Head/Division Director will appoint an ad hoc committee from within the Department to serve as adjudicator.

4. If the student is not satisfied with the results of Step 3, he or she must submit a written statement of the case for the appeal to the Vice President for Academic Affairs. The VPAA will obtain written statements from the faculty member who gave the grade, from the faculty member appointed in Step 2, and from the faculty committee appointed in Step 3. The VPAA then will submit all statements to the Faculty Affairs Committee for investigation and decision. The decision of the Faculty Affairs Committee is final.

Graduation

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

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.

All graduating students must officially check out of School, 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.

M.S. and Ph.D. students must complete the checkout process within 45 calendar days after a successful defense of thesis. Failure to comply with this policy may require a redefense of thesis. Exceptions to this rule are granted only upon request to the Dean of Graduate Studies. 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 before the date of graduation. Students who fail to graduate at the time originally anticipated must reapply 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 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.

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 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.

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 eight 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.

Grading System

Grades.

When a student registers in a 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 values:

- A   Excellent
- B   Good
- C   Satisfactory
- D   Poor (lowest passing)
- F   Failed
- S   Satisfactory, C or better, used at mid-term
- U   Unsatisfactory, below C, used at mid-term
- WI   Involuntarily Withdrawn
- W   Withdrew, No Penalty
- T   Transfer Credit
- PRG In Progress
- PRU In Progress Unsatisfactory
- INC Incomplete
- NC   Not for Credit
- Z   Grade not yet Submitted
- M   Thesis Completed

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 unless the Registrar extends the time upon the written recommendation of the instructor granting the Incomplete.

Progress Grade.

A student may receive a grade of In Progress for independent study courses extending for more than one semester. The progress grade has no point value and is used only for multi-semester courses, such as thesis or certain special project courses, or for special sections of one-semester courses which are spread over two terms. In such cases, the student receives a grade of PRG, which indicates that the work is not completed. The independent study 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, reregister in that course in the summer session, in which case the letter grade must be given at the end of the summer session.

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. The system for expressing the quality of a student's work is based on quality points and quality hours. The grade A represents four quality points, B three, C two, D one, F none. 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 of A, B, C, D, or F 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, M, 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 are calculated, recorded, and reported to three decimal places for whatever purposes those averages are used.

Access to Student Records

In compliance with Article 99.6 of the U.S. Department of Education regulations under the Family Education Rights and Privacy Act, Colorado School of Mines notifies its students each year in the Fall Schedule of Courses of their rights to inspect and review their education records, to correct inaccurate or misleading information through informal and formal hearings, and to prevent disclosure of individual student records.

CSM policy, which is available from the Registrar's Office, explains in detail the procedures to be used by the school to comply with the provisions of the Privacy Act. Students should be aware that such personal information as names, addresses, telephone numbers, date of birth, major field of study, degrees awarded, last school attended, dates of attendance, class, honors, and athletic participation is considered directory information which may be released by the school unless the student notifies CSM in writing before the end of the first two weeks of the fall semester the student is registered that he or she does not want that information disclosed.

Students can file complaints with the Family Educational Rights and Privacy Act Office about alleged failures by the school to comply with the Act.

Tuition and fees at CSM are kept at a minimum, consistent with the cost of instruction and the amount of state funds appropriated to the School.

The following rates are in effect for 2000-2001. Increases

Tuition , Fees, Financial Assistance

can be expected in subsequent years.

Tuition

Academic and Field Courses

Sem Hrs	Resident	Non-res
Up to 10 (undergraduate)	$158/sem hr.	$510/sem hr.
Up to 10 (graduate)	$237/sem hr.	$765/sem hr.
10 or more	$2,375/sem	$7,652/sem

The above are applicable to all academic periods and to both graduate and undergraduate courses.

Other Courses and Programs

Executive Master of Science Program
Environmental Science & Engineering - $16,500

Fees

Regular Semester (Fall/Spring)

During a regular semester, students taking less than 4 credit hours are not required to pay student fees, except for the Technology Fee. Any such student wishing to take part in student activities and receive student privileges may do so by paying full semester fees. All students carrying 4 or more credit hours must pay full student fees as follows:

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 Health Center* .............................. $45.00
Associated Students ......................... 56.00
Athletics ......................................... 42.20
Student Services ............................. 115.00
Student Assistance .......................... 13.00
Technology Fee ................................ 60.00
Total .......................................... $331.20
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*A health insurance program is also available. Health insurance is a mandatory fee unless the student can prove coverage through another plan.

Summer Session

Academic Courses & Thesis Research

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Health Center .................................. $22.50
Athletics .......................................... 21.10
Student Services ............................... 57.50
Technology Fee ................................ 30.00
Total .......................................... $131.10
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Field Term Courses

On-campus: Health Center $17.00
             Student Services $43.00
Off-campus: Arrangements and payment for transportation, food, lodging, and other expenses must be made with the department concerned. (Geology Department camping fee is $135.)

Graduation Fee

(includes thesis binding and other expenses)

Professional	$130.00
Masters (Thesis)	$235.00
Masters (Non-Thesis)	$145.00
Doctors	$265.00

Student Health Plan*

	Fall or Spring/Summer	Summer Only
Student only	$375.00	135.00
Spouse only	1203.00	401.00
Child(ren) only	813.00	271.00
Spouse & Child(ren)	1989.00	662.00

The Spring Semester includes Summer Session coverage through August.

Student Fees and Descriptions

All students enrolled for four semester hours or more are charged the following mandatory, non-waivable fees by CSM. Some of the fees listed are not relevant for graduate students.

Health Center Fee: Revenues support physician/medical services to students. $45.00/term

Associated Students Fee: Revenues support student organizations/events/activities, i.e., newspaper, homecoming, E-Days. $56.00/term

Athletic Fee: Revenues support intercollegiate athletics and entitles student entrance to all scheduled athletic events and use of the facilities. $42.20/term

Student Assistance Fee: Funds safety awareness programs, training seminars for abuse issues, campus lighting, and parking facility maintenance. $13.00/term

Student Services Fee: Revenues support bonded indebtedness; other student services, i.e., Placement/Co-Op, Student Activities, Student Life, Student Development Center, and services provided in the student center. $115.00/term

Technology Fee: Funds technology infrastructure and equipment for maximum student use. The School matches the student fee revenues dollar for dollar. $60.00/term

All degree students enrolled for 7.0 semester hours or more are charged the following mandatory, waivable fees by CSM:

Student Health Insurance: Revenues contribute to a self insurance pool. $375.00/FY 00-01.

Students pay the following fees based on enrollment in specific courses or other circumstances:

Late Insurance Waiver Fee: Revenues provide funds for the administration of the health insurance program. $40.00

Transcript Fee: Revenues support the cost of providing

transcripts. $2.00/term

Yearbook Fee: Revenues support the publication of the CSM yearbook, the Prospector. $30.00/yr.

Add/Drop Charge: Revenues offset the cost of processing Add/Drop registration. $4.00 each

Late Registration Fee: Revenues offset the cost of processing late registration. Assessed after 5 days. $100.00 (graduate students)

Late Payment Penalty: Revenues offset billing costs for late tuition payments. 1.5% of outstanding balance

Damage Charges (Housing): Revenues are used to repair or replace damaged items/rooms in CSM rental units. Residence halls - $50.00; Mines Park & Prospector Village - $400.00

Refrigerator/Microwave Permits: Revenues are used to offset extra electrical usage consumed by residence hall occupants who choose to bring these personal items. $15.00 per permit

Bike Locker Rental: Revenues provide and maintain locker facilities for resident students. $45.00/term

Residence Hall Room Charge: Revenues support maintenance, improvements, and residence hall administration. See page 10

Meal Plan Charges: Revenues provide meals and maintain cafeteria equipment for the students on meal plans. See page 10

Residence Hall Association Fee: Revenues support social activities for the residence halls. $35.00/year

Housing and Rental Fees: Rental fees for housing rentals maintain the rental properties, pay utility charges, maintain and improve properties. See Housing page 8

Tuition Paid-Out: CSM has advanced tuition to another school. Charges are reimbursement request for those advances. Only for sponsored students - paid by sponsor

Books/Supplies Fees: Advances made to or on behalf of the students. Charges are reimbursement only. Only for sponsored students - paid by sponsor

Computer Usage Fees: Revenues assist in providing institutional/research computing services. $500.00/term - paid by sponsor

Refunds or Advances: These charges are simply reimbursement requests for funds advanced to or on behalf of the student. Funds received merely replace those advances. N/A

Payments: CSM must repay to the bank any student funds for which a student becomes ineligible. Funds collected from the student replace those advances. N/A

Grants and Scholarships (Recalled): When students become ineligible for grant, loan, or scholarship money which they have received, the recall of those funds are reflected. N/A

Return Check: The amount of a student's check which has been returned for insufficient funds.

Return Check Charge: Revenues offset bank fees for returned checks. $20.00

Phonemail Fee: Assessed to students living in the residence halls who request voice mail services. (Optional.)

The Colorado School of Mines does not automatically assess any optional fees or charges.

Note: 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 Guggenheim Hall. Please write your social security number 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 assessments 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.

To comply with federal regulations surrounding student financial aid programs, the Director of Financial Aid may modify this schedule in individual circumstances.

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.

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 contract, which gives the terms of appointment and specifies the amount 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.

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.

Colorado Graduate Fellowships.

The Dean of Graduate Studies awards Colorado Fellowships based on the student's academic performance. Students need to be recommended by their departments.

Graduate Student Loans.

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

Forms are available from the Financial Aid Office, which handles student loans. The Financial Aid Office telephone number is 303-273-3301.

Graduate Degrees and Requirements

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

I. Professional Programs

A. Graduate Certificate Program

The Division of Liberal Arts and International Studies offers two graduate certificate programs with specialization in International Political Economy (IPE) and International Political Economy of Resources (IPER). For more information about these programs, please refer to the "Graduate Degree Programs and Description of Courses" section of this Bulletin.

Other graduate certificate programs may be introduced from time to time in response to demand from students. Please contact the appropriate department or division to learn about any offerings that might not have been announced at the time this Bulletin was pubished.

B. Professional Degree

CSM offers a post-baccalaureate professional degree program emphasizing graduate level course work.

Intended to be an intermediate program between the bachelor's and master's degree levels, this program is ideal for professionals who desire to return to school to enhance their education, or who wish to change their career emphasis in the resource industries. It is also available to recent college graduates who wish to further their education in these fields without enrolling in a regular graduate program.

1. Departments Offering the Degree

Professional degrees are offered by the Departments of Geology and Geological Engineering and Geophysics. Each department has its own specific course requirements for the Professional degree, and students are encouraged to check with the appropriate department or the "Graduate Degree Programs" section of this Bulletin for these requirements.

2. Program Requirements and Structure

The professional degree program requires a minimum of 30 credit hours of additional course work beyond the Bachelor of Science degree. Fifteen of these credit hours must be taken as a registered Professional degree student at CSM.

The course of study can be structured to meet the needs of each student, but the department and the Graduate Dean must approve the student's program during the first semester of enrollment.

3. Admission to Candidacy

The professional degree candidate must submit to the Office of Graduate Studies an application for Admission to Candidacy with the student's Request for Graduation form. Please refer to the current Graduate Student Handbook to determine the deadline for submission of these documents. The application for Admission to Candidacy must be approved by the student's faculty advisor, department head and the Graduate Dean, and must contain a complete list of courses being applied toward the degree.

4. Transfer to Master's or Doctoral Program

Even though the professional degree is intended to be a final degree, students may transfer from the professional degree program to a master's or doctoral degree program. To make this transfer, students must apply for the master's or doctoral program using the normal application procedures and be admitted to the applicable department.

Course credits taken under the Professional degree program may be applied to the master's or doctoral degree programs with the approval of the student's Thesis Committee and department head.

5. Grades and Time Limitation for Completion of Degree Requirements

Professional degree students must maintain a cumulative grade point average of 3.0 or better in CSM course work. All degree requirements must be completed within five years of initial registration at CSM, unless an extension is granted by the Graduate Dean.

C. Master's Degrees - Non-Thesis

In lieu of preparing a thesis, the non-thesis master's program students are required to complete more credit hours of course work than that required of the master's-thesis candidates. 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. Students must complete all candidacy requirements except those pertaining to thesis preparation and defense. Non-thesis master's degrees are offered in Chemical Engineering and Petroleum Refining, Environmental Science and Engineering, Materials Science, Mathematical and Computer Sciences, Metallurgical and Materials Engineering, Mineral Economics, Mining, and Petroleum Engineering. Please refer to the "Graduate Degree Programs and Description of Courses" section of this Bulletin for more information about these programs.

1. Academic Requirements

CSM non-thesis master's programs typically require a minimum of 36 credit hours of course work, although the student's home department may require additional semester hours in particular subject areas. Twenty-one of these credit hours must be taken as a registered master's degree student at CSM.

Master's students must maintain a cumulative grade point average of 3.0 or better in CSM course work. All course work must be completed within five years after

entering the Graduate School. Time spent on approved leaves of absence is included in the five-year time limit.

2. Transfer of Credits

Up to 12 graduate credit hours from another institution may be accepted for transfer toward the student's degree if the student achieved a grade of B or better in these courses and the transfer is approved by the student's faculty advisor and department head or division director. Courses transferred from another institution are not included in calculating the student's grade point average at CSM.

3. Minor Programs

Students may choose to have a minor program at the master's level, but the minor program may not be taken in the student's major area of study. A designated minor requires a minimum of nine 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.

4. Admission to Candidacy

The master's degree candidate must submit to the Office of Graduate Studies an application for Admission to Candidacy with the student's Request for Graduation form. Please refer to the current Graduate Student Handbook to determine the deadline for submission of these documents. The application for Admission to Candidacy must be approved by the student's faculty advisor, department head or division director, and the Graduate Dean, and must contain a complete list of courses being applied toward the degree.

II. Combined Undergraduate/Graduate Programs

A. Overview

Several degree programs offer undergraduate students the opportunity to begin work on a Graduate Certificate, Professional Degree, or Master's Degree while completing the requirements for their Bachelor's Degree. 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 a field that complements their undergraduate major or, in special cases, in the same field.

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 program leading to a Graduate Certificate 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. Students may receive both degrees at the same time, providing them access to both undergraduate and graduate benefits (such as financial aid) while completing their programs.

7. In many cases, students will be able to complete both Bachelor's and Master's Degrees in five years of total enrollment at CSM.

At the time of publication of this Bulletin, Combined Programs were available leading to graduate certificates in International Political Economy and International Political Economy of Resources, and leading to Master of Science or Master of Engineering degrees in Engineering Systems, Materials Science, and Metallurgical and Materials Engineering. Additional programs may be added in the future, and students interested in Combined Graduate Programs not listed here are encouraged to contact the Graduate School or their department of choice for current information.

B. Admission Process

Students may apply for Early Admission to the Combined Graduate Program any time after completing the first semester of their sophomore year at CSM. Applicants should submit the standard Graduate Application form indicating that they are applying for the Combined Graduate Program. GRE scores and letters of reference are not required. Transcripts are required only if the applicants received part of their freshman/sophomore credits at another institution.

Following Early Admission, students will be assigned graduate advisors in the programs in which they plan to receive their graduate certificates or degrees. Prior to registration for the next semester, students and their graduate advisors will plan a strategy for completing both the undergraduate and graduate programs as efficiently as possible. The students also will continue to have undergraduate advisors in the home department or division for their Bachelor's Degrees.

Upon achieving Senior standing, students may request admission to full graduate status. Admission will be automatic for students who have maintained good standing as defined below and who will be candidates for certificates or non-thesis degrees. Those students may submit their requests to the Graduate Office by memo or email. Students

who have not maintained good standing or who will be candidates for thesis degrees must submit a standard application package for the certificate or degree being sought.

C. Requirements

In order to maintain good standing in the Combined Program:

1. Students who have been granted Early Admission to the Combined Program must register full time and maintain a minimum semester GPA of 3.0 during each semester subsequent to admission, including the semester in which they were accepted.

2. Students who have been granted full graduate status must satisfy all requirements (course, research and thesis credits, minimum GPA, etc.) of the graduate program in which they are enrolled. Note that all courses, undergraduate and graduate, taken after full admission count toward the minimum GPA required to be making satisfactory progress.

After students have been accepted into full graduate status, they will have dual status and will have all of the privileges and be subject to all expectations of both undergraduate and graduate programs. Students having dual status may take both undergraduate and graduate courses, may register for internship, research, or thesis credits as required for their graduate program and may have access to financial aid available through both programs.

III. Thesis-Based Master's Degree Programs

A. General

Graduate study at CSM can lead to one of a number of master's degrees, depending on the interests of the student. All thesis-based master's degree programs share the same requirements for grades, full-time and part-time status, transfer credits, advising committees, minor programs, and admission to candidacy.

B. Credits and Academic Requirements

A minimum of 36 credit hours of acceptable course work and research or engineering design experience, completion of a satisfactory thesis and successful oral defense of this thesis are required for the Master of Science and Master of Engineering degrees. At least 12 of the credit hours must be designated for research under the direct supervision of the student's faculty advisor. The student's home department may require additional credit hours in particular subject areas. At least 15 credit hours of the course work must be taken at Colorado School of Mines as a registered graduate student.

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.

Master's degree students must maintain a cumulative grade point average of 3.0 or better in CSM course work. Other details regarding grades and academic probation are provided in the "General Regulations" section above.

C. Transfer of Credits

Up to nine graduate credit hours from another institution may be accepted for transfer toward the student's degree if the student achieved a grade of B or better in these courses and if the transfer is approved by the Dean of Graduate Studies, the student's faculty advisor and Thesis Committee. Courses transferred from another institution are not included in calculating the student's grade point average at CSM.

D. Minor Programs

Students may choose to have a minor program at the master's level. The minor program may not be taken in the student's major area of study. A designated minor requires a minimum of nine credit hours of course work and must be approved by the Thesis Committee and the student's home department head or division director. If a minor program is declared, a member of the minor area of study will serve on the student's Thesis Committee.

E. Faculty Advisor Appointment

Each master's student must select a faculty advisor to provide advice regarding the student's thesis direction, research and selection of courses. 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 advisor. In that case, a co-advisor must be selected from the student's home department.

F. Admission to Candidacy

The master's degree candidate must submit to the Office of Graduate Studies an application for Admission to Candidacy with the student's Request for Graduation form. Please refer to the current Graduate Student Handbook to determine the deadline for submission of these documents.

The application must be approved by the student's faculty advisor, Thesis Committee, department head and the Graduate Dean, and must contain a complete list of courses being applied toward the degree. In a thesis program, Admission to Candidacy must be granted before a student can defend the thesis.

G. 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. 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. In addition, 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, the Thesis Committee must have at least four members from the home or an allied department.

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.

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's 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.

H. 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 studies. This defense session,

which may include an examination of material covered in the student's course work, will be open to the public. It must be scheduled with the Graduate Dean's office at least one week in advance of the defense date.

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.

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.) Master's students must also complete the graduate checkout process within 45 calendar days following the successful defense of thesis. A more detailed explanation of this policy can be found in the General Regulations section of this Bulletin under "Graduation." Should the student fail to complete the checkout within the prescribed period, the Thesis Committee may require the student to orally defend, again, his or her thesis.

IV. Doctor of Philosophy
A. Credits, Academic and Campus Residence Requirements

The Doctor of Philosophy degree requires a minimum of 72 credit hours (course work and research combined) beyond the bachelor's degree. At least 24 of these hours must be designated for research under the direct supervision of the student's faculty advisor. The student's major department or division establishes course work requirements for the doctoral degree in their field, which are stated 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

Students who enter the Ph.D. program with a bachelor's degree may transfer up to 24 graduate credit hours from another institution toward the CSM doctorate, if the student achieved a grade of B or better in these courses and if the transfer is approved by the student's faculty advisor, Doctoral Thesis Committee, and department head or division director. Courses transferred from another institution are not included in the calculation of the student's grade-point average at CSM.

Students who enter the Ph.D. program with a master's degree may transfer, upon the approval of the student's faculty advisor, Doctoral Thesis Committee and department head or division director, up to 36 credit hours granted for study and research in a master's program at another institution.

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. 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 advisor. In that case, a co-advisor must be selected from the student's home department.

D. Minor Programs

All doctoral candidates except those in the Materials Science and Geochemistry programs must complete 12 credit hours in a minor program of study. This program is intended to provide a breadth of knowledge in support of the student's principal research interests. The student's faculty advisor, Doctoral Thesis Committee and home department head must approve the course selection and sequence in the minor program.

E. Doctoral Thesis Committee

The Graduate Dean appoints a Doctoral Thesis Committee whose members have been recommended by the student's home department or division. This Committee will have a minimum of five voting members, including the student's faculty advisor, who are familiar with the student's area of study. Of these Committee members, at least three must be from the home department or, in the case of interdisciplinary degree programs, an allied department, or division.

The Doctoral Committee must also have at least one representative from the minor field, if applicable, and a member at large designated by the Graduate School. Minor representatives must be full-time members of the CSM faculty. 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 the 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 an allied department must be added to the Doctoral Thesis Committee.

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 comprehensive examinations, and scheduling the thesis defense with the Graduate Office.

F. Comprehensive Examination

The student must satisfactorily complete a series of written and/or oral examinations covering all phases of major and minor fields at least six months before the student's anticipated graduation date and no later than three years after the student begins the doctoral program. Part-time students may request an extension of up to one year to complete their examinations. This request must be submitted in writing to the Graduate Dean prior to the commencement of the student's third year in the program.

The individual departments will structure and administer the exams for their respective doctoral students. The designated Examining Committee must submit a written report to the Graduate Dean setting forth the results of the comprehensive examination within seven days of the completion of the examination.

If the student fails the comprehensive examination, he or she may request a re-examination. This request must be

submitted in writing to the student's department head no later than 30 days following the date the student was notified of the failure. The Examining Committee and the department head must approve the request. A second failure will result in the termination of the student's graduate program.

G. Admission to Candidacy

Following the succesful completion of the comprehensive examinations and prior to the defense of thesis, the student must submit to the Office of Graduate Studies an Application for Admission to Candidacy. This application must be approved by the student's department head or division director, the Doctoral Thesis Committee and the Dean of Graduate Studies, and must contain a complete list of courses being applied toward the degree.

H. 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 Doctoral Thesis Committee shortly after the committee is formed. 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. This oral defense may include an examination of material covered in the student's course work. The defense will be open to the public and must be scheduled with the Office of Graduate Studies at least one week prior to the defense date.

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 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.

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.

Doctoral students must also complete the graduate checkout process within 45 calendar days following the successful defense of thesis. A more detailed explanation of this policy can be found in the General Regulations section of this Bulletin under "Graduation." Should the student fail to complete the checkout within the prescribed period, the Doctoral Thesis Committee may require the student to orally defend, again, his or her thesis.

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 and Petroleum Refining

JAMES F. ELY, Professor and Department Head
ANTHONY M. DEAN, W.K. Coors Distinguished Professor
ROBERT M. BALDWIN, Professor
ANNETTE L. BUNGE, Professor
RONALD L. MILLER, Professor
M. SAMI SELIM, Professor
E. DENDY SLOAN, Weaver Distinguished Professor
VICTOR F. YESAVAGE, Professor
JOHN R. DORGAN, Associate Professor
DAVID W.M. MARR, Associate Professor
J. THOMAS MCKINNON, Associate Professor
J. DOUGLAS WAY, Associate Professor
COLIN A. WOLDEN, Assistant Professor
DAVID T. WU, Assistant Professor
JAMES H. GARY, Professor Emeritus
JOHN O. GOLDEN, Professor Emeritus
ARTHUR J. KIDNAY, Professor Emeritus
MICHAEL S. GRABOSKI, Research Professor
ROBERT D. KNECHT, Research Professor
ROBERT L. MCCORMICK, Research Associate Professor

Degrees Offered:

Master of Science (Chemical and Petroleum-Refining Engineering)

Doctor of Philosophy (Chemical and Petroleum-Refining 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 at Colorado School of Mines in Chemical Engineering. Undergraduate course deficiencies must be removed prior to enrollment in graduate coursework.

Required Curriculum:

Master of Science Program For Students with Non-Engineering Degrees:

The chemical engineering department recognizes that there are a number of well qualified students desiring to enter the field of chemical engineering who hold baccalaureate degrees in scientific or other engineering disciplines. To accommodate these students, the department has formulated a master of science program open to qualified students with undergraduate science and engineering degrees. The program is adjusted to fit the background of the individual, but will normally consist of the courses shown below:

First Year	
ChEN201	ChEN357
ChEN307	ChEN375
ChEN308	
Second Year	
ChEN418	ChEN516
ChEN507	ChEN518
ChEN509	

In addition to the courses listed above, six more hours of graduate credit must be earned.

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 course work. All students must complete the four chemical engineering core graduate courses (ChEN507, ChEN509, ChEN516, and ChEN518) and an additional six hours of approved electives. In addition, students must complete and defend an acceptable Masters dissertation. Full-time Masters students must enroll in graduate colloquium (ChEN605) each semester 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 36 semester hours of course work. All students must complete the four chemical engineering core graduate courses (ChEN507, ChEN509, ChEN516, and ChEN518) and 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.

Doctor of Philosophy Program:

The course of study for the Ph.D. degree consists of a minimum of 30 semester hours of course work. All Ph.D. students must complete the four core courses (ChEN507, ChEN509, ChEN518, and ChEN516) and an additional six 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 dissertation. Full-time Ph.D. students must enroll in graduate colloquium (ChEN605) each semester they are in residence.

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, MACS315, 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, MACS315, 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, MACS315, 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 simulation. Prerequisite: ChEN307, ChEN308, ChEN357, MACS315, 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: MACS315, 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, MACS315, 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 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, MACS315, 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.

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 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 contactors. 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.

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

ChGN550 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: CRGN375, CRGN430 or consent of instructor. 3 hours lecture; 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.

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.

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.

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.

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 MECHAN-ICS 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 THERMODYNAM-ICS 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 THERMODYNAM-ICS 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; 6 semester hours maximum credit.

ChEN615. ADVANCED TOPICS IN MASS TRANSFER In-depth analyses 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.

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 ENGI-NEERING 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.

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.

ChEN701. GRADUATE THESIS-MASTER OF SCIENCE Library search and laboratory work for the master's thesis in petroleum refining under the supervision of the graduate student's advisory committee. 6 semester hours upon completion of report.

ChEN703. GRADUATE THESIS-DOCTOR OF PHI-LOSOPHY Preparation of the doctoral thesis under supervision of the graduate student's advisory committee. 30 semester hours.

ChEN704. 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.

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.

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.

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.

