DEPARTMENT OF
ENGINEERING SCIENCE

First Year Syllabus

Work is mostly arranged around the syllabus for four written papers of the Preliminary Examination, held in June:

- P1 Mathematics
- P2 Electronic and Information Engineering
- P3 Structures and Mechanics
- P4 Energy

There are 36 lectures for each paper, supported by one example sheet of about ten tutorial problems for every four (or thereabouts) lectures.

There is a fifth 'paper', P5, consisting of assessment of coursework during the year which is considered to be equivalent to half of a three hour written paper. In 2017-2018 the hours required for each laboratory are:

Drawing and Design	10 hours
Workshop Practice	2 hours
Computing Laboratory	25 hours
Mechanical Laboratory	25 hours
Electrical Laboratory	25 hours
Thermodynamics Laboratory	5 hours

For the Preliminary Examination, the possible outcomes are Pass, Pass with Distinction, pass in less than five papers or Fail. Those who fail some of the written papers may, if their college permits, retake them in September. Candidates must offer all subjects at one examination provided that: (i) a candidate who fails in one or two written papers may offer those written subjects at one subsequent examination; (ii) a candidate who fails three or four written papers must offer all four written subjects at one subsequent examination. The coursework for paper P5 may not be retaken, so failure in it will normally constitute failure of the examination.

Accreditation: Principles of sustainability

The MEng degree in Engineering Science is accredited by the Professional Engineering Institutions; the first step towards full membership of one of the intuitions and Engineering Chartership. The course has been designed to achieve certain thresholds of knowledge and standards of learning across key areas that satisfy the criteria set out by the accrediting institutions; including acquiring the knowledge and ability to handle broader implications of work as a professional engineer. It is especially important that the principles of sustainability (environmental, social and economic) are embedded in the teaching and learning throughout the course in lectures, tutorials, laboratories and project work; in the first year, paper P4 and the Design Build and Test exercises (P5) include principles of sustainability.

Paper P1: Mathematics

p101: Calculus 1; Matric 2021, Y 1; Paper P1: 4 Lectures, 1 Tutorial Sheet

The function concept. Definition and simple properties of elementary functions. Differentiation of a product, quotient and function of a function. Elementary integration, including substitutions, integration by parts, partial fractions, tan half-angle, recursive formulae.

Elementary series: sum to n terms of linear and geometric series, and the concept of a limit. Maclaurin and Taylor expansions in one variable and their use for linearization of elementary functions. The error term. de l'Hopital's theorem.

Learning Outcomes:

1. Understand the concept of a function.
2. Work with and understand circular and hyperbolic trig functions.
3. Differentiate products and quotients of functions, including the use of Leibnitz's rule.
4. Perform integration by parts, using substitutions, partial fractions and recursive formulae.
5. Work with simple series, and be able to define and test their convergence properties.
6. Expand functions using McLaurin and Taylor series.
7. Understand the concept of a limit and be able to use de l'Hopital's theorem to obtain limits where appropriate.

p102: Calculus 2; Matric 2021, Y 1; Paper P1: 4 Lectures, 1 Tutorial Sheet

Partial differentiation: the chain rule and simple transformations of first-order partial differential coefficients. Multiple integrals and their evaluation, with applications to finding areas, volumes, masses, centroids, inertias etc. (excluding line and surface integrals and using Cartesian, cylindrical and spherical coordinate systems only).

Vector functions: differentiation of a vector function: gradient, divergence and curl – definitions and physical interpretations; product formulae. Description of space curves, Frenet-Serret relationships.

Learning Outcomes:

1. Be familiar with the basic operations of calculus of functions of several variables.
2. Understand and perform partial differentiation on a function of multiple variables, using the chain rule and including composite and implicit functions.
3. Understand the concept of a Jacobian and its use.
4. Understand and evaluate multiple integrals and use this to calculate relevant physical quantities.
5. To be able to differentiate vector expressions given in fixed and changing coordinate systems.

6. To appreciate the significance of the position vector and its differential in defining space curves; and to be able to use the position vector to establish definitions of, and relationships between, curve tangents, normals, and binormals.
7. To understand how to define elements of displacement, surface, and volume using vector methods, and to set up and evaluate line and surface integrals.
8. To appreciate the physical significance of the differential vector operators grad, div, and curl, and to be able to define and manipulate these in Cartesian coordinates.

