| **Course Name** | | | | | | |
|---|---|---|---|---|---|---|
| **Physical Metallurgy** | | | | | | |
| **Code** | **Semester** | **Local Credits** | **ECTS Credits** | **Course Implementation, Hours/Week** | | |
| | | | | **Theoretical** | **Tutorial** | **Laboratory** |
| **MET311E** | 5 | 3 | 5 | 3 | - | - |

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| **Department/Program** | Metallurgical and Materials Engineering |
| **Course Type** | Required — **Course Language**: English |
| **Course Prerequisites** | Met 221E min FF |

| **Course Category by Content, %** | **Basic Sciences** | **Engineering Science** | **Engineering Design** | **General Education** |
|---|---|---|---|---|
| | | 80 % | 20 % | |

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|---|---|
| **Course Description** | This course aims to introduce a theoretical basis for understanding how structure is controlled by means of providing a link between various transformations taking place in materials and the resulting microstructural and physical properties. For this reason, it is a mandatory course for the three options of the Metallurgical and Materials Engineering department. |
| **Course Objectives** | **1.** To introduce the field of Physical Metallurgy and some related applications; to provide phenomenological explanations for plastic deformation, dislocations and dislocation interactions and their contributions to the slip mechanism.<br>**2.** To explain qualitatively vacancy formation in crystalline materials; concept of diffusion and various diffusion mechanisms in crystals; the importance of interface concept and their classification, dihedral angle and final microstructure relations.<br>**3.** To explain the phenomena of nucleation and solidification by using Arrhenius type equations and to demonstrate, in detail, the thermodynamic and kinetic aspects of phase transformations on the structure of materials.<br>**4.** To describe the morphologies of the phases during phase transformations (nucleation, crystal growth, solidification and precipitation mechanisms and the effect of deformation on recovery, recrystallization and grain growth.<br>**5.** To describe the Fe-C phase diagram and the TTT diagrams for steels and describe the pearlite, austenite, bainite and martensite phases and to design suitable heat treatment procedures for annealing, tempering and solutionizing and to predict the age hardening behavior of an alloy on the basis of its phase diagram and composition.<br>**6.** To provide information on diffusionless transformations, shape memory alloys: the Ni-Ti and other example systems and its martensitic reactions. To motivate students for continuous learning about Special Topics in Materials Science related to Physical Metallurgy using their basic knowledge gained during the course. |
| **Course Learning Outcomes** | **1.** To understand the field of Physical Metallurgy and learn phenomenological explanations related to dislocations and dislocation interactions and their contributions to the slip mechanism during plastic deformation; and be able to calculate the critical shear stress and most favored slip directions in different lattices to comprehend the concept of the critical resolved shear stress and Schmid factor.<br>**2.** To learn the vacancy formation in crystalline materials; concept of diffusion and various diffusion mechanisms in crystals; the importance of interface concept and its classification, dihedral angle and final microstructure relations and to be able to solve the problems related to first and second Fick's law and new phase formation during diffusion.<br>**3.** To understand the phenomena of nucleation and solidification by using Arrhenius type equations and thermodynamic and kinetic aspects of phase transformations on the structure of materials.<br>**4.** To understand how the different phase morphologies occur during phase transformations (nucleation, crystal growth, solidification and mechanisms precipitation);learn the effect of deformation on recovery, recrystallization and grain growth and differentiates their morphologies.<br>**5.** To learn Fe-C phase diagram and TTT diagrams for steels and to describe the pearlite, austenite, bainite and martensite phases and to be able to design suitable heat treatment cycles and post treatment (annealing, tempering) to yield final desired properties.<br>**6.** To predict the possibility of age hardening behavior of an alloy on the basis of its phase diagram and composition. To learn diffusionless transformations, Shape memory effect and the alloys having this behavior: the Ni-Ti and other example systems and its martensitic reactions. |
| **Textbook** | - John D. Verhoeven, "Fundamentals of Physical Metallurgy", John Wiley & Sons, New York, 1974.<br>- Robert E. Reed-Hill, "Physical Metallurgy Principles", Brooks/Cole Engineering Division, Monterey, CA, 1973. |
| **Other References** | **-William F. Hosford, "Physical Metallurgy", Taylor & Francis, 2005** |
| **Homework & Projects** | **There is an optional term project under the theme "Special Topics in Physical Metallurgy" provided that the number of students enrolled in course do not exceed 25.** |
| **Laboratory Work** | none |
| **Computer Use** | |
| **Other Activities** | |

| **Assessment Criteria** | **Activities** | **Quantity** | **Effects on Grading, %** |
|---|---|---|---|
| | **Midterm Exams** | MIN 1 | 25-30 |
| | **Quizzes** | MIN 4 | 16-30 * |
| | **Homework** | | |
| | **Projects** | | |
| | **Term Paper/Project** | MAX 1 | 0-14 * |
| | **Laboratory Work** | | |
| | **Other Activities** | | |
| | **Final Exam** | 1 | 40-45 |

***** Total percentage of quizzes and term project grades should not exceed 30 %.
****** This is an optional project based on the decision of the lecturer if the total number of students enrolled in the course do not exceed 25.

