Metallurgical and Materials Engineering

Program Description

Metallurgical and materials engineering plays a role in all manufacturing processes which convert raw materials into useful products adapted to human needs. The primary goal of the Metallurgical and Materials Engineering program is to provide undergraduates with a fundamental knowledge base associated with materials-processing, their properties, and their selection and application. Upon graduation, students will have acquired and developed the necessary background and skills for successful careers in materials-related industries. Furthermore, the benefits of continued education toward graduate degrees and other avenues, and the pursuit of knowledge in other disciplines should be well inculcated.

The emphasis in the Department is on materials processing operations which encompass: the conversion of mineral and chemical resources into metallic, ceramic or polymeric materials; the synthesis of new materials; refining and processing to produce high performance materials for applications from consumer products to aerospace and electronics; the development of mechanical, chemical and physical properties of materials related to their processing and structure; and the selection of materials for specific applications.

The metallurgical and materials engineering discipline is founded on fundamentals in chemistry, mathematics and physics which contribute to building the knowledge base and developing the skills for the processing of materials so as to achieve specifications requested for a particular industrial or advanced product. The engineering principles in this discipline include: crystal structure and structural analysis, thermodynamics of materials, reaction kinetics, transport phenomena, phase equilibria, phase transformations, microstructural evolution, mechanical behavior, and properties of materials.

The core-discipline fundamentals are applied to a broad range of materials processes including extraction and refining of materials, alloy development, casting, mechanical working, joining and forming, ceramic particle processing, high temperature reactions and synthesis of engineered materials. In each stage of processing, the effects of resultant microstructures and morphologies on materials properties and performance are emphasized.

Laboratories, located in Nathaniel Hill Hall, are among the finest in the nation. The laboratories, in conjunction with classroom instruction, provide for a well-integrated education of the undergraduates working towards their baccalaureate degrees. These facilities are well equipped and dedicated to: particulate and chemical/extraction, metallurgical and materials processing, foundry science, corrosion and hydro/electro-metallurgical studies, physical and chemical metallurgy, welding and joining, forming, processing and testing of ceramic materials. Mechanical testing facilities include computerized machines for tension, compression, torsion, toughness, fatigue and thermo-mechanical testing.

There are also other highly specialized research laboratories dedicated to: vapor deposition, and both plasma and high-temperature reaction systems. Supporting analytical laboratories also exist for surface analysis, emission spectrometry, X-ray analysis, optical microscopy and image analysis, scanning and transmission electron microscopy, and micro-thermal-analysis/mass spectrometry. Metallurgical and materials engineering involves all of the processes that transform precursor materials into final engineered products adapted to human needs. The objective of the metallurgical and materials engineering program is to impart a fundamental knowledge of materials processing, properties, selection and application in order to provide graduates with the background and skills needed for successful careers in materials-related industries, for continued education toward graduate degrees and for the pursuit of knowledge in other disciplines.

The program leading to the degree of Bachelor of Science in Metallurgical and Materials Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org (http://www.abet.org/).

Metallurgical and Materials Engineering (MME) Program Educational Objectives

The Metallurgical and Materials Engineering (MME) program emphasizes the structure, properties, processing and performance of materials. Program educational objectives are broad statements that describe what graduates are expected to attain within a few years of graduation. The Metallurgical and Materials Engineering program at Mines prepares graduates who:

1. obtain a range of positions in industry or positions in government facilities or pursue graduate education in engineering, science, or other fields;
2. demonstrate advancement in their chosen careers;
3. engage in appropriate professional societies and continuing education activities.

The three MME program educational objectives were determined by using inputs from program constituencies (faculty, students, visiting committee, industry recruiters and alumni). These objectives are consistent with those of the Colorado School of Mines. Mines is an engineering and applied science institution, dedicated to the education and training of students who will be stewards of the earth’s resources.

Curriculum

The Metallurgical and Materials Engineering (MME) curriculum is organized to educate students in the fundamentals of materials (MME Basics) and their applications (MME Applications) with the option of pursuing a track in one of four focus areas.

A. MME Basics: The basic curriculum in the Metallurgical and Materials Engineering program will provide a background in the following topic areas:

1. Crystal Structures and Structural Analysis: crystal systems; symmetry elements and Miller indices; atomic bonding; metallic, ceramic and polymeric structures; x-ray and electron diffraction; stereographic projection and crystal orientation; long range order; defects in materials.
2. Thermodynamics of Materials: heat and mass balances; thermodynamic laws; chemical potential and chemical equilibrium; solution thermodynamics & solution models; partial molar and excess quantities; solid state thermodynamics; thermodynamics of surfaces; electrochemistry.
3. Transport Phenomena and Kinetics: Heat, mass and momentum transport; transport properties of fluids; diffusion mechanisms; reaction kinetics; nucleation and growth kinetics.
4. Phase Equilibria: phase rule; binary and ternary systems; microstructural evolution; defects in crystals; surface phenomena; phase transformations: eutectic, eutectoid, martensitic, nucleation and growth, recovery; microstructural evolution; strengthening mechanisms; quantitative stereology; heat treatment.

5. Properties of Materials: mechanical properties; chemical properties (oxidation and corrosion); electrical, magnetic and optical properties; failure analysis.