Chemistry and Geochemistry

STEPHEN R. DANIEL, Professor and Department Head
DEAN W. DICKERHOOF, Professor
RONALD W. KLUSMAN, Professor
DONALD L. MACALADY, Professor
PATRICK MACCARTHY, Professor

MICHAEL J. PAVELICH, Professor
KENT J. VOORHEES, Professor
THOMAS R. WILDEMAN, Professor
SCOTT W. COWLEY, Associate Professor
MARK E. EBERHART, Associate Professor
E. CRAIG SIMMONS, Associate Professor
KIM R. WILLIAMS, Associate Professor
C. JEFFREY HARLAN, Assistant Professor
DANIEL M. KNAUSS, Assistant Professor
KEVIN W. MANDERNACK, Assistant Professor
DAVID T. WU, Assistant Professor
DAVID M. UPDEGRAFF, Research Professor
FRANCO BASILE, Research Assistant Professor
STEVEN F. DEC, Research Assistant Professor
JAMES F. RANVILLE, Research Assistant Professor
RAMON E. BISQUE, Professor Emeritus
KENNETH W. EDWARDS, Professor Emeritus
GEORGE H. KENNEDY, Professor Emeritus
DONALD LANGMUIR, Professor Emeritus
GEORGE B. LUCAS, Professor Emeritus
MAYNARD SLAUGHTER, Professor Emeritus
JOHN T. WILLIAMS, Professor Emeritus
ROBERT D. WITTERS, Professor Emeritus
CHARLES W. STARKS, Associate Professor Emeritus

Degrees Offered:

Master of Science (Chemistry)

Doctor of Philosophy (Applied Chemistry)

Master of Science (Geochemistry)

Doctor of Philosophy (Geochemistry)

All of the Department's degree programs have been admitted to the Western Regional Graduate Program. This 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:

There are two basic graduate programs offered by the Department of Chemistry and Geochemistry. Undergraduate deficiencies of students entering one of these programs will be determined by the Department of Chemistry and Geochemistry for applied chemistry students and by the geochemistry faculty for geochemistry students through interviews and placement examinations at the beginning of the student's first semester of graduate work.

Prerequisites:

The candidate for an advanced degree in applied chemistry should have completed an undergraduate program which is essentially equivalent to that required at Colorado School of Mines in chemistry. The candidate for an advanced degree in geochemistry should have completed an undergraduate program 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. For a more

complete description, refer to the Geochemistry program description below.

Required Curriculum:

Applied Chemistry:

The program of study is selected by the student in consultation with the advisor and thesis committee. Thesis, seminar, and the core courses CHGN502 (inorganic), CHGN503 (physical), CHGN505 (organic), and CHGN507 (analytical) are required.

M.S. The program of study includes CHGN560, CHGN502, CHGN503, CHGN505, CHGN507, and the M.S. thesis research. At least 15 of the required 24 semester hours of course work must be taken in the Department of Chemistry and Geochemistry at CSM.

Ph.D. The program of study includes CHGN560, CHGN660, CHGN502, CHGN503, CHGN505, CHGN507, a minor (at least 12 hours of graduate level course work) and the Ph.D. dissertation research. The student's thesis committee may set additional course requirements and will decide on transfer credit.

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. Thesis is required. The Geochemistry program comprises a core group of courses and four optional tracks: Mineralogy-Petrology, Aqueous-Environmental, Ore deposits-Exploration, Organic-Petroleum. All geochemistry students must complete all core courses. Students may elect any one of the four tracks. The core courses are CHGC503 - Introduction to Geochemistry, CHGC504 - Methods in Geochemistry, CHGN503 - Advanced Physical Chemistry. Students may elect courses in the selected track with advice from their advisors and/or thesis or dissertation committees. Students with deficient backgrounds in chemistry or geology must complete a deficiency course in physical chemistry (for geologists) or geology (for chemists). Students reside in either the Department of Geology and Geological Engineering or the Department of Chemistry and Geochemistry.

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 explora-
tion 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.

Description of Courses

CHGN401. THEORETICAL INORGANIC CHEMISTRY (I) 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-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.

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.

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.

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. INORGANIC CHEMISTRY OF METALS (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.

CHGN504. ADVANCED PHYSICAL CHEMISTRY II (II) Application of quantum chemistry, thermodynamics, statistical mechanics and kinetics to the solid, liquid and gas states. Prerequisite: Consent of instructor. 2 hours lecture; 2 semester hours. Offered alternate years.

CHGN505. ORGANIC REACTION MECHANISMS (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. CHEMICAL BONDING THEORY (I) Theoretical basis of bonding with emphasis on molecular orbital approach. Pi electron energy calculations. Spectra of conjugated systems. Acid-base equilibria. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

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 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 nonthesis 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.

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.

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.

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.

CHGN701. GRADUATE THESIS-MASTER OF SCIENCE (I, II) Preparation of the master's thesis under the supervision of the graduate student's thesis committee. Required of all candidates for the degree of Master of Science. 6 semester hours upon completion of thesis.

CHGN703. GRADUATE THESIS-DOCTOR OF PHILOSOPHY (I, II) Preparation of the doctoral thesis under the supervision of the graduate student's thesis committee. Required of all candidates for the degree of Doctor of Philosophy. 30 semester hours.

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.

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.

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 principles of geochemistry with discussion of elemental distributions, chemical equilibrium, mineral chemistry and chemical bonding, the geochemistry of isotopes, organobiological systems, and low and high temperature water-rock systems. Prerequisite: Physical chemistry, mineralogy, and petrology. 3 hours lecture, 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. 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 contami-

nants. 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 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.

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
CAROL A. DAHL, Professor and Director, Joint Degree Program in Petroleum Economics and Management
JOHN E. TILTON, William J. Coulter Professor
R.E.D. WOOLSEY, Professor and Director,

Operations Research Program

GRAHAM A. DAVIS, Associate Professor

WADE E. MARTIN, Associate Professor

MICHAEL R. WALLS, Associate Professor and Director of
Graduate Programs

JANIS M. CAREY, Assistant Professor

SHEKHAR JAYANTHI, Assistant Professor

IRINA KHINDANOVA, Assistant Professor

ALEXANDRA NEWMAN, Assistant Professor

JAMES M. OTTO, Research Professor and Acting Director,
Institute for Global Resources Policy and Management

ANN DOZORETZ, Instructor

JOHN STERMOLE, Instructor

DAVID E. FLETCHER, Professor Emeritus

ALFRED PETRICK, JR., Professor Emeritus

ODED RUDAWSKY, Professor Emeritus

FRANKLIN J. STERMOLE, Professor Emeritus

JOHN A. CORDES, Associate Professor Emeritus

Degrees Offered:

Master of Science (Mineral Economics)

Doctor of Philosophy (Mineral Economics)

Program Description:

The Division of Economics and Business offers graduate programs leading to M.S. and Ph.D. degrees in Mineral Economics. Course work and research emphasize the application of economic principles and business methods to mineral, energy, and environmental, and technology issues. Students select from one of two areas of degree specialization: Economics and Public Policy (E&PP) and Quantative 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 economic, 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 as they apply to risk and financial management, project evaluation and decision making. This specialization also focuses on the use of operations research techniques for optimization and managerial decision making in a variety of business environments.

Program Requirements:

M.S. Degree. Student may choose from either the thesis or non-thesis option in the Master's Program. Each student takes a set of core courses that includes managerial microeconomics and macroeconomics, econometrics, natural resource economics, and mathematical economics. These 15 credit hours of core courses provide the student with the foundational tools to conduct economic and investment analysis. Students then select 12 hours of courses from their Areas of Specialization (E&PP or QBM/OR) and nine hours of elective courses. Thesis students select 9 hours of courses from their specialization and complete 12 credit hours of a Master's level thesis under the direct supervision of the student's faculty advisor.

Ph.D. Degree. The Division offers a demanding Ph.D. program for a select group of very promising applicants. The program aims to be distinctive not only by providing sound training in the theory and methodolgy of the student's chosen field, but also by training students to perform applied research of relevance to both practitioners and academics. The doctoral student may also select one of the two areas of specialization (E&PP or QBM/OR) and the student, along with his advisory committee, develops a customized curriculum to fit the student's needs. The Ph.D. in mineral economics requires a minimum of 72 graduate credit hours (course work and research combined) beyond the bachelor's degree. Included in this 72 hours are 48 hours of approved graduate course work, plus 24 hours of thesis credit, completion of a satifsactory doctoral thesis, and successful oral defense of this thesis.

Prerequisites:

Applications for graduate admission are considered at any time. A complete application package consists of a CSM Graduate School Application for Admission, test scores from either the Graduate Record Exam (GRE) or the Graduate Management Admission Test (GMAT), transcripts from the applicant's undergraduate degree granting institution, letters of reference, and the applicant's statement of purpose. International students whose native language is not English, except for those with degrees from English-speaking universities, must submit evidence of a Test of English as a Foreign Language (TOEFL) score or an International English Language Testing System (IELTS) score.

Entering students must demonstrate successful completion of undergraduate courses in (1) principles of economics, (2) probability and statistics, and (3) one semester of college-level calculus. A student not demonstrating staifsactory standing in these areas may be accepted; however, he or she 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:

The M.S. Degree in Mineral Economics

There are two options available for the M.S. degree: the *thesis* option and the *non-thesis* option. The non-thesis option requires 36 semester hours of course work. The thesis option requires a minimum of 24 semester hours of graduate course work and 12 credit hours of Master's level thesis under the direct supervision of the student's faculty advisor. Thesis and non-thesis Master's students take the following 15 hours of core courses:

EBGN 409 Mathematical Economics
EBGN 510 Natural Resource Economics

EBGN 511 Microeconomics

EBGN 512 Macroeconomics

EBGN 590 Econometrics and Forecasting

Areas of Specialization:

Non-thesis M.S. students are required to complete at least 12 semester hours in one of the following two fields of specialization, Economics & Public Policy (E&PP) or Quantitative Business Methods/Operations Research (QBM/OR). Thesis students are required to complete at least 9 hours in their area of specialization. Three credit hours are required in each area, as noted below.

Economics & Public Policy

EB530 Economics of International Energy markets

EB535 Economics of Metal Industries & Markets

EB536 Mineral Policies & International Investment

EB590 Econometrics & Forecasting

EB570 Environmental Economics

EB610 Advanced Natural Resources

EB611 Advanced Microeconomics (area requirement)

EB690 Advanced Econometrics

Quantitative Business Methods/Operations Research

EB505 Financial/Managerial Accounting (area requirement)

EB513 Industrial Psychology

EB526 Manufacturing Management

EB525 Introduction to Operations Research

EB528 Simulation

EB545 Corporate Finance

EB546 Investments & Portfolio Management

EB547 Financial Risk Management

EB554 Integer Programming

EB555 Linear Programming

EB556 Network Models

EB558 Geometric Programming

EB560 Decision Analysis in the Energy & Mineral Industries

EB575 Advanced Mineral Asset Valuation

EB580 Exploration Economics

EB690 Advanced Econometrics

Non-thesis M.S. students complete their 36 semester hours curriculum plan by choosing at least an additional nine hours of elective courses from the Division, other departments on the CSM campus, or courses at surrounding universities. Thesis students are required to complete 12 hours of thesis credit (EBGN701) and complete a Master's level thesis under the direct supervision of the student's faculty advisor..

The Ph.D. in Mineral Economics

The Ph.D. in mineral economics requires a minimum of 72 graduate credit hours (course work and research combined) beyond the bachelor's degree. Included in this 72 hours are 48 hours of approved graduate course work, plus

24 hours of thesis credit and completion of a satisfactory doctoral thesis and successful oral defense of this thesis. The student's faculty advisor and the Doctoral Thesis Committee must approve the student's program of study and the topic for the thesis. Students who enter the Ph.D. program may transfer up to 24 graduate credit hours from another institution toward the CSM doctorate, if the student achieved a grade of B or better in these courses and if the transfer is approved by the student's Doctoral Thesis Committee and the Division Director.

Courses Requirements

Ph.D. students are required to take the following 24 hours of **core courses:**

EBGN 409 Mathematical Economics

EBGN 510 Natural Resource Economics

EBGN 511 Microeconomics

EBGN 512 Macroeconomics

EBGN 590 Econometrics and Forecasting

EB611 Advanced Microeconomics

EB690 Advance Econometrics

EB695 Research Philosophy

Ph.D. students are also required to complete at least 12 semester hours in one of the previously defined fields of specialization, Economics & Public Policy (E&PP) or Quantitative Business Methods/Operations Research (QBM/OR). In addition, students are required to complete 12 hours of graduate course work in an approved minor. The minor may be within the Division or from a related field outside the Division but must be approved by a student's doctoral committee.

Qualifying and Comprehensive Examinations

Students must pass a qualifying examination to become a candidate for the Ph.D. degree. The qualifying exam is offered once a year and is administered by the Division qualifier committee. This exam is designed to test the student's competence in the following core courses:

EBGN 409 Mathematical Economics

EBGN 510 Natural Resource Economics

EBGN 511 Microeconomics

EBGN 512 Macroeconomics

EBGN 590 Econometrics and Forecasting

EB611 Advanced Microeconomics

In addition, the qualifer committee will provide a reading list of additional and/or advanced related topics that are also subject to examination during the qualifying exam.

The Ph.D. student is also required to complete a written and oral comprehensive examination. This exam is prepared and administered by the student's thesis committee and generally relates to the student's thesis topic and the student's minor field.

Fields of Research:

Faculty apply a wide variety of economic and business

analytical tools to the study of energy, minerals and related environmental issues. They include those of 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.

Description of Courses

EBGN409. MATHEMATICAL ECONOMICS This course covers the mathematical tools needed to read published economic literature and to do advanced work in economics. It includes topics from differential and integral calculus, matrix algebra and dynamic programming. Applications are taken from mineral, energy and environmental issues, requiring both analytical and computer solutions using such programs as GAMS, Mathematica and SAS. Prerequisites: MACS111, or permission of instructor.

Graduate Courses

500- and 600-level courses are open to qualified seniors with the permission of the department and Dean of Graduate Studies and Research.

EBGN504. ECONOMIC EVALUATION & INVEST-MENT 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 analyses using expected value concepts, and (4) mutually exclusive alternative analyses and service producing alternatives. Case study analysis of a mineral or petroleum investment situation required in a formal report.

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, and mineral policy issues; international mineral trade. This course is designed for entering graduate students in mineral economics.

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. Prerequisite: MACS111. Co-requisite EBGN409 or permission of instructor.

EBGN512. MACROECONOMICS The development of macroeconomic models to determine the equilibrium level of inflation, interest rates, unemployment and other basic macroeconomic variables. 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. Prerequisite: MACS111.

EBGN513. SEMINAR IN INDUSTRIAL PSYCHOLOGY Early experimentation with small group dynamics relative to economic incentive will be first presented. Hawthorne experiments, experiments of Asch on perception, analysis of case studies of work productivity in minerals, process, and manufacturing industries. Review of work of F. W. Taylor, McGregor, and others in terms of optimum working conditions relative to wage and fringe benefits. This course has, as its primary aim, the equipping of a future consultant to deal with socio-economic, behavioral, psychological, and political problems in the workplace. This course teaches the survival, report writing, and presentation skills and cultural awareness needed for success in the real international business world. Format is case studies, reported and presented.

EBGN525. INTRODUCTION TO OPERATIONS RESEARCH This course is an introduction to selected methods of management science and operations research applied to operations, management, and planning functions in the minerals, manufacturing, and other industries. Emphasis will be on economic modeling of production scheduling, inventory control, supply-chain, and distribution, production planning, project planning, and capital budgeting. There will be an introduction to various modeling approaches, such as linear programming, Markov chains, network flows, integer programming, and geometric (nonlinear) modeling, immediately applicable in the workplace.

EBGN526. MANUFACTURING MANAGEMENT Topics to be covered include forecasting, inventory management, material requirements planning, aggregate planning, capacity planning, and facility layout. Special emphasis will be placed on the role of uncertainty and methods for dealing with it. Prerequisites: EBGN525 or permission of instructor.

EBGN528. SIMULATION Advanced study of simulation techniques for modeling complex queuing systems, such as production lines, computer systems, harbors and airports. Topics include random number and variate generation, Monte Carlo techniques, using a computer simulation language, experimental design, and variance reduction. Prerequisite: 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 in the course are supply and demand, market structure, transportation models, game theory, futures markets, environmental issues, energy policy, energy regulation, input/output models, linear and nonlinear programming 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: EBGN409, EBGN511 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: EBGN510, EBGN511, EBGN590 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: EBGN409, EBGN510, EBGN511 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: EBGN409, EBGN511, EBGN512 or permission of instructor.

EBGN545. CORPORATE FINANCE Introduction to 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. Prerequisites: EBGN505 or permission of instructor.

EBGN546. INVESTMENT & PORTFOLIO MANAGE-MENT The environment and process of investment in theory and practice, providing a comprehensive understanding of the dynamics of securities markets, valuation techniques and trading strategies for stocks, bonds, and derivative securities. This includes the mean-variance efficient portfolio theory, the arbitrage pricing theory, bond portfolio management, investment management functions and policies, and portfolio performance evaluation. Prerequisite: EBGN545 or permission of instructor.

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 interest rate risks and foreign exchange risks will be explored and ways of handling them will be reviewed and critiqued. Prerequisites: EBGN546 or permission of instructor.

EBGN554. ECONOMIC MODELING WITH INTEGER PROGRAMMING Survey of economic modeling formulation using methods of integer and mixed-integer programming. Survey of application-oriented integer programming methods. Course emphasis will be on the formulation and solution of capital budgeting, capital allocation, distribution and personnel problems, and production planning problems. Application examples provided for mineral resource, manufacturing, production, processing, and marketing. Course will concentrate on formulation methods using case studies and examples from the mineral and other industries. Prerequisite: permission of instructor.

EBGN555. LINEAR PROGRAMMING Geometric interpretation of linear programming problems, the simplex method, the revised simplex method, and the product form of the inverse, duality theory, duel simplex, and applications, sensitivity analysis, complementary slackness and applications. The emphasis is on formulation of business and economic problems as linear programs, including production planning, staffing, scheduling, blending and product mix applications, and modeling and solving the problems on the computer. Efficiency and implementation issues are discussed, and advanced topics include decomposition methods for large-scale problems. The aim of the course is to equip students to formulate and solve real world problems as linear programs. Prerequisites: MACS111, EBGN409 or permission of instructor.

EBGN556. NETWORK MODELS Network optimization deals with the modeling of optimization problems that contain a very particular type of structure. Topics include minimal spanning trees, shortest path algorithms, maximum flow, minimum cut methods, out-of-kilter and node-chain algorithms. Prerequisites: EBGN 555 or permission of instructor.

EBGN558. ECONOMIC & ENGINEERING APPLICA-TIONS OF GEOMETRIC PROGRAMMING Kuhn-Tucker-Karush conditions for optimality. Formulation of mathematical models and solution methods using methods of nonlinear and geometric programming presented. Examples presented defining the relationship of geometric programming to general nonlinear economic models and engineering design. Course is strictly applications-oriented, with main emphasis on engineering design and engineering economic models.

EBGN560. DECISION ANALYSIS IN THE ENERGY AND MINERAL INDUSTRIES 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. Prerequisites: EBGN504 or 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. Prerequisites: EBGN510, EBGN511 or permission of instructor.

EBGN575. ADVANCED MINERAL ASSET VALUA-TION 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: EBGN409, EBGN421 or EBGN504, EBGN510, EBGN511 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: EBGN510 or permission of instructor. Offered when student demand is sufficient.

EBGN590. ECONOMETRICS AND FORECASTING Ordinary least squares and single equation regression models; two stage least squares and multiple equation econometric models; specification error, serial correlation, heteroskedasticity, and other problems; distributive lag and other extensions; applications to mineral commodity markets; hypothesis testing; forecasting with econometric models, time series analysis, simulation, and other techniques. Prerequisite: MACS530 or permission of instructor.

EBGN598. SPECIAL TOPICS IN ECONOMICS AND BUSINESS Pilot course or special topics course. Topics chosen from special intersts of instructor(s) and student(s). Usually the course is offered only once.

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.

EBGN610. ADVANCED NATURAL RESOURCE ECONOMICS Topics covered include optimal resource use in a dynamic context. The tools used are 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. Prerequisites: EBGN409, EBGN510, EBGN511 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. Prerequisite: EBGN409, EBGN511 or permission of instructor.

EBGN690. ADVANCED ECONOMETRICS A second course in econometrics. Compared to EBGN590, this course provides a more theoretical and mathematical treatment of econometrics; matrix algebra is used; model construction and hypothesis testing are emphasized rather than forecasting. Prerequisites: EBGN409, EBGN590 or permission of instructor.

EBGN695. RESEARCH PHILOSOPHY An in-depth research project supervised by a faculty member from the student's field of specialization. Lectures provide an overview of methods used in economic research, and information on how to carry out research and present research results. Students give a seminar on their research. This course must be taken by all Ph.D. students during spring semester of their second year. Prerequisite: permission of instructor.

EBGN698. SPECIAL TOPICS IN ECONOMICS AND BUSINESS Pilot course or special topics course. Topics chosen from special intersts of instructor(s) and student(s). Usually the course is offered only once.

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.

EBGN701. GRADUATE THESIS: MASTER OF SCIENCE Preparation of the master's thesis under the supervision of the graduate student's advisory committee.

EBGN703. GRADUATE THESIS: DOCTOR OF PHILOSOPHY Preparation of the doctoral thesis under the supervision of the graduate student's advisory committee.

EBGN705 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.

EBGN706 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.

Engineering

JOAN P. GOSINK, Professor and Division Director
JIN S. CHUNG, Professor
D. VAUGHAN GRIFFITHS, Professor
ROBERT J. KEE, George R. Brown Distinguished Professor
of Engineering
ROBERT H. KING, Professor and Assistant Division Director
MARK A. LINNE, Professor
RAHMAT A. SHOURESHI, Gerard August Dobelman Distinguished Professor of Engineering
JOHN R. BERGER, Associate Professor
PANOS D. KIOUSIS, Associate Professor
MARK T. LUSK, Associate Professor
NIGEL T. MIDDLETON, Associate Professor and Associate Vice-President for Academic Affairs
DAVID R. MUÑOZ, Associate Professor
GRAHAM G. W. MUSTOE, Associate Professor
KARL R. NELSON, Associate Professor
TERENCE E. PARKER, Associate Professor
MARCELO GODOY SIMOES, Associate Professor
CATHERINE K. SKOKAN, Associate Professor
CHRISTIAN DEBRUNNER, Assistant Professor
JEAN-PIERRE DELPLANQUE, Assistant Professor
WILLIAM A. HOFF, Assistant Professor
LAXMINARAYAN L. RAJA, Assistant Professor
NING LU, Assistant Professor
JOHN A. PALMER, Assistant Professor
DOUGLAS E. SMITH, Assistant Professor
JOHN P. H. STEELE, Assistant Professor
TYRONE VINCENT, Assistant Professor
RAY RUICHONG ZHANG, Assistant Professor
SANAA ABDEL-AZIM, Lecturer
CANDACE S. AMMERMAN, Lecturer
RON KNOSHAUG, Lecturer
HAROLD W. OLSEN, Research Professor
MASAMI NAKAGAWA, Research Professor
MICHAEL B. McGRATH, Emeritus Professor
GABRIEL M. NEUNZERT, Emeritus Associate Professor

Degrees Offered:

Master of Engineering (Engineering Systems)

Master of Science (Engineering Systems)

Doctor of Philosophy (Engineering Systems)

Program Description:

The Engineering Systems Program offers a graduate multidisciplinary education that is at the intersections of the traditional engineering disciplines. The Engineering Division's faculty represents Civil, Electrical, and Mechanical Engineering, as well as Engineering Science, with much of the research occurring at these intersections. It is also common to pursue education and research that is at intersections between Engineering and other disciplines. The program demands academic rigor and depth, yet also addresses the real-world problems of advanced engineering and technology. The choice of research topics and course offerings prepares graduates for a range of industrial or academic careers.

Program Requirements:

M.E. (Engineering Systems) 36 credit hours

M.S. (Engineering Systems) 36 credit hours

Ph.D. (Engineering Systems)720 credit hours

Students must have a faculty supervisor in the Engineering Division to direct and monitor their research, and a degree committee to oversee their progress. A Masters student's committee must have at least three members, two of whom must be faculty in the Engineering Division. A Doctoral student's committee must have at least five members; at least three members must be faculty in the Engineering Division, and at least one member must be from the department in which the student is pursuing a minor program. Minor programs of at least 12 semester hours, which further the interdisciplinary concept of engineering systems, are required for doctoral students.

Doctoral students must pass a Preliminary Examination, which is intended to gauge the student's capability to pursue research in Engineering Systems. The Preliminary Examination is based principally on the material in the Engineering core courses Advanced Engineering Measurements and Interdisciplinary Modeling and Simulation, as well as relevant undergraduate material. The Preliminary Examination is given once per year at the beginning of the Spring semester. Normally, Ph.D. students will take the preliminary Examination in their first year, but it must be taken within three semesters of entering the program.

Within 18 months after passing the Preliminary Examination, the Ph.D. student must prepare a written thesis proposal and present it formally to the thesis committee and other interested faculty. The Ph.D. Comprehensive Examination coincides with the thesis proposal presentation. The student will be questioned about the proposal, as well as other topics within the field of major and minor studies. After passing the Comprehensive Examination, the student will be admitted to candidacy for the Ph.D..

At the conclusion of the MS and Ph.D. programs, the student will be required to make a formal presentation and defense of his/her thesis research.

Applicants for the Master of Science degree must complete 24 semester hours of approved course work and at least 12 hours of thesis research. The credit-hour requirement is the same for the Master of Engineering degree, but the thesis is exchanged for a design of development report on a comprehensive engineering project.

Prerequisites:

The requirements for admission for the M.E., M.S., and Ph.D. degrees in Engineering Systems are a baccalaureate degree in engineering, a physical science, or math from an ABET-accredited program or equivalent four-year engineering program, with a grade-point average over 3.0/4.0; Graduate Record Examination scores of 600 (analytical) and 700 (quantitative); and a TOEFL score of 550 or higher 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.

Required Curriculum:

For both Masters and Ph.D. degrees
- ◆ EGES 501 Advanced Engineering Measurements
- ◆ EGES 502 Interdisciplinary Modeling and Simulation
- ◆ EGES 503 Modern Engineering Design and Management
- ◆ EGES 504/604 Engineering Systems Graduate Colloquium

Doctoral students must take a minor program of at least 12 semester hours.

Fields of Research:

Advanced Sensing and Automation

Projects in this area develop and apply advanced sensing and automation research to a variety of engineering systems. Current multidisciplinary projects span traditional electrical, mechanical, and civil engineering, as well as computer science and other disciplines. A common thread is the use of signal processing and intelligent control techniques. Current projects encompass development of machine vision techniques for applications in robotics, radar, and medical imaging; diagnostics and health monitoring for structures and systems, fuzzy logic and neural network techniques in decision processing, intelligent biomedical devices; augmented reality; and intelligent electric-power-system control.

Geomechanics and Environmental Geotechnics

The geomechanics and environmental geotechnics area of study actively explores research subjects in the following fundamental and practical fronts: computational numerical and analytical methods in geomechanics, stochastic finite element modeling of heterogeneous soils, experimental and theoretical investigation on coupled phenomenon in expansive geomaterials, coupled fluid and chemical transport in partially saturated soils, and discrete element modeling of particulate systems.

Mechanics and Materials

Research projects in mechanics and materials focus on the static and dynamic behavior of solids and emphasize the coupling among the thermal, mechanical, kinematic and kinetic character of materials. Investigations draw form the basic physical sciences, applied mathematics, computational mechanics, and materials engineering. Current projects consider the flow and compaction of granular materials, fracture phenomena, phase transitions and recrystallization, bridging of length scales, the properties of material interfaces, and the effect of mechanical loading on the transport properties of multi-phase materials. Researchers in this group typically

investigate basic physical issues through the development and use of sophisticated numerical simulations and experimental studies.

