Metallurgical and Materials Engineering

Degrees Offered
- Master of Engineering (Metallurgical and Materials Engineering)
- Master of Science (Metallurgical and Materials Engineering)
- Doctor of Philosophy (Metallurgical and Materials Engineering)

Program Description
The program of study for the Master or Doctor of Philosophy degrees in Metallurgical and Materials Engineering is selected by the student in consultation with her or his advisor, and with the approval of the Thesis Committee. The program can be tailored within the framework of the regulations of the Graduate School to match the student’s interests while maintaining the main theme of materials engineering and processing. There are three areas of specialization within the Department:

- Physical and Mechanical Metallurgy;
- Physicochemical Processing of Materials; and,
- Ceramic Engineering.

The Department is home to six research centers:
- Advanced Coatings and Surface Engineering Laboratory (ACSEL);
- Advanced Steel Processing and Products Research Center (ASPPRC);
- Center for Advanced Non Ferrous Structural Alloys (CANFSA);
- Center for Welding Joining, and Coatings Research (CWJCR);
- Colorado Center for Advanced Ceramics (CCAC); and,
- Kroll Institute for Extractive Metallurgy (KIEM).

The Nuclear Science and Engineering Center (NuSEC) also operates closely with the Department.

A Graduate Certificate is offered by each Department Center – the requirements for the Graduate Certificate are:
1. Be admitted to MME Graduate Certificate Program upon the recommendation of the MME Department.
2. Complete a total of 12 hours of course credits of which only 3 credit hours can be at the 400 level.

The specific courses to be taken are determined by the Graduate Advisor in the Department Center selected by the candidate. A cumulative grade point average of B or better must be maintained while completing these requirements.

Degree Program Requirements
The program requirements for the three graduate degrees offered by the Department are listed below:

Master of Engineering Degree
Requirements: A minimum total of 30.0 credit hours consisting of:
1. A minimum of 24.0 credit hours of approved course work and 3.0 hours of either a three-credit hour research-based Independent Study (MTGN599) or a designated design course (minimum of 3 credit hours) and graduate seminar enrollment (MTGN501) during the duration of the program (up to a maximum of 1 credit hour).
2. The designated design courses include the following courses: MTGN114, MTGN445, MTGN450, MTGN461, MTGN464, MTGN466, MTGN475/477, MTGN549, MTGN564, MTGN560. Alternative courses can be substituted with approval from the advisor and department head.

Restrictions:
1. Only three (3) credit hours of independent course work, e.g. MTGN599, may be applied toward the degree.
2. A maximum of nine (9) credit hours of approved 400-level course work may be applied toward the degree.
3. Courses taken to remove deficiencies may not be applied toward the degree.

The Master of Engineering Degree can also be obtained as part of the combined undergraduate/graduate degree program.

Master of Science Degree
Requirements: A minimum total of 30.0 credit hours, consisting of:
1. A minimum of 18.0 credit hours of approved course work and a minimum of 6.0 hours of graduate research-credits listed under MTGN707.
2. Approval of all courses by the Thesis Committee and the Department Head. (Thesis Committee: consisting of 3 or more members, including the advisor and at least 1 additional member from the Metallurgical and Materials Engineering Department.)
3. Submittal and successful oral defense of a thesis before a Thesis Committee. The thesis must present the results of original scientific research or development.
4. Graduation seminar enrollment (MTGN501) during duration of program (up to a maximum of 1 credit hour).

Restrictions:
1. Only three (3) credit hours of independent course work, e.g. MTGN599, may be applied toward the degree.
2. A maximum of nine (9) credit hours of approved 400-level course work may be applied toward the degree.
3. Courses taken to remove deficiencies may not be applied toward the degree.

Doctor of Philosophy Degree
Requirements: A minimum total of 72.0 credit hours consisting of:
1. A minimum of 36.0 credit hours of approved course work and a minimum of 24.0 hours of research-credits (MTGN707). Credit hours previously earned for a Master’s degree may be applied, subject to approval, toward the Doctoral degree provided that the Master's degree was in Metallurgical and Materials Engineering or a similar field. At least 21.0 credit hours of approved course work must be taken at the Colorado School of Mines.
2. All courses and any applicable Master’s degree credit-hours must be approved by the Thesis Committee and the Department Head (Thesis Committee consisting of: 4 or more members, including the advisor, at least 2 additional members from the Metallurgical and Materials Engineering Department, and at least 1 member from outside the Department.)
5. Presentation of a Progress Report on their Research Project to the Thesis Committee; this presentation is usually 6 months after successfully completing the Q.P. Examinations and no fewer than 6 weeks before the Defense of Thesis.
6. Submittal and successful oral defense of a thesis before the Thesis Committee. The thesis must present the results of original scientific research or development.
7. Graduation seminar enrollment (MTGN501) during duration of program (up to a maximum of 1 credit hour).

