Materials Science
Prelims Lecture Course Synopses
2023-24
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Materials Science 1: Physical Foundations of Materials
Materials Science 1: Physical Foundations of Materials

Summary
This paper introduces the physical foundations underpinning important areas of Materials Science. You will learn some basic concepts of atomic arrangements in perfect crystals and how we can use diffraction of X-ray and electron waves to measure these arrangements. The use of waves will also be used to explore basic concepts in wave mechanics and quantum theory, and how these theories can be used to explore the behaviour of electrons in materials and how bonding occurs. Quantum theory involves randomness and probability, and these ideas are continued in the study of random processes in materials to explain phenomena such as diffusion and the behaviour of gases. The physical principles of electricity and magnetism are introduced and used to explore the electrical and magnetic properties that are so important for many applications of materials.

Physical Foundations of Materials comprises:
• The Study of Crystalline materials by Diffraction (8 lectures)
• Electromagnetic Properties and Devices (12 lectures)
• Random Process and Statistical Physics (8 lectures)
• Wave mechanics, Quantum Theory and Bonding (12 lectures)
The Study of Crystalline Materials by Diffraction

Overview
The vast majority of materials are crystalline, and so any study of materials must start with introducing some basics of crystallography including the use of a unit cell to describe the periodicity in the crystal and how to represent symmetry in crystals. In a crystal, the atoms form a periodic lattice that can act as a diffraction grating to radiation, and diffraction is therefore an important characterisation tool. The use of diffraction as a practical tool for identifying crystal structures in materials will be introduced.

Lecture Content

Lecture 1. The Periodic lattice
- Definitions of a lattice, mesh, unit mesh and motif
- The Unit Cell and basis vectors
- The structure of metals and some binary compounds

Lecture 2. Symmetry in 2D
- Symmetry elements in 2D
- Lattice symmetry in 2D
- The 2D plane point groups

Lecture 3. Crystallographic planes and directions
- Miller and Miller Bravais indices describing planes and directions
- Calculation of interplanar spacings, angles between planes and directions

Lecture 4. Waves
- Wave particle duality for X-Rays, electrons and neutrons
- Mathematical representation of harmonic travelling waves
- Interference of waves and the principle of superposition
Lecture 5. Diffraction in 2D and 3D

Diffraction from a 2D grating, the effects of slit width, separation and grating size
Diffraction from a 3D lattice; The Laue equation
Braggs law

Lecture 6. Scattering by atoms

Scattering factors for electrons, X-rays and neutrons
Structure factors
Forbidden reflections in cubic systems

Lecture 7. The reciprocal lattice

Constructing the reciprocal lattice
The Ewald sphere construction for single crystal and powder diffraction
Observing the reciprocal lattice with electron diffraction

Lecture 8.

Practical X-ray, electron and neutron diffraction experiments
Indexing powder x-ray and electron diffraction patterns
Example phase identification using powder diffraction

Further reading

Electromagnetic Properties and Devices

Overview
Next generation batteries for electric vehicles; sustainable materials for touch screen displays; faster, more compact and efficient computing; futuristic cloaking devices: these are just a few examples of the wide range of technological applications which exploit electromagnetic phenomena in materials. This course introduces the physics of classical electromagnetism and how different kinds of material respond to electrical and magnetic fields. We will explore how the structure of a material influences its electromagnetic properties including the origins of phenomena such as ferroelectricity and piezoelectricity, and how the coupling between electric/magnetic/strain fields can be exploited in real devices.