<u>P103: Linear Algebra and Complex Algebra: Matric 2021, Y 1, Paper P1: 8 Lectures, 2 Tutorial Sheets</u>

Rudiments of vector algebra including dot and cross product, geometrical applications. Addition, multiplication and inversion of matrices. Determinant and trace of matrices. Axes and linear transformations. Orthogonal matrices. Properties of rotation matrices. Solution of simultaneous equations using matrices (Gaussian elimination and LU decomposition).

Eigenvalues and eigenvectors of real symmetric matrices. Concept of orthogonality of eigenvectors. Expansion of an arbitrary vector in eigenvectors.

Complex Algebra: Definition of i, complex arithmetic and the Argand plane, polynomials of the complex variable with real coefficients. The complex exponential, nth-roots of complex numbers. Elementary functions of complex variables. Loci in the complex plane. Differentiation and integration of complex functions. Phasors.

<u>p104 Ordinary Differential Equations 1; Matric 2021, Y 1; Paper P1: 8 Lectures, 2 Tutorial Sheets</u>

Homogeneous and non-homogeneous equations. Principle of superposition for linear ODEs. Complementary function and particular integral. The auxiliary equation: distinct and repeated roots. Finding particular integrals for forcing functions which are constants, polynomials, and exponentials. Special cases. Full treatment of second-order ODEs: Damping ratio and natural frequency, poles and zeros. Elementary simultaneous ODEs. Sinusoidal forcing functions and the use of the complex exponential. Frequency response functions.

Definition of Fourier series (including the complex form), orthogonality, Fourier series of basic waveforms (square, saw-tooth, finite pulse train). Fourier series of odd and even functions, implications of half-wave symmetry. Parseval's theorem. Use of Fourier series in solving ODEs.

Learning outcomes:

1. Be able to solve first-order linear ODEs using separation of variables, the exact-differential method, the integrating-factor method.
2. Understand the terms `complementary function' and `particular integral' in the context of linear ODEs.
3. Be able to find the complementary function for linear, second-order ODEs with constant coefficients

4. Be able to find particular integrals for linear, second-order ODEs with constant coefficients via the method of undetermined coefficients.
5. Understand how the mathematical terms `complementary function' and `particular integral' relate to the transient and steady-state responses of a system.
6. Understand how the nature of the transient response of a second-order system is related to the locations of the roots of the characteristic equation in the Argand diagram.
7. Be able to solve elementary simultaneous ODEs by uncoupling them via matrix diagonalisation.
8. Understand the concept of `frequency-response function' and be able to use it to find the steady-state response of a system.
9. Be able to calculate Fourier coefficients for periodic functions.
10. Understand how to obtain Fourier series steady-state solutions to linear ODEs for periodic forcing functions
11. Be able to apply the methods described above to mechanical and electrical systems.

<u>p105: Ordinary Differential Equations 2: Matric 2021, Y 1; Paper P1: 8 Lectures, 2 Tutorial Sheets</u>

Definition of the Laplace transform: transforms of elementary functions and derivatives. Transfer functions. Solving ODEs by Laplace transforms. Inverse Laplace transform by partial fractions and by using tables. Shifting in time. The Heaviside step function and the Dirac delta function. The concept of a transfer function.

Application of transfer functions: modelling of the physics of mechanical, electro-mechanical, thermal and fluid systems mathematically in terms of ordinary differential equations. Linearization. Block diagram representations and manipulation of block diagrams to simplify systems.

Learning Outcomes:

1. Understand the definition of the Laplace transform and be able to find the Laplace transform of simple functions by direct integration.
2. Know (or be able to find in HLT) the Laplace transforms of common functions and the properties of Laplace transforms.
3. Find inverse Laplace transforms by using tables of Laplace transforms in conjunction with (where necessary) partial fractions and the shift theorems on the s and time axes.
4. Solve ordinary differential equations with initial conditions using the Laplace transform method.
5. Solve simultaneous differential equations using the Laplace transform method.
6. Be aware of the concept of Laplace transform transfer function.
7. Be aware of the significance of the terms ‘poles’ and ‘zeros’ of a transfer function.
8. Apply the methods described above to mechanical systems involving mass, spring and damper elements, and to electrical systems involving resistance, capacitance and inductance components.

9. Generate mathematical models of simple Mechanical, Electro-Mechanical, Fluid and Thermal Systems.
10. Understand how the mathematical models of systems are related to the underlying physics.
11. Understand the meaning of state and how this concept leads to a block diagram representation of a system.
12. Develop simple linear differential equations that approximate the behaviour of the models of the above systems.
13. Derive a transfer function of a simple linear approximate model of a system through simplification of a block diagram model.
14. Describe the likely step response of a system model based on its poles and zeros.

