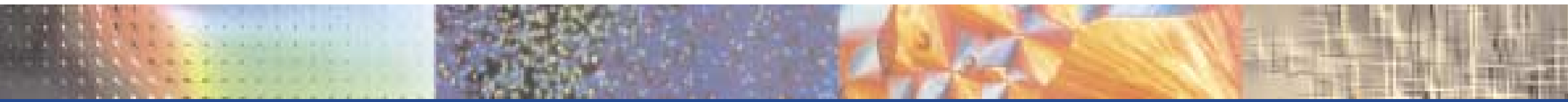
OxfordMaterials

Materials Science (MS)
Final Honours School
Core Lecture Course Synopses
2016 - 2017



Department of Materials

Materials Science (MS)

Final Honours School

Core Lecture Course Synopses 2016-2017

General Paper 1: Structure & Transformation of Materials

GP1: Structure & Transformation of Materials Michaelmas Term

2nd year MS

Prof M R Castell

4 lectures

Surfaces & Interfaces

1. Introduction:
   Why are we interested in interfaces?
   Interfacial free energy: Thermal grooving, triple junctions and wetting.
   Thermodynamic degrees of freedom and excess quantities at interfaces.

2. The Gibbs adsorption equation and interfacial segregation.
   Influence of segregation phenomena on materials properties.

3. The effect of interfacial curvature on equilibrium - the Gibbs-Thomson effect.
   Grain growth, Ostwald ripening.

4. Measurements of surface and interfacial energy.

5. Surfaces and interfaces involving solids.
   Anisotropy of surface and interfacial energy.
   Interfacial coherency and the shape of precipitates.

Background reading:

Physical Metallurgy Principles, chapter 6, Reed-Hill and Abbaschian. Very good on grain boundaries.

Phase Transformations, chapter 3, Porter and Easterling. Gentle introductory text.

Interfaces in Crystalline Materials, Sutton and Balluffi. Formal and complete text, particularly strong on thermodynamics.

Physics at Surfaces, Andrew Zangwill, CUP.

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2nd year MS

Prof C.R.M Grovenor & Dr K Borisenko

16 lectures

Phase Transformations & Diffusion

General principles

- Kinetics vs thermodynamics: role of interface energy.
- Progress of a reaction and the classification of transformations.

Diffusion

- Mechanisms of diffusion: activation energies and fast diffusion paths.
- Fick's 2nd law: specific solutions to time-dependent diffusion problems.
- Diffusion in substitutional alloys: Kirkendall effect.
- Darken's equations and interdiffusion coefficient: Matano analysis.
- Atomic mobilities and chemical potential gradients.

Interfacial structure and mobility

- Facetting, coherency, and the Jackson alpha factor model of S/L interfaces.
- Continuous and step growth mechanisms in S/L interfaces.
- Solid state interface mobility, glissile interfaces.

Nucleation

- Homogeneous and heterogeneous nucleation.
- Nucleation in the solid state: incubation, strain effects, transition phases and coherency loss.

Rate laws and the Avrami equation

- Interface-controlled vs diffusion-controlled growth.
- Rate laws for different growth geometries and coarsening.
- The Avrami equation and growth exponents for different situations.

Alloy solidification

- Solute distributions, including the Scheil equation.
- Constitutional supercooling and interface stability.
- Macro- and micro-segregation in castings.

Coupled growth mechanisms

- Eutectic/eutectoid and cellular transformations.

'Diffusionless' transformations

- Ordering, recrystallisation, the massive transformation and martensite (basics only).

Required reading:

Basic coverage of all aspects of the course:

Phase Transformations in Metals and Alloys, especially chapters 2 to 5, Porter. and Easterling.

Diffusion in Solids, Shewmon

The required reading Phase Transformations in Metals and Alloys Chapter 2 to 5 for Diffusion also contains main material for Phase Transformation part of the course.

Background reading:

Physical Metallurgy Principles, Reed-Hill.

Physical Metallurgy, 3rd edition, chapters 8, 9 and 14, Cahn and Haasen.

The Stability of Microstructure in Metallic Systems, especially chapters 1, 2 and 4, Martin and Doherty (and Cantor).

More detailed aspects of diffusion:

For solidification, see section 53 in the Departmental Library:

The Solid-Liquid Interface, Woodruff.

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2nd year MS

Prof S Lozano-Perez

8 lectures

Corrosion & Protection

- Corrosion of metals: simple electrochemical theory, polarisation curves, activation and concentration polarisation; Evans diagrams.
- Passivity, pitting, localised corrosion.
- Common problems: galvanic corrosion, differential aeration, crevice corrosion.
- Corrosion prevention: cathodic protection, anodic protection, inhibitors.
- Paint: modes of protection, inhibitive and metallic pigments.
- Metal coatings: action, methods of application.
- Anodising of aluminium.
- Design and materials selection.

Background reading:

Principles and prevention of corrosion, especially chapters 2 to 4, 6, 7 and 12 to 14, D A Jones, Prentice Hall, 1996.

Basic corrosion and oxidation, J M West, Ellis Horwood, 1980.

Corrosion for science and engineering, mainly chapters 2 to 7 and 14 to 17, K R Trethewey and J Chamberlain, Longman, 1995.

Principles of metal surface treatment and protection, D A Gabe, Pergamon, 1972.