B. MME Applications: The course content in the Metallurgical and Materials Engineering program emphasizes the following applications:

1. Materials Processing: particulate processing; thermo- and electrochemical materials processing; hydrometallurgical processing; synthesis of materials; deformation processing; solidification and casting; welding and joining.

2. Design and Application of Materials: materials selection; ferrous and nonferrous metals; ceramics; polymers; composites; electronic materials.

3. Statistical Process Control and Design of Experiments: statistical process control; process capability analysis; design of experiments.

C. MME Curriculum Requirements: The Metallurgical and Materials Engineering course sequence is designed to fulfill the program goals and to satisfy the curriculum requirements. The time sequence of courses organized by degree program, year and semester, is listed below.

### Degree Requirements (Bachelor of Science in Metallurgical and Materials Engineering)

#### Freshman

**Fall**

<table>
<thead>
<tr>
<th>Course</th>
<th>lec</th>
<th>lab</th>
<th>sem.hrs</th>
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<tr>
<td>CHGN121 PRINCIPLES OF CHEMISTRY I</td>
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<tr>
<td>CSM101 FRESHMAN SUCCESS</td>
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<td>EDNS151 DESIGN I</td>
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<td>MATH111 CALCULUS FOR SCIENTISTS AND ENGINEERS I</td>
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<td>MATH201 PROBABILITY AND STATISTICS FOR ENGINEERS, GEGN 101, or CBEN 110</td>
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<td>PAGN PHYSICAL ACTIVITY COURSE</td>
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### Sophomore

**Fall**

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<td>MATH213 CALCULUS FOR SCIENTISTS AND ENGINEERS III</td>
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<td>PHGN200 PHYSICS II - ELECTROMAGNETISM AND OPTICS</td>
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<td>MTGN251 METALLURGICAL AND MATERIALS THERMODYNAMICS</td>
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<td>CEEN241 STATICS</td>
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<td>EBGN201 PRINCIPLES OF ECONOMICS</td>
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<td>MTGN211 STRUCTURE OF MATERIALS</td>
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<td>MTGN281 INTRODUCTION TO PHASE EQUILIBRIA IN MATERIALS SYSTEMS</td>
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<td>EDNS263 DESIGN II: MATERIALS, 251, 261, 262, 263, 264, CEEN 267, or EDNS 269</td>
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**Fall**

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<tr>
<td>CEEN311 MECHANICS OF MATERIALS</td>
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<tr>
<td>MTGN352 METALLURGICAL AND MATERIALS KINETICS</td>
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<td>TECH ELECT Restricted Technical Elective</td>
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<td>MTGN314 PROPERTIES AND PROCESSING OF CERAMICS</td>
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<td>MTGN350 STATISTICAL PROCESS CONTROL AND DESIGN OF EXPERIMENTS</td>
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### Senior

**Fall**

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<td>MTGN348 MICROSTRUCTURAL DEVELOPMENT</td>
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### Summer

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<td>FREE Free Elective</td>
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ELECTIVE  HUMANITIES & SOCIAL SCIENCE (H&SS) Mid-Level Restricted Elective  3.0
MTGN315 ELECTRICAL PROPERTIES AND APPLICATIONS OF MATERIALS  3.0

Senior
Fall

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<th>Course</th>
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<th>lab</th>
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<td>MTGN461 TRANSPORT PHENOMENA AND REACTOR DESIGN FOR METALLURGICAL AND MATERIALS ENGINEERS</td>
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<td>MTGN467 MATERIALS DESIGN: SYNTHESIS, CHARACTERIZATION AND SELECTION</td>
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<td>MTGN MTGN Elective</td>
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<td>FREE Free Elective</td>
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<tr>
<td>MTGN468 MATERIALS DESIGN: SYNTHESIS, CHARACTERIZATION AND SELECTION</td>
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<tr>
<td>ELECTIVE HUMANITIES &amp; SOCIAL SCIENCE (H&amp;SS) 400-Level Restricted Elective</td>
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Total Semester Hrs: 137.5

** Restricted Technical Electives: **

CBEN120 FUNDAMENTALS OF BIOLOGY II  4.0
CEEN301 FUNDAMENTALS OF ENVIRONMENTAL ENGINEERING: WATER  3.0
CHGN209 INTRODUCTION TO CHEMICAL THERMODYNAMICS  3.0
or CBEN210 INTRO TO THERMODYNAMICS
CHGN221 ORGANIC CHEMISTRY I  3.0
CHGN335 INSTRUMENTAL ANALYSIS  3.0
CHGN336 ANALYTICAL CHEMISTRY  3.0
CHGN351 PHYSICAL CHEMISTRY: A MOLECULAR PERSPECTIVE I  4.0

CSCI261 PROGRAMMING CONCEPTS  3.0
EENG281 INTRODUCTION TO ELECTRICAL CIRCUITS, ELECTRONICS AND POWER  3.0
ENGY200 INTRODUCTION TO ENERGY  3.0
MATH201 PROBABILITY AND STATISTICS FOR ENGINEERS  3.0
MATH332 LINEAR ALGEBRA  3.0
MATH348 ADVANCED ENGINEERING MATHEMATICS  3.0
PHGN215 ANALOG ELECTRONICS  4.0
PHGN300 PHYSICS III-MODERN PHYSICS I  3.0

Major GPA

During the 2016-2017 Academic Year, the Undergraduate Council considered the policy concerning required major GPAs and which courses are included in each degree’s GPA. While the GPA policy has not been officially updated, in order to provide transparency, council members agreed that publishing the courses included in each degree’s GPA is beneficial to students.

