Department of Materials
Imperial College London

Materials Science and Engineering (MEng)
Biomaterials and Tissue Engineering (MEng)
Materials with Nuclear Engineering (MEng)
Materials Science and Engineering (BEng)
Materials with Management (BEng)
Introduction

This handbook contains specific information for the Year 1 students in the 2018-2019 cohort, including the module details, assessment deadlines and year composition for this academic year. It is to be used in conjunction with the General Handbook for all students for full regulations and guidance on the undergraduate programmes in the Department of Materials.

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1. Programme Information

Key dates 2018–19

Term dates
Autumn term: 29 September - 14 December 2018
Spring term: 5 January - 22 March 2019
Summer term: 27 April - 28 June 2019

Closure dates
Christmas/New year: 24 December 2018 – 1 January 2019
(College reopens on 2 January 2019)
Easter holiday: 18 April – 23 April 2019
(College reopens on 24 April 2019)
Early May bank holiday: 6 May 2019
Spring bank holiday: 27 May 2019
Summer bank holiday: 26 August 2019

Year structure

1st year comprises 6 modules: 4 which are primarily lectures courses, 1 which has a significant lab and computer-based component and 1 which is around engineering essential skills. These modules are listed below along with the relative module weighting in the year structure.

MSE 101 Mathematics and computing (19%)
MSE 102 Materials Chemistry and Biology (22%)
MSE 103 Mechanical Behaviour (5%)
MSE 104 Microstructure and Properties of Materials (26%)
MSE 105 Materials Physics (18%)
MSE 106 Materials Engineering (9%)

Progression

Progression criteria for Year 1 are:

- passing every module with a minimum of 40%
- passing the combined coursework from all modules with a minimum of 40%

The combined coursework mark is calculated by summing the module and coursework item weighting.
2. Module Information

MSE 101
Mathematics and Computer Programming

Course Co-ordinator: Prof Andrew Horsfield
Status: First Year Core
Prerequisites: Mathematics to A-level or equivalent

Aims
This course is designed to give students a firm foundation in the aspects of Mathematics and Computing of most relevance to Materials Science and Engineering, especially the topics required in subsequent years of study. The missions of Mathematics and Computer Programming are to provide tools, and sufficient knowledge to use them effectively, for the purpose of understanding and applying the quantitative methods of Materials Science and Engineering. The course content takes into account the broad spectrum of pre-university syllabi.

Learning outcomes
By the end of the course, students should know and understand the following concepts and methods and be able to apply them in solving problems.

Basics (Dr Paul Franklyn)
Fundamental concepts of complex numbers and error analysis.

Vectors (Dr Iain Dunlop)
Vectors as quantities with magnitude and direction; basic rules of vector algebra; basis vectors; Cartesian coordinates as an example of an orthogonal basis; direction cosines. Scalar and vector products: definition; geometric interpretation; applications in science and geometry. The concept of vector area. Triple products. The reciprocal lattice. Equations of lines and planes.

Matrices (Prof A Mostofi)
Basic rules of matrix algebra; simple operations such as transpose and trace; special types of matrix (e.g., orthogonal, symmetric, etc.) and their properties. Suffix notation and Einstein summation convention. Linear transformations: orthogonal matrices as a rotation of basis. Determinants: basic properties; 2x2 and 3x3 cases. Linear equations: homogeneous and inhomogeneous; conditions for solution to exist; solution by Cramer’s rule and by inversion; cofactors and adjoint matrices; inverse of 2x2 and 3x3 matrices; singular matrices. Eigenvectors and eigenvalues: 2x2 and 3x3 matrices; quadratic forms and diagonalisation.

Calculus (Prof Peter Haynes)
Differentiation from first principles; chain, product and quotient rules; higher derivatives; location and characterisation of stationary points; curvature; partial differentiation; definite and indefinite integrals; integration by inspection, partial fractions, substitution and parts; reduction formulae; convergence and divergence of series; power series; Maclaurin series; l'Hôpital's rule.

Data Analysis (Dr Paul Franklyn)
Error analysis. Logarithms, indices and changing base. Simple linear regression; logarithmic scales for power-law and exponential curve fitting; error estimates for coefficients. Stationary points and points of inflection; curve sketching; data plotting. Taylor Series. Newton’s method. Non-linear curve fitting

Complex numbers (Dr P Tangney)
The complex plane; polar representation. De Moivre’s theorem. ln z and exp z. Complex roots of polynomials. hyperbolic functions: definitions; inverse functions; series expansions; relation
to trigonometric functions. Applications of complex numbers to dissipative oscillatory systems. LCR circuits.

**Ordinary differential equations (Prof A Horsfield)**

**Computer Programming (Dr Stefano Angioletti-Uberti)**

**Recommended textbooks**
- **A** = required, **B** = recommended but not essential, **C** = background reading.

**Mathematics**
- **A** Mathematical Methods for Physicists and Engineers, K. F. Riley, M. P. Hobson and S. J. Bence, CUP 2006
- **C** Mathematical Methods in the Physical Sciences, M. Boas, Wiley 2006
- **C** Practical Physics, G. Squires, CUP 2001

**Computer Programming**
- **A** Think Python 1st Edition, by Allen B. Downey

**Structure, teaching and learning methods**

**Mathematics**
- 48 lectures: Autumn and Spring terms
- 9 tutorials: Autumn and Spring terms

**Computer Programming**
- 5 practical classes: Autumn term

**Assessment**

**Mathematics**
- **Examination**
The course is examined in the summer term. The examination paper, duration 3 hours, is in two sections. Section A is compulsory and consists of four short answer questions on all parts of the course. Section B contains four questions of which students must answer three.

