Materials Science

Degrees Offered

- Master of Science (Materials Science; thesis option or non-thesis option)
- Doctor of Philosophy (Materials Science)

Program Description

The interdisciplinary graduate program in Materials Science exists to educate students, with at least a Bachelor of Science degree in engineering or science, in the diverse field of Materials Science. This diversity includes the four key foundational aspects of Materials Science – materials properties including characterization and modeling, materials structures, materials synthesis and processing and materials performance – as applied to materials of a variety of types (i.e., metals, ceramics, polymers, electronic materials and biomaterials). The Materials Science graduate program is responsible for administering MS (thesis and non-thesis) and PhD Degrees in Materials Science.

This interdisciplinary degree program coexists along side strong disciplinary programs in Chemistry, Chemical and Biochemical Engineering, Mechanical Engineering, Metallurgical and Materials Engineering, Mining, and Physics. The student's graduate committee will have final approval of the course of study.

Fields of Research

- Advanced polymeric materials
- Alloy theory, concurrent design, theory-assisted materials engineering, and electronic structure theory
- Applications of artificial intelligence techniques to materials processing and manufacturing, neural networks for process modeling and sensor data processing, manufacturing process control
- Atomic scale characterization
- Atom Probe Tomography
- Biomaterials
- Ceramic processing, modeling of ceramic processing
- Characterization, thermal stability, and thermal degradation mechanisms of polymers
- Chemical and physical processing of materials, engineered materials, materials synthesis
- Chemical vapor deposition
- Coating materials and applications
- Computational condensed-matter physics, semiconductor alloys, first-principles phonon calculations
- Computer modeling and simulation
- Control systems engineering, artificial neural systems for senior data processing, polymer cure monitoring sensors, process monitoring and control for composites manufacturing
- Crystal and molecular structure determination by X-ray crystallography
- Electrodeposition
- Electron and ion microscopy
- Energetic materials (explosives) and processing
- Energy storage
- Experimental condensed-matter physics, thermal and electrical properties of materials, superconductivity, photovoltaics
- Fuel cell materials
- Fullerene synthesis, combustion chemistry
- Heterogeneous catalysis, reformulated and alcohol fuels, surface analysis, electrophotography
- High temperature ceramics
- Intelligent automated systems, intelligent process control, robotics, artificial neural systems
- Materials synthesis, interfaces, flocculation, fine particles
- Mathematical modeling of material processes
- Mechanical metallurgy, failure analysis, deformation of materials, advanced steel coatings
- Mechanical properties of ceramics and ceramic composites
- High entropy alloys
- Mössbauer spectroscopy, ion implantation, small-angle X-ray scattering, semiconductor defects
- Nano materials
- Non-destructive evaluation
- Non-ferrous structural alloys
- Novel separation processes: membranes, catalytic membrane reactors, biopolymer adsorbents for heavy metal remediation of ground surface water
- Numerical modeling of particulate media, thermomechanical analysis
- Optical properties of materials and interfaces
- Phase transformations and mechanisms of microstructural change
- Photovoltaic materials and device processing
- Physical metallurgy, ferrous and nonferrous alloy systems
- Physical vapor deposition, thin films, coatings
- Power electronics, plasma physics, pulsed power, plasma material processing
- Processing and characterization of electroceramics (ferro-electrics, piezoelectrics, pyroelectrics, and dielectrics)
- Semiconductor materials and device processing
- Soft materials
- Solidification and near net shape processing
- Surface physics, epitaxial growth, interfacial science, adsorption
- Thermoelectric materials
- Transport phenomena and mathematical modeling
- Weld metallurgy, materials joining processes
- Welding and joining science

COMBINED DEGREE OPTION

Mines undergraduate students have the opportunity to begin work on a MS non-thesis degree while concurrently completing their Bachelor's degree at Mines.