Power System

Curriculum and research projects in the power-engineering program are directly linked to the activities of the CSM National Science Foundation research center for Advanced Control of Energy and Power Systems (ACEPS). Arizona State University, Purdue University, and Wichita State University are member institutions in ACEPS. Research projects of this center directly impacting the utility industry include intelligent substation diagnostics and predictive maintenance; advanced automatic generation control; new sensors for real-time NOx control; optical fiber-based in-situ sensor for health assessment of high voltage transformer; electro-magneto-acoustic transducers for monitoring of transmission and distribution equipment. Several laboratories as well as direct access to the ACEPS member utilities' facilities provide a unique hands-on experience for the graduate students in our power system program.

Structural Dynamics

Emphasis is placed upon analytical description of overall structural behavior under external loads (e.g., earthquake and wind). Study is made of the nature of these loads, static or dynamic, and random and deterministic, with implications being drawn for design. Students in this area can also have opportunities to participate in the USGS and international collaboration. Current work supported by various federal and local agencies and private sectors includes innovative design of a new generation of high-rise buildings; active, passive and hybrid vibration control of such engineering systems as offshore structures and civil infrastructures subjected to earthquake motion, turbulent wind and currents; reliability analysis of large-scale engineering systems; simulation of stochastic processes and fields relevant to civil/mechanical engineering issues; wave phenomena modeling (e.g., earthquake and wind loads) and its engineering applications.

Thermal Systems

A number of projects span from traditional mechanical-engineering areas of fluid mechanics, heat transfer, and physical gas dynamics, to chemical engineering, electrical engineering, mathematics, and material science. For example, research includes understanding combustion-generated pollutant formation and abatement, combustion synthesis of materials, and advanced material processing using chemically reacting flow. An important research emphasis is in optical diagnostics to measure composition and flow fields, including real-time process sensors. Another important research area is modeling and simulation, especially for complex chemically reacting flows. An application here is the design and control of processes for the manufacture of electronic thin films by chemical vapor deposition.

Description of Courses

EGGN400/MNGN400. INTRODUCTION TO ROBOTICS FOR THE MINERALS AND CONSTRUCTION INDUSTRIES (II) Focuses on construction and minerals industries applications. 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: PHGN200/210. 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 multicomponent systems, simultaneous chemical reaction of real combustion processes, ionization, application to real industrial problems. Prerequisite: EGGN351, EGGN371. 3 hours lecture; 3 semester hours.

EGGN407. INTRODUCTION TO FEEDBACK CONTROL SYSTEMS (I, II) System modeling through an energy flow approach is presented, and modeling of electromechanical and thermofluid systems are discussed. Feedback control design techniques using pole-placement, root locus, and lead-log compensators are presented. Case studies using real-life problems are presented and analyzed. Prerequisite: MACS315 and DCGN381 3 hours lecture; 3 semester hours.

EGGN408. INTRODUCTION TO OFFSHORE TECHNOLOGY (II) Introduction to practical offshore engineering/ design technology for the exploration, drilling, production and transportation of petroleum in the ocean. Practical analysis methods of environmental forces, hydrodynamics, structural responses, and pipe flows for the design of platform, riser, subsea completion and pipeline systems, including environment-hydrodynamic-structure interactions. System design parameters. Industry practice and the current state-of-the-art technology for deep ocean drilling. Prerequisites: MACS315, EGGN320, EGGN351 and consent of instructor. 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. Analytical and computer graphical techniques are used to solve dynamic and kinematic analysis and synthesis problems. Emphasis is given to design projects that are aimed at developing skills for design process, including problem specification, modeling, analysis and visual display using computer-aided design equipment and software. Prerequisite: EGGN320. 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 to 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. 3 hours lecture; 3 semester hours.

EGGN430. GLOBAL POSITIONING (II) A follow-up course to basic surveying which answers the fundamental question "where are you?". Determination of latitude and longitude by astronomical and by GPS (Global Positioning System) from satellites. Reduction of this data through conformal and non-conformal projections to NAD'27 and NAD'83 State Plane Coordinates, UTM and computer based mapping bases, GIS (Geographic Information Systems). The major user of this concept is anybody who uses a map or who has to add information to a mapping base. Data gathering will be optional. Prerequisite: EGGN233. 3 hours lecture; 3 semester hours.

EGGN442. FINITE ELEMENT METHODS FOR ENGINEERS (II) A course combining finite element theory with practical programming experience in which the multi-disciplinary 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) Steel properties; design of tension and compression members;

beams; bolted and welded connections and plate girders; both elastic and plastic methods will be applied to the design of a commercial building. Prerequisite: EGGN342. 2 hours lecture; 3 hours design lab; 3 semester hours.

EGGN445. DESIGN OF REINFORCED CONCRETE STRUCTURES (II) Loads on structures, design of columns, continuous beams, slabs, retaining walls, composite beams, introduction to prestressed and precast construction. Prerequisite: EGGN342. 2 hours lecture; 3 hours design lab; 3 semester hours.

EGGN450. MULTIDISCIPLINARY ENGINEERING LABORATORY III 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, EGGN383, 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.

EGGN461. SOIL MECHANICS (I, II) Fundamental relations, methods of soil classification, seepage and water flow in soils, consolidation and settlement, shear strength and deformation characteristics, slope stability analysis, lateral earth pressures and bearing capacity. Special emphasis will be placed on earth structures, porous flow, slope stability, retaining walls and foundation reactions. Prerequisite: EGGN320 or concurrent enrollment. 3 hours lecture; 3 semester hours.

EGGN463. SOIL MECHANICS LABORATORY (I, II) Methods of sampling and testing soils for engineering purposes. Prerequisite: EGGN461 or concurrent enrollment. 3 hours lab; 1 semester hour.

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.

EGGN466. CONSTRUCTION SITE ENGINEERING (I) Construction site investigations. Project planning, management, and scheduling. Construction equipment, materials, and methods. Engineering parameters affected by the geologic environment. Construction organization, bidding,

contracts. Prerequisite: Senior standing in EG or GE or consent of instructor. 3 hours lecture; 3 field trips required; 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: MACS315, 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 MACS315. 3 hours lecture; 3 semester hours.

EGGN481. ADVANCED ELECTRONICS AND DIGITAL SYSTEMS (I, II) Device models; transistors as amplifiers, switches, and gates; integrating differentiating wave shaping and signal processing circuits. Small scale (SSI), medium scale (MSI), large scale (LSI) integration; logic components, subsystems; analog-to-digital and digital-to-analog conversion techniques. Laboratory experience, evaluation, application and extension of lecture concepts. Prerequisite: DCGN381 and EGGN250 or PHGN317 or consent of instructor. 3 hours lecture; 3 hours lab; 4 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: EGGN481 or consent of instructor. 3 hours lecture; 3 hours lab; 4 semester hours.

EGGN483. INTRODUCTION TO COMMUNICATION AND SIGNAL PROCESSING (I) Signal classification;

Fourier transform; filtering; sampling; signal representation; modulation; demodulation; applications to broadcast, data transmission, and instrumentation. Prerequisite: EGGN382 or consent of department. 3 hours lecture; 3 hours lab; 4 semester hours.

EGGN484. POWER SYSTEMS ANALYSIS (I) Power systems, three-phase circuits, per unit calculations, system components, stability cirteria, network faults, system instrumentation, system grounding, load-flow, economic operation. Prerequisite: EGGN384 or 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 princippes 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: EGGN407 or concurrent enrollment. 3 hours lecture; 3 semester hours.

EGGN487. ENGINEERING CONTROL LABORATORY I (II) Experiments to verify principles of feedback control systems. Prerequisite: EGGN486 or concurrent enrollment. 3 hours lab; 1 semester hour.

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: MACS323. 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: EGGN342 or EGGN382 and concurrent enrollment in EGGN407 and EGGN481, orconcurrent enrollment in EGGN411, and 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.

EGGN499. 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.

Graduate Courses

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

EGES501. ADVANCED ENGINEERING MEASURE-MENTS (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: EGGN 250, DCGN381 or equivalent, and MACS 323 or equivalent; graduate student status or consent of the instructor. 3 hours lecture, 1 hour lab; 4 semester hours.

EGES502. 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.

EGES503. 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: EGGN 491 and EGGN 492, or equivalent

senior design project experience, or equivalent industrial design experience, or consent of the Engineering Division. 3 hours lecture; 3 semester hours.

EGES504. ENGINEERING SYSTEMS SEMINAR (II) This is a seminar and discussion forum for graduate students to present their research projects, critique others' presentations, understand the breadth of engineering projects across the Division, hear from leaders of industry about the contemporary engineering as well as socio-economical, marketing and behavioral issues facing today's competitive business environment. In order to improve communication skills, each student is required to present a seminar in this course before his/her graduation from Engineering Systems graduate program. Also students are required to write weekly critiques about materials delivery techniques used in the previous week's seminar by the presenter. Prerequisite: Graduate standing. 1 hour seminar, 1 semester hour.

EGES510. 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: EGGN 388 or equivalent. 3 hours lecture; 3 semester hours.

EGES511. 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: EGGN 483 and EGGN 407, EGGN 388, approved undergraduate coursework in Linear Systems, or consent of instructor. 3 hours lecture; 3 semester hours.

EGES512. 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.

EGES514/MNGN. 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: EGGN 407, or consent of instructor. 3 hours lecture; 3 hours lab; 4 semester hours. Fall semesters, every two years.

EGES517. THEORY AND DESIGN OF ADVANCED CONTROL SYSTEMS (II) A unified energy-based approach to modeling of dynamic systems is presented to handle transient analysis of complex and integrated processes and systems. Linear, nonlinear, and time varying systems are analyzed using matrix notation and linear algebra. Concepts of controllability and observability are presented. Design techniques for optimal open loop and closed loop systems using Hamiltonian and Pontryagin principles are described. Analysis and design of optimal feedback control systems and design of observers are presented. Prerequisite: EGGN 407 or consent of instructor 3 hours lecture; 3 semester hours. Spring semester of odd years.

EGES518. 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: EGGN 407, EGGN 400, or consent of instructor. 3 hours lecture; 3 semester hours. Fall semesters, ever year, or every other year, depending on interest.

EGES521. 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: EGGN 381, EGGN 383. EGGN 481 and EGGN 482 recommended. 3 hours lecture; 3 semester hours. Spring semesters, every other year.

EGES523. DESIGN OF DIGITAL CONTROL SYSTEMS (II) Discrete system representation in time and z-domain is described. Difference equations describing dynamic systems are presented. Discrete equivalents of continuous systems are introduced. Stability analysis for digital systems is described. Control design focuses on state space representation. Pole-placement design and digital optimal control design are covered, including Kalman filtering. Limitations on control performance are discussed along with robust control design concepts. Prerequisite: EGGN 407 or consent of instructor. 3 hours lecture; 3 semester hours Spring, even numbered years

EGES532/MTGN 545. 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. EGES534. 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

EGES535. 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.

EGES538/PEGN538. INTRODUCTION TO OFFSHORE TECHNOLOGY (II) Introduction to offshore engineering technology for exploration, drilling, production and transportation of resources in the ocean. Practical and computer-based analysis methods for determining ocean waves and spectrum, environmental forces on and motions of structures, structural responses, and internal flows for the design of platforms, risers, subsea completion and pipeline systems. Dynamic positioning control and acoustics. Oil spill flow and control. System design parameters. Industrial practice and introduction of the state-of-the art technology. Prerequisite: MACS315, EGGN351 and EGGN320 or consent of instructor 3 hours lecture; 3 semester hours.

EGES539/MNGN539. MARINE MINING SYSTEMS (I) Introduction to ocean resources and exploitation. General review of deep-ocean engineering systems. Deep-seafloor geotechnology. Exploration, processing and environmental impact. Overview of technology and systems requirements of mining systems. Physical environments. Surface systems. Acoustics and track-keeping control. Seafloor systems and vehicle track-keeping control. Multiphase flows and pipe systems/dynamics. Ocean transshipment. Integrated production system and control. Review of environment impact and legal issues. Prerequisite: MACS315, EGGN351 and EGGN320, GEOC408 or consent of instructor 3 hours lecture; 3 semester hours. Fall semester, every third year.

EGES540. 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 MAGN315 or consent of instructor. 3 hours lecture; 3 semester hours. Fall semesters, odd numbered years

EGES542. 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 emphasised. 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

EGES543. 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. PrerequisiteEGGN320 or equivalent, MACS315 or equivalent. 3 hours lecture; 3 semester hours.

EGES544. 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 EGES543 or consent of instructor. 3 hours lecture; 3 semester hours. Spring semester, even numbered years.

EGES545. 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: EGES502, EGES540 or consent of instructor 3 hours lecture; 3 semester hours Spring Semester, odd numbered years.

EGES546. ADVANCED ENGINEERING DYNAMICS (I) Review of vibration theory as applied to single- and multi-degree-of-freedom systems. Free and forced vibrations. Different types of loading-step, sinusoidal, random, earthquake, periodic. Transmissibility. Importance of resonance. Role of damping. Natural frequencies. Modal superposition method. Rayleigh damping. Numerical solution techniques. Introduction to dynamic analysis by finite element method. Newmark methods for time integration. Hysteretic materials and stiffness degradation. Equivalent viscous damping. Liquefaction in geomaterials. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours

EGES548. 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

EGES550. 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: MACS315 or consent of instructor. 3 hours lecture; 3 semester hours.

EGES551. 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. Multiphase 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; EGGN 351 and MACS 315 or consent of instructor 3 hours lecture; 3 semester hours

EGES552. VISCOUS FLOW AND BOUNDARY LAYERS (I) This course establishes the theoretical underpinnings of fluid mechanics, including fluid kinematics, stress-strain relationships, and derivation of the fluid-mechanical conservation equations. These include the mass-continuity and Navier-Stokes equations as well as the multicomponent 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.

EGES553. 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: EGGN 351, or consent of instructor. 3 hours lecture; 3 semester hours. Fall semesters, even years.

EGES554. 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: EGGN 351, or consent of instructor. 3 hours lecture; 3 semester hours. Spring semesters, odd years.

EGES559. 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

EGES564. 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.

EGES566. 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.

EGES567. 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: EGGN 471, or equivalent or consent of instructor. 3 hours lecture; 3 semester hours.

EGES572. 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: EGGN 552 or consent of instructor. 3 hours lecture; 3 semester hours. Spring semesters, every other year.

EGES573. 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: EGGN 473 or

consent of instructor. 3 hours lecture; 3 semester hours.

EGES585. 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: EGGN 385; EGGN 389 or equivalent 3 hours lecture; 3 semester hours.

EGES588. ADVANCED RELIABILITY OF ENGINEER-ING 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: MACS 324 (Probability and Statistics for Engineers II) 3 hours lecture; 3 semester hours

EGES598. 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

EGES599. 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

EGES604. ENGINEERING SYSTEMS SEMINAR (II) This is a seminar and discussion forum for graduate students to present their research projects, critique others' presentations, understand the breadth of engineering projects across the Division, hear from leaders of industry about the contemporary engineering as well as socio-economical, marketing and behavioral issues facing today's competitive business environment. In order to improve communication skills, each student is required to present a seminar in this course before his/her graduation from Engineering Systems graduate program. Also students are required to write weekly critiques about materials delivery techniques used in the previous week's seminar by the presenter. Prerequisite: Graduate standing. 1 hour seminar; 1 semester hour.

EGES617. 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: EGES517, or consent of instructor. 3 hours lecture; 3 semester hours. Spring semester of even years.

EGES618. SYSTEM IDENTIFICATION AND ADAP-TIVE 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: EGGN 517 or EGGN 523 or consent of instructor. 3 hours lecture; 3 semester hours. Spring, odd numbered years.

EGES619. 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: EGGN 411, EGGN 478, or consent of instructor. EGES617 recommended. 3 hours lecture; 3 semester hours. Spring semesters, every other year.

EGES638. OFFSHORE TECHNOLOGY II (I) Surface waves, dynamics of the ocean, and ice mechanics are independently treated. Fluid-structure interactions and ice-structure interactions are treated in an integrated approach with the associated forces and the dynamic responses of structures, including flow-induced vibrations. Interdisciplinary problems of fluid-structure-ice interactions are solved

in an integrated approach with computer-aided designs of industry problems. Prerequisites: EGES538, EGES551 or consent of the instructor. 3 hours lecture: 3 semester hours. Fall semester, every other year.

EGES642. 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. Pre-requisites: EGGN320, EGGN315, EGES542 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.

EGES649. 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 : EGES551, MACS514 or consent of the instructor. 3 hours lecture; 3 semester hours Spring semester, every third year.

EGES657/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.

EGES658. 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 matrix equations, or the spectroscopy of polyatomic species. Prerequisite: EGES564, or consent of instructor. 3 hours lecture; 3 semester hours. Spring semesters, every other year (opposite EGES659 Optical Measurements in Reacting and Nonreacting Flow Systems)

EGES659. 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: EGES501, EGES564, PH optics course (no number at present), or consent of instructor. 3 hours lecture; 1hour lab; 4 semester hours. Spring semesters, every other year (opposite Molecular Spectroscopy).

EGES698. 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.

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.

EGES700. GRADUATE ENGINEERING REPORT - MASTER OF ENGINEERING (I,II,S) Laboratory, field, and library work for the Master of Engineering Report under the supervision of the student's advisory committee. Required of candidates for the degree of Master of Engineering. 6 semester hours upon completion of report.

EGES701. GRADUATE THESIS - MASTER OF SCIENCE (I,II,S) Laboratory, field, and library work for the Master of Science thesis under the supervision of the student's advisory committee. Required of candidates for the degree of Master of Science. 6 semester hours upon completion of report.

EGES703. GRADUATE THESIS - DOCTOR OF PHILOSOPHY (I,II,S) Laboratory, field, and library work for the Doctor of Philosophy thesis under the supervision of the student's advisory committee. Required of candidates for the degree of Doctor of Philosophy.

EGES704 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.

EGES705 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.

EGES706 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.

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.

Environmental Science and Engineering

PHILIPPE ROSS, Professor and Division Director
BRUCE D. HONEYMAN, Professor
TISSA ILLANGASEKARE, Professor and
AMAX Distinguished Chair
RONALD R.H. COHEN, Associate Professor
JOHN C. EMERICK, Associate Professor
LINDA A. FIGUEROA, Associate Professor
KENNETH E. KOLM, Associate Professor
ROBERT SEIGRIST, Associate Professor
DIANNE AHMANN, Assistant Professor
NEVIS E. COOK, JR., Assistant Professor
JUNKO MUNAKATA MARR, Assistant Professor
ROBERT F. HOLUB, Research Professor
MATTHIAS KOHLER, Research Associate Professor

Degrees Offered:

Master of Science (Environmental Science and Engineering)

Doctor of Philosophy (Environmental Science and Engineering)

Program Description:

The Division of Environmental Science and Engineering offers programs leading to M.S. and Ph.D. degrees.

Two M.S. degree options are available: thesis and non-thesis.

The division also offers a M.S. degree program for individuals who can only attend part-time. This non-thesis, fixed-course-sequence **Executive Program** is offered during evening hours and takes about 26 months to complete. All admission, performance and credit hour rules are the same as those for the day time program.

The Ph.D. degree in environmental science and engineering is a research degree which builds upon the M.S. degree program. Students, with advice of faculty, will establish a curriculum which supports the need to complete a comprehensive examination and original research dissertation. Since the program is interdisciplinary in scope, appropriate coursework is available from many CSM departments.

Program Requirements:

The Division offers programs leading to M.S. and Ph.D. degrees. The curriculum is built around a common concentration of core classes.

Two M.S. degree options are available: thesis and non-thesis. Students following the thesis option must sit for at least 32 credit hours beyond deficiencies and defend a research thesis. Non-thesis option students must complete at least 36 semester hours of credit beyond deficiencies. All M.S. students must register for ESE seminar (ESGN598S) for at least two semesters.

The Ph.D. degree in environmental science and engineering is a research degree which builds upon the M.S. degree program. Students, with advice of faculty, will establish a curriculum which supports the need to complete a comprehensive examination and original research dissertation. A defined minor program must also be completed.

Prerequisites:

Candidates for a graduate degree in Environmental Science and Engineering should have earned a baccalaureate degree in a natural science, physical science or engineering discipline. Previous coursework must include at least one year of physics, calculus through differential equations, and one year of general chemistry. All students admitted to the program should have knowledge of the basic concepts and fundamentals of general biology, physical geology and physical chemistry. Applicants must have completed all prerequisites prior to admission to the program.

Required Curriculum:

The required core curriculum is generally structured around the following courses. Individualized course plans are designed around a student's interests and background in conjunction with an assigned advising committee. For further information please refer to the Division web page.

ESGN500-Principles of Environmental Chemistry
ESGN500L-Environmental Water Chemistry Lab
ESGN501-Principles of Environmental Science & Engineering
ESGN502-Environmental Law
ESGN503-Environmental Pollution: Characteristics, Sources and Transport
ESGN504-Treatment of Waters and Waste
ESGN504L-Treatment of Waters and Waste Lab
ESGN505-Experimental Design and Environmental Data Analysis.

Elective coursework beyond the required core may be selected from a combination of courses in the areas of characterization, fate and transport; environmental remediation; and environmental law, regulatory analysis and decision making.

Fields of Research:

Research is focused in four main areas: 1) characterization, fate, and transport of contaminants; 2) the development of unit processes for water and waste treatment; 3) environmental remediation; and 4) applied ecology, hydrology, and natural systems characterization. Within these areas, established research programs have developed in the physical/chemical processes controlling non-aqueous phase liquid (NAPL) transport, the biological treatment of metal-and radionuclide-containing wastes, environmental chemistry, in situ remediation of soil and groundwater systems, evaluating the role of wetlands in regulating the water quality of watersheds, analyzing hydrologic systems, and modeling environmental systems (water resources and water quality).

Description of Courses

ESGN401. FUNDAMENTALS OF ECOLOGY Biological and ecological principles discussed and industrial examples of their use given. Analysis of ecosystem processes, such as erosion, succession, and how these processes relate to engineering activities, including engineering design and plant operation. Criteria and performance standards analyzed for facility siting, pollution control, and mitigation of impacts. North American ecosystems are analyzed. Concepts of forestry, range, and wildlife management 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 instructor. 3 hours lecture; 3 semester hours.

ESGN412. ENVIRONMENTAL TOXICOLOGY Introduction to general concepts of ecology, biochemistry,

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, others. Prerequisites: ESGN301, or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN/ESGN 453. WASTEWATER ENGINEERING (II) Analysis and design of primary, secondary and advanced wastewater treatment systems. Includes analysis of nutrient and toxic removal and residual issues. Also includes the design of collection system and pump stations. Regulatory analysis under the Clean Water Act (CWA). Prerequisite:EGGN353 or ChEN 201 & ChEN 307. 3 hours lecture; 3 semester hours

EGGN/ESGN 454. WATER SUPPLY ENGINEERING (I) Water supply availability and quality. Theory and design of conventional potable water treatment unit processes. Design of distribution systems. Also includes regulatory analysis under the Safe Drinking Water Act (SDWA). Prerequisite: EGGN353 or ChEN 201 & ChEN 307. 3 hours lecture; 3 semester hours.

EGGN/ESGN 455. SOLID AND HAZARDOUS WASTE ENGINEERING (I) 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:EGGN354 or ChEN 201 & ChEN 307. 3 hours lecture; 3 semester hours.

EGGN/ESGN 456. SCIENTIFIC BASIS OF ENVIRONMENTAL REGULATIONS 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. Student directed design of improved regulations. Prerequisite:EGGN353.
3 hours lecture; 3 semester hours.

EGGN/ESGN 457. SITE REMEDIATION ENGINEERING (II) 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 while the emphasis will be on remedial action screening processes and 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 ChEN 201 & ChEN 307. 3 hours lecture; 3 semester hours.

Graduate Courses

ESGN500. PRINCIPLES OF ENVIRONMENTAL CHEMISTRY (I) 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: Physical chemistry and consent of instructor. 2 hours lecture; 3 semester hours.

ESGN500L ENVIRONMENTAL WATER CHEMISTRY LAB (I) 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. Prerequisites: chemical thermodynamics and consent of the instructor; co-enrollment in ESGN500. 3 hours lab; 1 semester hour.

ESGN501. PRINCIPLES OF ENVIRONMENTAL SCIENCE AND ENGINEERING (I) To introduce students to some of the important environmental issues facing today's society. Provides essential background to the field of environmental science and engineering. Various environmental problems and technologies will be examined, including water pollution, water and wastewater treatment, solid waste treatment and disposal, agriculture pollution control air pollution and emissions control, and fundamental principles of ecology. Student will also be introduced to the concept of mass balance and the equation of continuity in preparation to studies of environmental models. 3 hours lecture; 3 semester hours.

ESGN 502: ENVIRONMENTAL LAW (I) 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. 3 hours lecture; 3 semester hours.

ESGN503. ENVIRONMENTAL POLLUTION: SOURCES, CHARACTERISTICS, TRANSPORT AND FATE (II) The environmental behavior of inorganic 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 the mining, petroleum, and chemical refining 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. Prerequisites: Consent of instructor. 3 hours lecture; 3 semester hours.

ESGN504. TREATMENT OF WATER AND WASTES (II) Unit operations and processes in environmental engineering. Physical, chemical, and biological treatment processes for liquid, gas, and solid wastes of municipal or industrial origin. Treatment objectives and process theory followed by design for selected processes. Prerequisites: Consent of instructor. 3 hours lecture; 3 semester hours.

ESGN504L. TREATMENT OF WATERS AND WASTE LAB (II) This course provides students with laboratory exercises that complement lectures given in ESGN504. Topics include reactor behavior, sedimentation, coagulation, sorption, and biological waste treatment. This course must be taken concurrently with ESGN504. Prerequisites: Consent of the instructor; co-enrollment in ESGN504. 3 hours lab; 1 semester hour.

ESGN505. EXPERIMENTAL DESIGN AND ENVIRONMENTAL DATA ANALYSIS (I) 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. Prerequisite: Consent of instructor. 3 hours lecture; 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 instructor. 3 hours lecture; 3 semester hours.

ESGN513. LIMNOLOGY The course will cover the natural chemistry, physics and biology of lakes and rivers as well as some basic principles concerning contamination of those water bodies. Topics will include heat budgets; water circulation and dispersal; sedimentation processes; organic compounds and their transformations; radionuclide

limnochronology; redox, metals and other major ions; carbon dioxide system; oxygen; nutrients; planktonnic, benthic and other communities; light in water and lake modeling. Prerequisites: ESE Masters degree core program or consent of instructor. 3 hours lecture; 3 semester hours.