Restrictions:
1. Only six (6) credit hours of independent course work, e.g. MTGN599, may be applied toward the degree.
2. A maximum of nine (9) credit hours of approved 400-level course work may be applied toward the degree.
3. Courses taken to remove deficiencies may not be applied toward the degree.

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 undergraduate program should have included a background in science fundamentals and engineering principles. A student, who possesses this background but has not taken specific undergraduate courses in Metallurgical and Materials Engineering, will be allowed to rectify these course deficiencies at the beginning of their program of study.

Mines’ Combined Undergraduate / graduate degree Program for non-thesis MS
Students with continuous registration at Mines from the undergraduate to the graduate degree may fulfill part of the degree requirements by double counting six credit hours, which were also used in fulfilling the requirements of their undergraduate degree at Mines. These courses must have been passed with a “B” or better and meet all other University and Department requirements for graduate credit, but their grades are not included in calculating the graduate GPA.”

Fields of Research

Coatings Research
- Chemical vapor deposition
- Coating materials, films and applications
- Epitaxial growth
- Interfacial science
- Physical vapor deposition
- Surface mechanics
- Surface physics
- Tribology of thin films and coatings

Extractive and Mineral Processing Research
- Chemical and physical processing of materials
- Electrometallurgy
- Hydrometallurgy
- Mineral processing
- Pyrometallurgy
- Recycling and recovery of materials
- Thermal plasma processing

Nonferrous Research
- Aluminum alloys
- High entropy alloys
- Magnesium alloys
- Nonferrous structural alloys
- Shape memory alloys
- Superalloys
- Titanium alloys

Polymers and Biomaterials Research
- Advanced polymer membranes and thin films
- Biopolymers
- Bio-mimetic and bio-inspired materials engineering
- Calcium phosphate-based ceramics
- Drug delivery
- Failure of medical devices
- Interfaces between materials and tissue
- Living/controlled polymerization
- Organic-inorganic hybrid materials
- Porous structured materials
- Self- and directed-assembly
- Structural medical alloys
- Tissue as a composite material

Steel Research
- Advanced high strength steels
- Advanced steel coatings
- Carburized steels
- Deformation behavior of steels
- Fatigue behavior of steels
- Microalloyed steels
- Nickel-based steels
- Quench and partitioned steels

Ceramic Research
- Ceramic processing
- Ceramic-metal composites
- Functional materials
- Ion implantation
- Modeling of ceramic processing
- Solid oxide fuel cell materials and membranes
- Transparent conducting oxides
• Plate steels
• Sheet steels

Welding and Joining Research
• Brazing of ultra wide gaps
• Explosive processing of materials
• Laser welding and processing
• Levitation for kinetics and surface tension evaluation
• Materials joining processes
• Pyrochemical kinetics studies using levitation
• Underwater and under oil welding
• Welding and joining science
• Welding rod development
• Welding stress management
• Weld metallurgy
• Weld wire development

Nuclear Materials Research
• Nuclear materials characterization
• Nuclear materials processing
• Nuclear materials properties

Experimental Methods
• 3D atom probe tomography
• Atomic force microscopy
• Computer modeling and simulation
• Electron microscopy
• Mathematical modeling of material processes
• Nanoindentation
• Non-destructive evaluation
• X-ray diffraction

Other Research Areas
• Combustion synthesis
• Corrosion science and engineering
• Failure analysis
• Mechanical metallurgy
• Phase transformation and mechanism of microstructural change
• Physical metallurgy
• Reactive metals properties
• Strengthening mechanisms
• Structure-property relationships

Professors
Angus Rockett, Department Head
Michael J. Kaufman, Dean of CASE
Ryan O’Hayre, Program Director of Material Science
Ivar E. Reimanis, Professor, Herman F. Coors Distinguished Professor of Ceramics
Sridhar Seetharaman

John G. Speer, John Henry Moore Distinguished Professor of Metallurgical and Materials Engineering

Associate Professors
Geoff L. Brennecka
Amy Clarke
Emmanuel De Moor
Kip O. Findley
Brian Gorman
Jeffrey C. King
Corinne E. Packard

Assistant Professors
Kester Clarke, FIERF Professor
Vladan Stevanovic
Zhenzhen Yu

Teaching Professor
Gerald Bourne, Assistant Department Head

Research Professors
William (Grover) Coors
Ivan Cornejo
Robert Field
Terry Lowe
Stephen Midson
Paul Queneau
D. (Erik) Spiller

