COURSE OBJECTIVES <Student Competencies>:

Understand relationship of: Processing, Structure, Properties & Performance \{ SP³ \}

a. Practical understanding of key principles of Physical Metallurgy
b. Know commercially important metals and alloys - with practical engineering constraints.
c. Ability to select a metal system and/or an alloy*
d. Ability to select casting and/or mechanical forming methods*

* based upon advantages/disadvantages of different technologies including:
  Cost (Economics), Performance, Manufacturability, Environmental Concerns, & Sustainability

COURSE FORMAT:

The course is provided in PowerPoint™ format as lively, highly interactive lecture/recitations. Physical Metallurgy stresses practical, common engineering via lectures, readings and exercises concentrating on technology backed by science.

Course material is derived from Metallurgy for Non-Metallurgists a weeklong intensive course initiated, directed and taught by the instructor. This popular short course has been taught internationally, publicly and in-plant to many thousands of professional engineers and scientists for >30 years. It is imitated by several professional materials societies. Students are provided, free of charge, expanded and updated Metallurgy for Non-Metallurgists - in PowerPoint™ presentation visuals (metallograph, schematic, graph, table...) plus new outlines, notes and supplemental reference information. The PowerPoint™ visuals are used for all presentations. A full online version allows students to take personal notes directly on the lecture material. Each subject has an extended written “outline” of major concepts for learning reinforcement. A brief review of relevant material of prior MSE courses is included. The gratis lecture notes constitute the official course text.


Samples, examples of actual engineering problems, open-ended problem solving and application choices are incorporated both to extend knowledge of practical application and to provide engineering “experience”. Students will complete these exercises as part of “independent” study both individually and in small groups. These realistic problems in materials selection and processing will be based chiefly on use of the complete Metals Handbook™ as a resource.

Voluntary extra workshops, review sessions and seminars will be provided in topic areas related to course materials. This will include:

- Enrichment workshops in: failure analysis & prevention, corrosion analysis & control, SEM, materials selection, process selection, specific metal/alloy systems …
- Review of the INVERSE Lever Law for binary alloy phase diagram determination
- Review for Midterm and Final Exams
- Possible plant trips (mini-mill, casting shop, forging shop…)

* Courtesy: Profs. John D. Wood & Victor A Greenhut and the Center for Professional Advancement, E. Brunswick NJ
** Courtesy: ASM International, Materials Park, OH

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REQUIRED TEXT

Cost-free, PowerPoint™ visuals & extended notes are furnished to students for direct in-class note taking and out-of-class review of subject matter.

The material is derived from Metallurgy for Non-Metallurgists (1979-2009) provided courtesy of Profs. John D. Wood & Victor A. Greenhut the Center for Professional Advancement

REFERENCE TEXTS – practical sourcebooks for engineering solutions


** Metals Handbooks + Desk Ed. available for student use at MS&E Undergraduate Computer Room (CCR 213)

COPYING OF THESE MATERIALS IS STRICTLY PROHIBITED, EXCEPT UNDER LEGAL “FAIR USE” DOCTRINE.

SUPPLEMENTAL TEXTS – review and study aids useful to students


Notes:


Most Junior & Senior MS&E majors now join Materials Advantage™ as student members of the American Ceramic Society, ASM International, The Metallurgical Society. Materials Advantage™ membership is currently $25 per annum.


   This text is a lifelong learning reference.
   Continued use will be encouraged by instruction plus provision at an ultra-low price.

   **Metals Handbook™, 9th Edition**
   Computer versions have been donated for student use by Victor A. Greenhut.
   They are available exclusively for student use on computers in the MSE Student Computer Room (CCR 213) by courtesy of the publisher, ASM International, Materials Park, OH

COPYING OF THESE MATERIALS IS STRICTLY PROHIBITED, EXCEPT WITHIN LEGAL “FAIR USE” DOCTRINE.

*** A special bulk minimum price will be negotiated by the instructor.

Engineered Materials Handbook: Desk Edition (Ceramics, Polymers, Composites) may be added at similar savings

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**Final Grade (Spring 2010)**

The credit formula followed per student vote at the organizational meeting (no subsequent “veto”):

- Up to 2 points per Summary (0, ½, 1, 1½, 2 pt) * - 28 pts. {28% of grade}
- ¼ point for attending class** - 7 {7% of grade}
- Up to 35 points for Midterm Exam (35%) - 25 {25% of grade}
- Up to 45 points for Final Exam (45%) *** - 40 {40% of grade}

**TOTAL 100 pts. {100% of grade}

* A summary of the prior week’s notes and lectures is due at the immediately following Monday class. A summary furnished after the Monday class due date and at or before the following Wednesday class will receive 1 point. No points will be given for further lateness.