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2nd year MS

Prof C R M Grovenor

4 lectures

Ternary Phase Diagrams

1. Gibbs triangle, isothermal sections, contour maps, vertical sections. Lever rule. Free energy curves.
2. Three phase reactions. Eutectic. Peritectic. Criterion for determining type of reaction.
3. Four phase reactions. Ternary eutectic. Quasi-peritectic. Ternary peritectic.
4. Examples of engineering ternary diagrams.

Background reading:

Ternary equilibrium diagrams, D R F West.

Alloy phase equilibria, A Prince.

Phase transformations in metals and alloys, D A Porter and K E Easterling.

An introduction to metallurgy, A H Cottrell.

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2nd year MS

Dr B J Gabrys

4 lectures

Microstructure of Polymers

The main objectives of this course are to link chemistry and stereochemistry of polymers to their structure and bulk properties such as crystallinity and amorphicity. Model vinyl polymers exemplify these points. Physio-chemical properties such as solubility and melting are linked to formation and phase diagrams of polymer blends.

Molecular structures:

Essential terminology, examples of common synthetic polymers, molecular shape.

Configuration:

Tacticity, head-tail/head-head isomerism, geometric isomerism, copolymerisation.

Conformation:

Torsion angles, trans & gauche conformers, relationship to molecular structure.

Solubility and melting:

Flexibility of polymer molecules, the effect of flexibility on melting point and solubility, the effect of molecular weight on solubility, lattice models for polymer solubility and mixing, polymer blends, upper and lower critical solution temperatures, chemical and mechanical cross-links, hydrogen bonds.

Crystallinity:

Liquid crystallinity, lamellae, chain folding, spherulites, lamellar thickness, isothermal thickening, loss, T_m and T_g, degree of crystallinity, hierarchical structures.

Required reading

Introduction to Physical Polymer Science, L H Sperling, 2006 Wiley-Interscience

Background reading:

Soft Condensed Matter, R A L Jones, OUP, 22JON/1.

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2nd year MS

Prof P S Grant

4 lectures

Powder Processing

Powder Production: Introduction. Advantages; economic aspects; chemical and electrolytic reactions; mechanical attrition; atomisation; heat flow and solidification in atomised powders; powder characteristics and microstructure.

Powder Compaction: Mixing and pressing; sintering and sintering mechanisms; sintering maps; post sinter operations; hot and cold isostatic pressing; injection moulding; designing with powder processed parts.

Powder based bulk products: Porous and non-porous bearings; filters; friction materials; structural parts; hard materials; electric and magnetic components; mechanical properties.

Alternative processes: Spray deposition, additive manufacture and other processes; advantages and disadvantages, future trends.

Background reading:

Introduction to Powder Metallurgy, F Thümmler and R Oberacker, Institute of Materials, 1994, 55 THU.

Powder Metallurgy - An Overview, eds. I Jenkins and J V Wood, Institute of Materials, 1991, 55 JEN.

Powder Metallurgy Science, 2nd edition, chapters 3, 4, 6, 7, 8, 9 and 11, R M German, Metal Powder Industries Federation 1994.

A Second Report on Sintering Diagrams, F B Swinkels and M F Ashby, Acta. Met., 1981, volume 29, page 259.

http://www.epma.com

General Paper 2: Electronic Properties

GP2: Electronic Properties Trinity Term

2nd year MS

Prof G A D Briggs

4 lectures

Tensor Properties of Materials

1. Basic principles
    - Scalar and vector variables
    - Tensor properties
    - Crystal symmetry, Neumann's principle
    - Transformation of vectors and tensors
    - Representation surface, principal axes
2. Second-rank tensors
    - Electrical and thermal and conductivity
    - Stress and strain
    - Thermal expansion
    - Electrical and magnetic susceptibility
    - Optical properties of crystals

Required reading:

Physical Properties of Crystals, chapters 1-6, J F Nye, Oxford, 22NYE. Looks a bit old fashioned but covers everything you will need.

Tensor Properties of Crystals, chapters 1-3, D R Lovett, Adam Hilger, 30LOV. Good introductory chapters with a more contemporary feel.

Background reading:

Crystallography and Crystal Defects, Kelly, Groves, and Kidd, Wiley.

Tensors and Group Theory for the Physical Properties of Crystals, A Wooster, Clarendon Press, Oxford.

Experimental Crystal Physics, W A Wooster, Clarendon Press, Oxford, 30WOOI2.

Introduction to Solid State Physics, C Kittel, Wiley & Sons, 22KIT.

Crystal Optics, P Gay, Longmans, 30GAY.

The Structure of Matter, A Guinier, Arnold, 20GUI.