DUAL DEGREE PROGRAM OPTION

Students have the opportunity to earn two degrees with the dual degree option. Students complete coursework to satisfy requirements for both a non-thesis MS in Materials Science from the Colorado School of Mines and a MS of Physical Chemistry and Chemical Physics from the University of Bordeaux.
Program Requirements
Each of the three degree programs (non-thesis MS, thesis-based MS, and PhD) require the successful completion of three core courses for a total of 9 credit hours that will be applied to the degree program course requirements. Depending upon the individual student's background, waivers for these courses may be approved by the program director. In order to gain a truly interdisciplinary understanding of Materials Science, students in the program are encouraged to select elective courses from several different departments outside of their home department. Course selection should be completed in consultation with the student's advisor or program director as appropriate.

Mines' Combined Undergraduate / Graduate Degree Program
Students enrolled in Mines' combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Double counting only applies towards the Master of Science Non-Thesis Option (not a thesis MS or a PhD).

Any 400+ level courses that count towards the undergraduate degree requirements as "Elective Coursework" or any 500+ level course, may be used for the purposes of double counting at the discretion of the graduate advisor. These courses must have been passed with a "B" or better, not be substitutes for required coursework, and meet all other University, Department, Division, and Program requirements for graduate credit.

Listed below are the three required Materials Science core courses:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>MLGN591</td>
<td>MATERIALS THERMODYNAMICS</td>
<td>3.0</td>
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<tr>
<td>MLGN592</td>
<td>ADVANCED MATERIALS KINETICS AND TRANSPORT</td>
<td>3.0</td>
</tr>
<tr>
<td>MLGN593</td>
<td>BONDING, STRUCTURE, AND CRYSTALLOGRAPHY</td>
<td>3.0</td>
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</table>

Total Semester Hrs 9.0

Master of Science (Thesis Option)
The Master of Science degree requires a minimum of 30.0 semester hours of acceptable coursework and thesis research credits (see table below). The student must also submit a thesis and pass the Defense of Thesis examination before the Thesis Committee.

<table>
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</tr>
<tr>
<td>MLGN593</td>
<td>BONDING, STRUCTURE, AND CRYSTALLOGRAPHY</td>
<td>3.0</td>
</tr>
<tr>
<td>MLGN5XX</td>
<td>Materials Science Courses</td>
<td>9.0</td>
</tr>
<tr>
<td>MLGN707</td>
<td>GRADUATE THESIS / DISSERTATION RESEARCH CREDIT</td>
<td>12.0</td>
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</tbody>
</table>

Total Semester Hrs 30.0

Master of Science (Non-Thesis Option with a case study)
The Master of Science degree requires a minimum of 24.0 semester hours of acceptable course work and 6.0 additional credit hours of either case study or designated design course including:

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<td>3.0</td>
</tr>
<tr>
<td>MLGN5XX</td>
<td>Materials Science Courses</td>
<td>15.0</td>
</tr>
<tr>
<td>MLGN707</td>
<td>GRADUATE THESIS / DISSERTATION RESEARCH CREDIT</td>
<td>6.0</td>
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</table>

Total Semester Hrs 30.0

MLGN Design Courses

<table>
<thead>
<tr>
<th>Course</th>
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<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>MLGN500</td>
<td>PROCESSING, MICROSTRUCTURE, AND PROPERTIES OF MATERIALS</td>
<td>3.0</td>
</tr>
<tr>
<td>MLGN501</td>
<td>STRUCTURE OF MATERIALS</td>
<td>3.0</td>
</tr>
<tr>
<td>MLGN503</td>
<td>CHEMICAL BONDING IN MATERIALS</td>
<td>3.0</td>
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<tr>
<td>MLGN505</td>
<td>MECHANICAL PROPERTIES OF MATERIALS</td>
<td>3.0</td>
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<tr>
<td>MLGN509</td>
<td>SOLID STATE CHEMISTRY</td>
<td>3.0</td>
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<tr>
<td>MLGN510</td>
<td>SURFACE CHEMISTRY</td>
<td>3.0</td>
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<tr>
<td>MLGN516</td>
<td>PROPERTIES OF CERAMICS</td>
<td>3.0</td>
</tr>
<tr>
<td>MLGN535</td>
<td>INTERDISCIPLINARY MICROELECTRONICS</td>
<td>3.0</td>
</tr>
<tr>
<td>MLGN544</td>
<td>PROCESSING OF CERAMICS</td>
<td>3.0</td>
</tr>
<tr>
<td>MLGN550</td>
<td>STATISTICAL PROCESS CONTROL AND DESIGN OF EXPERIMENTS</td>
<td>3.0</td>
</tr>
<tr>
<td>MLGN561</td>
<td>TRANSPORT PHENOMENA IN MATERIALS PROCESSING</td>
<td>3.0</td>
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<tr>
<td>MLGN569</td>
<td>FUEL CELL SCIENCE AND TECHNOLOGY</td>
<td>3.0</td>
</tr>
<tr>
<td>MLGN583</td>
<td>PRINCIPLES AND APPLICATIONS OF SURFACE ANALYSIS TECHNIQUES</td>
<td>3.0</td>
</tr>
<tr>
<td>MLGN5XX</td>
<td>Additional courses can be approved by MLGN Program Director</td>
<td>3.0</td>
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</table>