Points will be deducted for an incomplete summary or outline.

The summary may be either:

- A detailed written summary, for each topic (based on course notes, handouts, visuals & lecture) or
- A revised set of notes developed from the lectures, plus: visuals, course notes and handouts.

** Acceptable absence excuses: documented illness, professional travel, family loss, Dean’s excuse …

*** I reserve the right to count the all-inclusive Final Exam at more than 40%, if a student excels.

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**Assessment of Outcomes:**

Student progress is assessed by a midterm and final examination. Progress is monitored by recitation questions, hand in of personal notes (verifying attention to readings & lectures) and real-world problem solving/applications sometimes via hand-in assignments. Course outcomes are assessed formally through the examinations, recitation interaction and student evaluation forms. Additional assessment questions for course modification are occasionally added to the form. Informal evaluation occurs through contacts with alumni, many of who will find careers significantly incorporating the Physical Metallurgy course. About 5-10 contacts per year now occur from prior students who use the instructor as a resource for Physical Metallurgy questions. Students who took, 14-635:362 (& 14-150:426, Ceramic-Metal Systems) report significant use of the metallurgy course and the utility of the *Metals Handbook™: Desk Edition*, acquired as a recommended text. This includes recent graduates and graduates from prior decades.

**Relationship to Program & ABET Objectives & Proficiencies**

Program Objectives

The course provides contributions to program objectives 1 - 4.

**ABET General Proficiencies ("a. – k.")**

With respect to general ABET (Accreditation Board for Engineering and Technology) proficiencies it contributes significantly to items (a), (b), (c), (e), and (i) as they pertain to Materials Engineering and/or Metallurgy. Items (f), (g) and (h) are stressed through real world examples and examples in which other knowledge may contribute to solving engineering problems in Physical Metallurgy. The nature of multi-disciplinary teams (item d) in Physical Metallurgy, Materials Engineering, Plant Engineering, Engineering Design, etc. is discussed briefly. Several independent problems may be executed on a team basis with different teaming for each exercise in partial fulfillment of item d.

**ABET Program Specific Proficiencies**

As it is a vital part of Physical Metallurgy and its application to various technological applications, the relationships between processing, structure, properties and performance {SP³} are stressed in identifying required physical and chemical properties, selecting materials, system approaches, optimizing production variables and metal components (microstructure and/or macrostructure). Stress on mesostructure, microstructure and nanostructure is somewhat greater than in traditional Physical Metallurgy courses. Most lecture/recitations begin by treating the structure derived from processing metal and alloys. Structure is used as the rationale for properties and performance. The first major recitation is on Metallography. This satisfies the specialization requirements for {SP³} as set forth in both the requirements for Materials Engineering and in Metallurgy specializations in ABET requirements.

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WEEK-BY-WEEK SCHEDULE
Physical Metallurgy 14-635:362
Spring 2010
3:20 – 4:40 PM -- SEC 220

The 1st Class (1 A.) - Meets Wednesday 20 January 2010
The Last Class (14 B.) - Meets Monday 03 May 2010

Note: “TEXT” refers to chapter titles of the PowerPoint™ visuals & extended notes furnished for direct in-class note taking and out-of-class review.

WEEK 1: Wed - Mon, 20 – 25 January
A. Course Introduction
   Basic Principles of Physical Metallurgy
   Relationship of Extractive Metallurgy to Physical Metallurgy
   Why Metals are Useful Engineering Materials.
   Fundamental Overview of Relationships between:
      Processing, Structure, Properties and Performance { SP³ } 

   Overview of Course Content and Rules

B. Metallography
   Microscope Methods: Macro-scale Viewing, Optical Microscopy, SEM & TEM, Microanalysis
   Metallurgical Sample Preparation: Cutting, Grinding, Polishing, & Etching
   Precautions in Preparing Samples.
   Microstructural Analysis and Correlations in SP³

WEEK 2: Wed - Mon, 27 January – 01 February
A. Nature & Properties of Pure Metals
   Metallic Bonding: Free and Nearly-Free Electron Models
   Metal Properties: Optical, Thermal, Electrical, Mechanical, Chemical ...
   Metal Structure: Bravais Lattices, FCC, HCP, BCC
   Relationship of Valence & Ion Size to Structure