- **Coursework**
There are nine tutorials for which students need to prepare answers to problem sets.

- **Tests**
There are two tests that contribute to the overall mark, one at the start of the Spring term (as part of the first year progress test) and one at the start of the Summer term. Each test covers the material taught over the previous term.

**Computer Programming**
- **Marked coursework**
During each lab, students will write short programs aimed at solving a total of three sample problems. These programs should then be finished as a homework assignment and used to answer questionnaires which will be marked and evaluated. Questionnaires will have to be handed in starting from the 3\textsuperscript{rd} lab.
### Staffing

<table>
<thead>
<tr>
<th></th>
<th>Lectures</th>
<th>Tutorials*</th>
<th>Lab sessions</th>
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<tr>
<td>Dr Dunlop</td>
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<td>Prof Mostofi</td>
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<td>Dr Tangney</td>
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* Students will receive 9 tutorials through the year from a mathematics tutor.

### Course Material

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<tr>
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<th>Powerpoint Lectures</th>
<th>Lecture Handouts</th>
<th>Tutorial Sheets</th>
<th>Lab Scripts</th>
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* Students will receive 9 tutorials through the year from a mathematics tutor.
MSE 102
Materials Chemistry and Biology

Course Co-ordinator: Dr Martyn McLachlan
Status: First Year Core
Prerequisites: A-level Chemistry or Introduction to Materials Chemistry

Aims
This course is designed to give students the firm foundation in the fundamentals of Materials Chemistry and Biology required in subsequent years of study and to serve as a valuable self-standing unit. The missions of Materials Chemistry and Biology are to deliver a materials science view of fundamental chemistry concepts, as well as introduce a range of soft matter and polymeric materials. The course content takes into account the broad spectrum of pre-university syllabi.

Learning outcomes

**Chemical and Aqueous Ionic Equilibrium (Dr M McLachlan)**
At the end of this part of the course the student will be able to:

- Define Equilibrium and the concept of dynamic equilibrium
- Understand and calculate equilibrium constants and calculate equilibrium concentrations
- Understand and apply Le Châtelier's principle.
- Define acids and bases; understand dissociation constants and how these relate to strong/weak acids and bases.
- Understand the action of buffers (effectiveness and capacity) and design buffers to operate under given conditions.
- Develop a basic understanding of free-energy and thermodynamics.
- Understand spontaneity and its relationship to rate (chemical kinetics).
- Be able to explain the driving force behind simple chemical reactions.

**Chemical Kinetics and Mass Transport (Dr A Cairns)**

- Be able to distinguish between chemical equilibrium and chemical kinetics and how they relate to one another.
- Understand the activation energy of a chemical reaction and the factors that affect reaction rates.
- Understand the molecular collisions and how molecular velocities affect reaction rates
- Be able to determine reaction orders for chemical reactions and describe complex reaction pathways.
- Be able to solve problems involving reaction kinetics.
- Have an understanding of the driving forces for mass transport in solids and liquids (diffusion, migration, convection).
- Understand different areas in which mass transport is important for materials scientists.
- Be able to describe on an atomic scale the mechanisms of these processes.
- Be able to derive differential equations of mass transport.
- Be able to solve simple practical problems involving diffusion in solids.

**Electrochemistry (Dr S Pedrazzini)**
On successfully completing this course unit, students will be able to:

- Write balanced redox reactions
- Describe the distribution of ions at the solid-electrolyte interface
- Explain the development of a potential difference across an electrode/electrolyte interface
- Derive and use the Nernst equation
- Construct an electrochemical cell to investigate a specified redox reaction
- Relate electrochemical and thermodynamic data
• Explain the three-electrode system employed in dynamic electrochemistry experiments
• Discuss the role of supporting electrolytes in electrochemical studies
• Define the terms reversible and irreversible as applied to electron transfer reactions
• Employ the Butler-Volmer equation
• Determine diffusion coefficients of ions using the Cottrell equation
• Explain the shape of a cyclic voltammogram
• Discuss corrosion simply in terms of electrochemical thermodynamics and kinetics

**Biological Materials (Prof A Porter)**

• To know the basic features of biomaterials: The cell, cell organelles, cell transport mechanisms, structural proteins (silk, collagen, elastin and minerals)
• To describe the function of proteins, to describe the structure of amino acids and the condensation reaction involved in their formation, to understand the difference between simple and conjugated proteins, to describe primary, secondary and tertiary protein structure, to describe the structure of keratin, the α-helix and the β-pleated sheet, to understand protein denaturisation
• To understand the importance of wood as a structural materials and comparison with man-made materials. To know the structure and properties of hardwood and sapwoods.
• To explain mechanisms of biomineralisation in living systems (shells, bone, teeth). How the chemistry, structure, orientation, size, shape and hierarchical assembly of crystalline phases is controlled.
• To understand the structure and mechanical properties of bone, teeth and elastin.
• To know the different common types of materials used in for tissue replacement, to have a basic understanding of joint replacement surgery/ failure mechanisms and the requirements for candidate materials, to know the different fixation methods to the surrounding tissue.

**Soft Matter and Self-Assembly (Dr I Dunlop)**

• Passively and actively make use of terminology in the field of soft matter and self-assembly. Explain the meaning of the terminology.
• Appreciate the principles of the mathematical derivations given in the course, so as to be able to not only reproduce the derivations given, but also apply the same principles to similar situations.
• Solve problems similar to those on the question sheets.
• Explain the principles that underlie the calculations in the course and in problems, and interpret the results of calculations in physically meaningful ways.