Total Semester Hrs 30.0

Doctor of Philosophy
The Doctor of Philosophy degree requires a minimum of 72.0 hours of course and research credit including:

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<tr>
<td>MLGN593</td>
<td>BONDING, STRUCTURE, AND CRYSTALLOGRAPHY</td>
<td>3.0</td>
</tr>
<tr>
<td>MLGN707</td>
<td>GRADUATE THESIS / DISSERTATION RESEARCH CREDIT</td>
<td>Minimum 24.0</td>
</tr>
<tr>
<td>MLGN5XX</td>
<td>Materials Science Courses (minimum)</td>
<td>15.0</td>
</tr>
<tr>
<td>MLGN5XX</td>
<td>Thesis Research or Material Science Coursework</td>
<td>24.0</td>
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Total Semester Hrs 72.0

A minimum of 15 course credits earned at Mines is required for the PhD degree. In exceptional cases, this 15 Mines course credit hour requirement can be reduced in part or in full through the written consent of the student's advisor, program director, and thesis committee.

PhD Qualifying Process
The following constitutes the qualifying processes by which doctoral students are admitted to candidacy in the Materials Science program.
Core Curriculum – The three required core classes must be completed in the first full academic year for all doctoral candidates. Students must obtain a grade of B- or better in each class to be eligible to take the qualifying examination at the end of the succeeding spring semester. If not allowed to complete the qualifying examination at the end of the spring semester, students will be discouraged from the PhD program and encouraged, rather, to finish with a Masters degree.

PhD Qualifying Examination – A qualifying examination is given annually at the end of the spring semester under the direction of the Materials Science Graduate Affairs Committee. All first-year Materials Science PhD students are expected to successfully complete the qualifying examination to remain in good standing in the program. The examination covers material from the core curriculum plus a standard introductory text on Materials Science, such as "Materials Science and Engineering: An Introduction", by William Callister. If a student performs below the expectations of the Materials Science faculty on the written exam, they will be asked to complete a follow-up oral examination in the summer semester. The oral examination will be based on topics deemed to be deficient in the written examination. Satisfactorily completing the oral exam will allow the student to proceed with the PhD program. Students who perform below the expectations of the Materials Science faculty on the oral exam will not be allowed to continue with the PhD program.

Upon completion of these steps and upon completion of all required coursework, candidates are admitted to candidacy.

PhD Thesis Proposal – While the proposal itself should focus on the central topic of a student’s research efforts, during the proposal defense, candidates may expect to receive a wide range of questions from the Committee. This would include all manner of questions directly related to the proposal. Candidates, however, should also expect questions related to the major concept areas of Materials Science within the context of a candidate’s research focus. The Committee formally reports results of the PhD proposal defense to the Materials Science Program Director using the Committee Reporting form developed by the Office of Graduate Studies.

Following successful completion of coursework and the PhD qualifying process, candidates must also submit a thesis and successfully complete the PhD Defense of Thesis examination before the PhD Thesis Committee.