**COURSE PLAN**

| Weeks | Topics | Course Outcomes |
|---|---|---|
| 1 | Introduction to Physical Metallurgy and some related applications | I |
| 2 | The plastic deformation of metal crystals. (1) Slip systems. CRSS, Single Crystal and Polycrystalline deformation. | I |
| 3 | The plastic deformation of metal crystals (2) Dislocations: edge, screw dislocation and mixed dislocations , Energy of dislocations | I |
| 4 | Vacancies. Vacancy formation and related kinetic relations, Interfaces. Surface energy, Coherent Boundaries and Dihedral angle | II |
| 5 | Diffusion. (1) Fick's 1st and 2nd laws, Phenomological and atomistic approaches, Temperature and time dependence of diffusion coefficient, Interstitial and Substitutional Diffusion, Kirkendall effect, Matano Interface. | II |
| 6 | Diffusion (2) Carburization and decarburization of steel. Self diffusion in pure Metals, Interdiffusion between phases, behavior of two phase regions during diffusion. Surface, grain-boundary and bulk diffusion | II |
| 7 | Kinetics of nucleation. Homogeneous and heterogeneous nucleation. Growth kinetics | III |
| 8 | Solidification of pure metals and alloys. Equilibrium and non-equilibrium freezing equations. Eutectic and peritectic solidification. Cast metals. Dendritic solidification. Cast structures. Metallic Glasses | III |
| 9 | Recovery and recrystallization. The stored energy during deformation. Physical properties of during recovery and recrystallization. Kinetics of recovery and recrystallization Grain growth during annealing - I | IV |
| 10 | Recovery and recrystallization The stored energy during deformation. Physical properties of during recovery and recrystallization. Kinetics of recovery and recrystallization Grain growth during annealing -II | IV |
| 11 | The Fe-C binary system. The transformation of austenite to pearlite. Pearlite, ferrite and cementite phases. The effect of temperature on phase transformations. TTT curves, Bainite and Martensite formation- I | V |
| 12 | The Fe-C binary system. The transformation of austenite to pearlite. Pearlite, ferrite and cementite phases. The effect of temperature on phase transformations. TTT curves, Bainite and Martensite formation- II | V |
| 13 | Annealing. Precipitation from solid solutions. Nucleations in the solid solutions. Preferred crystallographic orientation- | VI |
| 14 | Diffusionless Transformations, Shape memory alloys: the Ni-Ti and other example systems and its martensitic reactions. | VI |

**Relationship between the Course and the Metallurgical and Materials Engineering Curriculum**

| | Program Outcomes | Level of Contribution | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| 1 | Ability to apply the knowledge of mathematics, science and engineering principles to solve problems in metallurgical and materials engineering (ABET:a) | | | X |
| 2 | Ability to characterize materials using standard and/or self designed experimental methods and to evaluate the results (ABET:b) | X | | |
| 3 | Ability to design a system or a process, taking into consideration of the desired specifications, quality, ethics and environment. (ABET:c) | | | |
| 4 | Ability to communicate both orally and in the written form and to take part in, and provide leadership of the teams in the elucidation of engineering problems; (ABET:d, g) | | | |
| 5 | Ability to define, formulate and solve engineering problems in the development, production, processing, protection and usage of engineering materials. (ABET:e) | | | X |
| 6 | An understanding of professional and ethical responsibilities(ABET:f) | | | |
| 7 | An understanding of current/contemporary issues and impact of engineering solutions in broad cultural, national and global levels;. (ABET:h, j) | X | | |
| 8 | A comprehension of the nature of engineering progress closely linked with the development of new materials and production processes. An ability to engage in life-long learning and a recognition of its necessity (ABET:i) | | X | |
| 9 | Ability to use essential tools and techniques of modern engineering in the development, production, processing, protecting and surface treatment of the existing and new engineering materials. (ABET:k) | | | X |

**1: Little, 2. Partial, 3. Full**

**Course relationships with major elements of the field and material classes**

| | | Level of Contribution | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| **MAJOR ELEMENT OF THE FIELDS** | STRUCTURE | | | X |
| | PROPERTIES | | | X |
| | DESIGN EXPERIMENT/ANALYSE DATA | X | | |
| | PROCESSING | | X | |
| | COST/PERFORMANCE | X | | |
| | QUALITY/ENVIRONMENT | X | | |
| | DESIGN PROCESS OR PRODUCT | | X | |
| **MATERIAL CLASSES** | METAL | | | X |
| | CERAMICS | | | |
| | POLYMERS | | | |
| | COMPOSITES | | | |

**1: Little, 2. Partial, 3. Full**

| **Prepared by** | Date | **Signature** |
|---|---|---|
| PROF.DR. LÜTFİ ÖVEÇOĞLU<br>YRD. DR. BURAK ÖZKAL | 20.12.2009 | |