B. Imperfections in Metals
   Vacancies: Entropy of Mixing, Number, Mobility, & Diffusion
   Substitutional & Interstitial Solid Solution: Impurities and Alloying
   Dislocations: Edge and Screw, Crystal Growth
      Theoretical Strength, Plastic Deformation
      Multiplication & Strengthening
      Crystal Growth Mechanisms
   Twinning: Growth Twins, Mechanical Twins, & Recrystallization Twins
   Martensite: Stress-Induced, Athermal, Type II
   Multiphase: Inter- and Intra- Granular

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WEEK 3: Wed - Mon, 03 – 08 February

A. **Alloying (Phase Diagrams)**

Isomorphous Alloys: Cu-Ni Phase Diagram, Microstructure, & Properties
Eutectic Alloys: Pb-Sn Phase Diagram, INVERSE Lever Law, Microstructure, & Properties
Cooling Rate Effects: Microstructure, Phase Distribution, Composition Change, & Properties
Other Phase Diagrams: Peritectic, Monotectic, Miscibility Gap,
Solid Phase Changes- Fe-C Phase Diagram, Magnetism, Steel & Cast Iron Phase Fields

B. **Casting Technologies**

Casting Grain Structure: Ingot Structure, Dendritic Growth, & Multiphase Structures
Compositional Segregation: Micro- & Macro- Segregation, Impurities
Porosity: Micro and Macro
Residual Stresses: In Castings, Deformation on Material Removal
Casting Technologies: Sand, Metal Mold, Investment, Die, Continuous, Metallic Glass

WEEK 4: Wed - Mon, 10 – 15 February

A. **Strength & Deformation of Metals**

Elastic Behavior: Stress Strain Relations, Directional Properties,
Structure Sensitive and Insensitive Properties
Plastic Behavior: Dislocation Slip, Theoretical Strength, Easy Glide, Yield Point
Stress-Strain Curve: Engineering Yield Point, Engineering vs. True Yield Point, Ultimate Stress
Loading & Unloading Curves, Work Strengthening (Work Hardening)
Strength, Ductility, Energy Input, Hardness

B. **Strengthening by Work Hardening (Strengthening)**

Mechanical Deformation: Tension, Shear, Bending, Torsion
Strain Hardening (Strengthening): Dislocation Multiplication, Forest Dislocations
Other Mechanisms of Strain Hardening (Strengthening): Twins, Martensites…
Polycrystalline Deformation, Strengthening and Introduction of Texture
Multiphase Microstructures
Effect of Crystal Size and Texture: Structure Sensitive and Insensitive Properties
Residual Stresses from Deformation

WEEK 5: Wed - Mon, 17 – 22 February

A. **Annealing Metals**

Effect of Degree of Cold Working: Percent Reduction
Recovery & Recrystallization of Cold Worked Metal
Grain Growth, Grain Size Control, Texture, \{ SP\}
Recrystallization Temperature, Cold Working vs. Hot Working

B. **Mechanical Forming Technologies**

Forging: Open and Closed Die, Grain Texture and Mechanical Properties
Rolling: Sheet, Rail, Die, Screw (rolled vs. cut thread)
Extrusion: Conventional and Hydrostatic, Triaxial Stress Effects
Drawing, Swaging, Deep Drawing: Forming Limit Diagrams
Embossing, Coining, Hobbing
Spinning, Brake Forming, Hypervelocity Forming
Spring-Back, Residual Stress, Finish, Tolerances

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WEEK 6: Wed - Mon, 24 February – 01 March

A. **Principles of Alloy Strengthening (Non-Ferrous)**

Solution Strengthening: Substitutional & Interstitial, Dislocation Atmospheres, Effect of Misfit, Concentration, Multiple Additives, Relation to Other Strengthening

Dispersions and Precipitates: Definitions and Mechanisms, Phase Diagrams, Reaction (ex. Carburizing, Nitriding)

Dispersion Hardening (Strengthening): Heat Treatment, Ductility Effects

Precipitation Hardening (Strengthening): Aging Heat Treatment

Forming and Heat Treatment: Thermo-Mechanical Treatments (TMT’s)

B. **Commercial Non-Ferrous Alloy Heat Treatment**

Alloy Designation Systems & Temper Designations
Copper and Nickel: Cu-Ni, Cu & Ni Alloys
Aluminum and Aluminum Alloys: Al 1100, Al 2024, Al 7075, Al-Si
Titanium and Titanium Alloys
Precious Metals
Other Metals

WEEK 7: Wed – Mon, 03 – 08 March

A. **Steel Metallurgy I – Microstructures & Properties**

Forming: Austenite, Ferrite & Cementite, Pearlite, Martensite, Bainite
Eutectoid (1080) Steel: Cooling Rate → Structure & Properties
Hypoeutectoid (1040) Steel: Cooling Rate → Structure & Properties
Low Carbon (1010) Steel: Cooling Rate → Structure & Properties