Research Associate Professors
Robert Cryderman
Brock O’Kelly

Research Assistant Professors
David Diercks
Judith C. Gomez
Juan Carlos Madeni
Michael Sanders

Professors Emeriti
Glen R. Edwards, University Professor Emeritus
John P. Hager, University Professor Emeritus
George Krauss, University Professor Emeritus
Stephen Liu
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

Associate Professors Emeriti
Gerald L. DePoorter
Robert H. Frost
Steven W. Thompson

Affiliate Faculty
Richard K. Ahrenkiel
Corby G. Anderson
Patrick R. Taylor, George S. Ansell Distinguished Professor of Chemical Metallurgy
Edgar Vidal
James C. Williams

Research Associates
Carole Graas
Gary Zito

Courses

MLGN500. PROCESSING, MICROSTRUCTURE, AND PROPERTIES OF MATERIALS. 3.0 Semester Hrs.
(II) 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.
Equivalent with CHGN410,
(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 DCGN210. 3 hours lecture; 3 semester hours.

MLGN511. KINETIC CONCERNS IN MATERIALS PROCESSING I. 3.0 Semester Hrs.
Equivalent with EGGN555,
(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 converters, 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.
(I) Review mechanics of materials. Introduction to elastic and non-linear continua. Cartesian tensors and stresses and strains. Analytical solution of elasticity problems. Develop basic concepts of fracture mechanics. Prerequisite: EGGN320 or equivalent, MATH225 or equivalent. 3 hours lecture; 3 semester hours.

MLGN518. 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.
(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. 3 hours lecture; 3 semester hours.

MLGN521. 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.

MLGN523. APPLIED SURFACE AND SOLUTION CHEMISTRY. 3.0 Semester Hrs.
(II) Solution and surface chemistry of importance in mineral and metallurgical operations. Pre requisite: 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, CRGN307, EGGN351 or equivalent. 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 syntheses 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 BELS555,CBEN555,CHEN555,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 CHEN569,EGGN569,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,
(II) 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.

(II) 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.

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) 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 Hrs.
(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.

MTGN501. MME GRADUATE SEMINAR. 0.5 Semester Hrs.
(I, II) All full-time MME graduate students must attend the Metallurgical and Materials Engineering seminar. Students must take the Graduate Seminar course every semester that they are enrolled at CSAM. At the end of each semester, students are assigned either a satisfactory or unsatisfactory progress grade, based on attendance, until the final semester of the student's degree program, when a letter grade is assigned based on all prior semesters' attendance grades. As a result, while these courses are taken each year, only a maximum of 1.0 hours total of course credit is conferred. Students who have official part-time status are not required to sign up for Graduate Seminar. Attendance of other seminars outside MME can substitute for seminar attendance in MME following course instructor approval. 1 hour lecture; 0.5 hours. Repeatable up to 1 hour.

MTGN505. CRYSTALLOGRAPHY AND DIFFRACTION. 3.0 Semester Hrs.
(I) Introduction to point symmetry operations, crystal systems, Bravais lattices, point groups, space groups, Laue classes, stereographic projections, reciprocal lattice and Ewald sphere constructions, the new International Tables for Crystallography, and, finally, how certain properties correlate with symmetry. Subsequent to the crystallography portion, the course will move into the area of diffraction and will consider the primary diffraction techniques (x-rays, electrons and neutrons) used to determine the crystal structure of materials. Other applications of diffraction such as texture and residual stress will also be considered. Prerequisites: Graduate or Senior in good standing. 3 hours lecture, 3 semester hours.

MTGN511. SPECIAL METALLURGICAL AND MATERIALS ENGINEERING PROBLEMS. 1-3 Semester Hr.
(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. 1 to 3 semester hours. Repeatable for credit under different titles.

MTGN512. SPECIAL METALLURGICAL AND MATERIALS ENGINEERING PROBLEMS. 1-3 Semester Hr.
(II) Continuation of MTGN511. Prerequisite: Selection of topic. 1 to 3 semester hours. Repeatable for credit under different titles.

MTGN514. DEFECT CHEMISTRY AND TRANSPORT PROCESSES IN CERAMIC SYSTEMS. 3.0 Semester Hrs.
(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; MTGN311. 3 hours lecture; 3 semester hours. (Fall of odd years only.).

MTGN516. MICROSTRUCTURE OF CERAMIC SYSTEMS. 3.0 Semester Hrs.
(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. 3 hours lecture; 3 semester hours. (Spring of even years only.).

MTGN517. REFRACTORIES. 3.0 Semester Hrs.
(i) The manufacture, testing, and use of basic, neutral, acid, and specialty refractories are presented. Special emphasis is placed on the relationship between physical properties of the various refractories and their uses in the metallurgical industry. Prerequisite: none. 3 hours lecture; 3 semester hours.