**Polymeric Materials (Dr T Georgiou)**

• Be able to differentiate polymer types based on their chemical structure.
• Be able to differentiate polymer types based on their solid state properties.
• Know how to synthesise polymers from their corresponding monomers using addition and condensation reactions.
• Be able to define the glass transition temperature \( T_g \), understand the microscopic processes occurring at \( T_g \), exploit various chemical and physical factors to manipulate \( T_g \) in a polymer and explain different techniques that can be used to determine \( T_g \) (static and dynamic methods).
• Know the various structures adopted by (semi)crystalline polymers and correlate these to the chemical characterisation of the polymers.
• Be able to tailor the structure and properties of polymers using copolymerisation.
• Be able to name typical polymers and their applications.
• Be able to identify which characterisation technique can be used to determine the molar mass and the diameter in solution of the polymer.
• Understand the main challenges in recycling polymeric materials / plastics.

**Recommended textbooks**  
A = required, B = recommended but not essential, C = background reading.
A Basic Chemical Thermodynamics, EB Smith, ICP 2004
Physical Chemistry 10th edition, PW Atkins and J De Paula, OUP 2009

B Electrode Dynamics, AC Fisher, OUP 1996
Electrode Potentials, RG Compton and GHW Sanders, OUP 1996
Biomineralization. S. Mann Oxford UP, 2001
Introduction to Polymers, R. J. Young, Chapman and Hall, 1981

C Electrochemistry, CH Hamann, A Hamnett and W Vielstich, Wiley 1998
Molecular Driving Forces, K A Dill and S Bromberg, Garland Science, 2010 (or earlier edition)

Structure, teaching and learning methods

60 lectures: Autumn, Spring and Summer terms
12 workshops: Autumn, Spring and Summer terms
5 practical classes: Autumn and Spring terms

Assessment

Examination
The course is examined by a 3 hour exam in the summer term. The exam paper consists of Section A all of which is compulsory; and Section B from which 4 questions should be answered.

Coursework
Students are expected to submit a report for each of the laboratories associated with the course:
Iodine Clock; Rheology; Synthesis of Polymers; Gold Nano; Viscosity of Glass; Titration (long lab); and Polymers Processing (long lab).
Tests
Material covered in the Autumn Term will be examined in the Progress Test held in January. The module contributes 140 marks of the 700 for the first year. 100 exams, 10 January diagnostic exam, 10 spring test plus 20 coursework. The pass mark for the module is 40%.

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<td>Dr M McLachlan</td>
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<td>Dr A Cairns</td>
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**MSE 103**
**Materials Engineering - Mechanics**

**Course Co-ordinator: Prof A Horsfield**

**Status: First Year Core**

**Prerequisites: A-level Maths**

**Aims**

This course is designed to give students the firm foundation in the fundamentals of mechanics (statics) required in subsequent years of study and to serve as a valuable self-standing unit.

**Learning outcomes**

After this course students should be able to

- Analyse the forces involved in maintaining bodies in equilibrium
- Apply the methods of joints and of frames for force determination in simple structures and frames
- Understand and use the concepts of elastic stresses and strains and their relationships
- Apply the analysis used for thin wall pressure vessels
- Calculate the shear stresses and displacements developed in cylindrical shafts
- Calculate shear and bending forces, bending moments and elastic deflections developed in beams subjected to loading
- Understand how stress and strain relate to atomic displacement

**Topics**

Resolution of a Force; Static Friction; Principle of Moments; Resultants; Bodies in Equilibrium; Structures; Frames and Machines; Free Body Diagrams; Categories of Equilibrium; Method of Joints; Method of Frames; Internal Forces and Moments; Sign Convention for Bending; Shearing Force and Bending Moment Diagrams; Torsion; Normal Stress; Shear Stress; Thin Wall Pressure Vessels; Normal Strain; Shear Strain; Stress vs Strain; Hooke’s Law; Young’s Modulus; Shear Modulus; Poissons Ratio; Plane Stress; Plain Strain; Torsion of Cylindrical Shaft; Relationships Between Loading, Shear Force and Bending Moment; Pure Bending of Beams; Slope and Deflection; Strain and Displacement. Atomic Description of Stress and Strain.

**Recommended textbooks**


Mechanics of Materials, Riley, Sturges and Morris, Wiley and Sons

The course is primarily based on Benham, Crawford and Armstrong

**Structure, teaching and learning methods**

10 lectures: Summer term
8 classwork sessions: Summer term
Assessment

Examination

The course is examined by two tests in the Spring term. Both tests are 1 hour long. The first test is an online multiple-choice test covering basic concepts, and is worth 13 marks. The second test is written, covers the whole course, and is worth 25 marks.

Coursework

Students are expected to complete the coursework sheets, though they do not contribute to the overall mark. Time is allocated in the timetable and the lecturer is available during these classwork sessions.

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<td>Prof A Horsfield</td>
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MSE 104
Microstructure and Properties of Materials

Course Co-ordinator: Dr M R Wenman
Status: First Year Core
Prerequisites: A Level Maths and Physics; GCSE Combined Science

Aims
To develop an understanding of basic crystallography and how microstructures are developed in materials, the fundamentals of strength and dislocations, and how microstructures are related to properties. To introduce key conceptual tools of Materials Science and Engineering, especially in structural materials.

Learning outcomes

Crystallography (Prof A Walsh)
The course will provide the skills and concepts that are necessary to enable you to relate the spatial distribution of atoms to other materials properties. You will become familiar with the crystal structures of metals, semiconductors, and ceramics, which will be recurrent themes in other courses.