B. **Steel Metallurgy II – CCT & TTT Diagrams**

TTT Diagrams: Microstructures and Properties
CCT Diagrams: Conventional CCT, Constant Rate CCT Diagrams, Effects C Content & Alloying
Jominy End Bar Quench Tests & Cooling Rate Curves
Shape-Dimension Cooling Plots: Predicting Microstructure & Properties

WEEK 8: Wed – Mon, 10 – 22 March

A. **MIDTERM EXAM --10 March --- Material through Week 7 --- MIDTERM EXAM --11 March**

Fiber Optics Auditorium (tentative)

Spring Break 13-20 March ● Spring Break 13-20 March ● Spring Break 13-20 March ● Spring Break 13-20 March

Continued -----WEEK 8: Monday, 22 March

B. **Steel Metallurgy III - Heat Treatment and Selection**

Quenching Media
Normalizing, Spheroidization, Quench and Temper, Martempering, Austempering...
Retained Austenite
Surface Hardening: Flame and Induction Hardening, Carburizing, Nitriding, Carbonitriding
High Strength Low Alloy (HSLA) Steels, Maraging Steels, Trip Steels
Tool Steels, Silicon Steels
Selecting Steels

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Physical Metallurgy 14-635:362 Week-by-Week Schedule Spring 2010 - continued
WEEK 9: Wed – Mon, 24 – 29 March
A. **Stainless Steel**
   Austenitic Stainless Steel: Phase Diagrams, Transformation, Sigma Phase
   Ferritic & Martensitic Stainless Steels
   PH Stainless Steels
B. **Cast Iron**
   Fe-C Eutectic Phase Diagram, Casting Additions, Eutectoid Reactions
   White, Gray, Ductile Cast Iron
   Malleable Iron, “Wrought Iron” (Then and Now)

WEEK 10: Wed. 31 March – Mon. 05 April
A. **Toughness and Fracture**
   Griffith Criterion
   Irwin Criterion
   General Fracture Toughness Formulation, $K_{1c}$
   Ductile-Brittle Transition, NDT
   Liberty Ships, $R_{1c}$
   Toughness Testing: Charpy & Izod Tests, Other Toughness Tests
   Material Selection: Toughness/Strength Trade-offs
B. **Long Term Performance Under Load – Fatigue**
   General Fatigue Behavior
   Low Amplitude, High Cycle Fatigue Behavior & Mechanisms
   Persistent Slip Lines & Surface Effects
   Fatigue Hardening/Softening (Dislocation/Vacancy Mechanisms)
   Fatigue Curves: Endurance & Fatigue Limit, Non-Zero Mean Stress, Environmental Factors
   Fatigue “Laws”: Relationship to Fracture Toughness, Cumulative Damage,
   Predicting Fatigue Failure, Fatigue Crack Inspection, High Amplitude Fatigue
   Failure Prevention & Control: Stop Drilling, Environmental Control, Ultrasonic Treatment …

WEEK 11: Wed – Mon, 07 – 12 April
A. **Long Term Performance Under Load–High Temperature Creep**
   Creep, Stress Relaxation, and Stress Rupture
   High Temperature Creep Behavior
   Creep Laws and Failure Prediction
   Metallurgical Change and Failure Prevention
   Preventing Creep Failure: Materials Selection, Creep Resistant Microstructure, W Alloys
B. **Metal Joining**
   Brazing & Soldering: Techniques, Fluxes, Cooling Rate, Mechanical Strength,
   Sweating, Wiping, Pb-Free Compositions
   Welding: Methods- Flame, Arc, Submerged Arc, Resistance, Inertial
   Weld Structure & Temperature Distribution: HAZ (Heat Affected Zone), Microstructure
   Joint Design
   Residual Stress & Distortion
   Weld Metal and Flux Selection

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WEEK 12: Wed – Mon, 14 – 19 April
A. **Powder Metallurgy**
   Physical Metallurgy Notes, Sect. V
   Sources of Metal Powders
   Pressing and Deformation Effects
   Sintering: Solid State, Liquid Phase, Activated, Hot Pressing
   Properties: Cost, Strength & Ductility vs. Conventional Forming
   Porosity: Self-Lubrication, Compositing & Dispersed Phases
   Tungsten
   Applications