Part I: Electrical properties of materials
Theory of electrostatics
- Basic concepts of charge, force on a charge, potential and electric field, capacitance
- Calculations using superposition principle and Gauss’ theorem in examples with simple geometries

Dielectric materials
- Concepts of polarisation, dielectric permittivity, susceptibility, and electric displacement (D).
- Calculations involving simple geometries of capacitor.
- Example devices

Piezoelectric, pyroelectric and ferroelectric materials
- Concept of coupling between fields (e.g. electrical and strain)
- Crystal symmetry requirements
- Examples of materials
- Applications (e.g. Atomic Force Microscope, ferroelectric RAM)
Electrical transport
  o Basic concepts of current, current density, resistance, Ohm’s law.
  o Electrical conductivity of metals – Drude model
  o DC circuits

Part II: Magnetic properties of materials

Theory of magnetostatics
  o Concepts of magnetic field, flux and induction.
  o Calculations of magnetic field from currents in simple geometries using Biot-Savart and Ampere’s laws (e.g. straight wire, loop, solenoid, toroid)
  o Lorentz force on charges moving in electric fields

Electromagnetic induction
  o Faraday’s law and Lenz’s law
  o Concepts of self and mutual inductance

Magnetic materials
  o Concepts of magnetisation, magnetic susceptibility, magnetic permeability and magnetic intensity (H)
  o Introduction to paramagnetic, diamagnetic and ferromagnetic materials
  o Applications of ferromagnets (saturation magnetisation, hysteresis loops, remanent field, coercivity, hard and soft ferromagnets)
  o Example magnetic devices

Part III: Electromagnetic waves

General theory of electromagnetism
  o Maxwell’s equations in integral form
  o Concept of displacement current

Electromagnetic waves
  o General wave equation
  o Formulation in integral form

Interaction of materials with EM waves
  o Refractive index
  o Conductors
  o Example applications
Further reading


Feynman, Richard P. et al. *The Feynman Lectures on Physics*. Addison-Wesley, 1963. Materials Dept. Library 20 FEY/Bb or 20 FEY/Cc or 20 FEY/Ac. Vol II, Ch. 1-22 are worth reading. The mathematical formalism is more complex, but is clearly explained in the text. Vol. 1, Ch. 2 gives an interesting historical overview of “Basic Physics” which helps set the classical physics discussed in this course in context.


Random Processes and Statistical Physics

Overview
Quantum theory shows us that probability plays an important role in the processes that control materials properties. This course explores that idea in more detail, looking at how randomness can control structure, how it plays a role in diffusion processes and in the interaction of gases with surfaces. The statistical concepts introduced can be used to explain classical thermodynamics, and the statistical natures of heat capacity is introduced.

Lecture Content

Random processes in materials
- Examples of random processes e.g. diffusion
- Random walks – applications (e.g. polymers)

Rapid random motion of gas molecules
- Basic assumptions of kinetic theory
- Simple derivations of pressure and temperature
- Ideal gas equations

Statistical distributions of molecular motions
- Statistical notation
- Collision with walls – relating pressure to collision rate
- Deposition of materials and thin film growth
- Effusion

Pressure and distribution of velocities
- Derivation of pressure as statistical average and need for mean-square velocity
- Maxwell-Boltzmann distribution of velocities
Collisions and transport
- Concept of mean free path
- Rate of collisions in gases and relation to reaction kinetics (effect of temperature and pressure)
- Rate laws. Determination of reaction order and rate constants/The Arrhenius equation.
- Transport in materials – diffusion, heat flow and viscosity
- Effect of temperature and pressure on transport

Non-ideal gas behaviour
- Interaction between molecules
- Modification to ideal gas law

Equipartition theory (links to thermodynamics course)
- Heat capacity of gases

Breakdown of classical physics
- Heat capacity of solids

Further reading
Overview
Many properties of materials are controlled by how electrons behave in them. Because of wave-particle duality, we need to consider electrons as waves. This course shows how these ideas lead onto quantum theory and the idea of discrete states. We can then think about what happens over different length scales including atoms and nanomaterials. The concept of bonding and molecular orbitals is introduced before thinking about entire crystals and how bands are formed.

Lecture Content

Wave particle duality
- Evidence, electron diffraction, photoelectric effect, atomic spectra
- DeBroglie wavelength
- Interpretation of quantum mechanical wave

Observation of quantum systems
- Perturbation of observed systems
- Postulates of quantum mechanics
- Operators and commutators
- Uncertainty principles – momentum-space / energy-time

Waves and the wave equation
- Wave packets
- Dispersion, phase velocity and group velocity for electrons and photons
- Schrödinger equation

Waves on a string, standing waves and boundary conditions
- Mathematical notations for waves
- Free and fixed boundaries
- Nodes and antinodes
- Harmonics
- Wave equations
Infinite potential well
   Waves in a 1D box, quantisation, quantum confinement
   Illustrated with energy levels in nanomaterials (QDs etc.)