GP2: Electronic Properties Michaelmas Term

2nd year MS

Prof J M Smith

12 lectures

Quantum & Statistical Mechanics

1. The need for a quantum description of matter.
2. The postulates of quantum mechanics. The uncertainty principle as the cornerstone of quantum mechanics. Commutation relations.
3. Schrodinger's equation. Particle in a 1-D box.
4. Particle approaching an energy barrier, transmission and reflection.
5. Summary of solutions for harmonic oscillator: relevance to thermal vibrations of matter.
6. Schrodinger's equation in 3-D. Separation of variables. Particle in a 3-D box.
7. Summary of quantum mechanical treatment of angular momentum and its relevance to the Periodic Table and directional bonding, relevance to the solutions of the hydrogen atom.
8. Two particle states: fermions and bosons. The exclusion principle, and its supreme importance for atomic structure, the Periodic Table, and electrons in solids.
9. Introduction to statistical mechanics. Its relation to thermodynamics, and statistical mechanics as the fundamental theory of macroscopic properties of materials in terms of their atomic constituents. $S = k \ln W$ and application to an ideal gas, $k = R/N$.
10. Concentration of vacancies in a crystal.
11. The Boltzmann distribution, the most fundamental of all in statistical mechanics.
12. The derivation of the entropy in terms of probabilities that states are occupied.
13. The partition function as the bridge between the microscopic world of quantum states and the macroscopic world of thermodynamics: $F = -kT \ln Z$.
14. Two-state systems: paramagnetism with $s = \pm \frac{1}{2}$ as a function of temperature in a magnetic field. Two state systems in glasses – specific heat.
15. Statement of Fermi-Dirac and Bose-Einstein statistics and how and when to use them. Qualitative explanation of their functional forms.

16. Einstein model of specific heat.
17. Free electron theory: particle in a box, k-space, Fermi sphere, Fermi energy, density of states.

Reading:

There is no one book that we will follow closely, so you are encouraged to dip into as many of those below as you can to develop an understanding of the topics. The 'core reading' consists of books that cover most - if not all - of the examinable topics with sufficient structure and detail to 'stand-alone'. 'Other useful books' have some good explanations but should be used as 'primers' or 'further reading'.

Required Core reading:

Introduction to Quantum Mechanics, David Griffiths, Pearson. (Chapters 1-5). An excellent book with good explanations and lots of problems to test you understanding!

Quantum Physics, Gasiorowicz, Wiley. (Chapters 1-5, and bits of Chapters 6, 9-12, and 19). Comprehensive, clear and uncluttered; a very good read but watch out for the non-SI units.

Quantum Mechanics for Chemists, David Hayward, Royal Society of Chemistry pubs. (Whole book, but only skim chapter 8) An excellent 'entry-level' introduction that covers most of the course well. One or two topics (such as 3-D Schrodinger equation) are a bit brief.

Introductory Statistical Mechanics, Bowley and Sanchez, OUP. (Chapters 1-10) A very comprehensive and readable text book – highly recommended.

Statistical Mechanics: a Survival Guide, Mike Glazer and Justin Wark, OUP. (Chapters 1-8) A very readable book that elegantly covers the basics.

Other useful books:

Introduction to quantum mechanics, Dicke & Wittke, Addison Wesley. Good on the theory (cuts no corners!) but feels quite old fashioned. Lots of textual explanations if you're suffering from algebra overload.

Introduction to Quantum Mechanics in Chemistry, Materials Science, and Biology, S. M. Blinder, Elsevier. Some good explanations, but moves quickly and (perhaps surprisingly given the title) doesn't pull any punches with the maths!

Lectures on Physics Vol III, Feynman, Leighton & Sands, Addison Wesley. Some great – if non-standard – insights from perhaps the finest physics teacher of the past century.

Quantum Mechanics Demystified, David McMahon, McGraw Hill. This book contains a lot of algebra and so might look daunting, but actually by doing things 'long hand' it is easier than many, and is good for building confidence. Not great for insight though – dives straight in! Recommend used sparingly.

Statistical Physics, Mandl, Wiley. (Chapters 1-6, 10) Takes a very 'thermodynamic' approach so may be hard going for some.

Electronic Structure of Materials, Sutton, OUP.

GP2: Electronic Properties Hilary Term

2nd year MS

Prof F Giustino

8 lectures

Electronic Structure of Materials

1. Introduction: aims of course.
2. Free electron theory: one-, two- and three-dimensional densities of states, Fermi-Dirac distribution, electronic specific heat, electrical and thermal conductivity, Hall effect, thermionic and field emission.
3. Band theory - general principles: periodic lattices and Bloch's theorem, Brillouin zones and reciprocal lattice, Kronig-Penney model and band gaps, Nearly Free Electron (NFE) and Tight Binding (TB) limits.
4. Band Theory - NFE approximation: NFE secular equation, band structure and density of states of simple metals.
5. Band theory - TB approximation: TB secular equation, band structure of *sp*-valent semiconductors and *d*-valent transition metals, direct and indirect band gaps, electrons and holes, effective mass.

Required reading:

Introduction to Solid State Physics, Kittel, Wiley, 22KIT, Ch. 6, 7, 8.

Solid State Physics, Ashcroft and Mermin, Harcourt, 22ASH, Ch. 9, 10.

Background reading:

Introduction to the Physics of Electrons in Solids, Tanner, CUP, 22TAN, Ch. 2, 3, 4.

Bonding and Structure of Molecules and Solids, Pettifor, OUP, 22PET, Ch. 3, 5, 6, 7.

The Electronic Structure and Chemistry of Solids, Cox, OUP, 40COX, Ch. 3.

Lectures on the Electrical Properties of Materials, Solymar and Walsh, OUP, 21SOL, Ch. 6.

Electronic Structure of Materials, Sutton, OUP, 23SUT, Ch. 7.