MTGN518. PHASE EQUILIBRIA IN CERAMIC SYSTEMS. 3.0 Semester Hrs.
(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: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

MTGN523. APPLIED SURFACE AND SOLUTION CHEMISTRY. 3.0 Semester Hrs.
(II) Solution and surface chemistry of importance in mineral and metallurgical operations. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

MTGN526. 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 Status. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

MTGN527. SOLID WASTE MINIMIZATION AND RECYCLING. 3.0 Semester Hrs.
(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. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

MTGN528. EXTRACTIVE METALLURGY OF COPPER, GOLD AND SILVER. 3.0 Semester Hrs.
Practical applications of fundamentals of chemical-processing-of-materials to the extraction of gold, silver and copper. Topics covered include: History; Ore deposits and mineralogy; Process Selection; Hydrometallurgy and leaching; Oxidation pretreatment; Purification and recovery; Refinement; Waste treatment; and Industrial examples. Prerequisites: Graduate or Senior in good-standing. 3 hours lecture, 3 semester hours.
MTGN529. METALLURGICAL ENVIRONMENT. 3.0 Semester Hrs.
(I) Effluents, wastes, and their point sources associated with metallurgical processes, such as mineral concentration and values extraction? providing for an interface between metallurgical process engineering and the environmental engineering areas. Fundamentals of metallurgical unit operations and unit processes, applied to waste and effluents control, recycling, and waste disposal. Examples which incorporate engineering design and cost components are included. Prerequisites: MTGN334. 3 hours lecture; 3 semester hours.

MTGN530. ADVANCED IRON AND STEELMAKING. 3.0 Semester Hrs.
(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 melting furnace, pneumatic steelmaking furnace, refining slags, deoxidation and degassing, ladle metallurgy, alloying, and continuous casting of steel. Prerequisite: DCGN209 or MTGN351. 3 hours lecture; 3 semester hours. (Fall of even years only.).

MTGN531. THERMODYNAMICS OF METALLURGICAL AND MATERIALS PROCESSING. 3.0 Semester Hrs.
(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. 3 hours lecture; 3 semester hours.

MTGN532. PARTICULATE MATERIAL PROCESSING I - COMMINUTION AND PHYSICAL SEPARATIONS. 3.0 Semester Hrs.
An introduction to the fundamental principles and design criteria for the selection and use of standard mineral processing unit operations in comminution and physical separation. Topics covered include: crushing (jaw, cone, gyratory), grinding (ball, pebble, rod, SAG, HPGR), screening, thickening, sedimentation, filtration and hydrocyclones. Two standard mineral processing plant-design simulation software (MinOCad and JK SimMet) are used in the course. Prerequisites: Graduate or Senior in good-standing. 3 hours lecture; 3 semester hours.

MTGN533. PARTICULATE MATERIAL PROCESSING II - APPLIED SEPARATIONS. 3.0 Semester Hrs.
An introduction to the fundamental principles and design criteria for the selection and use of standard mineral processing unit operations in applied separations. Topics covered include: photometric ore sorting, magnetic separation, dense media separation, gravity separation, electrostatic separation and flotation (surface chemistry, reagents selection, laboratory testing procedures, design and simulation). Two standard mineral processing plant-design simulation software (MinOCad and JK SimMet) are used in the course. Graduate or Senior in good-standing. 3 hours lecture; 3 semester hours.

MTGN534. CASE STUDIES IN PROCESS DEVELOPMENT. 3.0 Semester Hrs.
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: none. 3 hours lecture; 3 semester hours.

MTGN535. PYROMETALLURGICAL PROCESSES. 3.0 Semester Hrs.
(I) Detailed study of a selected few processes, illustrating the application of the principles of physical chemistry (both thermodynamics and kinetics) and chemical engineering (heat and mass transfer, fluid flow, plant design, fuel technology, etc.) to process development. Prerequisite: none. 3 hours lecture; 3 semester hours.

MTGN536. OPTIMIZATION AND CONTROL OF METALLURGICAL SYSTEMS. 3.0 Semester Hrs.
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: none. 3 hours lecture; 3 semester hours.

MTGN537. ELECTROMETALLURGY. 3.0 Semester Hrs.