The following list details the courses that are included in the GPA for this degree:

- MTGN100 through MTGN599 inclusive


The Departments of Metallurgical and Materials Engineering and Physics collaborate to offer a five-year program designed to meet the needs of the electronics and similar high-tech industries. Students who satisfy the requirements of the program obtain an undergraduate degree in either Engineering Physics or in Metallurgical and Materials Engineering in four years and a Master of Engineering degree in Metallurgical and Materials Engineering at the end of the fifth year. The program is designed to provide a strong background in science fundamentals, as well as specialized training in the materials-science and processing needs of these industries. Thus, the educational objective of the program is to provide students with the specific educational requirements to begin a career in microelectronics and, at the same time, a broad and flexible background necessary to remain competitive in this exciting and rapidly changing industry. The undergraduate electives which satisfy the requirements of the program and an overall curriculum need to be discussed with the student’s advisor and approved by the Physics or Metallurgical and Materials Engineering Departments. A Program Mentor in each Department can also provide counseling on the program.

Application for admission to this program should be made during the first semester of the sophomore year (in special cases, later entry may be approved, upon review, by one of the program mentors). Undergraduate students admitted to the program must maintain a 3.0 grade-point average or better. The graduate segment of the program requires a case study report, submitted to the student’s graduate advisor. Additional details on the Master of Engineering can be found in the Graduate Degree and Requirements section of the Graduate Bulletin. The case study is started during the student’s senior design-project and completed during the year of graduate study. A student admitted to the program is expected to select a graduate advisor, in advance of the graduate-studies final year, and prior to the start of their senior year. The case-study topic is then identified and selected in consultation with the graduate advisor. A formal application, during the senior year, for admission to the graduate
program in Metallurgical and Materials Engineering must be submitted to the Graduate School. Students who have maintained all the standards of the program requirements leading up to this step, can expect to be admitted.

General CSM Minor/ASI requirements can be found here (catalog.mines.edu/undergraduate/undergraduateinformation/minorasi/).

**Minor in Metallurgical and Materials Engineering**

A minor program in metallurgical and materials engineering consists of a minimum of 18 credit hours of a logical sequence of courses. Students majoring in metallurgical and material engineering are not eligible to earn a minor in the department.

A minor program declaration (available in the Registrar's Office) must be submitted for approval prior to the student's completion of half of the hours proposed to constitute the program. Approvals are required from the department head of metallurgical and materials engineering, the student's advisor, and the department head or division director in the department or division in which the student is enrolled.

Recommended Courses: The following courses are recommended for students seeking to earn a minor in metallurgical and materials engineering:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Hrs</th>
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<tbody>
<tr>
<td>MTGN202</td>
<td>ENGINEERED MATERIALS</td>
<td>3.0</td>
</tr>
<tr>
<td>MTGN311</td>
<td>STRUCTURE OF MATERIALS</td>
<td>3.0</td>
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<tr>
<td>MTGN311L</td>
<td>STRUCTURE OF MATERIALS LABORATORY</td>
<td>1.0</td>
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<tr>
<td>MTGN348</td>
<td>MICROSTRUCTURAL DEVELOPMENT</td>
<td>3.0</td>
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<tr>
<td>MTGN348L</td>
<td>MICROSTRUCTURAL DEVELOPMENT LABORATORY</td>
<td>1.0</td>
</tr>
<tr>
<td>MTGN445</td>
<td>MECHANICAL PROPERTIES OF MATERIALS</td>
<td>3.0</td>
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<tr>
<td>MTGN445L</td>
<td>MECHANICAL PROPERTIES OF MATERIALS LABORATORY</td>
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<tr>
<td>300- or 400- level course in metallurgical and materials engineering</td>
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<tr>
<td>Total Semester Hrs</td>
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<td>18.0</td>
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Other sequences are permissible to suit the special interests of individual students. These other sequences need to be discussed and approved by the department head in metallurgical and materials engineering.

**Courses**

**MTGN198. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING. 1-3 Semester Hr.**

(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). The course topic is generally offered only once. Prerequisite: none. 1 to 3 semester hours. Repeatable for credit under different titles.

**MTGN199. INDEPENDENT STUDY. 1-3 Semester Hr.**

(I, II, S) Independent 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; Independent Study Form must be completed and submitted to Registrar. 1 to 3 semester hours. Repeatable for credit.

**MTGN202. ENGINEERED MATERIALS. 3.0 Semester Hrs.**

Equivalent with SYGN202, (I, II, S) Introduction to the Metallurgical and Materials Engineering paradigm: processing, structure, and properties. The course will relate technology significantly to significant structures; The material structure will be examined to determine its effect upon material properties. Students will study materials engineering methodologies and learn terminology. Prerequisites: CHGN122 or CHGN125, MATH112, and PHGN100. 3 hours lecture; 3 semester hours.

**MTGN211. STRUCTURE OF MATERIALS. 3.0 Semester Hrs.**

(II) Principles of atomic bonding, crystallography, and amorphous structures. i) Atomic structure determination through diffraction techniques. Prerequisite: MTGN202. Corequisite: PHGN200. 3 hours lecture; 3 semester hours.