Courses

MLGN500. PROCESSING, MICROSTRUCTURE, AND PROPERTIES OF MATERIALS. 3.0 Semester Hrs.
(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: none. 3 hours lecture; 3 semester hours.

MLGN501. STRUCTURE OF MATERIALS. 3.0 Semester Hrs.
(I) 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, and direct methods. Prerequisite: none. 3 hours lecture; 3 semester hours. Offered alternate years.

MLGN502. SOLID STATE PHYSICS. 3.0 Semester Hrs.
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: PH320. 3 hours lecture; 3 semester hours.

MLGN503. CHEMICAL BONDING IN MATERIALS. 3.0 Semester Hrs.
(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: none. 3 hours lecture; 3 semester hours.

MLGN504. SOLID STATE THERMODYNAMICS. 3.0 Semester Hrs.
(I) Thermodynamics applied to solid state reactions, binary and ternary phase diagrams, point, line and planar defects, interfaces, and electrochemical concepts. Prerequisites: none. 3 hours lecture; 3 semester hours.

MLGN505. MECHANICAL PROPERTIES OF MATERIALS. 3.0 Semester Hrs.
(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. TRANSPORT IN SOLIDS. 3.0 Semester Hrs.
(II) Thermal and electrical conductivity. Solid state diffusion in metals and metal systems. Kinetics of metallurgical reactions in the solid state. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of even years only.).

MLGN509. SOLID STATE CHEMISTRY. 3.0 Semester Hrs.
(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: none. 3 hours lecture; 3 semester hours. Offered alternate years.

MLGN510. SURFACE CHEMISTRY. 3.0 Semester Hrs.
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.

MLGN511. KINETIC CONCERNS IN MATERIALS PROCESSING I. 3.0 Semester Hrs.
(I) Introduction to the kinetics of materials processing, with emphasis on the momentum, heat and mass transport. Discussion of the basic mechanism of transport in gases, liquids and solids. Prerequisite: MTGN352, MTGN361, MATH225 or equivalent. 3 hours lecture; 3 semester hours.
MLGN512. CERAMIC ENGINEERING. 3.0 Semester Hrs.
(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.

MLGN515. ELECTRICAL PROPERTIES AND APPLICATIONS OF MATERIALS. 3.0 Semester Hrs.
(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.. 3 hours lecture; 3 semester hours.

MLGN516. PROPERTIES OF CERAMICS. 3.0 Semester Hrs.
(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. 3 semester hours: 3 hours lecture.

MLGN517. SOLID MECHANICS OF MATERIALS. 3.0 Semester Hrs.
This Advanced Mechanics of Materials course builds upon the learning outcomes of the pre-requisite Mechanics of Materials (Solid Mechanics) course to teach students the fundamentals of elastic deformations. Introduction to Theory of Elasticity and to Fracture Mechanics is realized through theory development, application examples, and numerical solutions. Knowledge from this course will enable students to work on variety of engineering applications in Mechanical, Materials, Aerospace, Civil and related engineering fields. Major covered topics include: vector and tensor calculus, stress and strain, stress functions, elastic constitutive equations, yield theories, numerical implementation techniques, and an introduction to applications including fracture mechanics. Prerequisite: CEEN311 (C- or better) or MEGN212 (C- or better).

MLGN518. PHASE EQUILIBRIA IN CERAMICS SYSTEMS. 3.0 Semester Hrs.
(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: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

MLGN519. NON-CRYSTALLINE MATERIALS. 3.0 Semester Hrs.
(II) 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. 3 hours lecture; 3 semester hours.

MLGN520. KINETIC CONCERNS IN MATERIAL PROCESSING II. 3.0 Semester Hrs.
(I, II) Advanced course to address the kinetics of materials processing, with emphasis in those processes that promote phase and structural transformations. Processes that involve precipitation, sintering, oxidation, solgel, coating, etc., will be discussed in detail. Prerequisite: MLGN511. 3 hours lecture; 3 semester hours.

MLGN521. APPLIED SURFACE AND SOLUTION CHEMISTRY. 3.0 Semester Hrs.
(II) Solution and surface chemistry of importance in mineral and metallurgical operations. Prerequisite: none. 3 semester hours. (Spring of odd years only.).