Paper P2: Electronic and Information Engineering

<u>p201: Components and Circuits 1; Matric 2021, Y 1; Paper P2: 8 Lectures, 2 Tutorial Sheets</u>

Charge conservation, Kirchhoff's laws, mesh/nodal analysis. Concepts of ideal voltage and current sources, and resistances. Thevenin and Norton theorems with emphasis on concepts of input and output impedances.

Learning Outcomes:

1. Appreciate the origins of current, voltage, resistivity and power dissipation.
2. Be familiar with Ohm’s law and voltage and current sources, and their wider significance.
3. Develop basic skills in circuit analysis and its relationship with Ohm’s law.
4. Appreciate the significance and utility of Kirchhoff’s laws.
5. Become confident in applying Kirchhoff’s laws to simple circuit analysis.
6. Understand and apply nodal analysis and mesh analysis techniques.
7. Appreciate the importance of Thevenin and Norton equivalent circuits and the concepts of input and output impedance.
8. Understand and apply the principle of superposition of sources in linear circuits.
9. Become familiar with non-vector formulations of Gauss’s Law and its application to capacitors.
10. Become familiar with non-vector formulations of Ampere’s Law and its application to inductors.
11. Apply the differential and integral forms of capacitor and inductor I-V equations.
12. Observe that capacitors and inductors are energy storage elements and lead to time-varying behaviour of circuits.
13. Derive time-domain descriptions of first-order circuits and observe their characteristic behaviour.
14. Draw a distinction between transient and steady-state operation of circuits containing inductors and capacitors.

<u>p202: Components and Circuits 2; Matric 2021, Y 1; Paper P2: 8 Lectures, 2 Tutorial Sheet</u>

Gauss’s Law. Electric field D, E, ε, potential V, capacitance, stored energy. Magnetism, flux, flux density, flux over a closed surface = 0. Ampere’s law, calculating magnetic fields, fields around conductors. Inductance, stored energy.

Frequency response of a.c. networks including Bode diagrams, second-order and resonant circuits, damping and Q factors. Laplace transform methods for transient circuit analysis with zero initial conditions. Impulse and step responses of second-order network and resonant circuits.

Learning Outcomes:

1. Be familiar with current/voltage relationships for capacitors and inductors.
2. Appreciate the significance of the complex impedance of passive components (resistors, capacitors, inductors) and their limits at low and high frequencies.
3. Understand the concept and the use of phasor methods in the analysis of simple AC circuits.
4. Appreciate the significance and utility of Kirchhoff's laws in AC circuits.
5. Be familiar with use of phasors in node-voltage and loop analysis of AC circuits.
6. Be familiar with the use of phasors in deriving Thevenin and Norton equivalents for AC circuits.
7. Be familiar with the concept of super-position in AC circuits.
8. Understand impedance and power dissipation in AC circuits.
9. Be familiar with methods of describing the frequency response of AC circuits.
10. Be familiar with the Argand (polar) diagram and Bode diagram methods.
11. Understand these for key passive circuits such as low-pass and high-pass filters (first order passive circuits).
12. Be familiar with second order passive circuits and resonance phenomena in electrical circuits, and be able to plot their Bode diagrams.
13. Appreciate the significance of the Q factor and damping factor.
14. Appreciate the importance of the transient response of electrical circuits.
15. Be familiar with the use of Laplace transforms in the analysis of the transient response of electrical networks.
16. Be familiar with Laplace methods for first order and second order systems.
17. Appreciate the relationship between the use of Laplace transform and phasor techniques in circuit analysis.
18. Appreciate the significance of coupling between inductors and mutual inductance.
19. Understand the behaviour of simple circuits involving coupled inductors.

<u>p203: Digital Electronics; Matric 2021, Y 1; Paper P2: 8 Lectures, 2 Tutorial Sheets</u>

Basic gates, truth tables, combinational functions (AND, OR, NOT, EX-OR). The MOSFET as a switch; CMOS inverter, NOR and NAND gates. Boolean algebra, Karnaugh maps; Binary arithmetic: adders, subtractors Multiplexers, ROMs and PLAs.D-type flip-flops, registers, asynchronous counters.Synchronous counters, Karnaugh transition maps. Basics of finite state machines. Basic principles of Digital to Analogue conversion and Analogue to Digital conversion.