**MTGN219. ART AND SCIENCE OF GLASSBLOWING. 2.0 Semester Hrs.**

Explore the science of glass by learning artistic glassblowing. Lectures will cover basic glass network structure, melt processing and viscosity, forming and cold working, as well as optical and mechanical properties. Over the course of the semester, laboratory exercises will train students in basic glassblowing and safe use of a hot glass shop. Students who pass the course with a B or better will be certified to use the Hill Hall hot glass shop during open shop hours.

**MTGN251. METALLURGICAL AND MATERIALS THERMODYNAMICS. 3.0 Semester Hrs.**

(I) Applications of thermodynamics in extractive and physical metallurgy and materials science. Thermodynamics of solutions including solution models and thermodynamic properties of alloys and slags. Reaction equilibria with examples in alloy systems and slags. Phase stability analysis. Thermodynamic properties of binary alloys in the solid state, defect equilibria, and interactions. Prerequisites: MATH112, CHGN122 or CHGN125, and PHGN100. 3 hours lecture; 3 semester hours.

**MTGN272. MME FIELD SESSION. 3.0 Semester Hrs.**

(S) Introduction to the field of Metallurgical and Materials Engineering. Overview of opportunities, expectations, and practices within the MME department and the broader materials community. Introduction to bonding, crystal and grain structure, application space, and Structure-Property-Processing relationships. Laboratory projects and plant visits. Prerequisites: MATH112, PHGN100. 9 hours lab; 3 semester hours.

**MTGN281. INTRODUCTION TO PHASE EQUILIBRIA IN MATERIALS SYSTEMS. 2.0 Semester Hrs.**

(II) Review of the concepts of chemical equilibrium and derivation of the Gibbs phase rule. Application of the Gibbs phase rule to interpreting one, two and three component phase equilibrium diagrams. Application to alloy and ceramic materials systems. Emphasis on the evolution of phases and their amounts and the resulting microstructural development. Prerequisites: MTGN202, and MTGN251 or MTGN351. 2 hours lecture; 2 semester hours.

**MTGN298. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING. 3.0 Semester Hrs.**

(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). The course topic is generally offered only once. Prerequisite: none. 1 to 3 semester hours. Repeatable for credit under different titles.
MTGN298. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING. 3.0 Semester Hrs.
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). The course topic is generally offered only once. Prerequisite: none. 1 to 3 semester hours. Repeatable for credit under different titles.

MTGN299. INDEPENDENT STUDY. 1-3 Semester Hr.
(I, II, S) Independent 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; Independent Study Form must be completed and submitted to Registrar. 1 to 3 semester hours. Repeatable for credit.

MTGN300. FOUNDRY METALLURGY. 2.0 Semester Hrs.
(II) Design and metallurgical aspects of casting, patterns, molding materials and processes, solidification processes, risers and gating concepts, casting defects and inspection, melting practice, cast alloy selection. Corequisite: MTGN300L. 2 hours lecture; 2 semester hours.

MTGN300L. FOUNDRY METALLURGY LABORATORY. 1.0 Semester Hr.
Equivalent with MTGN302.

MTGN311. STRUCTURE OF MATERIALS. 3.0 Semester Hrs.
(I) Principles of crystallography and crystal chemistry. Characterization of crystalline materials using X-ray diffraction techniques. Applications to include compound identification, lattice parameter measurement, orientation of single crystals, and crystal structure determination. Prerequisites: PHGN200 and MTGN202. Co-requisite: MTGN311L. 3 hours lecture; 3 semester hours.

MTGN311L. STRUCTURE OF MATERIALS LABORATORY. 1.0 Semester Hr.
(I) (WI) Experiments in structure of materials to supplement the lectures of MTGN311. Co-requisite: MTGN311. 3 hours lab; 1 semester hour.

MTGN314. PROPERTIES AND PROCESSING OF CERAMICS. 2.0 Semester Hrs.
(I) Application of engineering principles and fundamental structure-processing-property relationship to inorganic non-metallic materials. Emergence of macroscopic characteristics and functional properties from bonding, structure, symmetry, and defects. Applications of basic thermodynamic and kinetic principles to powder-based processing. Corequisites: MTGN314L, MTGN202, and MTGN251 or MTGN351. 2 hours lecture; 2 semester hours.

MTGN314L. PROPERTIES AND PROCESSING OF CERAMICS LABORATORY. 1.0 Semester Hr.
(I) Laboratory for MTGN314. Corequisite: MTGN314. 3 hours lab; 1 semester hour.

MTGN315. 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. Functions, performance requirements and testing methods of material for each type of circuit component. General topics covered are conductors, resistors, insulators, capacitors, energy converters, magnetic materials and integrated circuits. Prerequisite: PHGN200. Corequisite: MTGN211 or MTGN311. 3 hours lecture; 3 semester hours.

MTGN333. INTRODUCTION TO BLADESMITHING. 3.0 Semester Hrs.
(I, II, S) An introduction to the metallurgy and art of bladesmithing. The course covers ferrous metallurgy with a focus on tools steels used for creating edged tools. Students will learn and execute techniques for alloy selection, shaping, profiling, beveling, heat treating, and sharpening knives. Students will complete at least two knives, one specified by the instructor, and one of the students own design. Co-requisite: MTGN348 or permission of instructor. 1 hour lecture; 2 hours lab; 3 semester hours.