MLGN526. GEL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.
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. 3 hours lecture; 3 semester hours. Spring of odd years only.

MLGN530. INTRODUCTION TO POLYMER SCIENCE. 3.0 Semester Hrs.
Chemistry and thermodynamics of polymers and polymer solutions. Reaction engineering of polymerization. Characterization techniques based on solution properties. Materials science of polymers in varying physical states. Processing operations for polymeric materials and use in separations. Prerequisite: CHGN221, MATH225, CHEN357. 3 hour lecture, 3 semester hours.

MLGN531. POLYMER ENGINEERING AND TECHNOLOGY. 3.0 Semester Hrs.
(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 co-extrusion will be covered as will injection molding. Graduate students are required to write a term paper and take separate examinations which are at a more advanced level. Prerequisite: CRGN307, EGGN351 or equivalent. 3 hours lecture; 3 semester hours.

MLGN535. INTERDISCIPLINARY MICROELECTRONICS PROCESSING LABORATORY. 3.0 Semester Hrs.
Equivalent with CBEN435,CBEN535,CHEN435,CHEN535,PHGN435,PHGN535,
(II) Application of science and engineering principles to the design, fabrication, and testing of microelectronic devices. Emphasis on specific unit operations and the interrelation among processing steps. Prerequisite: none. 3 hours lecture; 3 semester hours.

MLGN536. ADVANCED POLYMER SYNTHESIS. 3.0 Semester Hrs.
(II) An advanced course in the synthesis of macromolecules. Various methods of polymerization will be discussed with an emphasis on the specifics concerning the synthesis of different classes of organic and inorganic polymers. Prerequisite: CHGN430, ChEN415, MLGN530. 3 hours lecture, 3 semester hours.

MLGN544. PROCESSING OF CERAMICS. 3.0 Semester Hrs.
(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. 3 hours lecture; 3 semester hours.
MLGN550. STATISTICAL PROCESS CONTROL AND DESIGN OF EXPERIMENTS. 3.0 Semester Hrs.
(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: none. 3 hours lecture, 3 semester hours.

MLGN552. INORGANIC MATRIX COMPOSITES. 3.0 Semester Hrs.
(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/Co-requisite: MTGN311, MTGN352, MTGN445/ MLGN505. 3 hours lecture; 3 semester hours (Summer of even years only).

MLGN555. POLYMER AND COMPLEX FLUIDS COLLOQUIUM. 1.0 Semester Hr.
Equivalent with CBEN555,CHGN555.
The Polymer and Complex Fluids Group at the Colorado School of Mines combines expertise in the areas of flow and field based transport, intelligent design and synthesis as well as nanomaterials and nanotechnology. A wide range of research tools employed by the group includes characterization using rheology, scattering, microscopy, microfluidics and separations, synthesis of novel macromolecules as well as theory and simulation involving molecular dynamics and Monte Carlo approaches. The course will provide a mechanism for collaboration between faculty and students in this research area by providing presentations on topics including the expertise of the group and unpublished, ongoing campus research. Prerequisites: none. 1 hour lecture; 1 semester hour. Repeatable for credit to a maximum of 3 hours.

MLGN561. TRANSPORT PHENOMENA IN MATERIALS PROCESSING. 3.0 Semester Hrs.
(II) Fluid flow, heat and mass transfer applied to processing of materials. Rheology of polymers, liquid metal/particles slurries, and particulate solids. Transient flow behavior of these materials in various geometries, including infiltration of liquids in porous media. Mixing and blending. Flow behavior of jets, drainage of films and particle fluidization. Surface-tension-, electromagnetic-, and bubble-driven flows. Heat -transfer behavior in porous bodies applied to sintering and solidification of composites. Simultaneous heat-and-mass-transfer applied to spray drying and drying porous bodies. Prerequisites: ChEN307 or ChEN308 or MTGN461. 3 hours lecture; 3 semester hours.

MLGN563. POLYMER ENGINEERING: STRUCTURE, PROPERTIES AND PROCESSING. 3.0 Semester Hrs.
(II) 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. 3 hours lecture; 3 semester hours.