ESGN514. STREAM, RIVER, AND ESTUARINE Course provides an overview of stream, river, and estuarine processes, as well as those of associated wetland and riparian systems. The ecology of these systems will be discussed along with interactions with the physical and chemical environment. Topics include key biological processes important to the normal functioning of stream, riparian, and wetland environments; influence of stream channel morphology, water quality, and water management on the health of stream systems; use of various species of stream insects and other organisms as indicators of stream water quality; mitigation or rehabilitation of various impacts on degraded streams, estuaries, and associated environments; and management strategies for streams and estuaries. Three optional weekend field trips will introduce students to sampling methods and site characteristics of local streams, rivers, and riparian areas. Prerequisites: ESGN500 and ESGN501 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN520. SURFACE WATER QUALITY MODELING This course will cover modeling of rivers, lakes, reservoirs and estuaries. Topics include introduction to numerical methods; modeling of kinetics, discharge of wastewaters into a marine environment, sedimentation, growth kinetics, dispersion, biological changes in lakes, heat flux in streams; Lagrangian reference frame models; estuarine hydraulics. Prerequisites: Consent of instructor. 3 hours lecture; 3 semester hours.

ESGN522. SUBSURFACE CONTAMINANT TRANS-PORT Physical, chemical, and biological processes governing the transport and fate of contaminants in the subsurface. Theory and development of mass transport models. Applications include predicting the extent of contaminant migration and assessing the efficiency of remediation techniques. Prerequisites: ESGN503 or consent of instructor. 3 hours lecture; 3 semester hours.

ESGN525. CHEMISTRY OF 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 instructor. 3 hours lecture; 3 semester hours.

ESGN527. ENVIRONMENTAL SYSTEMS ANALYSIS Basic principles of environmental systems analysis required in industrial and governmental projects pertaining to environmental site characterization for natural resource evaluation, human impact on natural systems, and for developing remediation strategies are studied, including terrain analysis, and surface and subsurface characterization procedures and analysis. Basic principles are developed by investigating and applying systems analysis and site characterization techniques to environmental problems. Prerequisite: ESGN501 or concurrent registration, or consent of instructor. 3 hours lab per week; 3 credit hours.

ESGN528. MATHEMATICAL MODELING OF ENVI-RONMENTAL 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, how they are developed, tested, and used as decision-making (or policy-making) tools. Typical problems associated with environmental systems - 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, knowledge of basic statistics and computer programming. 3 hours lecture; 3 semester hours.

ESGN530. ENVIRONMENTAL ENGINEERING PILOT PLANT LABORATORY Introduction to bench and pilot-scale experimental methods used in environmental engineering. Emphasis is on unit operations associated with water and wastewater treatment. Investigations typically carried out during the semester include: BOD/COD tests, environmental solids analysis and jar testing; flow pattern analysis with tracers; batch aeration and countercurrent air stripping; activated carbon isotherm determination; absorption and exchange column 'breakthrough' investigations; membrane technology evaluation; biotransformations using activated sludge in sequencing batch reactors and biokinetics using respirometry. Includes 6 hours per week in lab. Prerequisites: ESGN500 and ESGN504, or consent of instructor. 3 semester hours

ESGN541. BIOCHEMICAL TREATMENT PROCESSES Analysis and design of biochemical processes used to transform pollutants. Suspended growth, attached growth, and porous media systems will be analyzed. Common named biochemical operations used for water, wastewater, and sludge treatment will be discussed. Biochemical systems for organic oxidation and fermentation and inorganic oxidation and reduction will be presented. Prerequisites: ESGN503 and ESGN504 or consent of instructor. 3 hours lecture; 3 semester hours.

ESGN545. ENVIRONMENTAL TOXICOLOGY (II) 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. Prerequisites: ESGN501, or consent of instructor. 3 hours lecture; 3 semester hours.

ESGN551. ENVIRONMENTAL FIELD METHODS AND APPLIED PROJECT MANAGEMENT A field-oriented course designed to prepare students to plan and conduct an environmental characterization and/or develop a site remediation plan. Activities include conceptualization of the environmental system at hand, project design, measurement and sampling, analysis, and reporting. Students will draw upon their knowledge gained from the core curriculum to design and complete the project, which will focus on an actual problem of interest to a firm or governmental agency. Field activities will emphasize initial site characterization and development of an appropriate sampling strategy; accepted protocols for sample collection and field measurements in water, air, biota, or other media appropriate to the project; and operation, maintenance, and calibration of field instrumentation. Some laboratory and computer time may be required for sample analysis, data processing, and report preparation. Prerequisites: Completion of ESE core curriculum. 3 semester hours.

ESGN552. RECLAMATION OF DISTURBED LANDS Basic principles and practices in reclaiming disturbed lands. Includes overview of present legal requirements for reclamation and basic elements of the reclamation planning process. Examination of reclamation methods including recontouring, erosion control, soil preparation, plant establishment, seed mixtures, nursery stock, and wildlife habitat rehabilitation. Practitioners in the field talk on their experiences. Prerequisites: Consent of instructor. 3 hours lecture; 3 semester hours.

ESGN562/MTGN527. SOLID WASTE MINIMIZATION AND RECYCLING (I) This course will examine, using case studies, how industry applies engineering principles to minimize waste formation and to meet solid waste recycling challenges. Both proven and emerging solutions to solid waste environmental problems, especially those associated with metals, will be discussed. Prerequisites: ESGN500 and ESGN504 or consent of instructor. 3 hours lecture; 3 semester hours.

ESGN563. INDUSTRIAL WASTE: CONVERSION AND MARKETING (II) Case studies are used to illustrate process technologies applicable to converting industrial waste to marketable by-products, with particular emphasis on locating and evaluating suitable consumers. Major components of a waste or waste-stream are matched with operations using similar components as raw materials. One then applies process technology to economically meet end-user specifications. This course identifies means to become sufficiently conversant on customer needs, particularly physical and chemical specifications to maximize plant productivity, in order to facilitate negotiation of mutually satisfactory sales contracts. Prerequisites: Consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN571. ENVIRONMENTAL PROJECT MANAGEMENT Investigates environmental project management and decision making from government, industry and contractor perspectives. Emphasis is on the (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. Prerequisites: Consent of 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 insitu 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. Field trips will be taken to hazardous waste sites and/or environmental firms and a class project will be completed. Prerequisites: Consent of instructor. 3 hours lecture; 3 semester hours.

ESGN580. INVESTIGATIONS IN ENVIRONMENTAL SCIENCES (I, II) Independent research and investigations on student's chosen topic in Environmental Science and Engineering. Prerequisite: Graduate standing and division approval. 1 or more semester hours.

ESGN586. MICROBIOLOGY OF ENGINEERED ENVIRONMENTAL SYSTEMS This course will explore the applications of microbial genetic and physiological processes to engineered and human-impacted systems for the purpose of achieving environmentally desirable results. Topics will include genetic engineering, microbial identification and enumeration, biofilms in engineered systems, industrial fermentations and respirations, biodegradation and bioremediation of organic and inorganic contaminants, enzyme kinetics applied to metabolic engineering, wastewater microbiology, renewable energy generation, and agricultural biotechnology. Prerequisite: CHGC 562 or equivalent, or ESGN 501 with consent of instructor.

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 instructor. 3 hours lecture, some field trips; 3 semester hours.

ESGN593. ENVIRONMENTAL PERMITTING AND REGULATORY COMPLIANCE To acquaint students with the permit writing process specifically, developing information requirements for permit applications, dealing with ambiguous regulations, negotiating with permit writers, and dealing with public comment. To develop an understanding of the process of developing an economic and legally defensible regulatory compliance program. Prerequisites: ESGN502 or consent of instructor. 3 hours lecture; 3 semester hours.

ESGN598. SPECIAL TOPICS IN ENVIRONMENTAL SCIENCE (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.

ESGN599. 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.

ESGN601. RISK ASSESSMENT 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. 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 instructor. 3 hours lecture; 3 semester hours.

ESGN602. INTERNATIONAL ENVIRONMENTAL LAW The course covers an introductory survey of International Environmental Law - multi-nation treaties, regulations, 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 your credentials for international work. Prerequisites: ESGN502 or consent of instructor. 3 hours lecture; 3 semester hours.

ESGN622. MULTIPHASE CONTAMINANT TRANS-PORT Principles of multiphase and multicomponent flow and transport applied to contaminant transport in the unsaturated and saturated zones. Focus 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 instructor. 3 semester hours.

ESGN698. SPECIAL TOPICS IN ENVIRONMENTAL SCIENCE (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.

ESGN699. 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.

ESGN701. MASTER OF SCIENCE THESIS RESEARCH AND PREPARATION (I, II) Required of candidates for the degree of Master of Science. 6 semester hours upon completion of thesis.

ESGN703. GRADUATE THESIS - DOCTOR OF PHILOSOPHY (I, II, S) Conducted under the supervision of student's doctoral advisor and committee. 30 semester hours total requried.

ESGN705 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.

ESGN706 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.

Geochemistry

WENDY J. HARRISON, Professor Geology and Geological Engineering

RONALD W. KLUSMAN, Professor Chemistry and Geochemistry

DONALD L. MACALADY, Professor Chemistry and Geochemistry

SAMUEL B. ROMBERGER, Professor Geology and Geological Engineering

RICHARD F. WENDLANDT, Professor Geology and Geological Engineering

THOMAS R. WILDEMAN, Professor Chemistry and Geochemistry

L. GRAHAM CLOSS, Associate Professor Geology and Geological Engineering

JOHN B. CURTIS, Associate Professor Geology and Geological Engineering

JOHN D. HUMPHREY, Associate Professor Geology and Geological Engineering

E. CRAIG SIMMONS, Associate Professor Chemistry and Geochemistry

KEVIN W. MANDERNACK, Assistant Professor Chemistry and Geochemistry

JOHN E. McCRAY, Assistant Professor, Geology and Geological Engineering

Degrees Offered:

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 an 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. Thesis is required. There shall be a formal written proposal for the thesis research. Due to the interdisciplinary nature of the Geochemistry Program, students are not required to take a minor.

Comprehensive Examination

A comprehensive 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 comprehensive 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 take placement examinations stressing the basic principles of chemistry and geology. Each department recognizes that entering students may not be proficient in both areas. Results of the examinations will be used to establish deficiency requirements. Credit toward a graduate degree will not be granted for courses taken to fulfill deficiencies.

Required Curriculum:

The Geochemistry program comprises a core group of courses and four optional tracks: Mineralogy-Petrology, Aqueous-Environmental, Ore deposits-Exploration, Organic-Petroleum. Satisfactory performance in all core courses is required of all geochemistry students. The core courses are

CHGC503 - Introduction to Geochemistry

CHGC504 - Methods in Geochemistry

CHGN503 - Advanced Physical Chemistry.

Evidence of a prior graduate-level course in these areas may be accepted by the thesis committee. Students may select any one of the four tracks. Courses in the selected track are selected with advice from the student's advisors and/or dissertation committees.

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 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.

Description of Courses

CHGC503. INTRODUCTION TO GEOCHEMISTRY (I) A comprehensive introduction to the basic principles of geochemistry with discussion of elemental distributions, chemical equilibrium, mineral chemistry and chemical bonding, the geochemistry of isotopes, organobiological systems, and low and high temperature water-rock systems. Prerequisite: Physical chemistry, mineralogy, and petrology. 3 hours lecture, 3 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.

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, 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.

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.

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 (MACS323 or MACS530 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 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 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.

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 GEGN 307 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 petrologenic 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 1996.

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.

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 equlibria, 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.

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.

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.

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.

Geology and Geological Engineering

MURRAY W. HITZMAN, Professor, Charles F. Fogerty Professor
of Economic Geology, & Interim Department Head
WENDY J. HARRISON, Professor
NEIL F. HURLEY, Professor, Charles Boettcher Distinguished Chair in Petroleum Geology
KEENAN LEE, Professor
EILEEN P. POETER, Professor
SAMUEL B. ROMBERGER, Professor
A. KEITH TURNER, Professor
JOHN E. WARME, Professor
RICHARD F. WENDLANDT, Professor
L. GRAHAM CLOSS, Associate Professor
TIMOTHY A. CROSS, Associate Professor
JOHN B. CURTIS, Associate Professor
JERRY D. HIGGINS, Associate Professor
GREGORY S. HOLDEN, Associate Professor & Assistant Department Head
JOHN D. HUMPHREY, Associate Professor
ERIC. P. NELSON, Associate Professor
JOHN E. McCRAY, Assistant Professor
RICHARD H. De VOTO, Professor Emeritus
JOSEPH J. FINNEY, Professor Emeritus
THOMAS L.T. GROSE, Professor Emeritus
JOHN D. HAUN, Professor Emeritus
RICHARD W. HUTCHINSON, Professor Emeritus
KARL R. NEWMAN, Professor Emeritus
ROBERT J. WEIMER, Professor Emeritus

Degrees Offered:
   Professional Degree (Geological Engineering)
   Professional Degree (Engineering Geology)
   Professional Degree (Resource Geosciences)
         Petroleum Exploration & Development Option
         Mineral Exploration Option
         Geosciences Option
   Professional Degree (Hydrogeology)
   Master of Engineering (Geological Engineer)
   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 and Doctor of Philosophy in Geological Engineering. Geological Engineering degrees require possession or acquisition of an undergraduate engineering degree or its equivalent.

   Graduate students desiring to study hydrogeology, geotechnical engineering, and some environmental applications are generally expected to pursue the Geological Engineering degree program. Students desiring to study petroleum or minerals exploration or development sciences,

geochemistry and/or geology generally pursue science 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:

Course work requirements for Geology degrees are the same as the general graduate school requirements (M.S. 36 hours course work and research combined and Ph.D. 72 hours course work and research combined.

To ensure breadth of background, the course of study for the degrees Master of Science (Geology) and Doctor of Philosophy (Geology) must include at least one semester of graduate work 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. All Master of Science (Geology) and Doctor of Philosophy (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 prior to embarking on substantial work on the thesis research.

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 Degree Course Requirements:

Professional degrees are offered in the fields of Geological Engineering, Engineering Geology, Hydrogeology, and Resource Geosciences (Petroleum Exploration and Development Option, Mineral Exploration Option, or Geosciences Option). Students must complete a 15-unit core course requirement (specific to each degree field) and 15 units of appropriate elective courses, to total 30 units. At least 15 units counted for the degree must be 500-level or above. Personalized course programs are possible with approval of the Professional Degree Advisor.

Geological Engineering Requirements:

The Master of Engineering (Geological Engineer) and Master of Science (Geological Engineering) academic programs 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 Graduate Engineering Report or thesis. Twelve of the 36 credit hours may be research credits. Course requirements for the M.E. and M.S. degrees in Geological Engineering are the same. An M.E. degree is awarded to students whose engineering report entails

applied engineering research, while an M.S. may be awarded to students whose thesis entails fundamental scientific research with a purpose of advancing topics in applied engineering. The student and the student's advisory committee determine the degree to be awarded. The number of required thesis credits (GEGN700 or 702) is determined by the thesis advisor, and is typically at least 6 hours.

Specific required courses for the degree of Doctor of Philosophy (Geological Engineering) are the same as for the Master's degree program in geological engineering. The number of courses required in the specialty area will be determined by the student in conjunction with the doctoral program committee. It is normally expected that the course of study for graduate degrees in geological engineering will contain strong emphasis in the areas of geology and engineering.

The Master's degree program in geological engineering includes three components:

1. Specific Required Courses (7 credits)

   a. GEGN 570 Case Histories in Geological Engineering and Hydrogeology (3) is required for students specializing in geological engineering or ground water engineering. GEGN 528 Mining Geology (3) or GEGN 518 Mineral Exploration (3) is required for students specializing in mining geology.

   b. GEGN 532 Geological Data Analysis (3)

   c. GEOL 607 Graduate Geology Seminar (1)

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 Master's program advisory committee. Specialty areas might include Geotechnical Engineering, Groundwater Hydrology, Contaminant Hydrology, Subsurface Remediation, Waste Management, Geomorphology, Environmental Hazards, Geographic Information Systems, and Mining Geology.

3. Master of Engineering Report (GEGN700) or Master of Science Thesis (GEGN702)

   The form and content of the engineering report or thesis are to be determined by the student and the student's advisory committee. The engineering report and Master's thesis must demonstrate creative and comprehensive ability in the development or application of geological and engineering principles. The format of the engineering report or thesis will follow the guidelines described under the **Thesis Writer's Guide.** The engineering report differs from a thesis by emphasizing the engineering design approach to problem solving. Typically, a report may (a) analyze a specific aspect of a larger problem, (b) propose a specific design, or (c) focus on engineering or economic concepts. Engineering reports are closely

aligned to industrial research reports, and commonly are undertaken with the cooperation of industry or governmental agencies. While such cooperation is not required, it frequently occurs because of the applied nature of the topics selected for engineering reports.

Specific required courses for the degree of Doctor of Philosophy (Geological Engineering) are the same as for the Master of Engineering (Geological Engineer). It is normally expected that the course of study for graduate degrees in geological engineering will contain strong emphasis in the areas of applied geology and engineering.

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:

CHGC 503 Introduction to Geochemistry,
CHGC 504 Geochemical Analysis and
CHGN 503 Advanced Physical Chemistry

See the Geochemistry program section in this bulletin for further details.

Comprehensive Examination

A comprehensive 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 comprehensive 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 semester of calculus)
An additional science course (other than geology) or advanced mathematics
Physics (2 semesters)

Professional Degree Programs:

Candidates for the Professional 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.

Geological 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, for which credit toward an advanced degree will not be granted.

Mathematics:

Four semesters including: Calculus (2 semesters) and one semester of any two of: calculus III, differential equations, statistics, numerical analysis, linear algebra, operations research, optimization

Basic Science:

Chemistry (2 semesters)
Mineralogy/Petrology
Physics (2 semesters)
Stratigraphy/Sedimentation
Physical Geology/Historical Geology
Computer Programming

Engineering Science:

Structural Geology and one semester in four of the following subjects:
Physical Chemistry/Thermodynamics
Soil Mechanics
Statics
Fluid Mechanics
Dynamics
Rock Mechanics
Mechanics of Materials

Engineering Design:

Field Geology (6 weeks)
One semester in two of the following subjects:
Mineral Deposits/Economic Geology
Hydrogeology
Engineering Geology and one semester in three of the following subjects:
Foundation Engineering
Engineering Hydrology
Geomorphology
Airphoto Interpretation, Photogeology, or Remote Sensing
Petroleum Geology
Introduction to Mining
Introductory Geophysics

Engineering Geology Design
Mineral Exploration Design
Groundwater Engineering Design

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 (I) 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 or concurrent enrollment. 2 hours lecture, 3 hours lab; 3 sememster 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: GEGN 306, GEGN401, or consent of instructor. 6 hours lab; 3 semester hours.

GEGN405. MINERAL DEPOSITS (II) 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: GEOL210, 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 avalanches 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 1996.

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 1997.

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 GPGN386 and PEGN316. 3 hours lecture, 3 hours lab; 4 semester hours.

GEGN439/GPGN439/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 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 and 303. PE majors: PEGN316, PEGN414, PEGN422, PEGN423, PEGN424 (or concurrent) GEOL308; GE Majors: GEOL308 or GEOL309, GEGN438, GEGN316. 2 hours lecture, 3 hours lab; 3 hours lecture; 3 semester hours.

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.

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 differential equations,

structural geology, and sedimentation/stratigraphy, 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 analyses are an important part of the course. Prerequisite: MNGN321 and concurrent enrollment in EGGN461/ EGGN463 or consent of instructor.
3 hours lecture, 3 hours lab, 4 semester hours.

GEGN469. ENGINEERING GEOLOGY DESIGN (II) 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.
2 hours lecture, 3 hours lab; 3 semester hours.

GEGN470. GROUND-WATER ENGINEERING DESIGN (II) 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, analyses, and results, will be required. Prerequisite: GEGN467 or equivalent or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours.

GEGN475. APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS (I) 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 GROUNDWATER SYSTEMS (II) Lectures, assigned readings, and direct computer experience concerning the fundamentals and applications of analytical and finite-difference solutions to 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 bases. May include lecture, laboratory and field trip activities. Prerequisite: Approval of instructor and department head. Variable credit; 1 to 3 semester hours.

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.

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.

Graduate 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) Advanced concepts in stratigraphy with their application to exploration and development of fossil fuels and other minerals. Methods and techniques of stratigraphic modeling utilizing surface and subsurface data in field and laboratory exercises. Prerequisite: Consent of instructor. 2 hours lecture, 4 hours lab; 3 semester hours.

GEGN503/GPGN503/PEGN503. INTEGRATED EXPLO-RATION 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.

GEGN504/GPGN504/PEGN504. INTEGRATED EXPLO-RATION AND DEVELOPMENT (II) 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.

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 1998

GEOL507. IGNEOUS AND METAMORPHIC PETROL-OGY (I) An overview of igneous and metamorphic petrology. Presentation of rock associations and examination of the constraints on models for their origin. Emphasis will be on processes. Field trips required. Prerequisite: GEGN307, DCGN209 or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours.

GEGN509/CHGC509. 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

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 1999

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, 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.

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.

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 1999.

GEGN528/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 lab; 3 semester hours. Offered alternate years; Fall 1999.

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 or 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 informations systems (GIS). Practical experience with geological applications via supplied software and data sets from case histories. Prerequisites: Introductory statistics course (MACS323 or MACS530 equivalent); and previous or concurrent enrollment in MACS532 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.

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 defendable 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

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 1998.

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 EGGN461/EGGN463. 3 hours lecture; 3 semester hours. Offered alternate years, Spring 1996.

GEGN575. APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS (I) 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 propogation, 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.

GEGN 577. 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: GEGN 475 or GEGN 575, and GEGN 576.
2 hours lecture; 2 semester hours. Offered on demand.

GEGN 578. GIS PROJECT DESIGN (I, II) Project implementation of GIS analyses. 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

analyses. Prerequisite: Consent of instructor. Variable credit, 1-3 semester hours, depending on project. Offered on demand.

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. 2 hours lecture, 3 hours lab; 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.

GEGN/GEOL 598. 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.

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.

GEOL 599. 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.

GEOL605. ADVANCED STRUCTURAL AND TECTONIC PRINCIPLES (I) Seminar discussions on geotec-

tonic 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 2001.

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 2000.

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.

GEOL611. ADVANCED STRATIGRAPHY (II) Seminar on history and development of stratigraphic concepts and terminology; sedimentary processes and related facies for detrital, carbonate, and evaporite sequences; tectonics and sedimentation; stratigraphic styles in plate tectonic models. Field trips and report required. Prerequisite: GEOL314 or equivalent or GEOL501. 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 analyses 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 1999.

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.

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 1999.

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: GEOL212 or 210, GEOL221 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: GEOL221 and GEGN306 or GEGN 307 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: Consent of instructor. 2 hours lecture and seminar, 3 hours lab; 3 semester hours. Offered alternate years; Fall 1998.

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, GEGN306 or GEGN307. 3 hours lecture, 3 hours lab; 3 semester hours. Offered alternate years; Fall 1999.

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 equlibria, 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.

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.

GEGN671. ADVANCED SITE INVESTIGATION PROJECTS (II) The geological engineer's role in assessment and design for heavy construction projects from the preliminary site investigation stage through the final design stage. An advanced course for the application of siting and design methods to complex projects. Prerequisite: GEGN571 or consent of instructor. 1 hour lecture, 6 hours lab; 3 semester hours. Offered on demand.

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, EGGN461/EGGN463 and MNGN321. 3 hours lecture; 3 semester hours.

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.

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.

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 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 credit hours.

GEGN/GEOL 698. 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.

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.

GEOL 699. 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.

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.

GEOL701. GRADUATE THESIS-MASTER OF SCIENCE, GEOLOGY (I, II, S) Laboratory, field, and library work for the Master's thesis under supervision of the student's advisory committee.

GEGN702. GRADUATE THESIS-MASTER OF SCIENCE, GEOLOGICAL ENGINEERING (I, II, S) Laboratory, field, and library work for the Master's thesis under supervision of the student's advisory committee. Required of candidates for the degree of Master of Science (Geological Engineering).

GEGN/GEOL703. GRADUATE THESIS-DOCTOR OF PHILOSOPHY (I, II, S) Conducted under the supervision of student's doctoral committee.

GEGN/GEOL704 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.

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.

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.

Geochemical Exploration

GXGN571. GEOCHEMICAL EXPLORATION (I, II) 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.

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 1998.

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.

GXGN637. 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: GXGN571 and consent of instructor. 1 to 3 semester hours.

Geophysics

TERENCE K. YOUNG, Professor and Department Head
THOMAS L. DAVIS, Professor
ALEXANDER A. KAUFMAN, Professor

KENNETH L. LARNER, Charles Henry Green Professor of Exploration Geophysics
GARY R. OLHOEFT, Professor
MAX PEETERS, Baker Hughes Professor of Petrophysics and Borehole Geophysics
PHILLIP R. ROMIG, Professor and Dean of Graduate Studies and Research
JOHN A. SCALES, Professor
ROEL K. SNIEDER, Keck Foundation Professor of Basic Exploration Science
ILYA D. TSVANKIN, Professor
THOMAS M. BOYD, Associate Professor
YAOGUO LI, Associate Professor
NORMAN BLEISTEIN, Research Professor
MICHAEL L. BATZLE, Research Associate Professor
ROBERT D. BENSON, Research Associate Professor
VLADIMIR GRECHKA, Research Associate Professor
HENGREN XIA, Research Assistant Professor
TIMOTHY M. NIEBAUER, Adjunct Associate 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, Professor Emeritus
GUY H. TOWLE, Professor Emeritus
JAMES E. WHITE, Professor Emeritus

Degrees Offered

Professional Degree (Geophysics)
Master of Engineering (Geophysical Engineering)
Master of Science (Geophysics)
Master of Science (Geophysical Engineering)
Doctor of Philosophy (Geophysics)
Doctor of Philosophy (Geophysical Engineering)

Program Description

Geophysics entails the study and exploration of 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.

Because the Earth supplies all of our material needs and is the repository of our waste products, the breadth and importance of this field of science are evident. Oil companies and mining firms use the exploratory skills of geophysicists to locate hidden resources throughout the world. Geophysicists assess the material properties near the Earth's surface when sites are chosen for large engineering and waste-management operations. Geophysical technology is used in environmental applications such as tracking the flow of contaminants and searching for groundwater. On the global scale, geophysicists attempt to unravel Earth processes and structures from its surface down to its central core using measurements of heat distribution and flow; gravitational,

magnetic, electric, thermal, and stress fields; and ground motion caused by earthquakes or explosions.

Founded in 1926, the Department of Geophysics at the Colorado School of Mines is the largest department in the U.S. specializing in applied geophysical research and education. Even so, with 12 full-time faculty and class sizes ranging from 12 to 20, students receive individualized attention in a close-knit environment. Given the interdisciplinary nature of geophysics, the undergraduate 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.

Traditionally, the resource industry has been, and continues to be, the largest employer of CSM geophysics graduates. Within this industry, graduates find employment with the major oil companies, contractors involved in seismic and borehole logging surveys, and mineral exploration. Graduates also find employment in the emerging engineering and geotechnical industries with positions offered by government agencies and the myriad of small contracting firms specializing in shallow subsurface characterization for environmental, water management, and civil engineering applications.

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.

The Center for Wave Phenomena (CWP) is a multidisciplinary research group with a total of six faculty members --- four from the Department of Geophysics, and two from the Department of Mathematics and Computer Sciences. 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 on the WWW 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 involved. More information about RCP can be obtained on the WWW 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 Near Surface Seismic (NSS) Group is involved in research activity related to using surface and borehole, multi-component observations in an attempt to quantify the upper 100 meters of the subsurface.