Measurement in quantum mechanics
   Decomposition into eigenstates
   Statistical nature of measurements and expectation values
   Wavefunction collapse and Schrödinger’s cat

Transmission and reflection of waves
   Finite boundary potentials
   Boundary condition matching
   Transmission and reflection coefficients
   Tunnelling and evanescent waves

Extension to 3D
   Separation of variables
   Angular momentum
   Quantum numbers $n$ and $l$

The hydrogen atom
   One electron atoms
   Heavier atoms

Spin
   Fermions and bosons
   Pauli exclusion principle
   Filling of atoms

Multiple finite wells
   Molecular orbital theory – bonding and antibonding
   The concept of the broadening of discrete states into bands
   The concept of a crystal momentum to describe a wave
Further reading
Materials Science 2: Structure and Mechanical Properties of Materials
Materials Science 2: Structure and Mechanical Properties of Materials

Summary
This paper introduces the basic structures of materials – both crystalline and amorphous and how they deform and fail under applied stresses. You will learn the theory behind methods used to study the atomic arrangement in perfect crystals and in then apply these to the common lattice defects which can occur. How these defects control the mechanical properties of the materials will be introduced in both single crystal and more engineering relevant material systems. This will cover elastic properties, including stress and strain analysis, yield phenomenon, post yield plastic flow and linear elastic fracture mechanics.

Structure and Mechanical Properties of Materials comprises:

- Elastic Deformation (8 lectures)
- Structures of Crystalline and Glassy Materials (12 lectures)
- Defects in Crystals (8 lectures)
- Mechanical Properties (12 lectures)
Elastic Deformation

Overview
This course introduces the basics of stress and strain. Analysis of simple bending conditions (cantilever, three point, four point) as required for mechanical testing analysis are developed, including shear force and bending moment diagrams. Mohr’s circle is introduced as a graphical method to calculate stress or strain states at any point in a plane for arbitrary loading conditions. The underlying physics of elastic constants and how they relate stress and strain will be derived. Time dependant elastic deformation (viscoelasticity) will be introduced through examples in polymeric materials. Stress states and the elastic deformation of thin wall pressure vessels and torsional deformation of prismatic rods will be discussed.

Lecture Content

Equilibrium
   Resolving forces
   Taking moments

Internal forces
   Shear force and bending moment diagrams

Stress
   Definitions, normal stress, shear stress, notation
   Transformation of axes
   Resolving stress onto an inclined plane
   Mohr’s circle for stress
   Principal stresses, maximum shear stress
Strain
Definitions, normal strains, shear strain
Engineering and tensor strains
Transformation of axes
Mohr’s circle for strain
Principal strains, maximum shear strain

Elasticity and interatomic forces
Recap of fundamentals
Physical basis for Hooke’s law

Hooke’s law
Relating stress and strain
Young’s Modulus
Shear modulus, bulk modulus
Poisson’s ratio

Viscoelastic deformation
Simple spring and dash pot models

Elastic deformation examples
Thin wall pressure vessels
Bending of beams
Torsional deformation

Further reading
Structures of Crystalline and Glassy Materials

Overview
This course will investigate why different classes of materials exist and how different forms of interatomic bonds lead to different materials properties. Ways to represent and describe bonding will be introduced through the use of example materials with common crystal structures. Key classes of materials (ceramics, metals, polymers, glasses) will be introduced and specific applications of these materials used to illustrate key points.