GP2: Electronic Properties — Hilary Term

2nd year MS

Prof P R Wilshaw

6 lectures

Semiconductor Materials

1. Brief review of band diagrams, donor and acceptor levels, defect states.
2. Electron and hole statistics, carrier concentration, temperature dependence, intrinsic and extrinsic materials.
3. Current flow, drift, mobility, conductivity, Hall effect.
4. Excess carriers, diffusion, recombination, lifetime, diffusion length.
5. P-n junctions, band bending, depletion region, I-V characteristics.
6. Metal-semiconductor contacts, Schottky barrier, ohmic contacts.

Background reading:

Electrical Properties of Materials, Solymar and Walsh, Clarendon Press.

Electronic Structure of Materials, A P Sutton, Oxford Science Publ.

Physical Electronics, Seymour, Pitman Paperbacks.

Physics of Semiconductor Devices, S M Sze, Wiley.

GP2: Electronic Properties Trinity Term

2nd year MS

Prof P R Wilshaw

8 lectures

Electrical & Optical Properties of Materials

Part 1. Electrical conductivity of materials with different types of bonding.
Metals, semiconductors and insulators; Ionic crystals: intrinsic & extrinsic vacancy density; energies of formation & activation; self-diffusion; ionic conductivity; superionic conductors; electron hopping conductivity. Superconductivity; metallic and ceramic superconductors.

Part 2. Dielectric Properties
Lorentz field, Clausius-Mossotti relation. Types of polarisation: electronic, ionic, orientation, space- charge. Static permittivities of gases, liquids and solids. Frequency dependent polarisation in non-polar and polar substances. Breakdown mechanisms.

Part 3. Piezo-, pyro- & ferro-electricity
Basics of phenomena. Piezoelectric materials. Ferroelectric phase transitions. Domains, hysteresis.

Part 4. Maxwells equations
Maxwell's equations & electromagnetic waves in 1D. Waves in free space, in insulating & conducting media. Impedance. The skin effect.

Part 5. Optical Properties
Reflection, refraction, absorption and propagation. Lens blooming & dielectric mirrors. Optic fibres. Some topics involving polarised light: liquid crystal displays.

Background reading:

Electroceramics, Moulson & Herbert, Chapman & Hall, 44MOU.

Lectures on the Electrical Properties of Materials, Solymar & Walsh, OUP, 21SOL.

Electricity & Magnetism, Bleaney & Bleaney, OUP, 21BLE.

Introduction to Solid State Physics, Kittel, Wiley, 22KIT/i.

Structure & Properties of Materials Vol.4, Rose et al., Wiley, 50WUL/Bd.

GP2: Electronic Properties Hilary Term

2nd year MS

Dr M T F Telling

4 lectures

Magnetic Properties of Materials

Part 1: Introduction to magnetism

Basic definitions. Magnetic moments of atoms.

Part 2: Types of magnetism

Classification of magnetic materials: diamagnetism, paramagnetism (Curie and Pauli), ferromagnetism, anti-ferromagnetism, ferrimagnetism. Theory of paramagnetism and ferromagnetism. Macroscopic properties of ferro- and ferr-magnetic materials, magnetisation curves, hysteresis. Magnetic domains.

Part 3: Measurements and applications of magnetic materials

Methods of measuring magnetic phenomena and observing domains. Soft and hard magnetic materials. Materials for special applications.

Background reading:

Suggested textbooks:

* **Magnetism and Magnetic Materials**, J P Jakubovics, Inst. of Metals, 21JAK.

* **Electrical Properties of Materials,** Solymar and Walsh, 21SOL

* **Magnetism and Magnetic Materials**, J. M. D. Coey

Electricity and Magnetism, Bleaney and Bleaney, 21BLE

Physical Principles of Magnetism, F Brailsford, Van Nostran), 21BRA

Physics of Magnetism, S Chikazumi, Wiley, 21CHI.

Intro. to Magnetism and Magnetic Materials, D Jiles, Chapman & Hall, 21JIL.

Introduction to Solid State Physics, C Kittel, Wiley, 22KIT.

Modern Magnetic Materials, R C O'Handley, Wiley, 21 OHA

Understanding Solids, Tilley [St Cats or RSL]

Reference books:

Magnetic Materials and Their Applications, C Heck, Butterworths, 21HEC.

Permanent Magnets in Theory and Practice, M McCaig and A G Clegg, Pentech Press, 21McC.

Ferrites, J Smit and H P J Wijn, Cleaver-Hulme, 21SMI/l.

Magnetic Materials, R S Tebble and D J Craik, Wiley, 21ThB.

Ferromagnetic Materials and Handbook of Magnetic Materials, E P Wohlfarth and K H J Buschow (eds), North-Holland, 13 volumes published so far, 21WOH.

Experimental Methods in Magnetism, H Zijlstra, volume 2, North-Holland, 21ZIJ.

General Paper 3: Mechanical Properties

GP3: Mechanical Properties Michaelmas Term

2nd year MS

Prof P D Nellist

4 lectures

Elastic Behaviour in Isotropic Materials

- Introduction.
- Stress-equations of equilibrium. Plane stress.
- Transforming stress (and strain) tensors, Mohr's circle revision.
- Strain.
- Hooke's law.
- Plane stress and plane strain problems. Compatibility equations. Airy stress function.
- Cylindrically symmetrical stress distributions and stresses around misfitting fibres. Stresses around holes under tensile forces; stress concentration factors.
- Spherically symmetrical stress distribution and stresses around misfitting spherical particles. Interaction between a dislocation and a particle.