MTGN538. HYDROMETALLURGY. 3.0 Semester Hrs.
(I) 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: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

MTGN539. PRINCIPLES OF MATERIALS PROCESSING REACTOR DESIGN. 3.0 Semester Hrs.
(II) Review of reactor types and idealized design equations for isothermal conditions. Residence time functions for nonreacting and reacting species and its relevance to process control. Selection of reactor type for a given application. Reversible and irreversible reactions in CSTRs under nonisothermal conditions. Heat and mass transfer considerations and kinetics of gas-solid reactions applied to fluid-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: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

MTGN541. INTRODUCTORY PHYSICS OF METALS. 3.0 Semester Hrs.
(I) Electron theory of metals. Classical and quantum-mechanical free electron theory. Electrical and thermal conductivity, thermo electric 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. 3.0 Semester Hrs.
(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 none. 3 hours lecture; 3 semester hours.
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<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
<th>Semester Hrs.</th>
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<tbody>
<tr>
<td>MTGN543</td>
<td>THEORY OF DISLOCATIONS</td>
<td>3.0</td>
<td>(I) Stress field around dislocation, forces on dislocations, dislocation</td>
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<td>reactions, dislocation multiplication, image forces, interaction with point</td>
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<td>defects, interpretation of macroscopic behavior in light of dislocation</td>
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<td>mechanisms. Prerequisite: none. 3 hours lecture; 3 semester hours. (Fall</td>
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<td>of odd years only.).</td>
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<tr>
<td>MTGN544</td>
<td>FORGING AND DEFORMATION MODELING</td>
<td>3.0</td>
<td>(I) Examination of the forging process for the fabrication of metal</td>
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<td>components. Techniques used to model deformation processes including slab</td>
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<td>equilibrium, slip line, upper bound and finite element methods. Application</td>
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<td>of these techniques to specific aspects of forging and metal forming</td>
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<td>processes. Prerequisite: none. 3 hours lecture; 3 semester hours. (Fall of</td>
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<td>odd years only.).</td>
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<tr>
<td>MTGN545</td>
<td>FATIGUE AND FRACTURE</td>
<td>3.0</td>
<td>(I) Basic fracture mechanics as applied to engineering materials, S-N</td>
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<td>curves, the Goodman diagram, stress concentrations, residual stress</td>
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<td>effects, effect of material properties on mechanisms of crack propagation.</td>
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<td>Prerequisite: none. 3 hours lecture; 3 semester hours. (Fall of odd years</td>
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<td>MTGN546</td>
<td>CREEP AND HIGH TEMPERATURE MATERIALS</td>
<td>3.0</td>
<td>(II) Overview of plasticity. Examination and Analysis of working</td>
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<td>fractures. Nondestructive testing.</td>
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<td>Mathematical description of creep process. Mathematical methods of</td>
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<td>extrapolation of creep data. Micromechanisms of creep deformation,</td>
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<td></td>
<td></td>
<td>including dislocation glide and grain boundary sliding. Study of various</td>
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<td>high temperature materials, including iron, nickel, and cobalt base alloys</td>
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<td>and refractory metals, and ceramics. Emphasis on phase transformations and</td>
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<td>microstructure-property relationships. Prerequisite: none. 3 hours</td>
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<td>lecture; 3 semester hours. (Fall of odd years only.).</td>
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<td>MTGN547</td>
<td>PHASE EQUILIBRIA IN MATERIALS SYSTEMS</td>
<td>3.0</td>
<td>(I) Phase equilibria of uniary, binary, ternary, and multicomponent</td>
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<td>systems, microstructure interpretation, pressure-temperature diagrams,</td>
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<td>determination of phase diagrams. Prerequisite: none. 3 hours lecture; 3</td>
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<td>semester hours.</td>
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<td>MTGN548</td>
<td>TRANSFORMATIONS IN METALS</td>
<td>3.0</td>
<td>(I) Surface and interfacial phenomena, order of transformation, grain</td>
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<td>growth, recovery, recrystallization, solidification, phase transformation</td>
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<td>in solids, precipitation hardening, spinodal decomposition, martensitic</td>
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<td>transformation, gas metal reactions. Prerequisite: none. 3 hours lecture;</td>
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<td>3 semester hours. (Fall of odd years only.).</td>
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<tr>
<td>MTGN549</td>
<td>CURRENT DEVELOPMENTS IN FERROUS ALLOYS</td>
<td>3.0</td>
<td>(I) Development and review of solid state transformations and strengthening</td>
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<td>mechanisms in ferrous alloys. Application of these principles to the</td>
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<td>development of new alloys and processes such as high strength low alloy</td>
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<td>steels, high temperature alloys, maraging steels, and case hardening</td>