MTGN334. CHEMICAL PROCESSING OF MATERIALS. 3.0 Semester Hrs.
(II) Development and application of fundamental principles related to the processing of metals and materials by thermochemical and aqueous and fused salt electrochemical/chemical routes. The course material is presented within the framework of a formalism that examines the physical chemistry, thermodynamics, reaction mechanisms and kinetics inherent to a wide selection of chemical processing systems. The general formalism provides for a transferable knowledge-base to other systems not specifically covered in the course. Prerequisites: MTGN272, MTGN351, and CEEN267 or EDNS251 or EDNS261 or EDNS282 or EDNS264 or EDNS269. Corequisite: MTGN334L. 3 hours lecture, 3 semester hours.

MTGN334L. CHEMICAL PROCESSING OF MATERIALS LABORATORY. 1.0 Semester Hr.
(II) Experiments in chemical processing of materials to supplement the lectures of MTGN334. Corequisite: MTGN334. 3 hours lab; 1 semester hour.

MTGN340. COOPERATIVE EDUCATION. 1-3 Semester Hr.
(I, II, S) Supervised, full-time, engineering-related employment for a continuous six-month period (or its equivalent) in which specific educational objectives are achieved. 1 to 3 semester hours. Cooperative education credit does not count toward graduation except under special conditions. Repeatable.

MTGN348. MICROSTRUCTURAL DEVELOPMENT. 3.0 Semester Hrs.
(I, II, S) An introduction to the relationships between microstructure and properties of materials, with emphasis on metallic and ceramic systems; Fundamentals of imperfections in crystalline materials on material behavior; recrystallization and grain growth; strengthening mechanisms: grain refinement, solid solution strengthening, precipitation strengthening, and microstructural strengthening; and phase transformations. Prerequisites: MTGN211 or MTGN311, and MTGN251 or MTGN351. Corequisites: MTGN281 or MTGN381, and MTGN348L. 3 hours lecture, 3 semester hours.

MTGN348L. MICROSTRUCTURAL DEVELOPMENT LABORATORY. 1.0 Semester Hr.
(II) Experiments in microstructural development of materials to supplement the lectures of MTGN348. Corequisite: MTGN348. 3 hours lab; 1 semester hour.
M T G N 3 5 0 . S T A T I S T I C A L  P R O C E S S  C O N T R O L  A N D  D E S I G N  O F  E X P E R I M E N T S . 3 . 0  S e m e s t e r  H r s .
(I) Introduction to statistical process control, process capability analysis and experimental design techniques. Statistical process control theory and techniques developed and applied to control charts for variables and attributes involved in process control and evaluation. Process capability concepts developed and applied to the evaluation of manufacturing processes. Theory of designed experiments developed and applied to full factorial experiments, fractional factorial experiments, screening experiments, multilevel experiments and mixture experiments. Analysis of designed experiments by graphical and statistical techniques. Introduction to computer software for statistical process control and for the design and analysis of experiments. 3 hours lecture, 3 semester hours.

M T G N 3 5 1 . M E T A L L U R G I C A L  A N D  M A T E R I A L S  T H E R M O D Y N A M I C S . 3 . 0  S e m e s t e r  H r s .
(I) Applications of thermodynamics in extractive and physical metallurgy and materials science. Thermodynamics of solutions including solution models, calculation of activities from phase diagrams, and measurements of thermodynamic properties of alloys and slags. Reaction equilibria with examples in alloy systems and slags. Phase stability analysis. Thermodynamic properties of phase diagrams in material systems, defect equilibrium and interactions. Prerequisite: MTGN209 or CBEN210. 3 hours lecture; 3 semester hours.

M T G N 3 5 2 . M E T A L L U R G I C A L  A N D  M A T E R I A L S  K I N E T I C S . 3 . 0  S e m e s t e r  H r s .
(I) Introduction to reaction kinetics: chemical kinetics, atomic and molecular diffusion, surface thermodynamics and kinetics of interfaces and nucleation-and-growth. Applications to materials processing and performance aspects associated with gas/solid reactions, precipitation and dissolution behavior, oxidation and corrosion, purification of semiconductors, carburizing of steel, formation of p-n junctions and other important materials systems. Prerequisite: MTGN272. Corequisite: MTGN251 or MTGN351. 3 hours lecture; 3 semester hours.

M T G N 3 8 1 . I N T R O D U C T I O N  T O  P H A S E  E Q U I L I B R I U M  I N  M A T E R I A L S  S Y S T E M S . 2 . 0  S e m e s t e r  H r s .
(I) Review of the concepts of chemical equilibrium and derivation of the Gibbs phase rule. Application of the Gibbs phase rule to interpreting one, two and three component phase equilibrium diagrams. Application to alloy and ceramic materials systems. Emphasis on the evolution of phases and their amounts and the resulting microstructural development. Prerequisite/Corequisite: MTGN351. 2 hours lecture; 2 semester hours.

(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). The course topic is generally offered only once. Prerequisite: none. 1 to 3 semester hours. Repeatable for credit under different titles.

M T G N 3 9 9 . I N D E P E N D E N T  S T U D Y . 1 - 3  S e m e s t e r  H r
(I, II, S) Independent 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; Independent Study Form must be completed and submitted to Registrar. 1 to 3 semester hours. Repeatable for credit.