Background reading:

Theory of Elasticity, Timoshenko & Goodier, McGraw-Hill.

The Mechanical Properties of Matter, Cottrell.

Elasticity Theory, Application and Numerics, Sadd.

GP3: Mechanical Properties Michaelmas Term

2nd year MS

Dr E K R Tarleton & Prof TJ Marrow

10 lectures

Microplasticity

1. Dislocations

Elastic properties of dislocations. Stress field of screw and edge dislocations, strain energy, line tension, the force on a dislocation. Forces between dislocations. Image force. Dislocation sources and multiplication. Plastic strain due to dislocation movement.

Dislocations in f.c.c. materials: Perfect dislocations, Shockley partials and Frank partials and stacking faults. Sessile dislocations and locks.

Dislocations in b.c.c. metals, h.c.p. metals, superlattices, ionic, and covalent materials.

2. Strengthening mechanisms

Intrinsic strength: bonding type

Solid solution effects: size effect and local modulus changes; interaction with dislocations, Cottrell atmospheres, yield point phenomena.

Precipitate and particle effects: interaction with dislocations, coherent, semi-coherent and incoherent particles, strong and weak obstacles.

Microstructural effects; grain boundaries and phase boundaries, Hall-Petch relation; dislocation pile-up.

Work hardening: interactions between dislocations, recovery mechanisms.

Ideal microstructures for strength.

Background reading:

Introduction to Dislocations, D. Hull and D. J. Bacon.

Crystallography and Crystal Defects, A. Kelly and G. W. Groves.

Microplasticity: Lecture notes by A.P. Sutton, Materials Dept. Library

Worked examples in strength of metals and alloys, J W Martin

Worked Examples in Dislocations, M.J. Whelan

Physical Metallurgy, R.W. Cahn and P. Haasen

GP3: Mechanical Properties Hilary Term

2nd year MS

Prof R I Todd

4 lectures

Creep

1. **Introduction to Creep**
   Time dependent deformation, creep curves, Andrade's law, regions of creep, importance of creep.
2. **Creep Mechanisms – background material**
   Dorn equation, Orowan equation, stress-directed diffusion.
3. **Creep by Movement of Lattice Dislocations**
   Harper-Dorn creep, power-law creep: work hardening versus recovery, Bailey-Orowan equation, pipe diffusion, power law breakdown.
4. **Diffusion Creep**
   Herring-Nabarro, Coble creep. Grain boundary sliding.
5. **Superplasticity**
   Micrograin superplasticity, superplastic forming in practice, SPF-DB.
6. **Deformation Mechanism Maps**
   Constant grain size, constant temperature.
7. **Creep Failure**
   Cavity nucleation, diffusional growth, plastic growth.
   Creep life prediction: Monkman-Grant, Larson-Miller parameter. Optimisation of creep life.

Background reading:

The Physics of Creep, Nabarro & de Villiers

Introduction to Creep, Evans & Wilshire

Deformation Mechanism Maps, Frost & Ashby

Creep of Metals and Alloys, Evans & Wilshire

Mechanisms of creep fracture, Evans

Creep of Crystals, Poirier

Physical Metallurgy, Cahn & Haasen (eds), Chapters: 20 Creep and superplasticity, 21 Solid solutions (parts), 22 Multi phase alloys (parts)
Creep, Gittus
Cavities and Cracks in Creep and Fatigue, Gittus
Fundamentals of Creep in Metals and Alloys, Kassner, Pérez-Prado
Mechanical Metallurgy, Dieter

GP3: Mechanical Properties   Trinity Term

2nd year MS

Prof M L Galano

8 lectures

Macroplasticity & Mechanical Working Processes

- **Macroplasticity**
  - Stress and Strain
  - Yield Criteria
  - Plastic Instability
  - Torsion
- **Metal working process**
  - Forging
  - Rolling
  - Extrusion
  - Wire-drawing
  - Thin sheet
- **Finite-element analysis** (largely non-examinable)
- **Effects on microstructure**

Background reading:

Mechanical Metallurgy, G E Dieter, McGraw-Hill

Metal Forming, WE Hosford and RM Caddell, Cambridge University Press

Manufacturing with Materials, L Edwards and M Endean, Butterworths

GP3: Mechanical Properties Hilary Term

2nd year MS

Prof R I Todd

8 lectures

Fracture

1. **Background.** Ideal strengths of materials in tension; real strengths of materials; brittle fracture.
2. **Griffith relation.** Generalising Griffith. Mechanical energy release rate, *G.*
3. **Linear Elastic Fracture mechanics.** LEFM, *K*, *Kc*, toughness measurement in brittle materials; non-elastic behaviour at the crack tip.
4. **Crack tip plasticity.** Irwin model for plastic zone; plane strain toughness testing, crack opening displacement (COD).
5. **Initiation of Fracture.** Surface damage; ductile-brittle transition (DBT); influence of particle dispersions, intergranular fracture.
6. **Ductile fracture.** Nucleation, growth and coalescence of cavities. Effects of particles.
7. **Fatigue failure;** Definitions; mechanical and microstructural characteristics, S-N curves; fatigue limit and endurance limit; high and low cycle fatigue, Basquin, Coffin-Manson, Goodman and Miner descriptions of fatigue life.
8. **Stages of fatigue;** crack initiation; crack growth; stress intensity factor range and the Paris law; use in life predictions; threshold stress intensity factor range; effect of environment and metallurgical variables on fatigue life; treatments to improve fatigue life.