Crystal structures and geometry
- Define a crystal structure in terms of a basis and a lattice.
- Define a unit cell and identify these in a lattice.
- Identify lattice vectors and define cell angles.
- State the names and identity of the 7 lattice systems and 14 Bravais lattices in 3D.
- Determine the Miller index of a plane in a crystal.
- Draw hcp / fcc / bcc lattices and calculate packing fractions.
- Distinguish between substitutional and interstitial solid solutions.
- Knowledge of common non-metallic structure types including NaCl, ZnS and CsCl.
- Ability to apply radius ratio rules to predict crystal structures.

Test 1 (50%) – All work up to this point.

Diffraction and structure determination
- Describe the fundamentals of X-ray diffraction.
- State Bragg’s law.
- Construct systematic absences for simple lattices.
- Knowledge of stereographic projections.
- Explain advantages and limitations of X-ray, electron, and neutron techniques.
- Knowledge of disorder in crystalline solids.

Test 2 (50%) – All work up to this point.

Phase Metallurgy (Prof M Shaffer)
The Aim of the course is to examine how microstructures are formed in metals during solidification and heat treatment. To motivate the course, the mechanical properties of structural materials are introduced. A major focus is the thermodynamics of the formation of phases and the construction of phase diagrams. The steels phase diagram is introduced. At the end of the course, students will have a be able to understand how to construct and use binary phase diagrams, including:
- Stress-Strain Curves and the Tensile Test. Aerospace materials property requirements.
- Basic Structure of Materials; Phases and Crystal Structures. Phase Diagrams.
- Phase Changes, e.g. liquid-solid and latent heat; cooling curves. Phase Diagrams and the lever rule. Interpreting phase diagrams. Continuous solid solutions and eutectics.
- Two phase equilibria; the enthalpy and entropy of mixing; the regular solution model.
- Derivation of phase diagrams using free energy - composition curves.
- Solidification and the Scheil equation. Segregation and homogenisation. Al-Cu.
- The Fe-C phase diagram; martensite; transformation kinetics; TTT diagrams; tempering.

**Glasses, Ceramics and Composites (Prof E Saiz)**
The aim of this course is to describe typical chemical compositions, structures, properties and uses – and their inter-relationships – for simple glasses, ceramics and composite materials. Topics that students will be able to discuss and analyse at the end of the course are:

- Silicates – structures and transformations
- Silica – crystalline, glass and gel
- Silicate-based glasses – fabrication, composition and structure
- Glass ceramics – fabrication and structure
- SiO₂-Al₂O₃ system and porcelains
- Sintering: solid state, liquid state
- Ceramics and glasses: fracture-toughness
- Composite materials – components, structure and stress-strain relationships of fibrous composites

**Strength and Deformation (Dr P J Franklyn)**
The aim of this aspect of the course is to understand the nature of plastic and elastic deformation in crystalline materials. The approach ranges from the scale at the atomic to the macroscopic. At the end of this section, the student will be able to:

- Define the fundamental mechanical response of materials, with particular emphasis on metallic materials (stress/strain, strength, Young’s modulus, Shear modulus).
- Relate applied external stress to internal stress, and the concepts of tension and shear.
- Give a quantitative description of elastic response and theoretical strength using simple atomic models.
- State why the theoretical strength differs from typical experimental data, introducing the concept of dislocations.
- Describe in overview the (structural) defects from 0D to 3D and their relationship to dislocations and strengthening.
- Explain evidence of dislocations (e.g. TEM, modelling).
- Relate a stress-strain curve from a uniaxial tensile test to microscopic phenomena, e.g. dislocation motion, source activation and strengthening mechanisms.
- Characterise dislocation types (edge, screw, mixed), slip plane and define the Burgers vector.
- Characterise a dislocation using a Burgers circuit construction, and define a slip system.
- Resolve applied stress onto a single slip system using Schmid’s law
- Understand the concept and impact of critical resolved shear stress.
- Realise that there is a stress at which dislocation motion occurs (Peierls-Nabarro stress).
- Describe basic strengthening mechanisms (dislocation-dislocation and dislocation-microstructure interactions)
- Describe the mechanism of dislocation multiplication (Frank-Reed source).
- Describe and understand macroscopic effects of these mechanisms with regards to microstructure, e.g. grain size strengthening
- Describe the effect of reduced ductility in some crystal systems, and alternative deformation mechanisms (e.g. twinning in Tin)

**The Metals Life Cycle – From Processing to Performance (Dr M R Wenman)**
The aim of this aspect of the course is to introduce the concept of engineering metallurgy from cradle-grave and how metals properties can be altered by the engineer to give the desired response by manipulation of the microstructure.