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<td>processes. Prerequisite: MTGN348. 3 hours lecture; 3 semester hours.</td>
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<tr>
<td>MTGN550</td>
<td>ADVANCED CORROSION ENGINEERING</td>
<td>3.0</td>
<td>(I) Advanced topics in corrosion engineering. Case studies and industrial</td>
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<td>application. Special forms of corrosion. Advanced measurement techniques.</td>
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<td>Prerequisite: MTGN451. 3 hours lecture; 3 semester hours. (Fall of even</td>
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<td>years only.).</td>
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<td>MTGN551</td>
<td>INORGANIC MATRIX COMPOSITES</td>
<td>3.0</td>
<td>Introduction to the processing, structure, properties and applications of</td>
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<td>metal matrix and ceramic matrix composites. Importance of structure</td>
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<td>and properties of both the matrix and the reinforcement and the types of</td>
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<td>reinforcement utilized-particulate, short fiber, continuous fiber, and</td>
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<td>laminates. Emphasis on the development of mechanical properties</td>
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<td>through control of synthesis and processing parameters. Other physical</td>
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<td>properties such as electrical and thermal will also be examined. Prerequisite</td>
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<td>/Co-requisite*: MTGN352, MTGN445/MLGN505*. 3 hours lecture; 3 semester</td>
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<td>hours. (Summer of even years only.).</td>
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<td>MTGN552</td>
<td>STRENGTHENING MECHANISMS</td>
<td>3.0</td>
<td>(II) Strain hardening in polycrystalline materials, dislocation inter</td>
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<td>actions, effect of grain boundaries on strength, solid solution hardening,</td>
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<td>martensitic transformations, precipitation hardening, point defects.</td>
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<td>Prerequisite: MTGN543 or concurrent enrollment. 3 hours lecture;3 semester</td>
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<td>hours. (Spring of even years only.).</td>
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<td>MTGN553</td>
<td>OXIDATION OF METALS</td>
<td>3.0</td>
<td>(I) Kinetics of oxidation. The nature of the oxide film. Transport in</td>
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<td>oxides. Mechanisms of oxidation. The Oxidation protection of high-temperature</td>
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<td>metal systems. Prerequisite:none. 3 hours lecture; 3 semester hours.</td>
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<td>(Spring of even years only.).</td>
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<td>MTGN554</td>
<td>SOLID STATE THERMODYNAMICS</td>
<td>3.0</td>
<td>(I) Thermodynamics applied to solid state reactions, binary and ternary</td>
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<td>phase diagrams, point, line and planar defects, interfaces, and electrochemical concepts. Prerequisite: none. 3 hours lecture; 3 semester hours.</td>
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<td>MTGN555</td>
<td>TRANSPORT IN SOLIDS</td>
<td>3.0</td>
<td>(I) Heat flow and fluid flow in solidification, thermodynamics of</td>
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<td>solidification, nucleation and interface kinetics, grain refining, crystal</td>
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<td>and grain growth, constitutional supercooling, eutectic growth, solidification of castings and ingots, segregation, and porosity. Prerequisite: none. 3 hours lecture; 3 semester hours. (Fall of odd years only.).</td>
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<tr>
<td>MTGN556</td>
<td>ANALYSIS OF METALLURGICAL FAILURES</td>
<td>3.0</td>
<td>(II) Applications of the principles of physical and mechanical metallurgy</td>
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<td>to the analysis of metallurgical failures. Nondestructive testing.</td>
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<td>Fractography. Case study analysis. Prerequisite: none. 3 hours lecture; 3</td>
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<td>semester hours. (Spring of odd years only.).</td>
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<tr>
<td>MTGN557</td>
<td>PHYSICAL METALLURGY OF ALLOYS FOR AEROSPACE</td>
<td>3.0</td>
<td>(I) Review of current developments in aerospace materials with particular</td>
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<td>attention paid to titanium alloys, aluminum alloys, and metal-matrix</td>
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<td>composites. Emphasis is on phase equilibria, phase transformations, and</td>
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<td>microstructure-property relationships. Concepts of innovative processing</td>
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<td>and microstructural alloy design are included where appropriate. Prerequisite</td>
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<td>none. 3 hours lecture; 3 semester hours. (Fall of even years only.).</td>
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<tr>
<td>MTGN558</td>
<td>ADVANCED FORGING AND FORMING</td>
<td>3.0</td>
<td>(II) Overview of plasticity. Examination and Analysis of working</td>
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<td>operations of forging, extrusion, rolling, wire drawing and sheet metal</td>
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<td>forming. Metallurgical structure evolution during working. Laboratory</td>
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<td>experiments involving metal forming processes. Prerequisites: MTGN445/ MLGN505, 2 hours lecture; 3 hours lab, 3 semester hours.</td>
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</table>
MTGN565. MECHANICAL PROPERTIES OF CERAMICS AND COMPOSITES. 3.0 Semester Hrs.
(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. 3 hours lecture; 3 semester hours. (Fall of even years only.).

