Catalog Descriptions and Course Outcomes for MSE Core Classes

Updated September 26, 2019

	NU MSE Course Sequence	
Fall	**Winter**	**Spring**
301, 314	315	316-1
316-2, 351-1, 391	351-2, 361, 332, 396-1	331, 390, 396-2

301: Materials Science Principles

Equilibrium and nonequilibrium development of microstructures. Mechanical behavior of metals, ceramics, and polymers. Corrosion and stability of engineering materials. Materials processing. Not to be taken for credit with or after 201. Prerequisite: CHEM 102.

At the conclusion of the course students will be able to:

1. Describe how atoms, ions and/or molecules assemble into particular crystal structures.
2. Describe how these structures dictate certain properties.
3. Describe how processing can alter the structures present and their attendant properties.
4. Select engineering materials for different applications.
5. Describe the importance of materials to society.

314: Thermodynamics of Materials

Classical and statistical thermodynamics; entropy and energy functions in liquid and solid solutions, and their applications to phase equilibria. Lectures, problem solving. Materials science and engineering degree candidates may not take this course for credit with or after CHEM 342 1. (new stuff)

At the conclusion of the course students will be able to:

1. articulate the fundamental laws of thermodynamics and use them in basic problem solving.
2. discriminate between classical and statistical approaches.
3. describe the thermal behavior of solid materials, including phase transitions.
4. use thermodynamics to describe order-disorder transformations in materials .
5. apply solution thermodynamics for describing liquid and solid solution behavior.

315: Phase Equilibria and Diffusion in Materials

Application of thermodynamics to ternary phase equilibria. Defects and diffusion in solids. Interdiffusion. Short-circuit diffusion. Defects and transport in ionic solids. Lectures, problem solving.
Prerequisite: MAT_SCI 314-0 or equivalent.

At the conclusion of the course students will be able to:

1. Classify, interpret, and analyze Type I, II, and III phase diagrams.
2. Construct schematic phase diagrams from elementary thermodynamics.
3. Navigate binary and ternary phase diagrams to assess phase equilibrium of mixtures.
4. Utilize ternary phase diagrams to follow crystallization paths and predict microstructure evolution. Utilize an understanding of the role of point defects in diffusion and atomistic behavior of solids.
5. Describe the equilibrium thermodynamics of point defects in both crystalline solids.
6. Use thermodynamics and computational tools to predict and interpret phase equilibria in simple unary and binary systems. Examine the role of phase equilibria and diffusion in the context of relevant applications --- alloys, batteries, fuel cells, etc.
7. Prepare alloy specimens for microstructural observation and measurement of hardness profile. Assess experimental results within the context of phase equilibria/diagrams and diffusion.

316-1,2: Microstructural Dynamics

Principles underlying development of microstructures. Defects, diffusion, phase transformations, nucleation and growth, thermal and mechanical treatment of materials. Lectures, laboratory. Prerequisite: 315 or equivalent.

At the conclusion of 316-1 students will be able to:

1. Describe the Kirkendall effect, diffusion in ternary systems, and the importance of short-circuit diffusion.
2. Describe the structure of various types of interfaces and the effects these structures have on interfacial energy.
3. Apply concepts of mathematics and physics to imperfections, diffusion and phase transformations.
4. Use basic concepts of dislocation theory: topology and energetics of dislocations in crystalline materials.
5. Exhibit a good understanding of dislocations as related to their type (edge, screw, mixed), stress fields, energies, geometry (bowing, kinks, jogs) and interaction.
6. Correlate dislocation motion to plastic flow.
7. Describe how the grain size of a material can be controlled by mechanical and thermal processing of materials
8. Demonstrate laboratory skills in structural and thermal processing of materials.

At the conclusion of 316-2 students will be able to:

1. Predict nucleation rates from thermodynamic data
2. Describe where precipitates are likely to form in a multicomponent material
3. Design processing histories to obtain a desired microstructure
4. Correctly use and interpret TTT diagrams

332: Mechanical Behavior of Solids

Plastic deformation and fracture of metals, ceramics, and polymeric materials; structure/property relations. Role of imperfections, state of stress, temperatures, strain rate. Lectures, laboratory. Prerequisites: 316 1; 316 2 (may be taken concurrently).