- Gibbs energy variation with temperature for a pure metal, describing the melting point and the latent heat of fusion.
- Derive an expression for the free energy change due to nucleation of a solid in a pure metal.
- Describe the difference between homogeneous and heterogeneous nucleation and why homogeneous nucleation is rarely observed.
- Explain why undercooling is usually necessary for solidification.
- Derive an equation for the critical radius and $\Delta G^*$ for homogeneous nucleation.
- Explain why crystals of pure metal have preferred orientations for growth and state what they are for cubic and hexagonal systems.
- Describe the conditions necessary for planar and dendritic growth of a pure metal.
- Describe the solidification of a casting and draw a section through a casting labelling the chill, columnar and equiaxed regions.
- Describe how the mechanical properties of a casting are related to the secondary dendrite arm spacing.
- Describe how the mechanical properties of a casting can be improved by inoculation of a melt.
- List some typical inoculants and what makes a good inoculant.
- Describe the process of cold working and its influence on the microstructure, ductility and tensile strength of a metal.
- Define the terms recovery and recrystallisation with reference to a metal. Understand stored strain energy due to plastic deformation in a deformed piece of metal.
- Calculate the stress/pressure acting on a grain boundary during grain growth and derive the drag force on grain boundaries due to particles.
- Describe with the aid of diagrams the recrystallisation process.
- Describe the polycrystalline state of metals and state the Hall-Petch relationship for grain size.
- Describe why a turbine blade is made as a single crystal.
- Describe and explain the different hardening/strengthening mechanisms used in steel and aluminium-copper alloys.
- Describe why a peak ageing time/temperature exists for aluminium-copper alloys.
- Recap how tensile tests are performed, calculate the 0.2% proof stress, ultimate tensile stress, ductility and where appropriate the upper and lower yield points.
- Explain why some metals exhibit yield phenomena and others do not.
- Calculate the binding energy of a foreign atom to a dislocations elastic field with position.
- Describe both temperature and strain rate effects on yield stress for different metals.
- Describe in basic terms the concept of dynamic strain ageing and why it can be a problem for metal forming operations.
- State Inglis solution for an elastic stress concentration in an infinite plate.
- State the definition of $K_{IC}$ and use the equation to calculate a critical stress or crack length.
- Describe the influence of specimen thickness on fracture toughness.
- Explain why some alloys show a ductile-to-brittle transition.
- Describe the Charpy impact test.
- Describe the phenomenon and micromechanism of fatigue.
- Draw an S-N curve.
- State the Paris equation and use it to calculate the cycles to failure, critical crack length and time to failure of a component.
- Describe factors that affect fatigue life of a component and methods for mitigation.

**Recommended textbooks:** All below are recommended but not essential,

RJ Young. Introduction to Polymers, Chapman and Hall, 1981.

Structure, teaching and learning methods
Autumn and Spring terms:
- 60 lectures
- 10 laboratory sessions
- 8 workshops

Assessment
Examination
The course is examined in the summer term in a single 3 hour examination paper composed of five questions, which will reflect the balance of lectures across the course. Students answer 3 questions from a choice of 4, plus students must complete a compulsory question covering all the topics. Each question is worth 20 marks giving a total of 80 for the paper (scaled to 100).

Progression Test
Tests
Material covered in the Autumn Term (excluding the portions from crystallography) will be examined in the Progress Test held in January. However crystallography is considered as being understood.

Laboratories
The metals labs course runs through the year and help embed basic practical skills and support the lectures. A report is written within one week of each lab, marked and returned. Each report is worth five marks in the year (10 reports in total)

The module contributes 100+10+5x10=160 marks towards the first year in both the BEng and MEng assessment schemes, with a pass mark of 40%.

Staffing
<table>
<thead>
<tr>
<th></th>
<th>Lectures</th>
<th>Tutorials</th>
<th>Lab sessions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prof M Shaffer</td>
<td>10</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Dr P J Franklyn</td>
<td>10</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Prof A Walsh</td>
<td>20</td>
<td>(classwork)</td>
<td></td>
</tr>
<tr>
<td>Dr M Wenman</td>
<td>10</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Prof E Saiz</td>
<td>10</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
# MSE 105
## Materials Physics

### Course Co-ordinator: Prof J Riley

Status: First Year Core  
**Prerequisites: A-level Physics and Mathematics**

### Aims

This course is designed to give students a firm foundation in the fundamentals of Materials Physics required in subsequent years of study and to serve as a valuable self-standing unit. The mission of Materials Physics is to explain the physical origins of materials properties. The course content takes into account the broad spectrum of pre-university syllabi.

### Learning outcomes

#### Statistical Mechanics (Prof J Riley)

This course will introduce the basic concepts that allow Materials Scientists and Engineers to predict whether particular reactions occur. A molecular based approach will be employed throughout. We will start looking at the pressure exerted by an ideal gas and how it is related to the speed of the molecules in the gas. We will then ask the question: why does a gas occupy all the space available to it? A relationship between the multiplicity of a configuration (the number of ways it is possible to achieve a particular arrangement) and it entropy will be presented. Consideration of systems with limited energy will allow us to demonstrate that the units of entropy are J mol$^{-1}$ K$^{-1}$. The Second Law of thermodynamics will then be discussed with consideration of the multiplicity of a system coupled to its surroundings. The Gibbs equation, that relates to entropy change of the system and the heat exchanged to the surrounding, will then be derived. It will be shown that for most chemical systems the heat transferred to the surroundings is given by enthalpy. Finally the equations derived through the course will be employed to predict the progress and the equilibria for some simple processes.

#### Atoms and waves (Dr D Payne)

From this part of the Materials Physics module the students will be able to:

- Understand the wave properties of light and of matter (including x-ray diffraction and spectroscopy).
- Build up a picture of the atomic orbitals needed to understand simple bonding.
- Define penetration and shielding, the building-up principle, atomic parameters, atomic and ionic radii, ionization energy, electron affinity, electronegativity and polarizability.
- Describe the Born-Oppenheimer Approximation, Valence bond (VB) theory, Molecular-orbital (MO) theory, linear combination of atomic orbitals (LCAO).
- Understand ionic bonding including extending heteronuclear MO theory to the bulk and Born-Haber cycles. Define the bulk modulus.
- Describe different types of chemical forces, covalent bonding, ionic bonding, ion-dipole forces, dipole-dipole forces, instantaneous-dipole -- induced-dipole interactions, hydrogen bonding.
- Study covalent solid elements, e.g. carbon (diamond, graphite, graphene), hybridization of MO's l – BeCl$_2$, C$_2$H$_4$.
- Understand conjugation e.g. butadiene, extending the model to forming bands in metals and insulators. Summary of all band structures types.
**Electrical Behaviour (Dr F Xie)**

On successfully completing this section of the course students will:

- Know the definitions of resistance, resistivity, conductivity and mobility. They will understand that conductivity can arise from the motion of free electrons, holes and ions and they will understand the key equation $\sigma = \Sigma nq\mu$.
- Be able to state the main experimentally observed properties of semiconductors.
- Be able to reproduce a simple one-dimensional band theory that includes the Fermi level. They will be able to state the Fermi-Dirac distribution function and to explain the origins of intrinsic conductivity.
- Be able to explain the effects of p and n type doping in silicon and to draw band diagrams that include the position of the Fermi level and the donor and acceptor levels. They will know the law of mass actions.
- Be able to explain the origin of the built-in potential at a p-n junction in terms of carrier diffusion and in terms of the band diagrams. They will be able to explain the current-voltage characteristics of the p-n junction diode.
- Be able to state the main experimentally observed properties of metals.
- Have a basic understanding of the classical and quantum free electron theories of metals and of the concept of wave particle duality.
- Be able to state the electrical properties of the materials at the extreme ends of the conductivity range of materials, namely superconductors and insulators.

**Dielectric and Magnetic Behaviour (Dr A Regoutz)**

On successfully completing this course, students will be able to:

- Understand what is a dielectric material and the parameters such as polarizability, dielectric constant, and dielectric susceptibility.
- Describe the induced dipole moments in dielectric materials and permanent dipole moments in ferroelectric materials.
- Calculate the electric field caused by a single dipole moment as well as by a polarized material.
- Describe the behaviour of a dielectric material in the presence of an external field and the electric field of charges in a dielectric medium.
- Understand the ac response of a dielectric material including the dielectric loss factor.
- Describe the magnetic response of diamagnetic, paramagnetic, and ferromagnetic materials and parameters such as magnetic susceptibility.
- Describe the microscopic origin of magnetism in magnetic materials.
- Explain what is a magnetic dipole moment and calculate the magnetic field from a magnetic dipole moment as well as from a magnetized material.
- Understand the types of magnetic ordering and distinguish between ferro-, ferri-, and antiferromagnetic behaviour.
- Understand the origin of magnetic domains in magnetically ordered systems and describe the development of a B-H loop in terms of the evolution of the magnetic domain structure.

**Introduction to wave and quantum mechanics, applications and molecules (Prof N Klein)**

At the end of this part of the course the student will be able to:

- Understand the concepts of classical mechanics; Newton’s laws, energy, momentum, angular momentum
- Explain the phenomena related to classical waves like running and standing waves, interference, transversal and longitudinal waves
- Describe the different types of sound waves that propagate through gas, solids and liquids
- Explain the spectrum of electromagnetic waves, relation between photon energy, frequency and wavelength, blackbody radiation
- Explain the particle wave dualism and calculate the de Broglie wavelength from the relativistic kinetic energy
• Explain the concepts of quantum mechanics; uncertainty relation, Pauli exclusion principle and Schroedinger equation
• Calculate the eigenstates of a quantum mechanical particle in a box
• Explain the energy levels of the hydrogen atom and the quantum numbers related to the angular momentum
• Explain why the periodic table is constructed as it is, in particular the relationship to the four quantum numbers
• Construct molecular and hybridized orbitals from hydrogen orbitals that describe simple molecules and understand how these lead to band structures.
• Calculate the properties of simple ionic molecules from pair potentials.

**Crystal Defects (Dr A Aguadero)**

From this part of the course students will be able to:

• Define the simple point defects which can form in crystalline lattices
• Use the derived definitions of point defects to define ionic Schottky, Frenkel and anti-Frenkel ionic and electronic intrinsic disorder in materials.
• Describe extrinsic disorder in terms of incorporation of dopants and redox processes in the crystal lattice.
• Calculate the equilibrium concentrations of vacancies at any temperature in an oxide when the enthalpy of vacancy formation is known.
• Describe defects in terms of Kröger-Vink notation, noting the defect type, location and charge, and use this to write defect chemical equations.
• Express the neutrality condition for a material in terms of intrinsic and extrinsic point defect concentrations.
• Solve a defect problem and obtain an algebraic expression for the concentration of defects at any temperature given the intrinsic disorder type and concentration of extrinsic impurities.
• Relate point defects to specific materials properties such as conductivity, diffusivity and colour.

**Recommended textbooks**

A = required, B = recommended but not essential, C = background reading.


   Physics Of Semiconductor Devices, S.M. Sze, John Wiley and Sons,
   Introduction To Solid State Physics, C. Kittel, John Wiley and Sons
   Thermodynamics of Solids, R.A.Swalin, John Wiley (1976)
   Physical Chemistry, 8th Edition, PW Atkins and J de Paula, Oxford 2006, Chapters 1 - 5, 7, 16-17

<table>
<thead>
<tr>
<th>Structure, teaching and learning methods</th>
</tr>
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<tbody>
<tr>
<td>Autumn, Spring and Summer terms:</td>
</tr>
<tr>
<td>60 lectures</td>
</tr>
<tr>
<td>12 Workshops</td>
</tr>
<tr>
<td>5 practical classes</td>
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</table>

<table>
<thead>
<tr>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Examination</td>
</tr>
<tr>
<td>The course is examined in the summer term. The examination paper, duration 3 hours, contains 6 questions of which students must answer 5 questions.</td>
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</table>

<table>
<thead>
<tr>
<th>Progress Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material covered in the Autumn Term will be examined in the Progress Test held in January.</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Laboratories associated with this module:</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEO; B-H Loop; and Crystal Radio and FET (long lab).</td>
</tr>
</tbody>
</table>

| The module contributes 130 marks of the 700 for the first year. 100 for the exam, 10 for the January diagnostic test plus 20 for coursework. The pass mark for the module is 40%. |