B. **Corrosion I - Basic Corrosion Concepts**
   Physical Metallurgy Notes, Sect. W
   Corrosion Types
   Corrosion Mechanisms
   Galvanic Corrosion: Galvanic Series, Electrochemical Series, Effect of Corrosion Environment
   Corrosion Curves, Current Density, Polarization
   Corrosion Examples
   Concentration/Dilution Effects
   Pourbaix Diagrams

WEEK 13: Wed – Mon, 21 – 26 April
A. **Corrosion II - Corrosion Under Stress**
   Physical Metallurgy Notes, Sect. X
   Stress Corrosion Cracking: Failure Prediction, Stainless Steel - Cl Attack, Control
   Fatigue Corrosion Cracking
   Fretting Corrosion
   Hydrogen Embrittlement
   Impingement and Cavitation
   Strength and Corrosion Properties

B. **Corrosion Control**
   Physical Metallurgy Notes, Sect. Y
   Electrical Isolation
   Environment Change
   Cathodic and Anodic Protection
   Passivation: Stainless Steel - Cl Attack, Mechanical Shock, Abrasion (particle & bubble)
   Protective Coatings- Metallic, Polymeric, Ceramic
   Vapor Phase Protection

WEEK 14: Wed – Mon, 28 April – 04 May
A. **Failure Analysis & Prevention – Principles & Practices**
   Physical Metallurgy Notes, Sect. Z
   Failure Analysis Protocols and Reports
   Brittle & Quasi-Brittle Failure: River Patterns, Hackle, Rib Marks, Chevron Marks,
   Identifying Failure Origins, Microstructural Effects
   Intergranular vs. Transgranular Failure
   Ductile Failure: Cup-Cone Failure; Tensile, Tearing, and Shear Failures
   Fatigue: Fatigue Striations, Fatigue Marks, Identifying Failure Origins

* A **Hands-On Failure Analysis Workshop** will be arranged, most likely for the period following class.
  Students completing the full set of optional, voluntary sessions will receive a signed certificate.
  Participation in such extra classes will in no way affect grading in Physical Metallurgy, 14-635:362.

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Continued -----WEEK 14: Monday, 04 May --- Last Class Session

B. **Frontiers in Physical Metallurgy**  
Video: “1+1+1+...= 1: Riddles Underlying Nano-Particles and Nano-Wire, The Takayanagi Particle/Surface Project”

- New Alloys
- Specialty Metals
- Metal Matrix Composites
- Metals in Solid State Electronics
- Surface Modification: Ion Bombardment, Sputtering, Nano-Metals

**Scheduled Official FINAL EXAM** (Full Semester Material)  
Noon – 3:00 PM --- Wednesday, 12 May 2010 – Fiber Optics Auditorium (tentative)  
*Final Exam date subject to change with consencus of class*

Students may, by request, have reasonable extra time for the Midterm and Final

Optional, Voluntary, Group Review Sessions (after class) - Dates (tentative):

- **INVERSE Lever Law - Phase Diagram Review** - Monday, 08 February
- **Midterm Exam Review** - Monday, 08 March + ?
- **Midterm Answer Review** - Monday, 22 March
- **Final Exam Review** - Monday, 03 May +/- or ? Reading Day?

Optional, Voluntary Enrichment Workshops – BY ARRANGEMENT (tentative dates)

- Scanning Electron Microscopy - 11 – 25 February - Sessions: 3 lecture, 2 workshops
- Failure Analysis & Prevention - 25 March – 01 April - Sessions: 1 lecture, 2 workshops
- Corrosion & Corrosion Control - 13 – 22 April - Sessions: 2 lecture, 1 workshop
- Ceramic- Metal Joining - ??

**Excused Absence:**  
Absence will only be excused (no point consequence) with an unavoidable absence with a verified, good excuse. Official proof must be provided. Examples are: medical condition, official professional activity, interview, personal crisis, administrative excuse (by Dean, Chair), etc.

**Rules of Good Behavior**

Avoid practices discourteous and distracting to serious students and the instructor.

- a. Entering or leaving class egregiously late or early is forbidden. It is disturbing to others.
- b. Take care of your rest room needs prior to class. If you must leave the room do not re-enter.
- c. No side conversations or whispering during class. You may be asked to leave.
- d. Cell phones and other communications devices must be turned **completely OFF** during class – not on Vibrate or Visible Signal.
- e. There is to be no text messaging, no computer chat, etc. during class.

I will try to remind you if you forget yourself, but continued or repeated behaviors will result in a request to depart (in some circumstances your device may be confiscated). Departure will result in zero attendance credit.

Special personal circumstances may arise requiring that a rule be relaxed. **See me about this well before class begins.**

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