At the conclusion of the course students will be able to:

1. Apply basic concepts of linear elasticity, including multiaxial stress-strain relationships through elastic constants for single and polycrystals.
2. Quantify the different strengthening mechanisms in crystalline materials, based on interactions between dislocations and obstacles, such as: point defect (solid solution strengthening), dislocations (work hardening), grain boundaries (boundary strengthening) and particles (precipitation and dispersion strengthening).
3. Apply fracture mechanics concepts to determine quantitatively when existing cracks in a material will grow.
4. Describe how composite toughening mechanisms operate in ceramic matrix and polymer matrix composties.
5. Derive simple relationships for the composite stiffness and strength based on those of the constituent phases.
6. Exhibit a quantitative understanding of high temperature deformation in metals and ceramics, based on various creep mechanisms relate to diffusional and dislocation flow (Coble, Nabarro-Herring and Dislocation creep/climb mechanisms).
7. Exhibit a basic understanding of factors affecting fatigue in engineering materials, as related to crack nucleation and propagation, as well as their connection to macroscopic fatigue phenomena.
8. Describe the interplay between surface phenomena (environmental attack) and stresses leading to material embrittlement.
9. Use the finite element method to calculate the stress and strain states for simple test cases, including a cantilever beam and a material with a circulat hole that is placed in tension.
10. Use complex moduli to solve mechanics problems involving an oscillatory stress.
11. Prepare and characterize specimens for measurement of mechanical properties.
12. Write results from a laboratory project in the form of a journal article, and present their work orally as would be required in a technical forum.
13. Select materials based on design requirements.

331: Soft Materials

Different kinds of polymeric materials. Relationships between structure and physical properties; rubber elasticity, the glassy state, crystallinity in polymers. Lectures, laboratory. Prerequisites: 301 or equivalent; 314 or CHEM 342 1.

At the conclusion of the course students will be able to:

1. Given the chemical structure of a common polymer, draw the chemical structures of the monomer(s) from which it was made.
2. Given the chemical structure of a monomer (or monomers), draw the chemical structure polymers that can be synthesized from it (or them).

3. Understand, describe and calculate the structural parameters of polymeric materials including monomer units, molecular weight, tacticity, coil dimension, crystallinity, and morphology.
4. Describe the relationship between the above structural parameters and the mechanical and thermal properties of polymeric materials.
5. Describe how the structure and mechanical properties of polymeric materials change at the glass transition temperature and at the melting temperature.
6. Describe how the molecular structure of a surfactant determines its micelle structure.
7. Describe how surfactant molecules and aggregates affect the optical properties, viscosity and surface tension of polymer solutions.
8. Calculate the intermolecular and surface forces for molecules and colloids of different geometries.
9. Design strategies to stabilize or destabilize colloidal systems.
10. Identify a soft material application in daily life, such as in arts, music, sports or food, and explain how material advancement has imporved the application.

351: Introductory Physics of Materials

Quantum mechanics; applications to materials and engineering. Band structures and cohesive energy; thermal behavior; electrical conduction; semiconductors; amorphous semiconductors; magnetic behavior of materials; liquid crystals. Lectures, laboratory, problem solving. Prerequisites: GEN ENG 205 4 or equivalent; PHYSICS 135 2,3.

At the conclusion of 351-1 students will be able to:

1. Solve the time-independent Schrödinger equation for simple one-dimensional potentials.
2. Calculate probabilities of reflection and transmission for 1-D potential barriers or wells.
3. Use the wavefunctions and energies of the hydrogen atom to determine the ground and excited state energies of hydrogenic systems.
4. Describe models of bonding, including ionic, covalent, metallic, and Van der Waals, using quantum mechanical concepts of energy minimization.
5. Calculate the specific heat for fermions (e.g. electrons) and bosons (e.g. phonons) in 1, 2, and 3 dimensions, given the density of states.
6. Describe the impact of Fermi statistics on the electrical properties of metals.
7. Use simple models of band-structure, such as the Feynman model and the Krönig-Penney model, to relate the properties of local atomic states to delocalized states (bands) in a material.
8. Given the dispersion relationship, calculate the effective mass and density of states in the nearly free electron approximation.
9. Determine the intrinsic and/or extrinsic carrier concentration in a semiconductor given the temperature, doping level, and other relevant quantities.