<table>
<thead>
<tr>
<th>Staffing</th>
<th>Lectures</th>
<th>Feedback Sessions</th>
<th>Lab Sessions</th>
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<tbody>
<tr>
<td>Prof N Klein</td>
<td>10</td>
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</tr>
<tr>
<td>Dr F Xie</td>
<td>10</td>
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<tr>
<td>Dr A Aguadero</td>
<td>10</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Prof J Riley</td>
<td>10</td>
<td>2</td>
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</tr>
<tr>
<td>Dr D Payne</td>
<td>10</td>
<td>2</td>
<td>2</td>
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<tr>
<td>Dr A Regoutz</td>
<td>10</td>
<td>2</td>
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</table>
3. Assessments

Coursework, tests and laboratory exercises make up the coursework mark that is used in the calculation of the year mark. The tables in this section will help you to be able to plan your study and revision timetable based on the due dates for the various elements. Each of the items here have a corresponding assessment description sheet that is included at the end of the handbook. This also includes a rough rubric for each assessment that can be used to guide the preparation of the item.

**Coursework elements (excluding laboratory exercises)**

<table>
<thead>
<tr>
<th>Module</th>
<th>Due Date</th>
<th>% Contribution to Module</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSE 106: Engineering drawing</td>
<td>Tue 14 May 2019</td>
<td>23%</td>
</tr>
<tr>
<td>MSE 106: Presentation Exercise</td>
<td>Draft</td>
<td>4%</td>
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<tr>
<td></td>
<td>Week 1, Term 3</td>
<td></td>
</tr>
<tr>
<td>MSE 106: Presentation Exercise</td>
<td>Week 3, Term 3</td>
<td>11%</td>
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</tbody>
</table>

**Coursework tests**

<table>
<thead>
<tr>
<th>Module</th>
<th>Due Date</th>
<th>% Contribution to Module</th>
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<tr>
<td>MSE104: Crystallography Test 1</td>
<td>06/11/2018</td>
<td>5%</td>
</tr>
<tr>
<td>MSE104: Crystallography Test 1</td>
<td>13/12/2018</td>
<td>5%</td>
</tr>
<tr>
<td>MSE101/102/104/105: Progress test</td>
<td>07/01/2019</td>
<td>MSE101 (7%); MSE102 (7%); MSE104 (5%); MSE105 (8%)</td>
</tr>
<tr>
<td>MSE 103: Mechanics Test 1</td>
<td>07/02/2019</td>
<td>34%</td>
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<tr>
<td>MSE 103: Mechanics Test 2</td>
<td>12/03/2019</td>
<td>66%</td>
</tr>
<tr>
<td>MSE 106: Solidworks Test</td>
<td>22/03/2019</td>
<td>62%</td>
</tr>
<tr>
<td>MSE101: Maths Progress test</td>
<td>08/05/2019</td>
<td>7%</td>
</tr>
</tbody>
</table>

Your academic performance in the laboratory sessions from autumn term will be used to determine your lab groups for the Spring Term. However your lab group will not affect your personal tutorial group, nor will it affect the afternoon on which you do a lab in the Spring term.
## Autumn term laboratory deadline

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Monday Lab Groups</th>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Thursday Lab Groups</th>
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</table>
### Spring term laboratory deadline

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Monday Lab Groups</th>
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<table>
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<tr>
<th>Experiment</th>
<th>Thursday Lab Groups</th>
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</table>

### Lab module contributions:

<table>
<thead>
<tr>
<th>Module</th>
<th>Experiment name</th>
<th>Wt</th>
<th>Module</th>
<th>Experiment name</th>
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<tbody>
<tr>
<td>MSE.102</td>
<td>Gold nano</td>
<td>3%</td>
<td>MSE.104</td>
<td>Cooling Curve</td>
<td>3%</td>
</tr>
<tr>
<td>MSE.102</td>
<td>Iodine clock</td>
<td>3%</td>
<td>MSE.104</td>
<td>Creep experiment</td>
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<tr>
<td>MSE.102</td>
<td>Polymer processing</td>
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<td>MSE.104</td>
<td>Fracture impact</td>
<td>6%</td>
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<td>MSE.102</td>
<td>Rheology</td>
<td>3%</td>
<td>MSE.104</td>
<td>Glass transition</td>
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<td>MSE.102</td>
<td>Synthesis of polymers</td>
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<td>MSE.104</td>
<td>Metallography</td>
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<td>MSE.102</td>
<td>Titration</td>
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<td>MSE.104</td>
<td>Steels</td>
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<tr>
<td>MSE.102</td>
<td>Viscosity of glass</td>
<td>3%</td>
<td>MSE.104</td>
<td>Tensile 1&amp;2</td>
<td>3%</td>
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<tr>
<td>MSE.104</td>
<td>Brass Rolling</td>
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<td>MSE.105</td>
<td>B-H loop</td>
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<td>MSE.104</td>
<td>Bubble raft experiment</td>
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<td>MSE.105</td>
<td>Crystal radio set experiment</td>
<td>7%</td>
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<tr>
<td>MSE.104</td>
<td>Casting and Heat treatment</td>
<td>3%</td>
<td>MSE.105</td>
<td>PEO</td>
<td>5%</td>
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</table>
4. Assessment forms and rubrics