M T G N 4 0 3 . S E N I O R  T H E S I S . 3 . 0  S e m e s t e r  H r s .
(I, II, S) Two-semester individual research under the direction of members of the MME faculty. Work may include library and laboratory research on topics of relevance. Oral presentation will be given at the end of the second semester and written thesis submitted to committee of evaluation. 3 hours research; 3 semester hours.

M T G N 4 0 7 . S T E E L  B A R  M A N U F A C T U R I N G . 1 . 0  S e m e s t e r  H r .
(I) Facilities and metallurgical principles for manufacturing carbon and low alloy steel bars that are further transformed into high performance parts. Discussion of steel melting, ladle refining, casting, heat treatment, final processing, inspection and testing methods. Implications of process design and control on chemical uniformity, macrostructure, microstructure, internal quality, surface quality, mechanical properties and residual stresses. Review of customer processes and requirements for manufacturing parts from bars by hot or cold forging, machining, surface treating, and heat treating. Applications include crankshafts, gears, axles, drive shafts, springs, bearings, rails, line pipe, oil well casing, etc. Prerequisite: MTGN348. 1 hour lecture; 1.0 semester hour.

M T G N 4 1 2 . C E R A M I C  E N G I N E E R I N G . 3 . 0  S e m e s t e r  H r s .
(I) 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.

M T G N 4 1 4 . A D V A N C E D  P R O C E S S I N G  A N D  S I N T E R I N G  O F  C E R A M I C S . 3 . 0  S e m e s t e r  H r s .
(II) Principles of ceramics processing and the relationship between processing and microstructure, with a focus on advanced microstructural control using thermal and athermal energy input in single and multiphase systems. Principles will be illustrated using case studies on specific ceramic materials. A project to design a ceramic fabrication process is required. Prerequisite: MTGN314. 3 hours lecture; 3 semester hours.

M T G N 4 1 5 . E L E C T R I C A L  P R O P E R T I E S  A N D  A P P L I C A T I O N S  O F  M A T E R I A L S . 3 . 0  S e m e s t e r  H r s .
(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. Functions, performance requirements and testing methods of materials for each type of circuit component. General topics covered are conductors, resistors, insulators, capacitors, energy converters, magnetic materials and integrated circuits. Prerequisites: PHGN200 and MTGN311. 3 hours lecture; 3 semester hours.

M T G N 4 1 9 . N O N - C R Y S T A L L I N E  M A T E R I A L S . 3 . 0  S e m e s t e r  H r s .
(I, II, S) 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: MTGN211 or MTGN311, and MTGN412 or MTGN314. 3 hours lecture; 3 semester hours.
MTGN429. METALLURGICAL ENVIRONMENT. 3.0 Semester Hrs.
(I) Examination of the interface between metallurgical process engineering and environmental engineering. Wastes, effluents and their point sources in metallurgical processes such as mineral concentration, value extraction and process metallurgy are studied in context. Fundamentals of metallurgical unit operations and unit processes with those applicable to waste and effluent control, disposal and materials recycling are covered. Engineering design and engineering cost components are also included for selected examples. Fundamentals and applications receive equal coverage. Prerequisites: MTGN334. 3 hours lecture; 3 semester hours.

MTGN430. PHYSICAL CHEMISTRY OF IRON AND STEELMAKING. 3.0 Semester Hrs.
(I, II, S) 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. Offered every other year. Prerequisites: MTGN334, and MTGN251 or MTGN351. 3 hours lecture; 3 semester hours.

MTGN431. HYDRO- AND ELECTRO-METALLURGY. 3.0 Semester Hrs.
(I, II, S) Physicochemical principles associated with the extraction and refining of metals by hydro- and electrometallurgical techniques. Discussion of unit processes in hydrometallurgy, electrowinning, and electrorefining. Analysis of integrated flowsheets for the recovery of nonferrous metals. Offered every other year. Prerequisites: MTGN334, MTGN352, and MTGN351 or MTGN251. Corequisite: MTGN461. MTGN461L. 3 hours lecture; 3 semester hours.

MTGN432. PYROMETALLURGY. 3.0 Semester Hrs.
(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 constraints. Prerequisite: MTGN334. 3 hours lecture; 3 semester hours.

MTGN442. ENGINEERING ALLOYS. 3.0 Semester Hrs.
(I, II, S) This course is intended to be an important component of the physical metallurgy sequence, to reinforce and integrate principles from earlier courses, and enhance the breadth and depth of understanding of concepts in a wide variety of alloy systems. Metallic systems considered include iron and steels, copper, aluminum, titanium, superalloys, etc. Phase stability, microstructural evolution and structure/property relationships are emphasized. Offered every other year. Prerequisite: MTGN348. 3 hours lecture; 3 semester hours.

MTGN445. MECHANICAL PROPERTIES OF MATERIALS. 3.0 Semester Hrs.

MTGN445L. MECHANICAL PROPERTIES OF MATERIALS LABORATORY. 1.0 Semester Hr.
(I) Laboratory sessions devoted to advanced mechanical-testing techniques to illustrate the application of the fundamentals presented in the lectures of MTGN445. Corequisite: MTGN445. 3 hours lab; 1 semester hour.