MTGN569. FUEL CELL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.
Equivalent with CBEN569.CHEN569,EGGN569,MEGN569,MLGN569.
(I) Investigate fundamentals of fuel-cell operation and electrochemistry from a chemical-thermodynamics and materials-science perspective. Review types of fuel cells, fuel-processing requirements and approaches, and fuel-cell system integration. Examine current topics in fuel-cell science and technology. Fabricate and test operational fuel cells in the Colorado Fuel Cell Center. 3 credit hours.

MTGN570. BIOCOMPATIBILITY OF MATERIALS. 3.0 Semester Hrs.
Equivalent with BELS570,
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: BIOL110 or equivalent. 3 hours lecture; 3 semester hours.

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

MTGN572. BIOMATERIALS. 3.0 Semester Hrs.
Equivalent with MLGN572,
(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.

MTGN573. COMPUTATIONAL MATERIALS. 3.0 Semester Hrs.
(II) Computational Materials is a course designed as an introduction to computational approaches and codes used in modern materials science and engineering, and to provide the hands?on experience in using massively parallel supercomputers and 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. Graduate students are expected to successfully complete 4 projects while the undergraduate students are required to finish 3 out of 4 projects. 3 hours lecture; 3 semester hours.

MTGN580. ADVANCED WELDING METALLURGY. 3.0 Semester Hrs.
(II) Weldability of high strength steels, high alloys, and light metals; Welding defects; Phase transformations in weldments; Thermal experience in weldments; Pre- and Post-weld heat treatment; Heat affected zone formation, microstructure, and properties; Consumables development. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

MTGN581. WELDING HEAT SOURCES AND INTERACTIVE CONTROLS. 3.0 Semester Hrs.
(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. 3 hours lecture; 3 semester hours. (Fall of odd years only.).

MTGN582. MECHANICAL PROPERTIES OF WELDED JOINTS. 3.0 Semester Hrs.
(II) Mechanical metallurgy of heterogeneous systems, shrinkage, distortion, cracking, residual stresses, mechanical testing of joints, size effects, joint design, transition temperature, fracture. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

MTGN583. PRINCIPLES OF NON-DESTRUCTIVE TESTING AND EVALUATION. 3.0 Semester Hrs.
(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. 3 hours lecture; 3 semester hours. (Fall of odd years only.).

MTGN584. NON-FUSION JOINING PROCESSES. 3.0 Semester Hrs.
(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: none. 3 hours lecture; 3 semester hours. (Spring of even years only.).

MTGN586. DESIGN OF WELDED STRUCTURES AND ASSEMBLIES. 3.0 Semester Hrs.
Introduction to the concepts and analytical practice of designing weldments. Designing for impact, fatigue, and torsional loading. Designing of weldments using overlapping and undermatching criteria. Analysis of combined stresses. Designing of compression members, column bases and splices. Designing of built-up columns, welded plate cylinders, beam-to-column connections, and trusses. Designing for tubular construction. Weld distortion and residual stresses. Joint design. Process consideration in weld design. Welding codes and specifications. Estimation of welding costs. Prerequisite/Co-requisite: MATH225 or equivalent, EGGN320 or equivalent, MTGN475. 3 hours lecture; 3 semester hours. (Summer of odd years only.).

MTGN587. PHYSICAL PHENOMENA OF WELDING AND JOINING PROCESSES. 3.0 Semester Hrs.
(I) Introduction to arc physics, fluid flow in the plasma, behavior of high pressure plasma, cathodic and anodic phenomena, energy generation and temperature distribution in the plasma, arc stability, metal transfer across arc, electron beam welding processes, keyhole phenomena. Ohmic welding processes, high frequency welding, weld pool phenomena. Development of relationships between physics concepts and the behavior of specific welding and joining processes. Prerequisite/Co-requisite: PHGN300, MATH225, MTGN475. 3 hours lecture; 3 semester hours. (Fall of even years only.).
MTGN591. PHYSICAL PHENOMENA OF COATING PROCESSES. 3.0 Semester Hrs.
(I) Introduction to plasma physics, behavior of low pressure plasma, cathodic and anodic phenomena, glow discharge phenomena, glow discharge sputtering, magnetron plasma deposition, ion beam deposition, cathodic arc evaporation, electron beam and laser coating processes. Development of relationships between physics concepts and the behavior of specific coating processes. Prerequisite/ Co-requisite: PHGN300, MATH225. 3 hours lecture; 3 semester hours. (Fall of odd years only.).