The Environmental Geophysics Group investigates the uses of complex resistivity and ground-penetrating radar for the characterization of contaminated soils.

The Gravity and Magnetic Research Consortium carries out industry sponsored research in modeling, processing, and inversion of gravity and magnetic data. The emphasis is to develop efficient methods for imaging subsurface structures by inverting surface, airborne, and borehole observations to infer the below-ground distributions of density or magnetization, together with their structural boundaries. Developing fast forward-modeling techniques for calculating the gravity, gravity gradient, and magnetic fields from a given distribution of density or magnetization is an integral part of the research.

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

Degrees Offered

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. The Department maintains the Department of Geophysics, Graduate Student Handbook. This resource includes discussion of all of the current degree requirements,

a description of Departmental resources and activities, and descriptions of Departmental procedures governing graduate student progress through degree programs. The handbook can be viewed on the World Wide Web at http://trident.mines.edu/~sggs/handbook/intro.html. Like the CSM Graduate Student Bulletin, the Department of Geophysics, Graduate Student Handbook is updated annually.

Professional Degree in Geophysical Engineering

The Professional Degree in Geophysical Engineering is the Department's non-thesis postgraduate degree. The Professional Degree is awarded upon the completion of 38 hours of approved coursework. While individual courses constituting the degree are determined by the student, and approved by HIS/HER program advisor and committee (as described below), courses applied to all professional degrees must satisfy the following criteria.

◆ 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 Professional Degree.

◆ At least (21) credits must be at the 500 (graduate) level or above.

◆ At least (15) credits must be for courses taken within the Department of Geophysics at CSM.

◆ In addition, students must include the following courses in their Professional Degree program
GPGN599 – Geophysical Investigation (6 credits total)
LICM515 – Professional Oral Communication (1 credit)
GPGN581 – Graduate Seminar (1 credit)

Upon admission into the Professional Degree program, the Department's Graduate Advisory Committee (GAC) will assign each candidate an interim advisor and make a preliminary assessment of course deficiencies. Students in this program, like students in all of the Department's programs, are free to change advisors as they desire. Unlike the Department's other graduate programs, however, Professional Degree students are not free to choose their advisory committees. The GAC acts as the advisory committee to all Professional Degree students. Professional Degree candidates are required to meet at least once a semester with the GAC to discuss course requirements, deficiencies, and their independent investigation.

While no formal thesis is required, students obtaining the Professional Degree must complete, and then report on, an independent investigation for which six credits are awarded

under GPGN599. The work constituting the independent investigation can be completed at CSM under faculty guidance, or it can be completed in partnership with an industry sponsor. In either case, the candidate must submit to his or her advisor and committee a written proposal describing the scope and content of this work prior to enrolling in GPGN599.

As with the other graduate degrees offered by the Department of Geophysics, candidates in the Professional Degree program are expected to defend their independent investigation in an open oral defense. For the Professional Degree this requirement is fulfilled as part of enrollment in GPGN581. To successfully complete GPGN581, candidates are required to prepare and present a 20 minute oral presentation of their independent study to the Geophysics faculty and student body. At this time, students should be prepared to answer questions related to all aspects of the work presented.

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).

- Students must demonstrate breadth of geophysical knowledge by completing appropriate course work in Geophysical Theory and Modeling, Experimental/Data Acquisition, Data Processing, and Interpretation. See the latest version of the Graduate Student Handbook (HYPERLINK http://trident.mines.edu/~sggs/ handbook/intro.html   Appendix G) for courses that fulfill these requirements.

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. Up to 30 course credits can be awarded by the candidate's Ph.D. Thesis Committee for completion of a Master's Degree at CSM or 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)
  SYGN600 – Fundamentals of College Teaching (2 credits).
  GPGN681 – Graduate Seminar (1 credit)
  GPGN706 – Graduate Research – Doctor of Philosophy (24 credits in addition to the required 48 course credits)

- Students in the Ph.D. program must demonstrate breadth of geophysical knowledge by successfully completing appropriate course work in Geophysical Theory and Modeling, Experimental/Data Acquisition, Data Processing, and Interpretation. See the latest version of the Graduate Student Handbook (HYPERLINK http://trident.mines.edu/~sggs/ handbook/intro.html   Appendix G) for courses that fulfill these requirements.

- In addition to requiring SYGN600, students are also required to acquire at least one semester of 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 Comprehensive Examination no later than the fourth semester in residence. An extension of up to two more semesters may be petitioned by students through their Thesis Committees. If the Comprehensive Examination is not successfully completed within six semesters, the Department of Geophysics reserves the right to unilaterally terminate a student's Ph.D. program.

In the Department of Geophysics, the Comprehensive Examination consists of the preparation, presentation, and

defense of two research projects completed while in residence in the Ph.D. program at the Colorado School of Mines. The research projects used in this process must conform to the standards described in the Department's Graduate Student Handbook (HYPERLINK http://trident.mines.edu/~sggs/handbook/intro.html). The Department conducts Comprehensive Examinations in accordance with the Doctor of Philosophy, Comprehensive Examination section of the Graduate Bulletin.

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.

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 Deficiencies

All graduate programs in Geophysics require that applicants have a background that includes the equivalent of adequate undergraduate preparation in the following areas:

◆ Mathematics – Calculus, Linear Algebra or Linear Systems, Differential Equations, Engineering Mathematics, Computer Programming

◆ Chemistry – Chemistry I

◆ Physics – Classical Physics

◆ Geology – Structural Geology, Stratigraphy, Materials of the Earth, Geologic Field Methods

◆ Geophysics – Introductory courses that include both theory and applications in Gravity and Magnetics,

Seismology, Electromagnetism, Borehole Geophysics, and Geophysical Field Methods

◆ Senior Thesis or Project

◆ In addition, candidates in the Doctoral program are expected to have no less than one year of college level foreign language skills.

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: MACS213, MACS315, MACS349, and GPGN306, 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 EVLUATION (I) The basics of core analyses 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: MACS315, MACS349, GPGN302 GPGN303, 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.

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. 1 hour lecture, 6 hours lab; 3 semester hours.

GPGN439. GEOPHYSICS PROJECT DESIGN (II)
GEGN439/PEGN439. MULTI-DISCIPLINARY PETRO-LEUM 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. 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.

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, GPGN306, GPGN308, PHGN200, MACS315, and MACS349, 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 department. Credit – variable, 1 to 6 hours.

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, not to exceed 6 semester hours.

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: GEOL 501 or consent of instructors. 2 hours lecture, 3 hours lab; 3 semester hours.

GPGN504/GEGN504/PEGN504. INTEGRATED EXPLORATION AND DEVELOPMENT (II) 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.

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 petroleum development, minerals extraction, groundwater exploration, and environmental remediation. Prerequisite: Consent of instructor.3 hours lecture, 3 semester hours.

GPGN510. GRAVITY AND MAGNETIC EXPLORA-TION (I) 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. Instrumenta-tion. 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 ELEC-TROMAGNETIC 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 (mining, 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 tech-niques 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. Prerequi-sites: PHGN100, PHGN200, MACS111. GEGN401 or consent of the instructor. 2 hours lecture, 1 hour seminar; 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, MACS111,MACS112, MACS213. 2 hours lecture, 1 hour seminar; 3 semester hours.

GPGN551/MACS693. 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. 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 homoge-neous 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 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 (I) 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.

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.

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. 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; 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.

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, not to exceed 6 semester hours.

GPGN605. INVERSION THEORY (I) 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: MACS315 and knowledge of a scientific programming language. 3 hours lecture; 3 semester hours.

GPGN606. SIMUATION OF GEOPHYSICAL DATA (II) Efficiency of writing and running computer programs. Review 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 in anisotropic and inhomogeneous media. Topics include the Green's function for homogeneous anisotropic media, influence of anisotropy on body-wave polarizations and shear-wave splitting, traveltime analysis for transversely isotropic models, inversion of seismic data in the presence of anisotropy. Analytic and numerical description of surface waves in horizontally layered media, ray theory and dynamic ray tracing for body waves in homogeneous earth models. Prerequisites: GPGN552 and GPGN553 or consent of instructor. 3 hours lecture; 3 semester hours. Offered fall semester, even years.

GPGN658. SEISMIC MIGRATION (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. Offered spring semester, even 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. 1 hour seminar; 1 semester hour.

GPGN692. ADVANCED PHYSICS OF THE EARTH (II) This course emphasizes the observations, interpretive methods, external constraints, and assumptions used in constructing plausible models, both spherical and aspherical, of the earth. Modeled parameters considered in this course include seismic velocity, density, temperature, composition and state. Specific topics are chosen from those of interest to class members. These will be selected from the following: observations and constraints from earthquakes; heat flow, thermodynamics, and convection; geomagnetic observations and interpretations; gravitational properties and interpretations; and petrophysical and geochemical constraints. Prerequisite: GPGN494. 3 hours lecture; 3 semester hours. Offered spring semester, even years.

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.

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.

GPGN700. 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. 6 semester hours upon completion of report.

GPGN701. GRADUATE THESIS – MASTER OF SCIENCE (I, II, S) Required of candidates for the degree of Master of Science in Geophysics. 6 semester hours upon completion of thesis.

GPGN703. GRADUATE THESIS – DOCTOR OF PHILOSOPHY (I, II, S) Required of candidates for the

degree of Doctor of Philosophy in Geophysics. 30 semester hours.

GPGN704. 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.

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.

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.

Liberal Arts and International Studies

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BELLA VIVANTE, 2000-2001 Hennebach Visiting Professor
CARL MITCHAM, Professor
BARBARA M. OLDS, Professor
EUL-SOO PANG, Professor
JOSEPH D. SNEED, Professor
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CATHERINE FLYNN, Lecturer
TONYA LEFTON, Lecturer
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GEORGE W. JOHNSON, Emeritus Professor
ANTON G. PEGIS, Emeritus Professor
THOMAS PHILIPOSE, University Emeritus Professor
BETTY J. CANNON, Emeritus Associate Professor
PETER HARTLEY, Emeritus Associate Professor

The Liberal Arts and International Studies Division (LAIS) provides students with an understanding of the cultural, philosophical, social, political, and economic contexts in which science and engineering function. LAIS offerings enable students to learn how their responsibilities extend beyond the technical mastery of science and technology to the consequences for human society and the rest of life on earth. Because of those larger responsibilities, the LAIS mission includes preparing students for effective political and social thought and action.

The liberal arts exist for their intrinsic value. They are the arts of the free mind developing its powers for their own sake; they are the basis for the free, liberal, unhindered development of intellect and imagination addressing intrinsically worthy concerns. They are essential for preserving an open, creative, and responsible society. The liberal arts include philosophy, literature, language, history, political science, the creative arts, and the social sciences generally.

International Studies applies the liberal arts to the study of international political economy, which is the interplay between economic, political, cultural, and environmental forces that shape the relations among the world's developed and developing areas. International Studies focus especially on the role of the state and market in society and economy.

The LAIS mission is crucial to defining the implications of CSM's commitment to stewardship of the Earth and to the permanent sustainability of both social organization and environmental resources that such a commitment requires. A good foundation in the subjects provided by the LAIS Division is essential for graduating men and women who can provide the technical means for society's material needs in a

manner that leaves posterity an undiminished level of both social and environmental quality.

Graduate Certificates

In May 1999 the Graduate Council approved the introduction of two graduate certificates, one in International Political Economy (IPE) and one in International Political Economy of Resources (IPER), effective fall 1999. For the first three years, the IPE and IPER certificate programs will be offered; at the beginning of the fourth year, pending the required administrative approvals, it is the intent of the Division of Liberal Arts and International Studies to introduce a Master's in IPE and in IPER.

Graduate Certificate in International Political Economy

Graduate Certificate in International Political Economy of Resources

Program Description

The Division offers two graduate certificate programs with specialization in

International Political Economy (IPE)

International Political Economy of Resources (IPER)

The complete program requires two 15-hour certificates (30 hours total). The first 15-hour program is an introduction to the discipline; the second level develops the area of specialization.

The objective of the certificate programs is to provide research and analytical skills in the national and supranational relationships between the state and the market, the ramifications of economic policies on socio-political development, and the consequences of socio-political and environmental policies on economic and cultural transformations.

The IPE track will emphasize the macro dimensions of the role of the state and the market in the international political economy of development, trade, investment, and finance with a specific country or region focus. The IPER program will specialize in the role of a specific natural resource sector in inter-state relations and global contexts of trade, finance, investment, technology transfer, and environmental concerns.

There are four fields–clusters–in which the student can specialize.

International Political Economy of a Region (such as Asia Pacific, Latin America, or the Middle East)
  Economic and Political Geography of World Resources
  Global Environmental Policy
  International Political Risk Assessment and Mitigation

Since many of the courses in the program are currently under development, students must request a list of available courses from the Division of Liberal Arts and International Studies.

All entering students are required to take four introductory courses from each of the four clusters at the first level of the certificate program. Students may then opt to advance to the specialized second level certificate program wherein the student is required to specialize in a single field.

Program Requirements

Certificate I in IPE (15 credit hours):

International Political Economy of a Region (choose
    one: Asia Pacific, Latin America, the Middle East)
Economic and Political Geography of World Resources
Global Environmental Policy
International Political Risk Assessment and Mitigation

One additional course to be chosen from the International Political Economy cluster or International Political Risk Assessment and Mitigation cluster.

Certificate I in IPER (15 credit hours):

International Political Economy of a Region (choose
    one: Asia Pacific, Latin America, the Middle East)
Economic and Political Geography of World Resources
Global Environmental Policy
International Political Risk Assessment and Mitigation

One additional IPE course to be either an economics course or a geography course

Certificate II in IPE (15 credit hours):

9 hours from the first (major) cluster
3 hours from the second (minor) cluster
3 hours from a non-LAIS field such as economics and business, engineering, applied sciences, or the International Political Economy of a Region cluster or the International Political Risk Assessment and Mitigation cluster.

Certificate II in IPER (15 credit hours):

9 hours from the environment and/or geography cluster(s)
6 hours from environmental economics, resources economics, and/or geography

Prerequisites

The requirements for admission to the IPE and IPER graduate certificate programs are as follows:

1. BS or BA with a cumulative grade point average above 3.0 (4.0 scale)

2. Undergraduate CSM students who do not meet the overall GPA of 3.0 must at minimum have a 3.0 GPA in their undergraduate International Political Economy Minor or Certificate program

3. No GRE is required.

4. A TOEFL score of 550 or higher is required for students who are not native English speakers.

5. No foreign language is required at the time of admission, but demonstrated commitment to learn a second and/or third language during the residency in the program is encouraged in order to carry out research projects.

Fields of IPE/IPER Research

The research specialty of the program will parallel the

four clusters of the curriculum. The research methodology of IPE and IPER draws from such diverse disciplinary backgrounds as political science, history, economics, geography, sociology, literature, environmental studies, anthropology, area studies, international affairs and relations.

The principal fields of research are international political economy of development of a specific region or a country/countries; trade and investment; region-markets and region-states; international and multilateral governmental and nongovernmental organizations; economic and political geography of resources; global environmental policy and country-specific or region-specific environmental policy making and implementation; and international political risk assessment and mitigation with a specific country, countries, or region.

Graduate Individual Minor

Graduate students can earn a minor in Liberal Arts and International Studies if they complete 12 hours of course work from the Selected Topics or Independent Studies categories chosen under the supervision of an LAIS advisor.

Note: The Graduate Individual Minor must be approved by the student's graduate committee and by the LAIS Division.

Description of Courses

Humanities (LIHU)

LIHU401: 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: LIHU100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LIHU402. 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: LIHU100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LIHU403. MYTHOLOGY This course is designed to give students a familiarity with important Greek myths, especially in terms of their imaginative and dramatic appeal. Considerations regarding the nature of that appeal will provide means for addressing the social function of myth, which is a central issue for the course. The class will also examine various issues of anthropological and philosophical significance pertaining to the understanding of myth, including the issue of whether science is a form of myth. The final assignment will provide an opportunity to address either Greek or non-Greek myth. Prerequisite: LIHU100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LIHU404. TRANSCENDENT VISION Imagination can take us beyond the limits imposed by conventional mechanistic thinking about life and the universe. Spiritual vision can reveal a living universe of great power, beauty, and intrinsic value. Yet people accept existence in a world supposedly built out of dead matter. To transcend ordinary experience, we must set out on an adventure, a journey into new and strange worlds. Works of imaginative literature provide gateways to new worlds in which the universe is a transcendent experience that gives full meaning to existence. This course explores ideas and images of the universe as a revelation of transcendent value. A major issue considered in the course is the implication of comparing European and Native American world views. Prerequisite: LIHU100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LIHU410. ROMANTICISM TO IMPRESSIONISM Romanticism to Impressionism is a seminar on aspects of European (primarily French) cultural history of the nineteenth century. Emphasis is on art and literature from the era of Napoleon I to that of the Third Republic. This is the age of industrial revolution, rapid growth of cities, exploitation of the working class, the beginnings of social-ism, and the triumph of capitalism. Artists to be covered range from Delacroix to Monet; authors include Sir Walter Scott and Emile Zola. Prerequisite: LIHU100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LIHU470. 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. Primary 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: LIHU100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LIHU479. 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: LIHU100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours. Open to ROTC students or by permission of the LAIS Division.

LIHU480. URBAN QUALITY OF LIFE This course is intended to engage students with the marvelous potential and appalling problems of some of the world's cities. Primary focus will be on cultural history and the designed environment, including issues of traffic, housing, and environmental quality. Emphasis will be on the humanistic dimensions of a range of issues normally associated with urban sociology. Prerequisite: LIHU100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LIHU498. SPECIAL TOPICS IN HUMANITIES (1, 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. Prerequisite or corequisite: SYGN200. Variable credit: 1 to 6 semester hours.

LIHU499. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member. For students who have completed their LAIS requirements. Instructor consent required. Prerequisite: 'Independent Study' form must be completed and submitted to the registrar. Prerequisite or corequisite: SYGN200. Variable credit: 1 to 6 hours.

Social Sciences (LISS)
LISS 410. UTOPIAS/DYSTOPIAS This course studies the relationship between society, technology, and science using fiction and film as a point of departure. A variety of science fiction novels, short stories, and films will provide the starting point for discussions. These creative works will also be concrete examples of various conceptualizations that historians, sociologists, philosophers, and other scholars have created to discuss the relationship. Prerequisite: LIHU 100. Prerequisite or corequisite: SYGN200.
3 hours seminar; 3 semester hours.

LISS415. THE INVISIBLE MACHINE Did an Invisible Machine build the pyramids? Was the Invisible Machine reassembled in the 17th century? Did astronomy provide the blueprint? Why was Louis XIV called the "Sun King?" Is modern technology a servant that obeys, or a mega-technical system that dominates? Is human society becoming a technological paradise, or an urban nightmare? Why have a number of movies depicted the future as a nightmare city? Using selected readings plus films such as *Metropolis* and *Blade Runner*, this course will address these and other significant questions. Prerequisite: LIHU100. Prerequisite or corequisite: SYGN200.
3 hours seminar; 3 semester hours.

LISS430. GLOBALIZATION 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: LIHU100. Prerequisite or corequisite: SYGN200.
3 hours seminar; 3 semester hours.

LISS431. GLOBAL ENVIRONMENTAL ISSUES 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: LIHU100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LISS432. CULTURAL DYNAMICS OF GLOBAL DEVELOPMENT 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: LIHU100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LISS433. GLOBAL CORPORATIONS 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: LIHU100. Prerequisite or corequisite: SYGN200.
3 hours seminar; 3 semester hours.

LISS434. INTERNATIONAL FIELD PRACTICUM 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: LIHU100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LISS435/535. POLITICAL RISK ASSESSMENT 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: LIHU100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LISS436. ETHICS OF GLOBAL DEVELOPMENT This course looks at Western economic development efforts since World War II and asks basic questions about this process: What is development? How is it done, in practice, by

different actors? What motivates them to practice development? The course also asks fundamental questions about the ethics of these development practices: What are the philosophical goals of development? How can these goals be defended (or disputed) within the value systems of various cultures from East and West? Is there any ethical context in which development is not an unchallenged good? Is sustainability primarily a technical or an ethical concept? Included are discussions of the international 'development project' since 1945; globalization; elements of moral philosophy, including cultural relativism, subjectivism, egoism, utilitarianism, Kantian ethics, and the social contract; case studies of societies responding to changes brought by development; and statistical data about the progress of development worldwide in the past 50 years. Prerequisite: LIHU100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LISS439. POLITICAL RISK ASSESSMENT RESEARCH SEMINAR This international political economy seminar must be taken concurrently with LISS435, 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: LIHU100. Prerequisite or corequisite: SYGN200. Concurrent enrollment in LISS435. 1 hour seminar; 1 semester hour.

LISS440. LATIN AMERICAN DEVELOPMENT 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: LIHU100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LISS441. HEMISPHERIC INTEGRATION IN THE AMERICAS 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. If the Free Trade Area of the Americas (FTAA) becomes a reality, it will be the largest region-market in the world with some 800 million people and a combined GNP of over US$10 trillion. In the three other main languages of the Americas, the FTAA is know as the Area de Libre Comercio de las Américas (ALCA) (Spanish), the Area de Livre Comércio das Américas (ALCA) (Portuguese), and the Zone de libre échange des Amériques (ZLEA) (French). Negotiations for the FTAA/ALCA/ZLEA are to be concluded by 2005. Prerequisite: LIHU100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LISS442 ASIAN DEVELOPMENT 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: LIHU100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LISS450. AMERICAN MINING HISTORY This course asks the question, 'how do we know what happened in the past?' using Western American mining history as the case study. The course will include primary texts–those written at the time that the historical events occurred–and secondary sources, scholars' and popularizers' reconstructions. We will look at several approaches: scholarly studies, such as labor, technology, quantitative, and social history. Oral history will be approached through song and video material. We will study industrial archaeology by visiting the Western Mining Museum in Colorado Springs. The movie 'Matewan' illustrates how Americans make myths out of history. Students unfamiliar with mining can earn extra credit by a visit to the CSM experimental mine. In all these cases, we will discuss the standpoint of the authors of primary sources and scholarly accounts. We will discuss how we represent all different historical viewpoints and discuss how we know what is historically true–what really happened. Prerequisite: LIHU 100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LISS455. JAPANESE HISTORY AND CULTURE Japanese History and Culture is a senior seminar taught in Japanese that covers Japan's historical and cultural foundations from earliest times through the modern period. It is designed to allow students who have had three semesters of Japanese language instruction (or the equivalent) to apply their knowledge of Japanese in a social science-based course. Major themes will include: cultural roots; forms of social organization; the development of writing systems; the development of religious institutions; the evolution of legal institutions; literary roots; and clan structure. Students will engage in activities that enhance their reading proficiency, active vocabulary, translation skills, and expository writing abilities. Text is in Japanese. Prerequisites: LIHU 100; three semesters of college-level Japanese or permission of

instructor. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LISS460. TECHNOLOGY AND WILDERNESS A seminar on the values of wild nature in comparison to technological values with a view to the impact on environmental management policies. Prerequisite: LIHU100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LISS461. 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: LIHU100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LISS480/503. 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: LIHU100. Prerequisite or corequisite: SYGN200. 3 hours seminar; 3 semester hours.

LISS482/504. WATER POLITICS AND POLICY Seminar on water policies and the political and governmental processes that produce them, as an exemplar 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: LIHU100. Prerequisite or corequisite: SYGN200.   3 hours seminar; 3 semester hours.

LISS498. SPECIAL TOPICS IN SOCIAL SCIENCE (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. Prerequisite or corequisite: SYGN200. Variable credit: 1 to 6 semester hours.

LISS499. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member. For students who have completed their LAIS requirements. Instructor consent required. Prerequisite: 'Independent Study' form must be completed and submitted to the registrar. Prerequisite or corequisite: SYGN200. Variable credit: 1 to 6 hours.

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.

LIFL421. SPANISH III Emphasis on furthering conversational skills and a continuing study of grammar, vocabulary, and Spanish/American culture. 3 semester hours.

LIFL422. ARABIC III Emphasis on furthering conversational skills and a continuing study of grammar, vocabulary, and culture of Arabic-speaking societies. 3 semester hours.

LIFL423. GERMAN III Emphasis on furthering conversational skills and a continuing study of grammar, vocabulary, and German culture. 3 semester hours.

LIFL424. RUSSIAN III Emphasis on furthering conversational skills and a continuing study of grammar, vocabulary, and Russian culture. 3 semester hours.

LIFL425. FRENCH III Emphasis on furthering conversational skills and a continuing study of grammar, vocabulary, and French-speaking societies. 3 semester hours.

LIFL426. PORTUGUESE III Emphasis on furthering conversational skills and a continuing study of grammar, vocabulary, and Brazilian culture. 3 semester hours.

LIFL427. CHINESE III Emphasis on furthering conversational skills and a continuing study of grammar, vocabulary, and Chinese culture. 3 semester hours.

LIFL428. INDONESIAN III Emphasis on furthering conversational skills and a continuing study of grammar, vocabulary, and Indonesian culture. 3 semester hours.

LIFL429. JAPANESE III Emphasis on furthering conversational skills and a continuing study of grammar, vocabulary, and Japanese culture. 3 semester hours.

LIFL498. SPECIAL TOPICS IN A FOREIGN LANGUAGE (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 semester hours.

LIFL499. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member. For students who have completed their LAIS requirements. Instructor consent required. Prerequisite: 'Independent Study' form must be completed and submitted to the registrar. Variable credit: 1 to 6 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.