Lecture Content

Types of Bonding
Examples of simple crystal structures
Close packing of spheres. FCC and HCP and stacking sequences
Octahedral and tetrahedral interstices in close-packed structures
Basic Concepts
- Definition of metals, ceramics, polymers, glasses and semiconductors
- Types of bonding: ionic, covalent, metallic, van der Waals
- Dependence of interatomic forces on distance
- Non-directional bonds: van der Waals, metallic; close packing
- Directional bonds: the covalent bond, hybrids
- Electronegativity, ionic bonding, co-ordination
- Trends in the periodic table

Stereographic projections and the Weiss zone law
Pole figures
Stereographic projection. Properties of projection
Great circles, Small circles, Zones
Preservation of angular truth
Wulff net
Zone axes, Zone symbols
Weiss zone law
Crystallographic calculations
Addition rule, Use in plotting stereogram
Use to illustrate coordination, e.g. for tetrahedral structures, and symmetry
directions in common lattice, e.g. cubic
Examples from real structures (e.g. zinc blende, wurtzite, NiAs)

**Ceramic materials bonding**

**Ionic Structures**
- Structures of composition AX (CsCl, NaCl, ZnS)
- Principles of ionic bonding: radius ratio criterion, energy considerations,
  Madelung constant
- Structures of composition AX2
- Pauling's Rules

**Covalent Structures**
- Simple covalent structures (diamond, graphite)
- Molecular crystals
- Structures of some ceramics.

**Perovskite structures**
- Basic properties

**Glasses and amorphous materials**

Idea of local ordering
SiO$_2$ coordination
Network formers
Basic properties of glasses

**Bonding and structure of polymers, molecular crystals, polymorphism**

Mixtures of bonding. Tg. Random walk model
Thermosetting vs thermoplastics v rubbers
  - Rubber, polyethene, nylon6-6

**Polymer properties**
- Degree of polymerisation
- Molecular weight distribution
- Stereoregularity

Glass transitions
Metals, solid solutions and ordered alloys

Trends across the Periodic Table

Typical metallic structures (FCC, BCC, HCP); atomic packing factor, unit cell volume, theoretical density

Relationship between structure, bonding and properties of pure metals

Interstitial and substitutional alloys – iron-carbon, iron-chromium, aluminium-copper

Hume-Rothery Rules: size factor, electrochemical factor & relative valency factor

Electron compounds; normal valency compounds; size factor compounds - interstitial compounds

Further reading


Evans, Robert Crispin. An Introduction to Crystal Chemistry. 2nd edition, Cambridge University Press, 1964. Dept. of Materials Library 30 EVA/B or 30 EVA/A or 30 EVA/D or 30 EVA/E.


Defects in Crystals

Overview
This course will introduce the basic forms of defects present in crystalline materials. Their effect on physical properties will be considered. Diffusion of point defects and implications for systems such as ionic conductors will be covered. Dislocations will be given the fullest consideration. Differences between edge and screw dislocations. How dislocation move and control the mechanical properties in single crystal metals will be covered. Methods for imaging dislocations and calculating their nature will be introduced. This course will build on the diffraction and crystal structures courses and also use elasticity analysis introduced in elasticity and structures. It will lead into the mechanical properties course.

Lecture Content

Introduction
Types of lattice defects (point, line, planar)
What do defects control – e.g. (doping of semiconductors, strengthening in metals)

Introduction to dislocations
How do we know they exist?
Structure of edge and screw dislocations in simple cubic materials
Definition of the Burgers vector

Imaging dislocations
Microscopy and diffraction techniques
Introduction to diffraction contrast TEM imaging and $\mathbf{g} \cdot \mathbf{b}$ analysis
Etch pits methods

Dislocations in cubic lattices
Self-energy of a dislocation
Slip systems
Partial dislocations and stacking faults
Peach Koehler formula for force on dislocation
Motion of dislocations under an applied stress
Dislocation sources

**Point defects and diffusion**
- Point defect types
- Concentration of point defects
- Vacancy motion and solid state diffusion
- Diffusion mechanisms and Fick's first and second laws

**Planar defects**
- Planar defect types
- Stacking faults
- Twinning
- Structure of grain boundaries and concepts of grain boundary energy
- Interphase and antiphase boundaries