At the conclusion of 351-2 students will be able to:

1. Given basic information about a semiconductor including bandgap and doping level, calculate the magnitudes of currents that result from the application of electric fields and optical excitation, distinguishing between drift and diffusion transport mechanisms.

2. Explain how dopant gradients, dopant homojunctions, semiconductor-semiconductor hetero junctions, and semiconductor-metal junctions perturb the carrier concentrations in adjacent materials or regions, identify the charge transport processes at the interfaces, and describe how the application of an electric field affects the band profiles and carrier concentrations.

3. Represent the microscopic response of dielectrics to electric fields with simple physical models and use the models to predict the macroscopic polarization and the resulting frequency dependence of the real and imaginary components of the permittivity.

4. Given the permittivity, calculate the index of refraction, and describe how macroscopic phenomena of propagation, absorption, reflection and transmission of plane waves are affected by the real and imaginary components of the index of refraction.

5. Identify the microscopic interactions that lead to magnetic order in materials, describe the classes of magnetism that result from these interactions, and describe the temperature and field dependence of the macroscopic magnetization of bulk crystalline diamagnets, paramagnets, and ferromagnets.

6. Specify a material and microstructure that will produce desired magnetic properties illustrated in hysteresis loops including coercivity, remnant magnetization, and saturation magnetization.

7. Describe the output characteristics of p-n and Schottky junctions in the dark and under illumination and describe their utility in transistors, light emitting diodes, and solar cells.

8. For technologies such as cell phones and hybrid electric vehicles, identify key electronic materials and devices used in the technologies, specify basic performance metrics, and relate these metrics to fundamental materials properties.

361: Crystallography and Diffraction

Elementary crystallography. Basic diffraction theory; reciprocal space. Applications to structure analysis, preferred orientation. Film and counter techniques. Lectures, laboratory. Prerequisites: GEN ENG 205 4; PHYSICS 135 2,3.

At the conclusion of the course students will be able to:

1. Identify different types of crystal structures that occur in metals, ceramics, and polymers.

2. Perform standard x-ray diffraction measurements on metals, ceramics and polymers and quantitatively interpret the results.

3. Describe the basic particle and wave physical processes underlying x-ray emission, elastic and inelastic scattering, absorption, and interference of coherent waves.

4. Describe basic principles underlying synchrotron x-ray sources, x-ray fluorescence spectroscopy, and low-energy electron diffraction.

5. Use reciprocal space graphical constructions and vector algebra to interpret diffraction from 3D and 2D single crystals, and random and textured polycrystalline samples.

390: Materials Design

Analysis and control of microstructures. Quantitative process/structure/property/ performance relations, with case studies. Computer lab for modeling multicomponent thermodynamics and transformation kinetics. Prerequisites: 315, 316 1,2, or consent of instructor.

At the conclusion of the course students will be able to:

1. Apply a systems approach to complex problem identification and formulation.

2. Apply property/performance relations to materials selection, and to the specification of property objectives to meet user performance needs in evolving environments.
3. Apply mechanistic models in design integration of process/structure and structure/property relations in dynamic multilevel-structured materials systems
4. Synthesize results of interdisciplinary design research.
5. Apply computational skills in materials selection (CMS Selector), multicomponent thermodynamics (THERMOCALC) and diffusion (DICTRA), and integrate them in the theoretical conceptual design of materials.
6. Perform in cross-functional teams.
7. Communicate effectively in oral, written and graphical form.

391: Process Design

Processing of materials. Design and analysis of experiments to identify and optimize key parameters to control properties and performance. Resolving conflicting requirements. Statistical process control.