Materials Science

JOHN J. MOORE, 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

STEVE DANIEL, Professor and Head of Department

*DEAN W. DICKERHOOF, Professor

*KENT J. VOORHEES, Professor

THOMAS WILDEMAN, Professor

SCOTT W. COWLEY, Associate Professor

*MARK EBERHART, Associate Professor

STEVEN R. DEC, Research Assistant Professor

DANIEL M. KNAUSS, Assistant Professor

KIM R. WILLIAMS, Assistant Professor

Department of Chemical Engineering and Petroleum Refining

JAMES ELY, Professor and Head of Department

ROBERT BALDWIN, Professor

M. SAMI SELIM, Professor

*JOHN R. DORGAN, Associate Professor

J. DOUGLAS WAY, Associate Professor

*DAVID W.M. MARR, Assistant Professor, Representative of Graduate Affairs

COLIN WOLDEN, Assistant Professor

DAVID T. WU, Assistant Professor

Division of Engineering

JOAN GOSINK, Professor and Division Director

ROBERT J. KEE, George R. Brown Distinguished Professor of Engineering

RAHMAT A. SHOURESHI, Gerard August Dobelman Distinguished Professor of Engineering

JOHN R. BERGER, Associate Professor

*MARK A. LINNE, Associate Professor

*MARK LUSK, Associate Professor

DAVID R. MUNOZ, Associate Professor

*GRAHAM MUSTOE, Associate Professor

TERRY PARKER, Associate Professor

CHRISTOPHER BRAUN, Assistant Professor

JEAN-PIERRE DELPLANQUE, Assistant Professor

WILLIAM HOFF, Assistant Professor

JOHN P.H. STEELE, Assistant Professor

Department of Metallurgical and Materials Engineering

GLEN EDWARDS, Professor and Director of the Center for Welding and Joining Research

FREDERICK J. FRAIKOR, Research Professor

JOHN HAGER, Hazen Research Inc., Professor; Director, Kroll Institute for Extractive Metallurgy

*STEPHEN LIU, Professor

GERARD P. MARTINS, Professor

DAVID K. MATLOCK, ARMCO Foundation Fogarty Professor;
 Director, Advanced Steel Processing and Products Research Center

JOHN J. MOORE, Professor and Head of Department, and

Director, Advanced Coatings and Surface Engineering Laboratory
*DAVID L. OLSON, John Henry Moore Distinguished Professor
*DENNIS W. READEY, Herman F. Coors Distinguished Professor;   Director, Colorado Center for Advanced Ceramics
JOHN G. SPEER, ISS Professor
S. CHALLAPALLI, Research Professor
CHESTER J. VAN TYNE, FIERF Professor
ROBERT H. FROST, Associate Professor
BRAJENDRA MISHRA, Associate Professor, Associate Director,
Kroll Institute
IVAR E. REIMANIS, Associate Professor
STEVEN W. THOMPSON, Associate Professor
KELLY T. MILLER, Assistant Professor
ELI MATEEVA, Research Assistant Professor
JOHN P. WISE, Research Assistant Professor

Department of Physics
JAMES A. McNEIL, Professor and Head of Department
F. EDWARD CECIL, Professor
*REUBEN T. COLLINS, Professor
THOMAS E. FURTAK, Professor
VICTOR KAYDANOV, Research Professor
FRANKLIN D. SCHOWENGERDT, Professor
TIMOTHY R. OHNO, Associate Professor
*DAVID M. WOOD, Associate Professor
JON EGGERT, Assistant Professor
PETER W. SUTTER, Assistant Professor
DON L. WILLIAMSON, Emeritus Professor
* Members of the Materials Science Graduate Affairs Committee; or, Faculty Research-Opportunities Committee

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 and Petroleum Refining, 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 Committees 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 in one of the participating departments.

Program Requirements:

Master of Science (thesis option):

This Master of Science degree requires a minimum of 24 semester hours of acceptable coursework as outlined under Required Curriculum which follows. Also 12 semester hours of research credit must be completed. In addition, a student must submit a thesis and pass a Defense of Thesis examina-tion before their Thesis Committee.

Master of Science (non-thesis option):

This Master of Science degree requires a minimum of 39 credits of acceptable coursework as outlined under Required Curriculum which follows. Consult the section on Graduate Degrees and Requirements in this Bulletin for general information on this Master of Science - Non-Thesis degree.

Doctor of Philosophy:

The Doctor of Philosophy requires a minimum of 42 semester hours of acceptable coursework, of which minimum of 30 hours must be taken at CSM. The course work requirements include the core courses listed under Required Curriculum, plus 15 hours of course work in a selected primary area. In addition, 30 semester hours of research credit must be completed. A candidate for the degree must also pass both a written qualifying examination and an oral comprehensive examination, and must submit a thesis and pass a Defense of Thesis examination before their Thesis Committee.

Prerequisites

The primary admission requirement for this interdisciplinary program is a Bachelor of Science degree in physical science or engineering, equivalent to those offered at CSM in the following departments: Chemistry and Geochemistry, Engineering, Chemical Engineering and Petroleum Refining, 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 to satisfy any such deficiency early in their program of study: Mechanics Differential Equations Modern Physics Physical Chemistry/Chemical Thermody-namics

Required Curriculum:

1) The Master of Science degree (thesis option) requires a minimum of 24 semester-hours of acceptable course work, which must include the required core-courses listed below:

Master of Science (thesis option) Core Courses:
 MLGN500 - Processing, Microstructure and Properties of Materials
MLGN501/CHGN580 - Structure of Materials
MLGN501/PHGN440 - Introductory Solid State Physics
MLGN503/CHGN515 - Chemical Bonding in Materials
MLGN513 - Problem Solving in Materials Science
MLGN514 - Experimental Methods and Instrumentation (2 hours)
MLGN601 - Graduate Materials Science Seminar (1 hour)
MLGN Elective (9 hours)

Students who have taken the equivalent of any of the core-courses listed may petition the Materials Science Graduate Affairs Committee for transfer credit.

2) The Master of Science degree (non-thesis option) requires 36 semester-hours of acceptable course work which

must include the required core-courses listed below. In addition, 3 semester-hours of a case-study devoted to independent research must be conducted on a selected materials-processing or materials-characterization problem. Typically, this research would incorporate a concise analysis of various approaches to the problem, as reported in the technical literature, and culminate in a report submitted to the Faculty Advisor for approval.

Master of Science (non-thesis option) Core Courses:

MLGN500 - Processing, Microstructure and Properties of Materials

MLGN501/ CHGN580 - Structure of Materials

MLGN502/ PHGN440 - Introductory Solid State Physics

MLGN503/ CHGN515 - Chemical Bonding in Materials

MLGN504/ MTGN555 - Solid State Thermodynamics

MLGN511 - Kinetic Concerns in Materials Processing I

MLGN513 - Problem Solving in Materials Science

MLGN514 - Experimental Methods and Instrumentation (2 hours)

MLGN517 - Solid Mechanics of Materials

MLGN599 - Case Study - Materials Science

MLGN601 - Graduate Materials Science Seminar (1 hour)

In addition to the above, three other graduate-level courses (9 hours); by mutual agreement between the student and Faculty Advisor. The total course-work requirement, including the case-study, is therefore 39 semester-hours beyond the baccalaureate degree.

Students who have taken the equivalent of any of the core-courses listed may petition the Materials Science Graduate Affairs Committee for transfer credit.

The core-courses requirement for the Doctor of Philosophy degree is listed below. In addition, a minimum of 15 semester-hours of course work in a selected primary area must be part of the minimum requirement of 42 semester-hours beyond the baccalaureate degree.

Doctor of Philosophy Core Courses:

MLGN500 - Processing Microstructures and Properties of Materials

MLGN501/ CHGN580 - Structure of Materials

MLGN502/ PHGN440 - Introductory Solid State Physics

MLGN503/ CHGN515 - Chemical Bonding in Materials

MLGN504/ MTGN555 - Solid State Thermodynamics

MLGN511 - Kinetic Concerns in Materials Processing I

MLGN513 - Problem Solving in Materials Science

MLGN514 - Experimental Methods and Instrumentation (2 hours)

MLGN517 - Solid Mechanics of Materials

MLGN601 - Graduate Materials Science Seminar (1 hour)

Primary Areas:

Ceramics; Composites; Electronic Materials; Joining Science; Materials Chemistry; Mechanics of Materials; Metal and Alloy Systems; Polymeric Materials; Surface/

Interfaces, Thin Films and Coatings.

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 4 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. The member at large will be assigned by the Graduate Dean. 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

Fullerene synthesis, combustion chemistry

Transport phenomena, mathematical modeling, kinetic properties of colloidal suspensions, diffusion with chemical reaction

Novel separation processes: membranes, catalytical membrane reactors, biopolymer adsorbents for heavy metal remediation of ground surface water

Heterogeneous catalysis, reformulated and alcohol fuels, surface analysis, electrophotography

Computer modeling and simulation

Characterization, thermal stability, and thermal degradation mechanisms of polymers

Crystal and molecular structure determination by X-ray crystallography

Power electronics, plasma physics, pulsed power, plasma material processing

Control systems engineering, artificial neural systems for senior data processing, polymer cure monitoring sensors, process monitoring and control for composites manufacturing

Heat and mass transfer, materials processing

Numerical modeling of particulate media, thermomechanical analysis

Intelligent automated systems, intelligent process control, robotics, artificial neural systems

Ceramic processing, modeling of ceramic processing

Alloy theory, concurrent design, theory-assisted materials engineering, electronic structure theory

Physical metallurgy, Ferrous and nonferrous alloy systems

Archaeometallurgy, industry and university partnerships

Solidification and near net shape processing

Chemical processing of materials

Processing and characterization of electroceramics (ferroelectrics, piezoelectrics, pyroelectrics, and dielectrics), glass-

ceramics for electronic and structural applications, thermodynamic modeling of ferroelectrics

Applications of artificial intelligence techniques to materials processing and manufacturing, neural networks for process modeling and sensor data processing, manufacturing process control

Transformations, microstructure, deformation, fracture

Weld metallurgy, materials joining processes

Welding and joining science

Extractive and process metallurgy, electrochemical corrosion, synthesis of ceramic precursor powders and metal powders

Mechanical metallurgy, failure analysis, deformation of materials, advanced steel coatings

Pyrometallurgy, corrosion, materials synthesis, coatings

Chemical and physical processing of materials, engineered materials, materials synthesis

Reactive metals Properties and processing of ceramics and ceramic-metal composites, dielectrics and ferrimagnetics

Phase transformations and mechanisms of microstructural change, electron microscopy, structure-property relationships

Forging, deformation modeling, high-temperature material behavior

Materials synthesis, interfaces, flocculation, fine particles

Optical properties of materials and interfaces

Surface physics, epitaxial growth, interfacial science, adsorption

Experimental condensed-matter physics, thermal and electrical properties of materials, superconductivity, photovoltaics

Mössbauer spectroscopy, ion implantation, small-angle X-ray scattering, semiconductor defects

Computational condensed-matter physics, semiconductor alloys, first-principles phonon calculations

Physical vapor deposition, thin films, coatings

Chemical vapor deposition

Description of Courses (Interdisciplinary Program)

The interdisciplinary materials science program is administered jointly by the Departments of Chemical Engineering and Petroleum Refining, 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 Committees which are responsible for the operation of the 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. Discussion of experimental methods including photon and neutron scattering, charge and heat transport, action of simple solid state devices. Prerequisite: Physics III and MACS315. 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 materialÕs 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 THERMODY-NAMICS (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*/4 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 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 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.

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, MTGN 361, MACS315 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: MACS315 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.

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, MACS315 or equivalent. 3 hours lecture; 3 semester hours. Semester to be offered: Spring

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 MATERI-
ALS (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.

MLGN520 SPECIAL PROBLEMS May comprise
individual and group study. Not part of thesis. Prerequisite:
Consent of instructor. 1 to 3 semester hours.

MLGN521. KINETIC CONCERNS IN MATERIAL
PROCESSING II (I) Advanced course to address the
kinetics of materials processing, with emphasis in those
processes that promote phase and structural transforma-
tions. 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 APPLI-
CATIONS 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, superconductiv-
ity, 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 interations.
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 TECHNOL-
OGY 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 proper-
ties and statistics of polymer solutions, measurements of
molecular weights, molecular weight distributions, proper-
ties 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.

MLGN536/CHGN536. ADVANCED POLYMER SYN-
THESIS (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 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 of porous bodies. Prerequisites: ChEN307 or ChEN308 or MTGN461 or consent of instructor. 3 hours lecture; 3 semester hours

MLGN563. POLYMER ENGINEERING: STRUCTURE, PROPERTIES AND PROCESSING/MTGN463. POLYMER ENGINEERING 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 proper-

ties 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.)

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, metallurgy, adhesion science, microelectronics. 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.

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.

MLGN601. GRADUATE MATERIAL SCIENCE SEMINAR (I), (II) To develop an understanding of and practice in oral communication. Students will register each semester in residence. IPS or IPU grades will be given each semester until the final semester when a final letter grade will be assigned. Each student will be required to give one seminar during their program. Attendance at designated Materials Science seminars is also a requirement of the course. Prerequisite: Graduate standing 1 hour seminar: one semester hour.

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 background 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.

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.

MLGN701. GRADUATE THESIS - MASTER OF SCIENCE (I, II) Laboratory for Master's thesis under supervision of graduate student's advisory committee.

MLGN703. GRADUATE THESIS - DOCTOR OF PHILOSOPHY (I, II) Preparation of the doctoral thesis under supervision of the graduate student's advisory committee.

MLGN705. GRADUATE RESEARCH CREDIT: MAS-TER 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.

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.

Mathematical and Computer Sciences

GRAEME FAIRWEATHER, Professor and Department Head
BERNARD BIALECKI, Professor
JOHN DeSANTO, Professor
WILLY A.M. HEREMAN, Professor
RAGHU KRISHNAPURAM, Professor
PAUL A. MARTIN, Professor
JUNPING WANG, Professor
BARBARA B. BATH, Associate Professor
TRACY KAY CAMP, Associate Professor
MAARTEN V. DE HOOP, Associate Professor
DINESH P. MEHTA, Associate Professor
WILLIAM C. NAVIDI, Associate Professor
ROBERT G. UNDERWOOD, Associate Professor
ERIK S. VAN VLECK, Associate Professor
XINDONG WU, Associate Professor
BARBARA M. MOSKAL, Assistant Professor
LUIS TENORIO, Assistant Professor
HUGH KING, Senior Lecturer
G.GUSTAVE GREIVEL, Lecturer
TERI WOODINGTON, Lecturer
WILLIAM R. ASTLE, Professor Emeritus
ARDEL J. BOES, Professor Emeritus
NORMAN BLEISTEIN, Professor Emeritus
STEVEN A. PRUESS, Professor Emeritus
RUTH MAURER, 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, applied statistics, and computer sciences . 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. At least 12 of the credit hours must be designated for supervised research.

The Master of Science degree (non-thesis option) requires 36 credit hours of course work. Of these, eight courses (24 semester hours) comprise the core curriculum, which must be completed with a grade point average of 3.375 or higher. The degree is in the area of computational applied mathematics, and the core curriculum includes both applied mathematics and computer science courses.

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 a comprehensive examination, 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/macs/grad.html. 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)

Applied Statistics:
Linear algebra
Introduction to probability & statistics
Advanced calculus (Introduction to real analysis)

Computer Sciences:
Science - two semesters
Mathematics - two semesters of calculus, at least two courses from ordinary differential equations, linear algebra, statistics, discrete math
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

Fields of Research:
Applied Mathematics:
Dynamical Systems
Classical Scattering Theory

Classical Wave Propagation

Mathematical Methods for Wave Phenomena

Nonlinear Partial Differential Equations

Numerical Analysis

Optimal Control

Optimization Software

Regression Analysis

Seismic Inverse Methods

Symbolic Computing

Applied Statistics:

Inverse Problems in Statistics

Resampling Methods

Statistical Genetics

Stochastic Modeling

Computer Sciences:

Artificial Intelligence

Computer Networks

Data Mining

Fuzzy Sets

Machine Learning

Mathematical Software

Mobile Computing

Neural Networks

Pattern Recognition

Supercomputing and Parallel Processing

Description of Courses

MACS400. PRINCIPLES OF PROGRAMMING LANGUAGES (I, II) Study of the principles relating to design, evaluation and implementation of programming languages. Several languages of historical and technical interest are 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 issues. The primary languages discussed are FORTRAN, ALGOL, COBOL, PASCAL, LISP, ADA, C/C++, JAVA, PROLOG, PERL, BASIC. Prerequisite: MACS262. 3 hours lecture; 3 semester hours.

MACS401. APPLIED ANALYSIS (I) This course is a first course in analysis that lays out the context and motivation of analysis in terms of the transition from power series to those less predictable, especially Fourier series, and shows some of the traps into which even great mathematicians have fallen. The course is taught from an applied perspective. Differentiability, continuity, and convergence are studied in this setting. Prerequisite: MACS213 or MACS223, and MACS332. 3 hours lecture; 3 semester hours.

MACS403. DATABASE MANAGEMENT (I, II) 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 database 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: MACS262. 3 hours lecture; 3 semester hours.

MACS404. ARTIFICIAL INTELLIGENCE (I) General investigation of the Artificial Intelligence field. Approximately the first third of the course is devoted to developing a working knowledge of the LISP programming language. The remainder of the course is devoted to exploring various Artificial Intelligence applications such as computer vision, speech analysis, speech generation, robotics, reasoning, knowledge representation, natural language processing and expert systems. Prerequisite: MACS262, MACS358. 3 hours lecture; 3 semester hours.

MACS406. DESIGN AND ANALYSIS OF 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: MACS213 or MACS223, MACS262, MACS358. 3 hours lecture; 3 semester hours.

MACS407. INTRODUCTION TO SCIENTIFIC COMPUTING (I, II) Roundoff error in floating point arithmetic, conditioning and stability, contemporary mathematical software for solutions of linear algebraic systems, curve and surface fitting, zeros of nonlinear equations, adaptive quadrature, multivariate quadrature, initial value problems in ordinary differential equations. Codes and sample drivers are provided. Emphasis is on problem solving and the study of mathematical software using existing packages. Prerequisites: MACS315, knowledge of computer programming. 3 hours lecture; 3 semester hours.

MACS411. INTRODUCTION TO EXPERT SYSTEMS (I) General investigation of the field of expert systems. The first 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: Consent of instructor. 3 hours lecture; 3 semester hours.

MACS415. INTRODUCTION TO ROBOTICS AND COMPUTER VISION (II) General undergraduate-level introduction of Artificial intelligence techniques in robotics and computer vision. Reactive robot architectures are studied in detail. The course emphasizes hands-on experience with mobile robots and sensors. Field trips are arranged to local industries which manufacture or use robots. Prerequisite: Knowledge of C programming language, jr or sr standing. 3 hours lecture; 3 semester hours.

MACS428. APPLIED PROBABILITY (II) Basic probabil-

ity. Probabilistic modeling. Discrete and continuous probability models and their application to engineering and scientific problems. Empirical distributions, probability plotting, and testing of distributional assumptions. Prerequisite: MACS213 or MACS223 3 hours lecture; 3 semester hours.

MACS434. INTRODUCTION TO PROBABLILITY (I) An introduction to the theory of probability essential to applied problems in probability and statistics encountered in the physical and social sciences, as well as engineering. Topics covered include combinatorics, axioms of probability, conditional probability and independence, discrete and continuous probability density functions, expectation, jointly distributed random variables, Central Limit Theorem, laws of large numbers. Prerequisite: MACS323. 3 hours lecture; 3 semester hours.

MACS435. INTRODUCTION TO MATHEMATICAL STATISTICS (II) An introduction to statistical theory essential to applied problems in probability and statistics encountered in the fields of pure and applied science, as well as engineering. Topics covered include sampling distributions, methods of point estimation, methods of internval estimation, significance testing for population means and variances and goodness of fit, linear regression, analysis of variance. Prerequisite: MACS434. 3 hours lecture; 3 semester hours.

MACS440. PARALLEL COMPUTING FOR SCIENTISTS AND ENGINEERS (I) This course introduces all scientists and engineers to parallel computing. Students have access to state-of-the-art supercomputers and are taught how to solve scientific problems on the machines. They are 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.

MACS441. COMPUTER GRAPHICS (II) 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: MACS262. 3 hours lecture; 3 semester hours.

MACS442. 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: MACS262, MACS341. 3 hours lecture; 3 semester hours.

MACS454. COMPLEX ANALYSIS I (I) The complex plane. Analytic functions, harmonic functions. Mapping by

elementary functions. Complex integration, power series, calculus of residues. Conformal mapping. Prerequisite: MACS315. 3 hours lecture; 3 semester hours.

MACS455. PARTIAL DIFFERENTIAL EQUATIONS (II) Review of partial differentiation. Linear partial differential equations of the first and second order emphasizing the heat equation, wave equation, and potential equation. Methods including separation of variables with Fourier series, Sturm-Liouville techniques, and procedures to analyze forcing functions. Prerequisite: MACS315. 3 hours lecture; 3 semester hours.

MACS461. SENIOR SEMINAR I (I) Students present topics using undergraduate mathematical and computer sciences techniques, emphasizing critical analysis of assumptions and models. Prerequisite: Consent of department. 1 hour seminar; 1 semester hour.

MACS462. SENIOR SEMINAR II (II) 1 hour seminar; 1 semester hour.

MACS498. SPECIAL TOPICS (I, II, S) Selected topics chosen from special interests of instructor and students. Prerequisite: Consent of Department Head. 1 to 3 semester hours.

Graduate Courses

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

MACS500. 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: MACS401. 3 hours lecture; 3 semester hours.

MACS502. REAL AND ABSTRACT ANALYSIS (II) 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: MACS401. 3 hours lecture; 3 semester hours.

MACS503. 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: MACS502. 3 hours lecture; 3 semester hours.

MACS506. COMPLEX ANALYSIS II (II) Analytic functions. Conformal mapping and applications. Analytic continuation. Schlicht functions. Approximation theorems in the complex domain. Prerequisite: MACS454. 3 hours lecture; 3 semester hours.

MACS510. 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: MACS315 and MACS332 or equivalent. 3 hours lecture; 3 semester hours.

MACS514. 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: MACS454 and MACS455 or equivalent. 3 hours lecture; 3 semester hours.

MACS515. 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: MACS514. 3 hours lecture; 3 semester hours.

MACS518 (GPHY508). BOUNDARY VALUE PROBLEMS IN OCEAN ACOUSTICS AND SEISMOLOGY The application of boundary value methods to problems in wave theory. Specific applications are to propagation of sound in a bounded ocean waveguide, scattering of sound from rough boundaries, and the classical boundary value problems of seismology. Both direct and inverse problems are treated. Several of the problems are approached from both deterministic and statistical points of view. Offered on demand. Prerequisite: MACS347 and/or consent of instructor. 3 hours lecture; 3 semester hours.

MACS520. LINEAR PROGRAMMING (I) Convexity and geometric interpretation of linear programming problems, the simplex method, the revised simplex method, and the product form of the inverse, duality theory, sensitivity analysis, complementary slackness and some of its applications. Real world problems and analysis of the efficiency of the algorithms emphasized. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

MACS521. NONLINEAR PROGRAMMING (II) Necessary and sufficient conditions for optimality, convex functions, optimal search methods, methods of steepest descent, conjugate gradient and quasi-Newton methods, Kuhn-Tucker theory, Primal methods, Quadratic programming, and other specific programming techniques (such as separable programming, linear fractional, and integer) as time permits. Prerequisite: MACS520 or consent of instructor. 3 hours lecture; 3 semester hours.

MACS525. MATHEMATICAL CONTROL THEORY (II) This course is concerned with the analysis and design of

complicated (e.g., multivariate) dynamic systems. These systems are analyzed principally from the time domain viewpoint (as opposed to the frequency domain approach). The fundamental concepts discussed are stability, controllability, observability; feedback controllers and other optimal controllers. These concepts are first discussed for linear systems and then extended to nonlinear as time permits. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

MACS530. STATISTICAL METHODS I (I, S) 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. Intended primarily for graduate students in departments other than Mathematics. Prerequisite: MACS213 or equivalent. 3 hours lecture; 3 semester hours.

MACS531. STATISTICAL METHODS II (II, S) Continuation of MCSN530. 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: MACS323 or 530 or 535. 3 hours lecture; 3 semester hours.

MACS532. INTRODUCTION TO DATA ANALYSIS (II) Multiple linear and curvilinear regression analysis. Trend surfaces and response surfaces. Analysis of variance and multiple comparison techniques. Meets concurrently with MAGN531 for five weeks. Prerequisite: MACS323 or 530 or 535. 3 hours lecture (for 5 weeks); 1 semester hour.

MACS534. MATHEMATICAL STATISTICS I (I) The basics of probability, fundamental discrete, and continuous probability distributions, sampling distributions, including order statistics, and basic limit theorems, including the continuity theorem and the central limit theorem, are covered. Prerequisite: Consent of department. 3 hours lecture; 3 semester hours.

MACS535. MATHEMATICAL STATISTICS II (II) The basics of hypothesis testing using likelihood ration, point and interval estimation, including consistency, efficiency, and sufficient statistics, and some nonparametric methods are presented. Prerequisite: MACS534 or equivalent. 3 hours lecture; 3 semester hours.

MACS538. APPLIED MULTIVARIATE ANALYSIS (II) An introduction to the theory and applications of multivariate statistical analysis with an emphasis on its usage as an exploratory technique. Topics covered include: inference about mean(s) and co-variances, discriminant analysis, principal component analysis, canonical correlation analysis, and factor analysis. Computer programs illustrate the method. Prerequisite: MACS534 or 530 or 535. 3 hours lecture; 3 semester hours.

MACS540. STOCHASTIC PROCESSES (II) Poisson processes, renewal theory, and Markov chains are studied and applied to the theory of queues. Offered in even-numbered years. Prerequisite: MACS534 or equivalent. 3 hours lecture; 3 semester hours.

MACS541. QUEUEING THEORY Structure and techniques for the basic theory. Poisson and non-Poisson with various input and output distributions. Applications and renewal theory. Offered on demand. Prerequisite: MAGN540 or consent of department. 3 hours lecture; 3 semester hours.

MACS542. 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: MACS530. 3 hours lecture; 3 semester hours.

MACS544. STATISTICAL QUALITY CONTROL This course is designed to build upon the knowledge of probability and statistics gained in MACS530, MACS323, or the equivalent. The focus is application of that knowledge to problems of quality control in an industrial setting. The main goals of the course are introduction of the tools and language of statistical quality control and statistical process control, and to develop skill in their application. Topics to be covered include control charting by variables and attributes, acceptance sampling, process capability, and economic design of quality control programs. Prerequisites: MACS323 or MACS530 or equivalent. 3 hours lecture; 3 semester hours

MACS545. TIME SERIES Data are modeled and the model is used to forecast future values. The Box-Jenkins approach is used to determine the model form, estimate parameters, check for fit, and forecast. Economic and physical data are studied. Computer programs illustrate the methods. Seasonal and multidimensional transfer function models generalize the techniques. Taught on demand. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

MACS547. SPECTRAL ANALYSIS Frequency domain description of data are considered. The important cycles present in data are identified. The statistical problems in estimation are approached by windowing. Physical and economic data are analyzed. Taught on demand. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

MACS550. 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: MACS315, MACS332, or consent of instructor. 3 hours lecture; 3 semester hours.

MACS551. 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: MACS332, MACS407, or consent of instructor. 3 hours lecture; 3 semester hours.

MACS556. 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

MACS561. 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: MACS262, MACS358. 3 hours lecture; 3 semester hours.

MACS563. 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, software 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, 1 hour seminar; 4 semester hours

MACS565. DISTRIBUTED COMPUTING SYSTEMS (I) 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

MACS566. 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 management systems implementation, and management of scientific data. Each student develops a course project, as a vehicle for exploring and applying a database research issue chosen by the student. An object-oriented database management system is used in assignments. Prerequisite: MACS403 or equivalent 3 hours lecture; 3 semester hours

MACS567. ADVANCED OBJECT ORIENTED SOFTWARE ENGINEERING (I) 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.

MACS570. NEURAL NETWORKS (II) 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: MACS404. 3 hours lecture; 3 semester hours.

MACS571. 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: MACS262. 3 hours lecture;3 semester hours

MACS574. AI IN ROBOTICS AND COMPUTER VISION (II) Advanced treatment of Artificial Intelligence techniques in robotics and computer vision. Lectures cover the commonly used techniques in robotics and computer vision as well as new AI approaches to higher cognitive functions such as planning and problem solving. Theory behind current robot architectures and image understanding systems is emphasized through supplementary readings and case studies, discussed in a weekly seminar format. The course supplements the strong theoretical focus with a hands-on project with one or more mobile robots and sensors. Field trips are arranged to local industries which manufacture or use robots. Prerequisite: MACS404, knowledge of C programming language. 3 hours lecture, 1 hour seminar; 4 semester hours

MACS598. SPECIAL TOPICS IN MATHEMATICAL AND COMPUTER SCIENCES (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.