**Further reading**
Mechanical Properties

Overview
This course builds on the elastic behaviour course looking at how materials behave beyond the yield point and from the defects course, looking at how defects can control mechanical behaviour. The basic methods of materials testing will be introduced, this will link into several practical classes. Plastic behaviour will be covered both at the micro and macroscale. At the microscale building on the defects course, but concentrating on the strength of polycrystalline metals and introduce the concept of strengthening through precipitates, using aerospace aluminium alloys as examples. This will be followed by a macroscopic treatment of yield through Tresca, Von Mises and Coulombs Yield Criterion for deformation in bulk metals and polymers. Fracture will be covered in ceramics and glasses using a linear elastic treatment. Toughening mechanisms will be introduced including fibre toughening which will lead to a first treatment of composite materials. Finally optimisation of materials properties will be covered, looking at a range of properties including design for strength, stiffness and cost.

Lecture Content

Testing mechanical properties
- Why we test, how we test, what we test.
- Types of stress and strain
- Introduction to stress-strain curves for metals, ceramics, polymers

Microscale mechanisms of plasticity and how we control plastic strength
- Metals – chemistry and crystallographic effects
- Metals – grain size; Hall-Petch effect, how to control grain size
- Work hardening in metals. Single vs double slip. Effect of crystal structure and stacking fault energy on work hardening behaviour
Twinning deformation, difference to annealing twins
Plasticity in polymers, glass transitions temperatures

**Predicting plastic failure at bulk or component length scales**
Tresca and Von Mises yield criterion – metals
Coulomb yield criterion – polymers
Using yield criterion for combined tension-torsion loading

**Fracture processes**
Recap of theoretical strength
Stress concentrations at small flaws
Griffith theory
Orowan Modification
Ductile to brittle transitions in metals
Fracture and failure in polymers
Toughening mechanisms – transformation toughening, microcracking, composites

**Introduction to mechanics of composites**
Design of composites
Rules of mixture in long fibre composites
Rules of mixture in particulate composites

**Optimising materials selection**
Ashby Maps
Examples of using Ashby Diagrams and properties optimisation (design for stiffness, lightness, strength, cost etc).

**Further reading**


DoITPoMS. "The Dissemination of It for the Promotion of Materials Science." [https://www.doitpoms.ac.uk/](https://www.doitpoms.ac.uk/) This site has good introductions to many key concepts discussed in this course.
Materials Science 3: Transforming Materials
MS3: Transforming Materials
1st year MS

Materials Science 3: Transforming Materials

Summary
This paper introduces you to how the microstructure of materials can be transformed and controlled through processing, in order to control and optimise the properties that are required for the material to perform its function. The theory of thermodynamics is critical to all transformations in materials, and you will be introduced to the first and second laws of thermodynamics and their role in phase diagrams. This will be developed further in Microstructure and Processing of Materials I & II, which will describe how phase transformations can be used to control microstructure, with case studies in metallic, ceramic and polymeric systems. Electrochemical processes, which are driven by thermodynamics, are important in the production and degradation of materials, as well as the performance of materials for energy storage. The developing field of nanomaterials will also be introduced, with emphasis on nanomaterial synthesis, properties and applications.

Transforming Materials comprises:

- Thermodynamics (8 lectures)
- Introduction to Nanomaterials (8 lectures)
- Microstructure and Processing of Materials I (8 lectures)
- Electrochemistry (8 Lectures)
- Microstructure and Processing of Materials II (8 lectures)
Thermodynamics

Overview
Thermodynamics is fundamental to the physical and chemical processes that occur in materials. This course underpins many subsequent parts of the materials degree. It focuses on the first and second laws of thermodynamic, using practical examples, and leads to an understanding of phase stability.

Lecture Content

First law of thermodynamics
  Thermodynamic Definitions: work, heat, internal energy, state and path functions
  Simple gas expansion
  Reversible and irreversible processes

Enthalpy and heat capacity
  Heat capacity at constant volume
  Storage of internal energy
  Constant pressure processes
  Heat capacity at constant pressure
  Enthalpy variation with temperature
  Hess’s law. Kirchhoff’s equation