Background reading:

Mechanical Metallurgy, George E. Dieter

Deformation and Fracture Mechanisms of Engineering Materials, R W Hertzberg, Wiley (3rd edition 1989, especially Chapters 7 onwards).

Fracture Mechanics, H L Ewalds and R J H Wanhill, Arnold (1985).

Fundamentals of Fracture Mechanics, J F Knott, Butterworths (1973, especially Chapter 7).

Fracture Mechanics – Worked Examples, J F Knott & P Withey, Institute of Materials (1993).
Fracture of Brittle Solids, B Lawn, Cambridge University Press (2nd edition 1993, 1st edition 1975 by Lawn and Wilshaw,especially Chapters 1 and 2).
An Introduction to the Mechanical Properties of Ceramics, D J Green, Cambridge University Press (1998, esp. Chapter 8).
The Plastic Deformation of Metals, R W K Honeycombe, Arnold (1968, especially Chapters 7 and 13-15).
Micromechanisms in Particle-Hardened Alloys, J W Martin, Cambridge University Press (1980, especially Chapter 3).
Fatigue of materials, S Suresh, Cambridge University Press (2nd edition 1998).

GP3: Mechanical Properties Trinity Term

2nd year MS

Prof H E Assender

4 Lectures

Mechanical Properties of Polymers

Introduction to polymer deformation. Plastic deformation. Glassy behaviour. Rubbery behaviour.

Introduction to rubber elasticity. Entropic effects. Applications of rubbers.

Linear viscoelasticity. Creep. Stress relaxation. Spring and dashpot models. The standard linear solid. Time-temperature superposition.

Plastic deformation of thermoplastics. Yielding in polymers.

Temperature. Dependence of viscoelasticity and yielding on temperature. The ductile-brittle transition. Yield and necking.

Fracture. Fracture toughness in polymers. Crazing and rubber toughening.

Comparison of mechanical properties of metals and polymers.

Reading list:

Required reading (Those books core to the course material):

Principles of Polymer Engineering, N G McCrum, C P Buckley and C B Bucknall, OUP, 45McC/3A. Chapters 3, 4 & 5.

An Introduction to the Mechanical Properties of Polymers, I M Ward and D W Hadley, Wiley, 45WAR/3. Chapters 3, 4, 6, 9, 11, 12.

Background reading:

Introduction to Physical Polymer Science, L H Sperling, Wiley, 45SPE/1. Chapters 8, 9, 10 & 11.

Textbook of Polymer Science, F W Billmeyer, Wiley, 1984, 45BIL/B. Chapter 11

Fundamentals of Polymer Engineering, A Kumar and RK Gupta, McGraw-Hill, 1998. 45KUM/1 Chapter 12.

GP3: Mechanical Properties Trinity Term

2nd year MS

Prof J T Czernuszka

4 lectures

Mechanical Properties of Composites

Stiffening due to fibres:

- rule of mixtures (Voigt and Reuss averages) – revision.
- elastic shear lag model for short fibres (results only, not full derivation), stress transfer length, efficiency factor.

Elastic behaviour of composite sheets:

- orthotropic plates, reduced compliance tensor, stress & strain transforms.
- off axis properties, compliance transforms.

Strength of composites:

- longitudinal, transverse & shear strength of long fibre composites.
- longitudinal strength of short fibre composites.

Fracture of composites:

- toughening mechanisms.
- work of fracture for fibre pull-out.

Background reading:

Polymers and Composites 1st year lecture notes.

Mechanics of Composite Materials MATTER project interactive CD (available on Materials Teaching Labs Network).

Introduction to Composite Materials, D Hull & T W Clyne. CUP.

Materials for Engineering, chapter 8, B Derby, D A Hills & C Ruiz, Longman, 1992.

Composite Materials: Engineering and Science, F L Matthews & R R Rawlings, Chapman & Hall.

Engineering Composite Materials, B Harris, IoM.

General Paper 4: Engineering Applications of Materials

GP4: Engineering Applications of Materials Michaelmas Term

2nd year MS

Prof P D Nellist

8 lectures

Microstructural Characterisation of Materials

- The course covers practical techniques for the characterisation of the microstructures of materials, concentrating on various methods of microscopy.
- Introduction – what are microstructures? Modes of magnification. Field ion microscopy and the atom probe.
- Components of the conventional microscope. Optical microscopes and TEMs. Factors limiting resolution in optical and electron microscopy.
- Some special topics in optical microscopy: Polarised light, Phase contrast, Interference microscopy.
- Diffraction in the transmission electron microscope. Selected area diffraction patterns.
- Imaging in the transmission electron microscope. Contrast mechanisms. Diffraction contrast to image defects.
- Scanning electron microscopy. Performance and resolution in secondary electron and backscattered electron modes.
- Scanning transmission electron microscopy: annular dark-field imaging and electron energy-loss spectroscopy.
- X-ray microanalysis in the electron microscope. Energy-dispersive and wavelength-dispersive spectrometry.
- Scanning tunnelling microscopy and atomic force microscopy.

Background reading:

See **section 32** of Materials departmental library.