MLGN565. MECHANICAL PROPERTIES OF CERAMICS AND COMPOSITES. 3.0 Semester Hrs.
(II) 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. 3 hours lecture; 3 semester hours. (Fall of even years only.).

MLGN569. FUEL CELL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.
Equivalent with MTGN569,
(II) Investigate fundamentals of fuel-cell operation and electrochemistry from a chemical thermodynamics and materials science perspective. Review types of fuel cells, fuel-processing requirements and approaches, and fuel-cell system integration. Examine current topics in fuel-cell science and technology. Fabricate and test operational fuel cells in the Colorado Fuel Cell Center. Prerequisites: EGGN371 or ChEN357 or MTGN351 Thermodynamics I, MATH225 Differential Equations. 3 credit hours.

MLGN570. BIOCOMPATIBILITY OF MATERIALS. 3.0 Semester Hrs.
(II) Introduction to the diversity of biomaterials and applications through examination of the physiologic environment in conjunction with compositional and structural requirements of tissues and organs. Appropriate domains and applications of metals, ceramics and polymers, including implants, sensors, drug delivery, laboratory automation, and tissue engineering are presented. Prerequisites: ESGN 301 or equivalent. 3 hours lecture; 3 semester hours.

MLGN572. BIOMATERIALS. 3.0 Semester Hrs.
Equivalent with MTGN572.
(I) A broad overview on materials science and engineering principles for biomedical applications with three main topics: 1) The fundamental properties of biomaterials; 2) The fundamental concepts in biology; 3) The interactions between biological systems with exogenous materials. Examples including surface energy and surface modification; protein adsorption; cell adhesion, spreading and migration; biomaterials implantation and acute inflammation; blood-materials interactions and thrombosis; biofilm and biomaterials-related pathological reactions. Basic principles of bio-mimetic materials synthesis and assembly will also be introduced. 3 hours lecture; 3 semester hours.
MLGN583. PRINCIPLES AND APPLICATIONS OF SURFACE ANALYSIS TECHNIQUES. 3.0 Semester Hrs.

(I) Instrumental techniques for the characterization of surfaces of solid materials. Applications of such techniques to polymers, corrosion, metallurgy, adhesion science, micro-electronics. Methods of analysis discussed: X-ray photoelectron spectroscopy (XPS), auger electron spectroscopy (AES), ion scattering spectroscopy (ISS), secondary ion mass spectroscopy (SIMS), Rutherford backscattering (RBS), scanning and transmission electron microscopy (SEM, TEM), energy and wavelength dispersive X-ray analysis; principles of these methods, quantification, instrumentation, sample preparation. Prerequisite: B.S. in metallurgy, chemistry, chemical engineering, physics. 3 hours lecture; 3 semester hours. This course taught in alternate even numbered years.

MLGN591. MATERIALS THERMODYNAMICS. 3.0 Semester Hrs.

(I) A review of the thermodynamic principles of work, energy, entropy, free energy, equilibrium, and phase transformations in single and multi-component systems. Students will apply these principles to a broad range of materials systems of current importance including solid state materials, magnetic and piezoelectric materials, alloys, chemical and electrochemical systems, soft and biological materials and nanomaterials. Prerequisites: A 300 level or higher course in thermodynamics. 3 semester hours lecture, 3 semester hours.

MLGN592. ADVANCED MATERIALS KINETICS AND TRANSPORT. 3.0 Semester Hrs.

(I) A broad treatment of homogenous and heterogeneous kinetic transport and reaction processes in the gas, liquid, and solid states, with a specific emphasis on heterogeneous kinetic processes involving gas/solid, liquid/solid, and solid/solid systems. Reaction rate theory, nucleation and growth, and phase transformations will be discussed. A detailed overview of mass, heat, and charge transport in condensed phases is provided including a description of fundamental transport mechanisms, the development of general transport equations, and their application to a number of example systems. Prerequisites: A 300 level or higher course in thermodynamics, introductory college chemistry, electricity and magnetism, differential equations. 3 semester hours.