Entropy and the second law of thermodynamics
  Definition of a spontaneous process
  Entropy variation with temperature
  Entropy of phase changes
  Definition of the Gibbs function
  Thermodynamic Master Equations
  Gibbs function variation with temperature and pressure
  Gibbs Helmholtz equation
  Statistical mechanics definition of entropy
Mixtures and equilibria.
   Dealing with mixtures
   Chemical Potential
   The Van't Hoff isochore

Applications of thermodynamics to metallurgy
   Ellingham diagrams
   Stability of oxides
   Thermodynamics of the Blast Furnace
   Extraction of metals from Sulphides
   Predominance diagrams

Phase changes.
   The phase rule and phase diagrams
   The Clausius-Clapeyron equation
   Vapour pressure. Ideal solutions
   Non-ideal solutions
   Free energy of mixing
   Regular solutions
   The quasi chemical model

Further reading
Introduction to Nanomaterials

Overview
This course serves as an introduction to the rapidly developing area of Nanomaterials, beginning with the peculiar characteristics of materials at the nanoscale and the new technologies they enable. Important methodologies for nanomaterial synthesis are described, and the structures of key nanomaterials are introduced, including carbon nanomaterials and chalcogenides. The upscaling of the manufacture of nanomaterials is considered, together with associated ethical and safety issues. The course concludes with current and potential applications of nanomaterials in medicine and energy.

Lecture Content

Introduction
- Nanoscale,
- Nanotechnology,
- Surface areas per unit volume,
- 0-D, 1-D, 2-D materials

Synthesis of nanomaterials
- Chemistry of particle synthesis,
- Sol-gel processing,
- Core-shell nanoparticles,
- Composites, coatings, thin films,
- Chemical vapour deposition, arc discharge, exfoliation

Carbon nanomaterials
- Fullerenes, nanotubes, graphene

Other nanomaterials
- Chalcogenides, other 2-deg materials
Manufacturing
    Upscaling,
    Safety of nanomaterials,
    Ethics and regulation

Physical properties of nanomaterials
    Introduction to electrical, optical and mechanical properties at the nanoscale

Applications of nanomaterials
    Medical applications,
    Energy materials

Further reading
Endo, M and Dresselhaus MS, “Carbon Fibers and carbon nanotubes”


Rogers, MA, “Naturally occurring nanoparticles in food” *Current Opinion in Food Science*, vol 7, 2016, pp.14–19


Microstructure and Processing of Materials I

Overview
Material microstructures are the product of phase transformations that occur during processing, so an understanding of what controls phase transformations is important in all material systems. This course builds on the thermodynamics course to explain how we determine phase diagrams, and how they predict which equilibrium phases are formed by what reactions. This will be illustrated with examples of how to read phase diagrams to predict how to process a range of materials by both liquid-solid and solid-solid transformations.

Lecture Content

- Concepts of microstructure
- Terminology for microstructures
- Gibbs phase rule
- Solutions, compounds and mixtures
- Simple phase diagrams; tie lines and invariant points
- Ideal and regular solution models
- Tangent and lever rules

Phase diagrams

- Derivation from free energy-composition curves
- Continuous solutions, immiscibility and ordering
- Eutectic, peritectic, eutectoid peritectoid and monotectic reactions. Intermediate phases

Using phase diagrams

- Solidification: driving force for solidification; introduction to homogeneous and heterogeneous nucleation
Solidification of solutions: partition coefficient; Scheil equation and segregation; cells and dendrites, cored microstructures

Eutectic and peritectic transformations and microstructures

Solid state phase transformations

Introduction to precipitation, homogeneous and heterogeneous nucleation, equilibrium precipitation and age hardening

Heat treatments

Introduction to recrystallization and grain growth

Further reading


Electrochemistry

Overview
Electrochemistry is fundamental to the extraction of metals by electrolysis and also their corrosion and protection from degradation. The same processes of electrochemical thermodynamics are critical to the design and performance of materials for electrochemical energy storage, and sensors that rely on electrochemical processes. This course provides an introduction to applications of electrochemistry, and considers the thermodynamics of electrochemical processes. Factors that influence the kinetics of electrochemical reactions, including transport properties and interfaces are considered, using case studies.