Optical microscopy of metals[#], R C Gifkins, Pitman, 33GIF.

Metallurgical microscopy, H Modin and S Modin, Butterworths, 32MOD.

Geometrical & Physical Optics, R S Longhurst, Longmans, 33LON.

Progress in Microscopy, M Francon, Pergamon, 33FRA.

An Introduction to Interferometry, S Tolansky, Longmans, 33TOL.
Transmission electron microscopy#, D B Williams and C B Carter, Plenum Press, 32WIL.
Electron microscopy and analysis#, P J Goodhew and F J Humphreys, Taylor & Francis, 32GOO.
Techniques for Electron Microscopy, D H Kay (ed.), Blackwell, 32KAY.
Transmission Electron Microscopy of Materials, G Thomas and M J Goringe, Wiley, 32THO.
Scanning Electron Microscopy, P R Thornton, Chapman & Hall, 32THO.
Interpretation of Electron Diffraction Patterns, K W Andrews, Adam Hilger et al, 32AND.
Practical Electron Microscopy in Materials Science, J W Edington, MacMillan, 32EDI.
Scanning tunneling microscopy, D A Bonnell (ed.), VCH, 32BON.
Images of Materials, D B Williams et al, OUP.
#most useful books

GP4: Engineering Applications of Materials Hilary Term

2nd year MS

Prof P.R Wilshaw

6 lectures

Semiconductor Devices

1. Diode Devices: Rectifiers, varactors, fast switching, tunnel diode.
2. Bipolar Transistors: Operation (including amplification and switching), graded base devices, heterojunction bipolar transistors.
3. Field Effect Transistors: MOSFETs, MESFETs, HEMTs.
4. Microwave Devices: Transferred electron oscillators.
5. Optical devices: Photodetectors, solar cells, light emitting diodes, lasers, electrooptic modulators, fibre optics.

Background reading:

How the devices work:

Solid State Electronic Devices, B G Streetman, Prentice Hall.

Fundamentals of Semiconductor Devices, E S Yang, McGraw-Hill.

Physics of Semiconductor Devices, S M Sze, Wiley.

How the devices are processed:

Microelectronic Materials, C R M Grovenor, Adam Hilger.

VLSI Technology, S M Sze, McGraw-Hill.

GP4: Engineering Applications of Materials Trinity Term

2nd year MS

Prof R C Reed

14 lectures

Engineering Alloys

Intrinsic and secondary properties: basic engineering alloy requirements and the factors controlling hardness, strength, plasticity, etc.

The metals: their structure, properties, abundance and cost.

Steel making: Basic oxygen furnace, electric arc furnace, secondary steel-making, continuous casting, control of C, Si, Mn, P and S.

Plain carbon steels: Fe-C phase diagram; ferrite-pearlite steels; heat treatment, microstructure, properties, use; isothermal and continuous cooling transformations; martensitic and bainitic steels.

Alloy steels: alloy effects; transformation kinetics and mechanisms and use; tool, maraging and other special steels.

Stainless steels: classes, microstructures, properties and use;

Cast irons: types, effect of casting parameters, properties and use.

Aluminium alloys: cast and wrought alloys; precipitation hardening; non-heat treatable alloys; uses and limitations; aerospace alloys; composites.

Titanium alloys: α and β alloys; alloy additions; heat treatment, microstructure, properties and use; composites.

Nickel alloys: cast alloys and wrought alloys; alloying effects; directional solidification and single crystal alloys; microstructure, properties and use; thermal barrier coatings.

Magnesium alloys: alloys; microstructure; properties and use.

Background reading:

Physical Metallurgy Principles, 3rd edition, chapters 18 to 20, R E Reed-Hill and R Abbaschian.

Engineering Metallurgy, 6th edition, chapters 7, and 11 to 18, R A Higgins.

Steels, Metallurgy and Applications, 3rd edition, chapters 2, 3 and 4, D T Llewellyn.

Steels, Microstructure and Properties, 2nd edition, chapters 3 to 6, R W K Honeycombe and H K D H Bhadeshia.

Light Alloys, 3rd edition, chapters 2, 3, 5 and 6, I J Polmear.

The Superalloys: Fundamentals and Applications, chapters 2, 3 and 4, R C Reed.

Titanium and Titanium alloys: Fundamentals and Applications, chapters 1, 2, 8, 10 and 11, edited by C Leyens and M Peters.

Magnesium: Alloys and Technology, chapters 1, 2, 5 and 7, edited by K U Kainer.

Secondary Steelmaking: Principles and Applications, chapters 1, 5, 6 and 7, A Ghosh.

GP4: Engineering Applications of Materials Trinity Term

2nd year MS

Prof J T Czernuszka

8 lectures

Ceramics & Glasses

1. Definitions: Ceramics, glasses and cements. Typical properties and applications.
2. Lattice defects: aliovalent and isovalent substitutions. Balanced and unbalanced Frenkel and Schottky defects.
3. Engineering ceramics: Methods of manufacture. Powder production, compaction and sintering; residual porosity; liquid phase sintering, hot-pressing, *in situ* methods. Properties and examples.
4. Traditional ceramics: whiteware, clay products, refractories. Properties and examples.
5. Glasses: Definitions, compositions; devitrification, glass-ceramics.
6. Room temperature formation. Cements and concrete: Portland cement, composition, manufacture, additives and hydration; macro-defect free cement.
7. Partially stabilised zirconias – the ‘ceramic steel’.