MLGN593. BONDING, STRUCTURE, AND CRYSTALLOGRAPHY. 3.0 Semester Hrs.

(I) This course will be an overview of condensed matter structure from the atomic scale to the mesoscale. Students will gain a perspective on electronic structure as it relates to bonding, long range order as it relates to crystallography and amorphous structures, and extend these ideas to nanostructure and microstructure. Examples relating to each hierarchy of structure will be stressed, especially as they relate to reactivity, mechanical properties, and electronic and optical properties. Prerequisites: A 300 level or higher course in thermodynamics. 3 semester hours.

MLGN597. CASE STUDY - MATERIALS SCIENCE. 0.5-6 Semester Hr. Individual research or special problem projects supervised by a faculty member.

MLGN598. SPECIAL TOPICS. 6.0 Semester Hrs.

(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

MLGN599. CASE STUDY MATERIALS SCIENCE. 0.5-6 Semester Hr.

(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: Independent Study form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

MLGN607. CONDENSED MATTER. 3.0 Semester Hrs.

(I) Principles and applications of the quantum theory of electronic in solids: structure and symmetry, electron states and excitations in metals; transport properties. Prerequisite: PHGN520 and PHGN440/MLGN502. 3 hours lecture; 3 semester hours.

MLGN625. MOLECULAR SIMULATION METHODS. 3.0 Semester Hrs. (I Even Years), Principles and practice of modern computer simulation techniques used to understand solids, liquids, and gases. Review of the statistical foundation of thermodynamics followed by in-depth discussion of Monte Carlo and Molecular Dynamics techniques. Discussion of intermolecular potentials, extended ensembles, and mathematical algorithms used in molecular simulations. Prerequisites: graduate level thermodynamics (required), statistical mechanics (recommended). 3 semester hours.

MLGN634. ADVANCED TOPICS IN THERMODYNAMICS. 3.0 Semester Hrs.

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: none. 1 to 3 semester hours.

MLGN635. POLYMER REACTION ENGINEERING. 3.0 Semester Hrs.

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.

MLGN648. CONDENSED MATTER II. 3.0 Semester Hrs. (II) Principles and applications of the quantum theory of electronic and phonons in solids; phonon states in solids; transport properties; electron states and excitation in semiconductors and insulators; magnetism; superconductivity. Prerequisite: PHGN640/MLGN607. 3 hours lecture; 3 semester hours.

MLGN673. STRUCTURE AND PROPERTIES OF POLYMERS. 3.0 Semester Hrs.

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. 3 hours lecture; 3 semester hours.
MLGN696. VAPOR DEPOSITION PROCESSES. 3.0 Semester Hrs.
(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. 3 hours lecture; 3 semester hours.

MLGN698. SPECIAL TOPICS. 6.0 Semester Hrs.
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

MLGN699. INDEPENDENT STUDY. 0.5-6 Semester Hr.
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

MLGN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.
(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

Professors
Sumit Agarwal, Department of Chemical Engineering
John R. Berger, Department of Mechanical Engineering, Department Head of Mechanical Engineering
Cristian Ciobanu, Department of Mechanical Engineering
Mark Eberhart, Department of Chemistry
Kip Findley, Department of Metallurgical and Materials Engineering
Thomas Gennett, Department of Chemistry, Department Head of Chemistry
Michael J. Kaufman, Department of Metallurgical and Materials Engineering, Vice Provost, Graduate Initiatives and Dean of Materials and Energy Programs
Daniel M. Knauss, Department of Chemistry
Ryan P. O'Hayre, Department of Metallurgical and Materials Engineering
Ivar E. Reimanis, Department of Metallurgical and Materials Engineering, Herman F. Coors Distinguished Professor of Ceramic Engineering
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Aaron Stebner, Department of Mechanical Engineering
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Jeramy Zimmerman, Department of Physics

Professors Emeriti
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Stephen Liu, Department of Metallurgical and Materials Engineering
Brajendra Mishra, Department of Metallurgical and Materials Engineering
P. Craig Taylor, Department of Physics
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