At the conclusion of the course students will be able to:

1. Identify sources of variation in a given process when provided with appropriate data.
2. Understand the need to randomize and replicate experiments.
3. Pose and test hypothesis using appropriate statistical distributions and confidence levels.
4. Pose and test hypothesis using the analysis of variation (ANOVA) method.
5. Select an appropriate experimental design and apply to the problem at hand.
6. Analyze results of a designed experiment using appropriate statistical methods (ANOVA, R^2, residuals, etc).
7. Express results of experiments in the form of models or equations (regression analysis).
8. Design processing schemes to minimize the variation of properties (regression coefficients).

396: Senior Project in Materials Science and Engineering

To be taken in two consecutive quarters. Independent basic or applied research project, conceived and performed under the direction of a department faculty member. Prerequisite: senior standing in materials science program.

At the conclusion of the course students will be able to:

1. Understand the basis for making ethical decisions in the practice of science and engineering.
2. Write a review of the literature relevant to their research topic.
3. Give effective oral and written reports of ongoing and completed work.
4. Write a research report consistent with standard practices.

MSE Outcomes Table

	Analysis/Knowledge						Synthesis and Evaluation									
	Problem Solving / Modeling			Modern Tools			Systems Perspective					Design Integration				
MSE student outcome description	Multi-level microstructure	Apply math/science	Mechanistic modeling	Computational MSE	Characterize props/structure	Processing practice	ID complex problems	Mat'l performance reqs.	Global-societal context	Professional ethics	Contemporary issues	Theory/computational design	Statistical design of expt	Design mat'ls processes	Multifunctional teamwork	Communication
MSE student outcome	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
ABET student outcome	a	a	a	k	k	k	e	c	h	f	i,j	b	b	c	d	g
Primary program educational outcome	1	1	1	1	1	1	3	3	3	4	3	1	1	1	2	2
Program educational outcome description	Practice	Practice	Practice	Practice	Practice	Practice	Contemp issues	Contemp issues	Contemp issues	Ethics	Contemp issues	Practice	Practice	Practice	Communication	Communication
Secondary PEO							1	1,4	1,4	1	1			2,3	1,4	1,4
301: MatSci Princ	I	I	I													B
314: Thermo		I	B	B												
315: Phase Eq		I	I	I	I											B
316-1 Defects	A	I	A		B	I										B
316-2 Phase trans	A	I	A		B	I										I
331 Soft matls	I	I	I		B	I										
332: Mechan behav	I	I	I		B	I		I							I	I
351-1: Quantum		A	I													
351-2: Solid state		I	I		A			I								I
361: Crystallog	I	A		I	A								I		I	
390: Mat'ls design	A	A	A	A			A	A	A	I	A	A		I	A	A
391: Process design		I		I		A	A	A	A		A		A	A	A	A
396-1,2: Sr. projects		I			A		A			A	A		A			A

MSE Student Outcomes (ABET a-k in parentheses)

Analysis/ Knowledge

Mechanistic Perspective to Problem Solving

1. (a) Knowledge of sound fundamentals of dynamic multilevel microstructure.
2. (a) The ability to apply mathematics and science to engineering problems.
3. (a) The ability to perform mechanistic modeling.

Modern Tools

4. (k) Knowledge of computational materials science.
5. (k) Knowledge of basic and advanced instrumentation for the characterization of structure and properties.
6. (k) Knowledge of basic and advanced processing practice.

Synthesis / Evaluation

Systems Perspective

7. (e) The ability to identify and formulate complex problems.
8. (c) An understanding of how user needs define materials performance requirements
9. (h) An understanding of the global/societal context of engineering problems.
10. (f) Knowledge of professional ethics issues.
11. (i,j) Knowledge of the dynamic nature of all structure, including materials and the systems and environments they serve, requiring knowledge of contemporary issues and the need for lifelong learning.

Design Integration

12. (b1, b2) The ability to perform theoretical, conceptual and computational design approaches.
13. (b1, b2) The ability to perform experimental optimization employing statistical design of experiments techniques.
14. (c) The ability to apply theoretical and experimental design techniques to both materials and processes.
15. (d) The ability to function effectively in cross-functional teamwork, both within the materials discipline and from a multidisciplinary perspective.
16. (g1,g2) The ability to communicate effectively in written, spoken and graphical form.