MTGN450. STATISTICAL PROCESS CONTROL AND DESIGN OF EXPERIMENTS. 3.0 Semester Hrs.
(I) Introduction to statistical process control, process capability analysis and experimental design techniques. Statistical process control theory and techniques developed and applied to control charts for variables and attributes involved in process control and evaluation. Process capability concepts developed and applied to the evaluation of manufacturing processes. Theory of designed experiments developed and applied to full factorial experiments, fractional factorial experiments, screening experiments, multilevel experiments and mixture experiments. Analysis of designed experiments by graphical and statistical techniques. Introduction to computer software for statistical process control and for the design and analysis of experiments. Prerequisite: none. 3 hours lecture, 3 semester hours.

MTGN451. CORROSION ENGINEERING. 3.0 Semester Hrs.
(I, II, S) Principles of electrochemistry. Corrosion mechanisms. Methods of corrosion control including cathodic and anodic protection and coatings. Examples, from various industries, of corrosion problems and solutions. Prerequisite: MTGN251 or MTGN351. 3 hours lecture; 3 semester hours.

MTGN456. ELECTRON MICROSCOPY. 2.0 Semester Hrs.
(I, II, S) 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. Prerequisites: MTGN211 or MTGN311. Corequisite: MTGN456L. 2 hours lecture; 2 semester hours.

MTGN456L. ELECTRON MICROSCOPY LABORATORY. 1.0 Semester Hr.
Equivalent with MTGN458.
(I, II, S) Laboratory exercises to illustrate specimen preparation techniques, microscope operation, and the interpretation of images produced from a variety of specimens, and to supplement the lectures in MTGN456. Corequisite: MTGN456. 3 hours lab; 1 semester hour.

MTGN461. TRANSPORT PHENOMENA AND REACTOR DESIGN FOR METALLURGICAL AND MATERIALS ENGINEERS. 3.0 Semester Hrs.

MTGN461L. TRANSPORT PHENOMENA AND REACTOR DESIGN LABORATORY. 1.0 Semester Hr.
(II) Experiments in transport phenomena and reactor design to supplement the lectures of MTGN461. Co-requisite: MTGN431, MTGN461. 3 hours lab; 1 semester hour.
MTGN462. SOLID WASTE MINIMIZATION AND RECYCLING. 3.0 Semester Hrs.
(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: CEEN301, CEEN302, and CHGN403. 3 hours lecture; 3 semester hours.

MTGN463. POLYMER ENGINEERING. 3.0 Semester Hrs.
(I, 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 polymer solids and reinforced polymer composites. Emphasis will be placed 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. Offered every other year. 3 hours lecture; 3 semester hours.

MTGN464. FORGING AND FORMING. 2.0 Semester Hrs.
Introduction to plasticity. Survey and analysis of working operations of forging, extrusion, rolling, wire drawing and sheet-metal forming. Metallurgical structure evolution during working. Prerequisite: MTGN381 or CEEN311, MTGN348. Co-requisite: MTGN464L.

MTGN464L. FORGING AND FORMING LABORATORY. 1.0 Semester Hr.
(II) Experiments in forging and forming to supplement the lectures of MTGN464. Corequisite: MTGN464. 3 hours lab; 1 semester hour.

MTGN465. MECHANICAL PROPERTIES OF CERAMICS. 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 and creep deformation. Offered every other year. Prerequisites: MTGN211 or MTGN311, and MTGN314 or MTGN412. 3 hours lecture; 3 semester hours.

MTGN466. MATERIALS DESIGN: SYNTHESIS, CHARACTERIZATION AND SELECTION. 3.0 Semester Hrs.
(II) (WI) Application of fundamental materials-engineering principles to the design of systems, processes, and/or components for extraction, synthesis, operation and/or selection of materials in open-ended projects with realistic constraints. Project topics range from processes used for metallurgical processing and extraction to design and development of emergent materials to process/component analysis and (re)design. Chemical and microstructural characterization and property measurements provide the basis for linking synthesis to application and/or process to product. Selection criteria tied to specific requirements drive design under realistic constraints that include an appropriate mix of technical, economic, safety, and other considerations. Activities are carried out in teams in collaboration with project sponsors/clients. Prerequisite: MTGN348. Corequisites: MTGN461, MTGN445. 1 hour lecture, 3 hours lab; 2 semester hours.

MTGN467. MATERIALS DESIGN: SYNTHESIS, CHARACTERIZATION AND SELECTION. 2.0 Semester Hrs.
(I) Application of fundamental materials engineering principles to the design of systems, processes, and/or components for extraction, synthesis, operation and/or selection of materials in open-ended projects with realistic constraints. Project topics range from processes used for metallurgical processing and extraction to design and development of emergent materials to process/component analysis and (re)design. Chemical and microstructural characterization and property measurements provide the basis for linking synthesis to application and/or process to product. Selection criteria tied to specific requirements drive design under realistic constraints that include an appropriate mix of technical, economic, safety, and other considerations. Activities are carried out in teams in collaboration with project sponsors/clients. Prerequisite: MTGN352. Corequisites: MTGN348, MTGN334. 1 hour lecture, 3 hours lab; 2 semester hours.