Background reading:

Introduction to ceramics, W I Kingery, H K Bowen & D R Uhlmann, Wiley.

Mechanical behaviour of ceramics, R W Davidge, CUP.

Modern ceramic engineering, D W Richerson, Dekker.

Glass ceramics, P W McMillan, Academic Press.

Fracture of brittle solids, B R Lawn, CUP.

Cement chemistry, H F W Taylor, Academic Press.

Portland cement, composition, production and properties, G C Bye, Pergamon.

Glass science, R H Doremus, Wiley.

Biomineralization, Ed S Mann, J Webb, RJP Williams, VCH.

GP4: Engineering Applications of Materials Trinity Term

2nd year MS

Prof H E Assender

4 lectures

Engineering Applications of Polymers

General Application of Polymer Materials. Advantages and disadvantages of polymeric materials. Range of properties. Materials selection. Biodegradability and recyclability. Polymers and the environment.

Processing routes. Control of anisotropy. Melt vs. solution processing. Major processing routes: extrusion, injection moulding, vacuum forming, spin coating, printing, colloids.

Extreme anisotropy: Fibres**.** Melt spinning. Extended chain crystals. Extensional flow. Gel drawing. Colloids. Spin coating.

Additives.

Electrical conductivity in polymers. Polymers as insulators. Composite conductivity. Ionic conductivity. The conjugated chain. Conduction mechanisms. Applications.

Other conjugated polymer systems. NLO behaviour.

Some reading:

Required reading (Those books core to the course material):

Principles of Polymer Engineering, N G McCrum, C P Buckley & C B Bucknall, OUP, 1988, 45McC/3A. chapters 7 & 8.

Polymer electronics, Mark Geoghegan and Georges Hadziioannou, OUP, 2013., 45GEO chapters 2, 5, 8, 10

Background reading:

Introduction to Physical Polymer Science, L H Sperling, Wiley, 45SPE/1. sections 4.4 & 14.7-8.

Materials Selection in Mechanical Design, Fourth Edition MF Ashby, 56ASH/5

Textbook of Polymer Science, F W Billmeyer, Wiley, 1984, 45BIL/B. chapter 17.

Special Polymers for Electronics and Optoelectronics, J A Chilton & M T Goosey (eds), Chapman & Hall, 1995, 45CHI.

Conductive Polymers and Plastics, J M Margolis, Chapman & Hall, 1989, RSL TP 1122 CON.

Polymers: Chemistry and Physics of Modern Materials, J M G Cowie, Blackie, 1991, 45COW. chapter 17.

Conjugated polymer surfaces and interfaces: electronic and chemical structure of interfaces for polymer light emitting devices, W R Salaneck, CUP, 1996, 45SAL.

Fundamentals of Polymer Engineering, A Kumar and RK Gupta, McGraw-Hill, 1998. chapters 6, 15, 45KUM/1

Other Lectures

Other Lectures — Michaelmas Term

2nd year MS

Prof S C Benjamin

8 lectures

Maths - Partial Differential Equations & Fourier Series

Fourier Series

1. Background revision on the nature of periodic functions.
2. Introducing the notion of composing a general period function from a sum of elementary functions; Fourier's theorem.
3. Special cases of Fourier series; examples including the square and triangular waves.
4. Exploring Fourier Series with Matlab.
5. Fourier series for functions with periods other than 2π. Integration and differentiation of Fourier series.
6. Approximating periodic functions by finite sums of trigonometric functions.
7. Complex form of Fourier series.

Introduction to the Fourier Transform

8. Fourier transforms as a generalisation of Fourier series.
9. Applications of Fourier transforms, and exploration with Matlab.

Partial differential equations

10. Revision of core concepts for differential equations.

    Diffusion equation

11. Derivation of the diffusion equation.
12. Solution of the diffusion equation for
    - Simplified initial condition (sinusoidal distribution of density)
    - Realising initial conditions (block-like initial distribution)

    The latter introducing the notion of ***separation of variables***.
13. Introduction to the problem of a semi-infinite volume;

    derivation of the complimentary error function by similarity transformation.

    Wave equation for a taut string

14. Derivation of the wave equation; static and travelling waves.
15. Analysing the frequency composition of a plucked string.

Background reading:

A gentle introduction to Fourier series is provided by the book **Fourier Series** by William Bolton. There is a copy in the RSL, and St Edmund Hall has one in its library. This book doesn't cover all the topics in the lecture course, however.

A comprehensive book is **Fourier Series and Boundary Value Problems** by James Brown and Ruel Churchill. There are lots of copies of this around, e.g. in the Hooke Lending Library. We'll mainly be concerned with the material in the first four chapters.

There are also chapters on Fourier Series and PDEs in the standard comprehensive maths textbooks, such as:

- **Advanced Engineering Mathematics,** Erwin Kreyszig, 8th edition, John Wiley (1999). Chapters 10 and 11 cover Fourier series and PDEs.
- **Mathematical Methods for Physics and Engineering,** RHB. Chapter 10 covers Fourier Series, and chapters 16 and 17 cover PDEs.

There are also excellent resources online, both four Fourier series / transformation, and for PDEs. Tutorials in mathlab can also be found, on the www.mathworks.com site and elsewhere.

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