MTGN593. NUCLEAR MATERIALS SCIENCE AND ENGINEERING. 3.0 Semester Hrs.
(I) Introduction to the physical metallurgy of nuclear materials, including the nuclear, physical, thermal, and mechanical properties for nuclear materials, the physical and mechanical processing of nuclear alloys, the effect of nuclear and thermal environments on structural reactor materials and the selection of nuclear and reactor structural materials are described. Selected topics include ceramic science of ceramic nuclear material, ceramic processing of ceramic nuclear fuel, nuclear reaction with structural materials, radiation interactions with materials, the aging of nuclear materials, cladding, corrosion and the manufacturing of fuels elements. Relevant issues in the modern fuel cycle will also be introduced including nuclear safety, reactor decommissioning, and environmental impacts. Prerequisites: Graduate or Senior in good-standing. 3 hours lecture, 3 semester hours. (Fall of even years only.).

MTGN598. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING. 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.

MTGN599. INDEPENDENT STUDY. 0.5-6 Semester Hr.
(I, II, S) Individual research or special project 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.

MTGN605. ADVANCED TRANSMISSION ELECTRON MICROSCOPY. 2.0 Semester Hrs.
Introduction to transmission electron microscopy techniques and their application to materials characterization. Topics include electron optics, electron-specimen interactions, imaging, diffraction, contrast mechanisms, defect analyses, compositional measurements using energy dispersive x-ray spectroscopy and energy loss spectroscopy, scanning transmission electron microscopy, high angle annular dark field imaging, energy filtered TEM and high resolution phase contrast imaging. Prerequisite: MTGN 505. Co-requisite: MTGN 605L. 2 hours lecture, 2 semester hours.

MTGN605L. ADVANCED TRANSMISSION ELECTRON MICROSCOPY LABORATORY. 1.0 Semester Hr.
Specimen preparation techniques and their application to materials characterization. Topics include electron optics, electron-specimen interactions, imaging, diffraction, contrast mechanisms, defect analyses, compositional measurements using energy dispersive x-ray spectroscopy and energy loss spectroscopy, scanning transmission electron microscopy, high angle annular dark field imaging, energy filtered TEM and high resolution phase contrast imaging. Prerequisite: Concurrent enrollment in MTGN 605. 3 hours lab, 1 semester hour.

MTGN631. TRANSPORT PHENOMENA IN METALLURGICAL AND MATERIALS SYSTEMS. 3.0 Semester Hrs.
Physical principles of mass, momentum, and energy transport. Application to the analysis of extraction metallurgy and other physicochemical processes. Prerequisite: MATH225 and MTGN461 or equivalent. 3 hours lecture; 3 semester hours.

MTGN671. ADVANCED MATERIALS LABORATORY. 1-3 Semester Hr.
(I) Experimental and analytical research in the fields of production, mechanical, chemical, and/or physical metallurgy. Prerequisite: none. 1 to 3 semester hours; 3 semester hours.

MTGN672. ADVANCED MATERIALS LABORATORY. 1-3 Semester Hr.
(II) Continuation of MTGN671. 1 to 3 semester hours.

MTGN696. VAPOR DEPOSITION PROCESSES. 3.0 Semester Hrs.
(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 varia - bles rather than the structure and properties of the deposited film. Prerequisites: MTGN351, MTGN461, or equivalent courses. 3 hours lecture; 3 semester hours. (Summer of odd years only.).

MTGN697. MICROSTRUCTURAL EVOLUTION OF COATINGS AND THIN FILMS. 3.0 Semester Hrs.
(II) Continuation of MTGN691. 1 to 3 semester hours.

MTGN698. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING. 6.0 Semester Hrs.
(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, 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.

MTGN699. INDEPENDENT STUDY. 0.5-6 Semester Hr.
(I, II) Individual research or special project 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.

MTGN696. VAPOR DEPOSITION PROCESSES. 3.0 Semester Hrs.
(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 varia - bles rather than the structure and properties of the deposited film. Prerequisites: MTGN351, MTGN461, or equivalent courses. 3 hours lecture; 3 semester hours. (Summer of odd years only.).

MTGN697. MICROSTRUCTURAL EVOLUTION OF COATINGS AND THIN FILMS. 3.0 Semester Hrs.
(II) Continuation of MTGN691. 1 to 3 semester hours.
MTGN700. GRADUATE RESEARCH CREDIT: MASTER OF ENGINEERING. 1-6 Semester Hr.
(I, II, S) Research credit hours required for completion of the degree Master of Engineering. Research under the direct supervision of a faculty advisor. Credit is not transferable to any 400, 500, or 600 level courses. However, MTGN 705 credit hours may be transferred, in accordance with the requirements for this (M.E.) degree, by a Master of Science graduate-student who previously accumulated these credit-hours and subsequently opted to change their degree program to a Master of Engineering. Repeatable for credit. Variable: 1 to 6 semester hours.

MTGN707. 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.