MTGN468. FUEL CELL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.
(I) Fuel cells provide one of the most efficient means for converting the chemical energy stored in a fuel to electrical energy. Fuel cells offer improved energy efficiency and reduced pollution compared to heat engines. While composed of no (or very few) moving parts, a complete fuel cell system amounts to a small chemical plant for the production of power. This course introduces students to the fundamental aspects of fuel cell systems, with emphasis placed on proton exchange membrane (PEM) and solid oxide fuel cells (SOFC). Students will learn the basic principles of electrochemical energy conversion while being exposed to relevant topics in materials science, thermodynamics, and fluid mechanics. Offered every other year. Prerequisites: PHGN200, MATH315, and MTGN251 or MTGN351 or CHGN209 or CHGN210 or MEGN361. 3 hours lecture; 3 semester hours.
MTGN472. BIOMATERIALS I. 3.0 Semester Hrs.  
(I) This course introduces biomaterials by combining materials engineering principles with understanding of aspects of molecular and cellular biology so that students learn how materials interact with biological systems, particularly for medical use. The course is organized around four main topics: 1) fundamental properties of biomaterials; 2) fundamental concepts in biology relevant to biomaterials; 3) interactions of physiological systems with biomaterials, and 4) processing of biopolymers, bioceramics and glasses, biometals and composites. Key topics covered include processing of materials to achieve specific biological responses, surface energy and surface modification; protein adsorption; cell adhesion, spreading and migration; biomaterials implantation and acute inflammation; blood-materials interactions; biofilms and biomaterials degradation; and clinical applications of biomaterials. Offered every other year. Prerequisite: MTGN202. 3 hours lecture; 3 semester hours.

MTGN473. COMPUTATIONAL MATERIALS. 3.0 Semester Hrs.  
(II) Computational Materials is a course designed as an introduction to computational approaches used in modern materials science and engineering, and to provide the hands-on experience in using massively parallel supercomputers and executing popular materials software packages. The main goal is to provide exposure to students to the growing and highly interdisciplinary field of computational materials science and engineering, through a combination of lectures, hands-on exercises and a series of specifically designed projects. The course is organized to cover different length scales including: atomistic (electronic structure) calculations, molecular dynamics, and phase equilibria modeling. The emerging trends in data driven materials discovery and design are also covered. Particular emphasis is placed on the validation of computational results and recent trends in integrating theory, computations and experiment. 3 hours lecture; 3 semester hours.

MTGN475. METALLURGY OF WELDING. 2.0 Semester Hrs.  
(I, II, S) Introduction to welding processes; thermal aspects; selection of filler metals; stresses; stress relief and annealing; pre- and postweld heat treating; weld defects; welding ferrous and nonferrous alloys; weld metal phase transformations; metallurgical evaluation of resulting weld microstructures and properties; and welding tests. Offered every other year. Prerequisite: MTGN348. Corequisite: MTGN475L. 2 hours lecture; 2 semester hours.

MTGN475L. METALLURGY OF WELDING LABORATORY. 1.0 Semester Hr.  
Equivalent with MTGN477.  
(I, II, S) Experiments designed to supplement the lectures in MTGN475. Offered every other year. Corequisite: MTGN475. 3 hours lab; 1 semester hour.

MTGN497. SUMMER PROGRAMS. 0.0 Semester Hrs.  
(S) Summer registration. Repeatable.

MTGN498. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING. 3.0 Semester Hrs.  
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). The course topic is generally offered only once. Prerequisite: none. 1 to 3 semester hours. Repeatable for credit under different titles.

MTGN499. INDEPENDENT STUDY. 1-3 Semester Hr.  
(I, II, S) Independent advanced-work leading to a comprehensive report. This work may take the form of conferences, library, and laboratory work. Selection of problem is arranged between student and a specific Department faculty-member. Prerequisite: Selection of topic; Independent Study Form must be completed and submitted to Registrar. 1 to 3 semester hours. Repeatable for credit to a maximum of 6 hours.

**Professors**

Kip O. Findley  
Michael J. Kaufman, Vice Provost, Graduate Initiatives and Dean of Materials and Energy Programs  
Ryan P. O'Hayre  
Ivar E. Reimanis, Herman F. Coors Distinguished Professor of Ceramics  
Angus Rockett, Department Head  
Sridhar Seetharaman  
John G. Speer, American Bureau of Shipping Endowed Chair in Metallurgical and Materials Engineering

**Associate Professors**

Geoff L. Brennecka, Assistant Director, Materials Science, Fryrear Chair for Innovation and Excellence  
Amy Clarke  
Emmanuel De Moor  
Brian P. Gorman  
Jeffrey C. King  
Corinne E. Packard

**Assistant Professors**

Kester Clarke, FIERF Professor  
Vladen Stevanovic  
Zhennchen Yu

**Teaching Professor**

Gerald Bourne, Assistant Department Head

**Emeriti Professors**

Glen R. Edwards, University Professor Emeritus  
John P. Hager, University Professor Emeritus  
George Krauss, University Professor Emeritus  
Stephen Liu, University Professor Emeritus, Inaugural American Bureau of Shipping Chair Professor  
Gerard P. Martins, Professor Emeritus  
David K. Matlock, University Professor Emeritus  
Brajendra Mishra, University Professor Emeritus
John J. Moore, Professor Emeritus

David L. Olson, University Professor Emeritus

Dennis W. Readey, University Professor Emeritus

Chester J. Van Tyne, Professor Emeritus

**Emeriti Associate Professors**

Gerald L. DePoorter

Robert H. Frost

Steven W. Thompson

**Affiliate Faculty**

Corby G. Anderson, Harrison Western Professor

Patrick R. Taylor, George S. Ansell Distinguished Professor of Chemical Metallurgy