Lecture Content

Introduction to electrochemistry
Overview: electrodes, electrolytes and interfaces
Applications:
  o Electrolysis
  o Electrodeposition and electroplating
  o Electro-mining
  o Electroanalysis and sensors
  o Corrosion and protection
  o Energy conversion, production and storage

Electrochemical thermodynamics
The physics of phase potentials
Cell potential and Gibbs free energy
Electrochemical potential
Half-reactions and standard reduction potentials
Cell potential and concentrations: Nernst equation
Reference electrodes
Pourbaix Diagrams
Case studies: sensors (potentiometry), maximum theoretical specific energy in batteries

Electrolytes and transport properties
Electroneutrality
Non-ideal behaviour of electrolyte solutions: activity coefficient
Transport properties: conduction, diffusion, migration
Case studies: activity coefficient, diffusion coefficient and transference number

The electrode-electrolyte interface: the electrical double layer
Structure of the electrical double layer
Case study: supercapacitors

Kinetics of electrode reactions
Charge transfer across the interface
Overpotential
Butler-Volmer model and the Tafel equation
Case study: electrocatalysis

Further reading
Microstructure and Processing of Materials II

Overview
These lectures build on the MT course, using case studies in metallic (solidification and heat treatment), polymeric and ceramic systems to develop an understanding of how the microstructures of materials can be controlled through processing.

Lecture Content

The Al-Si system for casting
- Structures of cast metal, Na modification
- Engineering applications

The Fe-C system
- Eutectic reaction and cast irons
- Eutectoid decomposition
- Hypo and hyper eutectoid alloys
- Martensite and bainite
- TTT curves. Typical microstructures for different heat treatments
- Engineering applications

Polymers: The PS/PBD system
- Polymer blends and phase separation
- Control of microstructure
- Engineering applications – tyres and high impact polystyrene

Ceramics: Mullite
- Powder processing
- Sintering
- Ceramic microstructures
- Engineering applications
Further reading
Mathematics for Material Science
Mathematics for Material Science

1st year MS

Mathematics for Material Science

Summary

Mathematics is the language of the physical sciences. This course will cover the mathematics which will underpin the material science you will learn this year, and in future years. As well as learning the fundamentals you will gain experience at applying mathematics to physical problems.

Lecture Content

Mathematics for Materials Science I
- Ordinary and Partial Differentiation (7 Lectures)
- Vectors & Matrices (12 lectures)

Mathematics for Materials Science II
- Taylor Series and Limits (3 lectures)
- Integration (5 lectures)
- Complex Numbers (4 lectures)
- Ordinary Differential Equations (6 lectures)

Further reading
Mathematics for Material Science I

Ordinary differentiation (EL)
Differentiation from 1st principles, chain rule

Partial Differentiation (EL)
Total derivatives, exact differentials,
Change of variables, chain rule
Applications: Spherical and polar coordinates, thermodynamics

Vectors (SCB)
Scalar Product and Vector Product.
Introduction to Vector Calculus
Applications: Reciprocal lattice, Miller indices and planes

Matrices (SCB)
Inverse matrices
Determinants
Orthogonal matrices
Properties of symmetric Matrices - eigenvalues and eigenvectors
Applications: Conductivity – interpretation of principle value and directions.
Mathematics for Material Science II

Integration (JCAP)
Evaluation of definite integrals by substitution, partial fractions, integration by parts and reduction formulae
Multiple integrals in two and three dimensions - including polar and spherical coordinates.
Applications: areas, volumes, centroids, bending moments, Random Processes and Statistical Physics

Complex numbers (JCAP)
Exponential form.
Argand Diagrams
de Moivre’s theorem
Solutions of Polynomial Equations.
Applications: Complex Impedance, circuits involving inductors, capacitors and resistors.

Taylor series and limits (AAS)
Taylor series, limits and l'Hopital’s rule
Applications: Low and high temperature expansions

Ordinary differential equations (AAS)
Applications: Cooling, circuits
Second Order Equations: Linear homogeneous with constant coefficients. Linear inhomogeneous with constant coefficients. Method of solution via auxiliary equation and particular integral.
Applications: Resonance in electrical and mechanical systems.