Individual Coursework Information form

<table>
<thead>
<tr>
<th>Module code</th>
<th>MSE 106</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year of Study</td>
<td>1st Year</td>
</tr>
<tr>
<td>Assignment Name</td>
<td>MSE 106: Engineering drawing</td>
</tr>
<tr>
<td>Academic in Charge</td>
<td>Prof Andrew Horsfield</td>
</tr>
<tr>
<td>Marker</td>
<td>Xin Wang and Russell Stracey</td>
</tr>
<tr>
<td>Assignment presented to the students</td>
<td>Week 1 of Term 3</td>
</tr>
<tr>
<td>Method of submission</td>
<td>Hard copy</td>
</tr>
<tr>
<td>Student’s self-study hours</td>
<td>9 hours of self-study required</td>
</tr>
<tr>
<td>Deadline date</td>
<td>Tuesday 14th May 2019 9am</td>
</tr>
</tbody>
</table>

Assignment details

Engineering drawing coursework consists of three exercises:

a) Sketching: produce a free-hand sketch of an object or a component which students can choose from science museum or everyday life.

b) Engineering (projection) drawing: produce projection drawing (i.e., elevation, plan and end view) and dimensioning of the object which has been chosen for sketching exercise.

c) 3D reconstruction: produce 3D pictorial view of two objects based on the engineering drawings provided.

Other requirements

Please put your full name and CID on the front page.

For exercise a) one A4 page, pencil and eraser are needed but no ruler or compass.

For exercise b) one A4 or A3 page, pencil, eraser, ruler and compass are all necessary.

For exercise b) two A4 pages, pencil, eraser, ruler and compass are all necessary.

Guide Rubric:

The engineering drawing coursework consists of three exercises:

1) Sketching: produce a free-hand sketch of an object or a component which students can choose from science museum or everyday life. This should be one A4 page. A pencil and eraser are needed but no ruler or compass.

Marking will be based on: a) quality of the sketch 60% (accuracy 30%, neatness 15% and clarity 15%); b) complexity of the chosen object 40%.

2) Engineering (projection) drawing: produce projection drawing (i.e., elevation, plan and end view) and dimensioning of the object which has been chosen for sketching exercise. This should be one A4 or A3 page. A pencil, eraser, ruler and compass are all necessary.

Marking will be based on: a) complexity of the object 20%; b) Quality and accuracy of projection drawing (elevation view plus plan view and/or end view) 50%; c) dimensioning 20%; d) understanding and indication of used projection system in the drawing 10%.

3) 3D reconstruction: produce 3D pictorial view of two objects based on the engineering drawings provided. This should be two A4 pages. A pencil, eraser, ruler and compass are all necessary.

Marking will be based on: a) correctness and consistency of the projection used in the drawing 20%; b) accuracy of the drawing (including the consistency of scale used) 50%; c) neatness and clarity 30%.
Individual Coursework Information form

<table>
<thead>
<tr>
<th>Module code</th>
<th>MSE 106</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year of Study</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Year</td>
</tr>
<tr>
<td>Assignment Name</td>
<td>MSE 106: Presentation exercise</td>
</tr>
<tr>
<td>Academic in Charge</td>
<td>Dr Paul Franklyn</td>
</tr>
<tr>
<td>Marker</td>
<td>Personal tutors</td>
</tr>
<tr>
<td>Assignment presented to the students</td>
<td>At the beginning of Spring term</td>
</tr>
<tr>
<td>Method of submission</td>
<td>Presentation in tutor group</td>
</tr>
<tr>
<td>Student’s self-study hours</td>
<td>5-10 hours of self-study required</td>
</tr>
<tr>
<td>Deadline date</td>
<td>Draft: 1&lt;sup&gt;st&lt;/sup&gt; week of Summer term&lt;br&gt;Presentation 3&lt;sup&gt;rd&lt;/sup&gt; week of Summer term</td>
</tr>
</tbody>
</table>

Assignment details

You are required to prepare and deliver a presentation to your tutor group during the summer term – your tutor will award a mark based on your performance. Your tutor will ask each of you to prepare a short, 10-minute presentation using PowerPoint.

Your tutor will prepare or help refer you to articles from science magazines of significant discoveries. You will be asked to pick one. You are to present a 10-minute talk to the group on the topic as if you are the scientist who just made the discovery, re-enacting presenting this research as if for the first time.

Other requirements

The presentation is to last no more than 10 minutes.

Recommended Marking Rubric

<table>
<thead>
<tr>
<th>Item \ score</th>
<th>0-1</th>
<th>1-3</th>
<th>3-5</th>
<th>5-8</th>
<th>8-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality of draft</td>
<td>No draft submitted</td>
<td>Poor effort, a few slides put together without thought</td>
<td>Fair effort. Slides not well prepared or thought through</td>
<td>Good effort. Slides well put together. Several corrections required</td>
<td>Excellent. Very few corrections.</td>
</tr>
<tr>
<td>Quality of final presentation</td>
<td>Not done</td>
<td>Poor, changes from draft not effected</td>
<td>Fair effort, some changes effected, overall still poor though</td>
<td>Good effort. Slides well formatted. Most corrected effected</td>
<td>Excellent. All corrections effected. Well assembled</td>
</tr>
<tr>
<td>Content</td>
<td>Not done / lacking</td>
<td>Poor effort, did not interpret the paper</td>
<td>Fair effort, some of the main points included from the paper, but off target</td>
<td>Good effort, most of the points included, mostly on target. Some superfluous information</td>
<td>Excellent, all key points included. Well summarised. On target to the point of the paper.</td>
</tr>
<tr>
<td>Presentation skills</td>
<td>Not done</td>
<td>Poor, read/mumbled. Poor body language</td>
<td>Fair effort. Needs work to gain skills of presenting.</td>
<td>Good effort. Generally well presented. Good body language.</td>
<td>Excellent. Confident and clear in presentation</td>
</tr>
</tbody>
</table>