MACS599. 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.

MACS610. 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.

MACS614. 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.

MACS616. INTRODUCTION TO MULTI-DIMENSIONAL SEISMIC INVERSION (I) 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

MACS650. 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

MACS660. 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

MACS671. ADVANCED TOPICS IN ARTIFICIAL INTELLIGENCE (I) Topics from the current literature in artificial intelligence; for example, robotics, neural networks, robotics, expert systems, knowledge systems and evidential reasoning. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours

MACS691. 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.

MACS692. 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.

MACS693/GPHY562. WAVE PHENOMENA SEMINAR (I, II) Current research topics in wave phenomena, largely in the context of mathematical geophysics. Wave propagation in fluids and elastic media. Direct modeling, inversion, computer implementation. Prerequisite: Consent of instructor. 1 hour seminar; 1 semester hour.

MACS698. SPECIAL TOPICS IN MATHEMATICAL AND COMPUTER SCIENCES (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.

MACS699. 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.

MACS701. GRADUATE THESIS-MASTER OF SCIENCE (I, II) Preparation of the master's thesis under the supervision of the graduate student's advisory committee. 6 semester hours upon completion of thesis. Required of all candidates for the degree of Master of Science.

MACS703. GRADUATE THESIS-DOCTOR OF PHILOSOPHY (I, II) Preparation of the doctor's thesis under the supervision of the graduate student's advisory committee. 30 semester hours upon completion of thesis.

MACS705. 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.

MACS706. 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.

Metallurgical and Materials Engineering

JOHN J. MOORE, Professor and Department Head
GLEN R. EDWARDS, Professor
JOHN P. HAGER, Hazen Research Inc. Professor
STEPHEN LIU, Professor
GERARD P. MARTINS, Professor
DAVID K. MATLOCK, ARMCO Foundation Fogarty Professor
DAVID L. OLSON, John Henry Moore Distinguished Professor
DENNIS W. READEY, Herman F. Coors Distinguished Professor
JOHN G. SPEER, Professor
CHESTER J. VANTYNE, FIERP Professor
ROBERT H. FROST, Associate Professor
BRAJENDRA MISHRA, Associate Professor
IVAR E. REIMANIS, Associate Professor
STEVEN W. THOMPSON, Associate Professor
KELLY T. MILLER, Assistant Professor
FREDERICK J. FRAIKOR, Research Professor
C. SURYANARAYANA, Research Professor
JOHN P. WISE, Research Assistant Professor
ELI MATEEVA, Research Assistant Professor
GEORGE S. ANSELL, President and Professor Emeritus
W. REX BULL, Professor Emeritus
GERALD L. DePOORTER, Associate Professor Emeritus
GEORGE KRAUSS, Professor University Emeritus
WILLIAM M. MUELLER, Vice President for Academic Affairs
and Professor Emeritus

Degrees Offered:

Master of Science (Metallurgical and Materials Engineering)

Master of Engineering (Metallurgical and Materials Engineering)

Doctor of Philosophy (Metallurgical and Materials Engineering)

Program Description:

The program of study for the Master's 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 rules 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.

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 36 semester hours of acceptable course work; ii) case/independent study course work component cannot exceed 12 semester hours; and iii) submittal and presentation, and subsequent acceptance by the Graduate Advisor, of a case-study report. (*See pp. 30-1, Combined Undergraduate/Graduate Programs.)

II. Graduate Program: i) a minimum of 24 semester hours of acceptable course work; ii) 12 semester hours of research credit; and iii) submittal and successful oral defense of a thesis, 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 12 semester hours of research credit; and, ii) submittal and successful oral defense of a thesis, 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) a minimum of 12 semester hours of acceptable course work in a minor field of study; iv) a passing grade on the Comprehensive Examinations; and, v) submittal and successful defense of a thesis, which presents the results of original scientific research or development.

Notes: a) The minor may include course work in departments outside the Metallurgical and Materials Engineering Department, or from one of the Areas of Specialization within the Department different from that selected by the student as his/her major option. The minor must be approved by the student's Doctoral Committee and the committee member delegated to represent the Minor Department.

b) The comprehensive examinations are specific to the student's declared Area of Specialization, and consist of a written and oral component. The written examinations consist of a general-topics examination and an area-of-specialization examination. The oral examination consists of responses by the student to questions on the background, rationale and fundamentals related to the student's proposed research. A written document summarizing the student's proposed research is presented to the Examining Committee (different from the Thesis Committee) prior to this event. The student delivers an 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.

c) Although there is no formal seminar-course requirement, graduate students, as part of their professional development, are expected 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 make up 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
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 may, with the approval of the Thesis Committee, 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: MTGN311, MTGN331, and MTGN412/MLGN512 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, MTGN412/MLGN512, or consent of instructor. 3 hours lecture; 3 semester hours.

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, MTGN412 or consent of instructor. 3 hours lecture, 3 semester hours.

MTGN417. REFRACTORY MATERIALS (I) Refractory materials in metallurgical construction. Oxide phase diagrams to explain 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.

MTGN421. FLOTATION (I) Solution chemistry and surface chemistry as related to froth flotation. Absorption, interfacial free energy, flocculation, and dispersion and flotation kinetics. Prerequisite: MTGN331. Co-requisite: MTGN423 or consent of instructor. 2 hours lecture; 2 semester hours.

MTGN422. PROCESS ANALYSIS AND DEVELOPMENT (II) Aspects of process development, plant design, and management. Prerequisite: MTGN331. Co-requisite: MTGN424 or consent of instructor. 2 hours lecture; 2 semester hours.

MTGN423. FLOTATION LABORATORY (I) Experiments to accompany the lectures in MTGN421. Co-requisite: MTGN421 or consent of instructor. 3 hours lab; 1 semester hour.

MTGN424. PROCESS ANALYSIS AND DEVELOPMENT LABORATORY (II) Projects to accompany the lectures in MTGN422. Prerequisite: MTGN422 or consent of instructor. 3 hours lab; 1 semester hour.

MTGN429. METALLURGICAL ENVIRONMENT (I) This course covers studies of the interface between metallurgical process engineering and environmental engineering areas. 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 some examples chosen. The ratio of fundamentals to applications coverage is about 1:1. Prerequisites: 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 hyrdometallurgy, electrowinning, and electrorefining. Analysis of integrated flowsheets for the recovery of nonferrous metals. Prerequisite: MTGN334, MTGN351, MTGN461, MTGN352. Co-requisite: MTGN433 or consent of instructor. 2 hours lecture; 2 semester hours.

MTGN432. PYROMETALLURGY (II) Extraction and refining of metals including emerging 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 to accompany the lectures in MTGN431. Co-requisite: MTGN431 or consent of instructor.

MTGN434. DESIGN AND ECONOMICS OF METAL-LURGICAL 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 processes in physicochemical and physical metallurgy. Prerequisite: MTGN438 or consent of instructor. 2 hours lecture; 2 semester hours.

MTGN438. CONTROL AND INSTRUMENTATION OF METALLURGICAL PROCESSES LABORATORY (II) Experiments to accompany the lectures in MTGN436. Prerequisite: 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. Prerequisite: MTGN348. 3 hours lecture, 3 hours lab; 4 semester hours.

MTGN450/MLGN550. 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

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 COM-POSITES 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: MTGN311, MTGN331, MTGN348, MTGN351. 3 hours lecture; 3 semester hours

MTGN453. PRINCIPLES OF INTEGRATED CIRCUIT PROCESSING (I) An 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. Laboratory exercises to illustrate

specimen preparation techniques, microscope operation, and the interpretation of images produced from a variety of specimens. Prerequisite: MTGN311 or consent of instructor. Co-requisite: MTGN458. 2 hours lecture; 2 semester hours.

MTGN458. ELECTRON MICROSCOPY LABORATORY (II) Experiments to accompany 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: MACS315, 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. 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 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, 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 processesÐthermal aspects; metallurgical evaluation of resulting microstructures; attendant phase transformations; selection of filler metals; stresses; stress relief and annealing; preheating and post heating; difficulties 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 to accompany the lectures in MTGN475. Prerequisite: 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). Usually the course is offered only once. Prerequisite: Consent of Instructor. 1 to 3 semester hours.

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.

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.

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.

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 considered. 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.)

MTGN521. MATHEMATICAL MODELING OF SIZE REDUCTION AND SIZE SEPARATION (II) Mathematical modeling and simulation of size reduction and size separation operations. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MTGN522. MATHEMATICAL MODELING OF MINERAL CONCENTRATION (II) Mathematical modeling and simulation of mineral concentration operations, particularly flotation. Prerequisite: Consent of instructor.. 3 hours lecture; 3 semester hours.

MTGN523/MLGN523. APPLIED SURFACE AND SOLUTION CHEMISTRY (II) Solution and surface chemistry of importance in mineral and metallurgical operations. Prerequisite: Consent of instructor.1 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MTGN524. ADVANCED FLOTATION (II) Advanced treatment of the surface chemistry of froth flotation. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

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 level status or consent of instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

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.

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: MTGN331 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.

MTGN534. CASE STUDIES IN PROCESS DEVELOP-MENT 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) The detailed study of a 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 practice 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 reaction. Mixed potential systems. Electrode position 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.)

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 PROCESS-ING REACTOR DESIGN (II) Review of reactor types and idealized design equations for isothermal conditions. Residence time functions for nonreacting and reacting species and its importance 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) The 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 MODEL-ING (I) An 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 material, 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. Micromechanisms 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 uniary, 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. The 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 technique. 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/Corequisite*: MTGN311, MTGN348, MTGN351, MTGN352, MTGN445/ML505*; 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 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 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 as 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 the management of manufacturing operations. Topics include inventory control models; factory dynamics and flow through manufacturing processes; application of Little's Queueing 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 manufacturing 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 An introduction to the theory and practice of dynamic simulation of queueing systems such as those encountered in manufacturing systems and service operations. The topics include generation of random numbers and random variates, discrete and continuous statistical distributions used for simulation, simulation dynamics, queueing systems, statistical analysis of simulation output, entity transfer, conveyors, batching, statistical analysis of simulation output, and termination of simulation models. A commercial computer based simulation package will be used to provide the experience and background necessary to build and analyze simulation 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 MATE-RIAL 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. The use of these models in computer codes (especially finite element analyses) will be presented. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. (Fall of even years only.)

MTGN565 MECHANICAL PROPERTIES OF CERAM-ICS 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.)

MTGN571. METALLURGICAL AND MATERIALS ENGINEERING LABORATORY Basic instruction in advanced equipment and techniques in the field of mineral processing, extraction, mechanical or physical metallurgy. Prerequisite: Selection and consent of faculty instructor. 3 to 9 lab hours; 1 to 3 semester hours.

MTGN580. ADVANCED WELDING METALLURGY (II) Weldability, defects, phase transformations, heat flow, preheat 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 INTER-ACTIVE 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: MACS315 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, MACS315, 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, MACS315, 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). Usually the course is offered only once. Prerequisite: Consent of instructor. Variable hours lecture/lab; 1 to 6 semester hours.

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.

MTGN631. TRANSPORT PHENOMENA IN METAL-LURGICAL AND MATERIALS SYSTEMS Physical principles of mass, momentum, and energy transport. Application to the analysis of extractive metallurgy and other physicochemical processes. Prerequisite: MACS315 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 mineral dressing, 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 PRO-CESSES (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 thin films. 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; electrodeposi-tion 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: MACS315, 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). Usually the course is offered only once. Prerequisite: Consent of instructor.. 1 to 3 semester hours per semester.

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.

MTGN70l. GRADUATE THESIS-MASTER OF SCI-ENCE (I, II) Master's thesis supervision by student's advisor in collaboration with the Thesis Committee.

MTGN703. GRADUATE THESIS-DOCTOR OF PHILOSOPHY (I, II) Doctoral thesis supervision by student's advisor in collaboration with the Thesis Commit-tee.

MTGN704. GRADUATE RESEARCH CREDIT: MAS-TER 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.

MTGN705. GRADUATE RESEARCH CREDIT: MAS-TER 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.

MTGN706. GRADUATE RESEARCH CREDIT: DOC-

Mining Engineering

TIBOR G. ROZGONYI, Professor and Department Head
M.U. OZBAY, Professor
LEVENT OZDEMIR, Professor and
    Director of Earth Mechanics Institute
BAKI YARAR, Professor
KADRI DAGDELEN, Associate Professor
MATTHEW J. HREBAR, III, Associate Professor
MASAMI NAKAGAWA, Associate Professor
MARK KUCHTA, Assistant Professor
MIKLOS D. G. SALAMON, Professor Emeritus

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 and computer aided mine design, rock mechanics, operations research applied to the mineral industry, 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 (rock) systems, rock mechanics and earth (rock) 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, mechnization of mines and underground construction, environmental and management aspects, modeling and design in geoengineering.

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 24 semester credit hours of course work, approved by student's graduate committee, plus a master's thesis. The Master of Science - Non-Thesis option must complete a minimum of 36 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 90 credit hours, beyond the bachelor's degree of which the Ph.D. Thesis shall be no fewer than 30 credit hours. The usual departmental requirement is a minimum of 60 credit hours of course work and 30 credit hours for thesis work. 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:

All graduate students are required to complete three core courses during their first academic year of study at CSM, depending upon their specialty and background.

These courses are:

MNGN505 - Rock Mechanics in Mining
MNGN512 - Surface Mine Design
MNGN516 - Underground Mining
Advanced Soil Mechanics (new, to be advised)
Underground Excavation (new, to be advised)
Fundamentals of Engineering Geology (new, to be advised)

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 Openings

Computerized Mine Design and Related Applications (including Geostatistical Modeling)

Advanced Integrated Mining Systems Incorporating Mine Mechanization and Mechanical Mining Systems

Underground Excavation (Tunneling) and Construction

Site Characterization and Geotechnical Investigations, Modeling and Design in Geoengineering.

Rock Fragmentation

Mineral Processing, Communition, 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: MNGN210, 314. 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: EGGN320 or concurrent enrollment. 3 hours lecture; 3 semester hours. Offered in odd years.

MNGN414. MINE PLANT DESIGN (I) Analysis of mine plant elements with emphasis on design. Materials handling systems, dewatering, hoisting, compressed air, and other power systems. Prerequisite: EGGN351, DCGN381 or EGGN384. 2 hours lecture, 3 hours lab; 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: SYGN101, credit or concurrent enrollment in EGGN320. 3 hours lecture; 3 semester hours.

MTGN422. 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 included. Prerequisites: Consent of instructor. 2 hours lecture; 2 semester hours.

MNGN423. SELECTED TOPICS (I, II) Special topics in mining engineering. Prerequisite: Approval of instructor. 1 to 3 semester hours.

MNGN424. MINE VENTILATION (II) Fundamentals of mine ventilation, including control of gas, dust, temperature, and humidity; stressing analysis and design of systems. Prerequisite: EGGN351, 371 and MNGN314. 2 hours lecture, 3 hours lab; 3 semester hours.

MNGN427. MINE VALUATION (I) Course emphasis is on the business aspects of mining. Topics include time valuation of money and interest formulas, cash flow, investment criteria, 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 consent of instructor. 2 hours lecture; 2 semester hours.

MNGN428. MINING ENGINEERING EVALUATION AND DESIGN REPORT I (I) 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) Preparation of formal engineering report based on all course work in the mining option. Emphasis is on mine design, equipment selection, production scheduling and evaluation. Prerequisite: MNGN427, 428. 3 hours lab; 1 semester hour.

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: MACS323 or equivalent course in statistics; senior or graduate status. 2 hours lecture, 3 hours lab; 3 semester hours.

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 consent of instructor permitted. 3 hours lecture, 3 hours lab; 3 semester hours.

MNGN438. INTRODUCTION TO GEOSTATISTICS (I) Introduction to the application and theory of geostatistics in the mining industry. Review of elementary statistics and traditional estimations techniques. Variograms, estimation variance, block variance, kriging, and geostatistical concepts are presented. Prerequisite: MACS323 or equivalent. 1 hour lecture, 3 hours lab; 2 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.

MNGN445. OPEN PIT SLOPE DESIGN (II) Introduction to the analysis and design of optimal pit slopes. Topics include: economic aspects of slope angles, rock mass classification and strength determinations, geologic structural parameters, properties of fracture sets, data collection techniques, hydrologic factors, methods of analysis, macrofab analysis, wedge intersections, monitoring and maintenance of final pit slopes, classification of slides. Prerequisite: MNGN321, GEOL308 or 309. 2 hours lecture; 2 semester hours.

MNGN446. SLOPE DESIGN LABORATORY (II) Laboratory and field exercise in slope analysis and design. Collection of data and specimens in the field for laboratory determination of physical properties for determination of slope angle stability. Application of computer software to slope stability determination for hard and soft rock environments. Prerequisite: MNGN321 and credit or concurrent registration in MNGN445. 3 hours lab; 1 semester hour.

MNGN482. MINE MANAGEMENT (II) Basic principles of successful mine management, supervision, administrative policies, industrial and human engineering. Prerequisite: Senior or graduate status or consent of instructor. 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.

MNGN499. 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.

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.

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.

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.

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: MACS404 or consent of instructor. 3 hours lecture; 3 semester hours. Offered in 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

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.

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.

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, MACS455 or consent of instructor. 3 hours lecture; 3 semester hours. Offered in even years.

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.

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 COMPUT-ERS 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 ESTI-MATION (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: MACS323 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. Prerequisite: MACS323 or equivalent and approval of department. 3 hours lecture; 3 semester hours. Offered in odd years.

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.

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 fragmenta-tion, 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 environmen-tal 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 EBGN504 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 under-ground 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), applica-tions 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 ENGINEER-ING (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.

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.

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 ENGINEER-ING (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.

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.

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. 6 semester hours upon completion of report.

MNGN701. GRADUATE THESIS-MASTER OF SCIENCE (I, II) Laboratory, field , or library work on an original investigation for the master's thesis under supervision of the graduate student's advisory committee. 6 semester hours upon completion of thesis.

MNGN703. GRADUATE THESIS-DOCTOR OF PHILOSOPHY (I, II) Preparation of the doctoral thesis conducted under supervision of the graduate student's advisory committee. 30 semester hours.

MNGN704 GRADUATE RESEARCH CREDIT: MAS-TER 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.

MNGN705 GRADUATE RESEARCH CREDIT: MAS-TER 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.

MNGN706 GRADUATE RESEARCH CREDIT: DOC-TOR 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.

GOGN501. SITE INVESTIGATION AND CHARACTER-IZATION An applications oriented course covering: geological data collection, geophysical methods for site investigation; hydrological data collection; materials properties determination; and various engineering classifica-tion systems. Presentation of data in a format suitable for subsequent engineering design will be emphasized. Prerequi-site: Introductory courses in geology, rock mechanics, and soil mechanics. 3 hours lecture; 3 semester hours.

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 empha-sized. 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-reinforce-ment, 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.

Petroleum Engineering

CRAIG W. VAN KIRK, Professor and Department Head
JOHN R. FANCHI, Professor
RICHARD L. CHRISTIANSEN, Associate Professor
RAMONA M. GRAVES, Associate Professor
ROBERT S. THOMPSON, Associate Professor
ERDAL OZKAN, Associate Professor
ALFRED W. EUSTES III, Assistant Professor
JON R. CARLSON, Research Professor
MARK G. MILLER, Research Assistant Professor
BILLY J. MITCHELL, Professor Emeritus
HOSSEIN KAZEMI, Adjunct Professor

Degrees Offered:

Master of Engineering (Petroleum Engineer)

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 degree or a Master of Engineering degree. For the Master of Science degree, a thesis is required in addition to course work. For the Master of Engineering degree, no thesis is required, but the course work requirement is greater than for the MS and a report is required. The effort required and subsequent value of the MS degree is considered equal to those of the ME degree. After admission to the graduate program, students may change from ME to MS, or vice versa, according to their needs and interests.

Applications from students having an ME or MS in Petroleum Engineering, or in another discipline, will be considered for admission to the Ph.D. program. To obtain the Doctor of Philosophy degree, a student must demonstrate unusual competence, creativity, and dedication in their field. In addition to extensive course work, a dissertation is required.

Program Requirements:

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
Doctor of Philosophy	Minimum 90 credit hours of which no less than 30 credit hours earned by research beyond the bachelor's degree or minimum 54 credit hours of which no less than 30 credit hours earned by research beyond the Master's degree

Candidates for the non-thesis Master of Engineering degree must complete 36 hours of graduate course credit. At least 27 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 a faculty advisor from the Petroleum Engineering Department. No graduate committee is required. A portion of the course credit requirement is an engineering report directed by a member of the Petroleum Engineering faculty. No more than six credit hours can be earned through independent study. For the ME degree, the student must demonstrate sound engineering thought and practice.

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 15 of the course credit hours must be from the Petroleum Engineering Department. Up to 9 credit hours may be transferred from another institution. Up to 9 credit hours of senior-level courses may be applied to the degree. All courses must be approved by the faculty advisor and the graduate committee. For the MS degree, the student must demonstrate ability to observe, analyze, and report original scientific research. 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 Bachelor's degree or at least 24 hours of course credit and a minimum of 30 credit hours of research beyond Master's degree. The credit hours to be counted toward a Ph.D. are dependent upon approval of the student's graduate committee. Students who enter the Ph.D. program with a bachelor's degree may transfer up to 24 graduate credit hours from another institution with the approval of a graduate advisor from the Petroleum Engineering Department. Students who enter the Ph.D. program with a master's degree may transfer up to 36 credit hours of course and research work from another institution upon approval by a graduate advisor from the Petroleum Engineering Department. For other requirements, refer to the general directions of the Graduate School in 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 must take PE681 in the Fall semester, PE682 in the Spring semester, and LICM515 for credit for one semester during their graduate programs. Also, students who do not have a BS degree in PE must take PE514 and other deficiency courses as required by the department as soon as possible in their graduate programs.

Fields of Research:

Current research topics include
- Formation evaluation
- Reservoir characterization and simulation
- Simulation of directional drilling
- Remediation of contaminated soils and aquifers
- Oil recovery processes
- Rock and fluid properties
- Completion and stimulation of wells
- Economics and management
- Natural gas engineering
- Coalbed methane
- Geothermal energy
- Phase behavior
- Artificial lift
- Rock mechanics
- Directional drilling
- Drill bit vibration analysis
- Tubular buckling
- Drilling wave propagation
- Drillstring dynamics
- Fuzzy logic controllers

Research projects generally involve professors and graduate students from other disciplines - Geology, Geophysics, Chemical Engineering, and others - in addition to Petroleum Engineering. Projects often include off-campus laboratories, institutes, and other resources.

Special Features:

In an exchange program with the Petroleum Engineering Department of the University of Leoben, Austria (ULA), a student can spend one semester in Austria during graduate studies and receive full transfer of credit back to 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 session for undergraduate students. In the past, the field session students have visited oil and gas operations in Europe, Alaska, Canada, Southern California, and the Gulf Coast.

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

PEGN408/EGES408. INTRODUCTION TO OFFSHORE TECHNOLOGY (II) Introduction to practical offshore engineering/design technology for the exploration, drilling, production and transportation of petroleum in the ocean. Practical analysis methods of environmental forces, hydrodynamics, structural responses, and pipe flows for the design of platform, riser, subsea completion and pipeline systems, including environment-hydrodynamic-structure interactions. System design parameters. Industry practice and the current state of the art technology for deep ocean drilling. Prerequisite: MACS315 or consent of instructor 3 hours lecture; 3 semester hours.

PEGN411. MECHANICS OF PETROLEUM PRODUC-TION (II) Nodal analysis for pipe and formation deliverability including single and multiphase flow. Natural flow and design of artificial lift methods including gas lift, sucker rod pumps, electrical submersible pumps, and hydraulic pumps. Prerequisite: PEGN308, PEGN310, PEGN311, and EGGN351. 3 hours lecture; 3 semester hours.

PEGN413. GAS MEASUREMENT AND FORMATION EVALUATION LAB (I) This lab investigates the properties of a gas such as vapor pressure, dew point pressure, and field methods of measuring gas volumes. The application of well logging and formation evaluation concepts are also investigated. Prerequisites: PEGN308, PEGN310, and PEGN419. 3 hours lab; 1 semester hour.

PEGN414. WELL TEST ANALYSIS AND DESIGN (II) Solutions to the diffusivity equation. Transient well testing: build-up, drawdown, multi-rate test analyses for oil and gas. Flow tests and well deliverabilities. Type curve analysis. Superposition, active and interference tests. Well test design. 3 hours lecture; 3 semester hours.

PEGN419. WELL LOG ANALYSIS AND FORMATION EVALUATION (I) An introduction to well logging methods, including the relationship between measured properties and reservoir properties. Analysis of log suites for reservoir size and content. Graphical and analytical methods will be developed to allow the student to better visualize the reservoir, its contents, and its potential for production. Use of the computer as a tool to handle data, create graphs and log traces, and make computations of reservoir parameters is required. Prerequisites: PEGN308, PEGN310, concurrent enrollment in GEOL308. 2 hours lecture, 3 hours lab; 3 semester hours.

PEGN422. ECONOMICS AND EVALUATION OF OIL AND GAS PROJECTS (I) Project economics for oil and gas projects under conditions of certainty and uncertainty. Topics include time value of money concepts, discount rate assumptions, measures of project profitability, costs, state and local taxes, federal income taxes, expected value concept, decision trees, bayesian analysis, the decision to purchase imperfect information, gambler's ruin, and monte carlo

simulation techniques. Prerequisite: MACS323. 3 hours lecture; 3 semester hours.

PEGN423. PETROLEUM RESERVOIR ENGINEERING I (I) Data requirements for reservoir engineering studies. Material balance calculations for normal gas, retrograde gas condensate, solution-gas and gas-cap reservoirs with or without water drive. Primary reservoir performance. Forecasting future recoveries by incremental material balance. Prerequisites: PEGN316, PEGN419 and MACS315 (MACS315 only for non PEGN majors). 3 hours lecture; 3 semester hours.

PEGN424. PETROLEUM RESERVOIR ENGINEERING II (II) Reservoir engineering aspects of supplemental recovery processes. Introduction to liquid-liquid displace-ment processes (polymer, water, caustic, miscible, and surfactant flooding). Gas-liquid displacement processes (lean gas, rich gas, and CO2). Thermal recovery processes (steam and in situ combustion). Introduction to numerical reservoir simulation, history matching and forecasting. Prerequisite: PEGN423. 3 hours lecture; 3 semester hours.

PEGN426. WELL COMPLETION AND STIMULATION (I) Completion parameters; design for well conditions. Perforating, sand control, skin damage associated with completions and well productivity. Fluid types and properties; characterization of compatibilities. Stimulation techniques: acidizing and fracturing. Selection of proppants and fluids; types, placement and compatibilities. Estimation of rates, volumes and fracture dimensions. Reservoir considerations in fracture propagation and design. Prerequi-site: PEGN311, PEGN361, PEGN411 and MACS315. 3 hours lecture; 3 semester hours.

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.

PEGN439/GEGN439/GPGN439. MULTIDISCIPLINARY PETROLEUM DESIGN (II) This is a multidisciplinary design course that integrates fundamentals and design concepts in geology, geophysics, and petroleum engineering. Students work in integrated teams consisting of students from each of the disciplines. Multiple open-ended design problems in oil and gas exploration and field development are assigned. Several written and oral presentations are made throughout the semester. Project economics including risk analysis are an integral part of the course. Prerequisites: PE majors: PEGN316, PEGN414, PEGN422, PEGN423, PEGN424 (or concurrent) GEOL308; GE Majors: GEOL308 or GEOL309, GEGN316, GEGN438; GP Majors: GPGN302 and GPGN303. 2 hours lecure; 3 hours lab; 3 semester hours.

PEGN481. PETROLEUM SEMINAR (I) Written and oral presentations by each student on current petroleum topics, presentations by each student. Prerequisite: Consent of department. 2 hours; 1 semester hour.

PEGN498. SPECIAL TOPICS (I, II) Group 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 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 METH-ODS TO PETROLEUM ENGINEERING (I) 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 AND CEMENTING (I) The physical properties and purpose of drilling fluids and cement are investigated. Emphasis is placed on drilling fluid design, clay chemistry, cementing operations, design, and testing; and solids control. Prerequisite: PEGN428 or consent of instructor.
2 hours lecture, 3 hours lab; 3 semester hours.

PEGN503/GEGN503/GPGN503. INTEGRATED EXPLO-RATION 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.

PEGN504/GEGN504/GPGN504. INTEGRATED EXPLO-RATION AND DEVELOPMENT (II) Students work in multidisciplinary teams to study practical problems and case studies in integrated subsurface exploration and develop-ment. 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 presentations. Prerequisite: Consent of instructor. 3 hours lecture and seminar; 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 (II) 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 (II) 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 (I) 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: PEGN424 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 understand-ing 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 (I) 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 is presented. Both stabilized and isochronal deliverability testing of gas wells

will be illustrated. Finally, gas storage, to meet peak load demand is also covered. Prerequisite: PEGN423 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN513. RESERVOIR SIMULATION I (I) Mathematics for petroleum engineering calculations. Development of fluid flow equations pertinent to petroleum production. Solutions to diffusivity equations. Numerical reservoir simulation by finite differences and finite element methods. Prerequisite: PEGN424 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN514. PETROLEUM TESTING TECHNIQUES (I) 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. 3 hours lab; 1 semester hour. Required for students who do not have a B.S. in PE.

PEGN519. ADVANCED FORMATION EVALUATION (I) 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 DESIGN (I) 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 (I) 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 EBGN504 or ChEN504 or MNGN427 or ChEN421 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN524. PETROLEUM ECONOMICS AND MAN-AGEMENT (II) 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.

PEGN538/EGES538. INTRODUCTION TO OFFSHORE TECHNOLOGY (II) Introduction to offshore engineering technology for exploration drilling, production and transportation of petroleum in the ocean. Practical analysis methods for determining environmental forces, structural response, and pipe flow for the design of platforms, risers, subsea completion and pipeline systems, including environment-hydrodynamic-structure interactions. System design parameters. Industrial practice and state-of-the-art technology for deep ocean drilling. Prerequisite MACS315 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 composite models. 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. Spider diagrams. Two and three dimensional directional planning. Optimal plug back depths. Collison diagrams. Surveying and trajectory calculations. Surface and down hole equipment. Common rig operating procedures, and horizontal drilling techniques. Prerequisites: PEGN311, PEGN428 or equivalent, or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN595. ADVANCED DRILLING AND DEVELOP-MENT (I) Lectures, seminars, and technical problems with emphasis on well planning, rotary rig supervision, and field practices for execution of the plan. Prerequisite: PEGN428 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN596. PRESSURE CONTROL WHILE DRILLING 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 blowouts, 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. Prerequisites: PEGN311 and PEGN428 or consent of instructor. 2 hours lecture, 3 hours simulator; 3 semester hours.

PEGN597. WELL TUBULAR DESIGN Fundamentals of tubulars (casing, tubing, and drill pipe) design applied to

drilling. Major topics covered include: Dogleg running loads. Directional hole considerations. Writing of design criteria equations. 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. Connections. Common rig operating procedures. Much more. Prerequisites: PEGN311, PEGN428 or equivalent, or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN598. SPECIAL TOPICS IN PETROLEUM 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.

PEGN599. 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.

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 (II) 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: PEGN428 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 (II) 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 (II) 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 (I) 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 (II) 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 (II) Current techniques for conducting reservoir simulation studies of petroleum reservoirs. Methods for discretizing reservoirs, fluid, and production data. Techniques involved in model equilibration, history matching, and predictions. Black-oil and compositional models. Single-well and field-wide models including 3-dimensional and 3-phase flow. Prerequisite: PEGN513 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN681. PETROLEUM ENGINEERING SEMINAR (I) Comprehensive reviews of current petroleum engineering literature, research, and selected related topics. 2 hours seminar; 1 semester hour. Required of all candidates for advanced degree in petroleum engineering.

PEGN682. PETROLEUM ENGINEERING SEMINAR (II) Comprehensive reviews of current petroleum engineering literature, research, and selected related topics. 2 hours seminar; 1 semester hour. Required of all candidates for advanced degree in petroleum engineering.

PEGN698. SPECIAL TOPICS IN PETROLEUM 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.

PEGN699. 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.

PEGN701. GRADUATE THESIS-MASTER OF SCIENCE (I, II) Laboratory, field, and library work for the master's thesis under supervision of the graduate student's advisory committee.

PEGN703. GRADUATE THESIS-DOCTOR OF PHI-LOSOPHY (I, II) Investigations for Doctor of Philosophy thesis under direction of the student's advisory committee.

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.

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.

Physics

JAMES A. McNEIL, Professor and Department Head
F. EDWARD CECIL, Professor
REUBEN T. COLLINS, Professor
THOMAS E. FURTAK, Professor
FRANK V. KOWALSKI, Professor
FRANKLIN D. SCHOWENGERDT, Professor
JOHN U. TREFNY, Professor and Vice President for Academic Affairs
TIMOTHY R. OHNO, Associate Professor
DAVID M. WOOD, Associate Professor
CHARLES G. DURFEE, Assistant Professor
JON H. EGGERT, Assistant Professor
UWE GREIFE, Assistant Professor
MARIET A. HOFSTEE, Assistant Professor
PETER W. SUTTER, Assistant Professor
TODD RUSKELL, Lecturer
BRUCE H. MEEVES, Instructor
JAMES T. BROWN, Professor Emeritus
DON L. WILLIAMSON, Professor Emeritus
F. RICHARD YEATTS, Professor Emeritus
WILLIAM B. LAW, Associate Professor Emeritus
ARTHUR Y. SAKAKURA, Associate Professor Emeritus
ROBERT F. HOLUB, Research Professor
VICTOR KAYDANOV, Research Professor
JEROME G. MORSE, Research Professor
JAMES E. BERNARD, Research Associate Professor

Degrees Offered:

Master of Science (Physics)

Doctor of Philosophy (Applied Physics)

Program Description:

The Physics Department at CSM offers a full program of instruction and research leading to the Ph.D. in applied physics and the M.S. in 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 Physics and Applied Physics will select an initial program in consulta-tion with the departmental Graduate Council 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: 24 semester hours of course work in an approved program plus 12 semester hours of research credit, with a satisfactory thesis; no foreign language is required. Fifteen semester hours of course work plus thesis must be taken in residence.

Doctorate: 44 semester hours of course work in an approved program plus 28 semester hours of research credit,

with a satisfactory thesis. Minors are available in one of the following: Chemical Engineering, Chemistry, Geology, Geophysics, Materials Science, Mathematics, Metallurgy, Mining, or Petroleum Engineering. A written and oral comprehensive exam is required.

Prerequisites:

The Graduate School of Colorado School of Mines is open to graduates from four-year programs at recognized colleges or universities. Admission to the Physics Department M.S. and Ph.D. programs is competitive, 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, and a student may not be a candidate for a graduate and an undergraduate degree at the same time.

Required Curriculum:

Master of Science, Physics

PHGN505 Classical Mechanics I
PHGN507 Electromagnetic Theory I
PHGN520 Quantum Mechanics I
PHGN521 Quantum Mechanics II
PHGN530 Statistical Mechanics
Electives and Graduate Seminars - 9 hours.
Master's Thesis

Doctor of Philosophy, Applied Physics

PHGN505 Classical Mechanics I
PHGN507 Electromagnetic Theory I
PHGN511 Mathematical Physics I
PHGN520 Quantum Mechanics I
PHGN521 Quantum Mechanics II
PHGN530 Statistical Mechanics
PHGN608 Electromagnetic Theory II
Electives and Graduate Seminars - 11 hours.

12 hour minor: as specified in the general requirements of the graduate school

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..

Doctoral Thesis.

Fields of Research:

Theoretical

Field Theory
Nuclear Theory
Condensed Matter Theory

Experimental

Applied Optics: lasers, spectroscopy, near-field microscopy, non-linear optics
Nuclear: Low energy reactions, nuclear astrophysics, environmental physics

Electronic Materials: Photovoltaic materials, thin film semiconductors, transparent conductors, nanocrystalline materials, ion beam processing
Solid State: Mössbauer spectroscopy, small-angle x-ray scattering, x-ray diffraction, Raman spectroscopy, polymers, amorphous materials, magnetic materials, granular materials, high pressure physics
Surface and Interface Physics: X-ray photoelectron spectroscopy, Auger spectroscopy, scanning probe microscopies

Description of Courses

Senior Level

PHGN402. GREAT PHYSICISTS (II) The lives, times, and scientific contributions of key, historical physicists are explored in an informal seminar format. Each week a member of the faculty will lead discussions about one or more different scientists who have figured significantly in the development of the discipline. Prerequisite: None. 1 hour lecture; 1 semester hour.

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: MACS347. 3 hours lecture; 3 semester hours.

PHGN419. PRINCIPLES OF SOLAR ENERGY SYSTEMS(II) 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 (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. Prerequisite: PHGN320, PHGN350, PHGN361. 3 hours lecture; 3 semester hours.

PHGN421. ATOMIC PHYSICS (II) A study of the fundamental particles of matter, atomic structure, and spectra. Application of the Schroedinger equation to

hydrogen-like atoms. Prerequisite: PHGN320. 3 hours lecture; 3 semester hours.

PHGN422. NUCLEAR PHYSICS Introduction to sub-atomic (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 (I) 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/CRGN435. INTERDISCIPLINARY MICRO-ELECTRONICS PROCESSING LABORATORY (I) 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. Due to lab space the enrollment is limited to 20 students. 1.5 hours lecture, 4 hours lab; 3 semester hours.

PHGN440/MLGN502. SOLID STATE PHYSICS (II) 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 APPLI-CATION 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 (I) 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; MACS347. 3 hours lecture; 3 semester hours.

PHGN460. PLASMA PHYSICS Review of Maxwell's equations; charged-particle orbit in given electromagnetic fields; macroscopic behavior of plasma, distribution functions; diffusion theory; kinetic equations of plasma; plasma oscillations and waves, conductivity, magnetohydrodynamics, stability theory; Alven waves, plasma confinement. Prerequisite: PHGN300/310. 3 hours lecture; 3 semester hours. Offered on sufficient demand.

PHGN462. ADVANCED ELECTROMAGNETISM (I) Continuation of PHGN361. The solution of boundary value problems in curvilinear coordinates; solu tions to the wave equation including plane waves, refraction, interference and polarization; waves in bounded regions, radiation from charges and simple antennas; relativistic electrodynamics. 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 or special topics course. Prerequisites: Consent of department. 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, 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.

Graduate Courses

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

PHGN501. GRADUATE SEMINAR (I) Graduate students will attend the weekly Physics Colloquium and, in addition, attend a weekly, one-hour, student-based seminar coordinated by a faculty member. Students will be responsible for presentations during this weekly seminar. 1 hour seminar; 1 semester hour.

PHGN502. GRADUATE SEMINAR (II) Graduate students will attend the weekly Physics Colloquium and, in addition, attend a weekly, one-hour, student-based seminar coordinated by a faculty member. Students will be responsible for presentations during this weekly seminar. 1 hour seminar; 1 semester hour.

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: Consent of instructor. 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. Additional of angular momenta, Wigner-Eckart theorem, selection rules, identical particles. Prerequisite: PHGN520. 3 hours lecture; 3 semester hours.

PHGN525/MLGN525. 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.

PHGN530. STATISTICAL MECHANICS (II) Review of thermodynamics; equilibrium and stability; statistical operator and ensembles; ideal systems; phase transitions; non- equilibrium systems. Prerequisite: PHGN341or equivalent and PHGN520. Co-requisite: PHGN521. 3 hours lecture; 3 semester hours.

PHGN540/MLGN507. 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.

PHGN541/MLGN508. 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: PHGN540/MLGN507. 3 hours lecture; 3 semester hours.

PHGN542. SOLID STATE DEVICES (I) 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. Offered every other year in alternation with PHGN544.

PHGN544. THEORY AND OPERATION OF PHOTO-VOLTAIC DEVICES (I) 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. Offered every other year in alternation with PHGN542.

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 (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, 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.

PHGN601. ADVANCED GRADUATE SEMINAR (I) Graduate students will attend the weekly Physics Collo- quium and, in addition, attend a weekly, one-hour, student- based seminar coordinated by a faculty member. 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) Graduate students will attend the weekly Physics Collo- quium and, in addition, attend a weekly, one-hour, student- based seminar coordinated by a faculty member. 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.

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.

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, 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.

PHGN701. GRADUATE THESIS-MASTER OF SCI- ENCE (I, II, S) Preparation of master's thesis under supervision of the graduate student's advisory committee. Required of all candidates for the degree of Master of Science. 6 semester hours upon completion of thesis.

PHGN703. GRADUATE THESIS-DOCTOR OF PHI- LOSOPHY (I, II, S) Conducted under the supervision of student's doctoral committee. Required of candidates for the degree of Doctor of Philosophy. 30 semester hours credit

PHGN705. GRADUATE RESEARCH CREDIT: MAS- TER 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: DOC- TOR 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.

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 materials. The laboratory is supported by an industrial consortium that holds semi-annual meetings 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 National Science Foundation (NSF), the Department of Energy (DOE), the Electric Power Research Institute (EPRI), Colorado School of Mines (CSM) and several other universities. The mission of ACEPS is to conduct fundamental research and applied research supporting the technical advancement of the electric utility industry, their customers, and component suppliers in the field of electric power systems with special emphasis on the advanced/intelligent control and power quality in the generation, transmission, distribution, and utilization stages; using such research as a means of advancing graduate education.

Center research projects focus on the development of an intelligent energy system that will employ advanced power electronics, enhanced computer and communications systems, new smart sensor and actuators, and smart interactive utility/customer interface systems. Examples include: electric vehicles and their impact on power quality, localized and adaptive monitoring systems for transmission and distribution networks, and intelligent automatic generation control for transient loads.

Due to the strong interest shown by other institutions and national and international utilities, ACEPS has been transformed into an NSF Mega-Center which includes ten other universities and more than thirty industrial members. With this expansion, and given the electric power deregulation phase, the power center has become a key national resource for the Research & Development (R&D) needs of this major industrial sector.

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 Center for Automation, Robotics and Distributed Intelligence (CARDI) focuses on the study and application of advanced engineering and computer science research in neural networks, robotics, data mining, image processing, signal processing, sensor fusion, information technology, distributed networks, sensor actuator development and artificial intelligence, to problems in environment, energy, natural resources, materials, transportation, information, communications and medicine. CARDI 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. The systems require closed loop controllers that incorporate artificial intelligence and machine learning techniques to reason autonomously or in cooperation with a human supervisor.

Established in 1994, CARDI includes faculty from the Division of Engineering, departments of Mathematical and Computer Science, Geophysics, Metallurgical and Materials Engineering, and Environmental Science and Engineering. 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 robotics and intelligent systems.

Center for Combustion and Environmental Research

The Center for Combustion and Environmental Research (CCER) is an interdisciplinary research and educational unit specializing in the chemistry and physics of exothermic reacting flows. Specific research projects are varied, but they fall into five core areas: detailed combustion chemical kinetic modeling and experiment; combustion flow-field modeling and experiment; combustion spray and aerosol modeling and experiment; optical sensing techniques in combustion; and combustion emissions remediation.

Collaborative projects involve CSM's Engineering Division and Chemical Engineering and Petroleum Refining Department, and often include faculty and students from other universities. Interaction with federal and industrial sponsors not only helps to guide the Center's program, but offers students opportunities after graduation.

Center for Commercial Applications of Combustion in Space

The Center for Commercial Applications of Combustion in Space (CCACS) is a NASA/Industry/ University space commercialization center based at the Colorado School of Mines. The mission of the Center is to assist industry in developing commercial products by conducting combustion research which takes advantage of the unique properties of space.

The Center operates under the auspices of NASA's Office of Space Product Development (OSPD), whose mission is to provide access to space for commercial research and development activities by private industry. The focus of CCACS is on products and processes in which combustion plays a key role and which can benefit from knowledge to be gained through experiments conducted in space. Examples include combustors, fire suppression and safety, combustion synthesis of advanced materials and sensors and controls. The Center involves faculty and students from the departments of Chemical Engineering, Engineering, Metallurgical and Materials Engineering, and Physics. For further information, contact CCACS Director F.D. Schowengerdt, Physics Department, CSM, (303) 384-2091.

Center for Engineering Education

The CSM Center for Engineering Education marries educational research with assessment, outreach and teaching. The Center serves as a focal point for educational research conducted by CSM faculty. Successfully educating tomorrow's scientists and engineers 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 educational research, informed by the principles of cognitive and educational psychology, along with the application of that research, and teaching, are linked and interrelated.

The primary goals of the Center for Engineering Education are

♦ To conduct world-class research on teaching and learning in science and engineering.

♦ To use the results of that research to continually improve 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 and graduate 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, Economics and Business, 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, Rocky Mountain Musculoskeletal Research Laboratories (RMMRL), University of Colorado Health Sciences Center and the Colorado VA Research Center. Established at CSM as a National Science Foundation (NSF) Industry/University Cooperative Research Center, IBDMS is also supported by industry and State organizations.

IBDMS has become an international center for the development of Bionic Orthopaedics, sports medicine,

human sensory augmentation, and smart orthoses. Through the efforts of this center, new major and minor programs in bioengineering and biotechnology are being established at both the CSM graduate and undergraduate levels.

With its Industrial Advisory Board (IAB), IBDMS seeks to establish educational programs and long-term basic and applied research efforts that improve U.S. technology. 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.

Center for Research on Hydrates and Other Solids

The Center for Research on Hydrates and Other Solids is sponsored by a consortium of fifteen industrial and government entities. The center focuses on research and education involving solids in hydrocarbon and aqueous fluids which affect exploration, production and processing of gas and oil.

Involving over twenty students and faculty from five departments, the center provides a unique combination of expertise that has enabled CSM to achieve international prominence in the area of solids. CSM participants interact on an on-going basis with sponsors, including frequent visits to their facilities. For students, this interaction often continues beyond graduation, with opportunities for employment at sponsoring industries.

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 the area of electronic materials for solar and related applications. CSEM facilitates interdisciplinary collaborations across the CSM campus; fosters interactions with national laboratories, industries, public utilities, and other universities; and serves to guide and strengthen the electronic materials curriculum.

CSEM draws from expertise in the departments of Physics, Metallurgical and Materials Engineering, Chemical Engineering and Petroleum Refining, Chemistry and Geochemistry, and from the Division of Engineering. The largest research activity is directed at the photovoltaic industry. CSEM also supports research in thin film materials, polymeric devices, electrophotography, encapsulants, electronic materials processing, and systems issues associated with electronic materials and devices.

Graduate students in materials science and the above-mentioned departments can pursue research on center-related projects. Undergraduates are involved through engineering design courses and summer research. 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 attempt to solve real world problems. External contacts also provide guidance in targeting the educational curriculum toward the needs of the electronic materials industry.

Center for Wave Phenomena

With sponsorship for its research by 27 companies in the worldwide oil exploration industry, this interdisciplinary program, including faculty and students from the Mathematical and Computer Sciences and Geophysics Departments, is engaged in a coordinated and integrated program of research in inverse problems and problems of seismic data processing and interpretation. Its methods have applications to seismic exploration, mapping of the seabed, ocean sound-speed profiling, and nondestructive testing and evaluation, among other areas. Extensive use is made of analytical techniques, especially asymptotic methods and computational techniques. Methodology is developed through computer implementation, based on the philosophy that the ultimate test of an inverse method is its application to field or experimental data. Thus, the group starts from a physical problem, develops a mathematical model that adequately represents the physics, derives an approximate solution technique, generates a computer code to implement the method, tests on synthetic data, and, finally, tests on field data.

Center for Welding, Joining and Coatings Research

The Center for Welding, Joining and Coatings Research (CWJCR) is an integral part of the Department of Metallurgical and Materials Engineering. The goal of CWJCR is to promote education and research, and to advance understanding of the metallurgical aspects of welding, joining and coating processes. The Center's current activities include: education, research, conferences, short courses, seminars, information source and transfer, and industrial consortia.

The Center for Welding, Joining and Coatings Research assists the Metallurgical and Materials Engineering Department by providing numerous opportunities which directly contribute to the student's professional growth. Some of these opportunities include:

Direct involvement in the projects which constitute the Center's research program.

Interaction with internationally recognized visiting scholars.

Industrial collaborations which 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 and materials professional societies.

Colorado Advanced Materials Institute

With a mission to coordinate and foster research in materials science and engineering leading to economic development, CAMI was established in 1984 by the State of Colorado at CSM. Located at CSM, the Institute functions as a consortium of state government, research universities (CSM, CU, CSU, and DU), and private industries.

CAMI is funded by the Colorado Commission on Higher Education and has several programs aimed at promoting effective partnerships between Colorado industry and universities. CAMI's Seed Grant program provides grants to faculty for exploratory work on materials technology problems of interest to industry in the state. These seed grants enable investigators to develop subsequent proposals for additional funding from federal and industry sources, thus leveraging the state investment.

The Institute also sponsored an Entrepreneur's Technology Assistance Program that enabled start-up technology-based companies to use the unique expertise and equipment available at the research universities. These grants to university/small business teams were designed to help the entrepreneur develop his new technology into a commercial product or service. Currently CAMI has a similar program, the Colorado Tire Recycle Technology Assistance (Tire-Tap), which promotes development of new technologies focused on recycling the huge amount of scrap tires rapidly accumulating in the state.

CAMI grants are solicited annually with a Request For Proposals (RFP) and subsequently awarded on a competitive basis with reviews from a board of experts from Colorado Corporations, small business, academia, venture capitalists, business incubators and government leaders. These programs all provide an excellent opportunity for undergraduate and graduate students to work on real problems of immediate concern to industry.

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 porous ceramics and metals for filters; nano-scale powder preparation and mechanics; ceramic-metal composites; fuel cell, solar cell and battery materials; high temperature gas corrosion; glass fiber forming; 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 Institute for Fuels and High-Altitude Engine Research

The Colorado Institute for Fuels and High Altitude Engine Research (CIFER) is an interdisciplinary research institute involving faculty and students from several academic departments at the Colorado School of Mines. CIFER was formed to assist industry, State and Federal governments in developing and implementing clean air policy for the benefit of the U.S. and particularly for high altitude communities through the development of newer, cleaner burning fuels and the technology to properly use fuels.

The overall objective of CIFER is to enhance air quality through research, development and education in relation to heavy-duty mobile sources through its specific strengths in fuels science, catalysis, materials, combustion science and analytical chemistry.

CIFER manages two laboratory facilities: The Heavy Duty Laboratory, located at the Denver Regional Transportation District facility, performs complete emissions and performance analyses of transit buses and large trucks; and The CSM Fuels Laboratory, which operates on the CSM campus. Additional laboratory capabilities are available to CIFER through CSM member academic departments.

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.

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 a six-day interdisciplinary program for educators, the media, government officials, industry, and the financial community. A six-day program is also conducted for Washington congressional aides and agency personnel. 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.

Institute for Resource and Environmental Geosciences

The Institute for Resource and Environmental Geosciences (IREG) was established to advance interdisciplinary earth science research. Its board of directors is comprised of the heads of the Departments of Engineering, Geology and Geological Engineering, Geophysics, Math and Computer Science, Mineral Economics and Petroleum Engineering. IREG's mission is to stimulate innovation and support initiatives in integrated, multidisciplinary research and education of earth scientists and engineers for resource exploration and production, geo-engineering and applied environmental geo-sciences.

IREG conducts interdisciplinary energy and environmental restoration research projects for industry and government. Areas of expertise include: integrated geology, geophysics, environmental science and petroleum engineering; geohydrologic modeling; subsurface characterization; fate and transport; risk assessment; groundwater contamination and containment; remediation technologies testing; geostatistics/modeling/neural networks. Current projects include site characterization, development of test beds to test proposed in situ remediation technologies, rapid identification of microbes, dust and aerosol characterization, stratigraphic inversion at the Brent/Mesa Verde field, and development of geoscience inversion methods.

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.

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 Chemistry and Geochemistry, 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) works on the forefront of new multicomponent 3-D seismic technology in the optimization of reservoir development. Multicomponent seismic data are recorded, processed and interpreted to increase the fidelity of seismic data to define structural and stratigraphic variations in the subsurface. Application of the new integrated reservoir technologies leads to enhanced recovery of hydrocarbons from reservoirs.

The RCP consortium was established in 1985 and includes 30 national and international companies. Faculty and students from the departments of Geophysics, Geology and Geological Engineering, and Petroleum Engineering are provided the opportunity to work closely with industrial contacts in areas both educational and research.

W.J. Kroll Institute for Extractive Metallurgy

A grant from the late W.J. Kroll, the inventor of the Kroll Process for the production of Titanium and Zirconium, enabled the establishment of an Institute for Extractive Metallurgy in the Department of Metallurgical and Materials Engineering. Today the primary focus of the Institute is the development of new technologies for the physical-chemical processing of materials. This includes the production and refining of metals, the processing of wastes and hazardous materials, the recycling of materials, and the synthesis of advanced materials. The Institute supports the education of students through the awarding of Fellowships and Research Assistantships, provides opportunities for Visiting Scholars, arranges for the teaching of short courses in subjects related to the mission of the Institute, and undertakes a wide range of sponsored research projects.

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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 Personnel and Affirmative Action, 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 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 ten individuals shall be selected at random in the following manner. Five initial panel members shall be selected from the CSM group of which the Complainant is a member, i.e., classified staff, exempt employees, undergraduate students, or graduate students, and the five remaining initial panel members shall be selected from the CSM group of which the Respondent is a member. The Complainant and the Respondent shall each disqualify two of the initial panel members. The disqualifications exercised by the parties shall proceed in an alternate fashion beginning with the Complainant. Of the remaining initial panel members, the one chosen last shall serve as an alternate hearing panel member. The other five 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 any 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 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. Complaint'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 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 consists 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, 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 individual 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 Re-

sources 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 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 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.

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)

Index