<u>Learning Outcomes:</u>

1. Understand representation of numbers in binary, twos complement arithmetic and relevance to digital logic systems.
2. Work with truth tables to design and understand logic circuits for MOSFET and gate systems using Karnaugh maps and Boolean Algebra.
3. Be able to design a minimal logic to implement arbitrary truth tables using MOSFETS or Gates.

4. Implement binary arithmetic functions using combinations of gates.
5. Use ROMs and PLAs to implement logic functions of arbitrary complexity.
6. Understand and use registers for data storage, and the concept of synchronous vs asynchronous logic.
7. Understand and use the state-next state method and steering tables for sequential logic design to design sequencers using D-flip flops.
8. Understand and design simple finite state machines.
9. Understand the principles of Digital to Analogue conversion and Analogue to Digital conversion.

<u>P204: Active Circuits and Devices; Matric 2021, Y 1: Paper P2: 12 Lectures, 3 Tutorial Sheets</u>

Active Circuits and Devices 1
Electrical conduction in semiconductors, PN junctions. Diodes, rectification. Junction Field Effect Transistors.

Active Circuits and Devices 2
Incremental models and equivalent circuits including calculation of parameters from simple models. Single transistor circuits as switches, amplifiers and buffers. Calculation of voltage and current gain, input and output impedances.

Active Circuits and Devices 3
Characteristics of an ideal op-amp. Inverting and non-inverting op-amp configurations including voltage follower. Summing and differential amplifiers. A.C. response of ideal op-amp circuits. Op-amp filter circuits. Comparators.

Learning Outcomes:

1. Be familiar with electron and hole charge carriers in semiconductor materials.
2. Understand the origin of electrical conduction in semiconductors and how this can be influenced by doping.
3. Appreciate the band theory of solids.
4. Be familiar with the equilibrium electrical properties of semiconductor p-n junctions and the effect of the application of a bias voltage.
5. Appreciate the use of the pn-junction as a variable capacitor (varactor diode).
6. Describe the effects of light absorption at a p-n junction diode and familiarity with two optoelectronic devices, the solar cell and optical detector.
7. Be familiar with the uses of electrical diodes.
8. Understand the concept and use of load lines.
9. Understand the junction -field effect transistor (JFET) and be familiar with single FETs as switches.
10. Appreciate the need for biasing JFETs, methods of biasing and JFET equivalent circuits.
11. Be familiar with the use of JFETs as voltage and buffer amplifiers.
12. Be able to calculate the voltage gain and input and output impedances of such amplifiers.
13. Understand the characteristics of an ideal op-amp and the importance and difference between the two op-amp inputs.
14. Be able to explain the use of an op-amp as a voltage follower buffer.

15. Application of nodal analysis on circuits containing ideal op-amps, including amplifiers and filters.
16. Understand the features of two of simple amplifiers and comparator circuits.
17. A familiarity of the different types of filters and the benefits of active filter circuits.
18. Be able to calculate the component values needed to obtain a required filter response.

Paper P3: Structures and Mechanics

<u>p301: Bending and Torsion; Matric 2021, Y 1; Paper P3: 8 Lectures, 2 Tutorial Sheets</u>

Shear force and bending moment diagrams. Elastic bending stresses and deflections. Properties of sections: neutral axis, second moment of area. Use of standard solutions and symmetry. Analysis of simple redundant beams. Elementary elastic torsion.

Learning Outcomes:

1. Ability to solve structural problems using the appropriate combination of equilibrium, compatibility, and material properties.
2. Understanding of the importance of both strength (i.e. limiting the maximum stresses) and stiffness (i.e. limiting the deformations) in structural analysis and design.
3. Understanding of the concept of internal forces in structures and ability to use free-body diagrams to find internal forces.
4. Ability to calculate and sketch shear force and bending moment diagrams and to relate these to the deflected shapes of beams.
5. Ability to calculate bending properties of symmetric cross-sections and to choose optimal section shapes to resist bending loads.
6. Understanding of the governing equation for bending of symmetric beams and ability to use this in calculations.
7. Ability to calculate bending stresses and deflections.
8. Familiarity with the use of short-cuts (e.g. data-book solutions for standard cases, symmetry, superposition) to obtain the quickest solution to beam problems.
9. Understanding of the principle of superposition and ability to apply it to beam calculations.
10. Familiarity with the similarities between the analysis methods for torsion and bending.

<u>p302: Dynamics; Matric 2021, Y 1; Paper P3: 8 Lectures, 2 Tutorial Sheets</u>

Plane kinematics of particles: rectilinear and curvilinear motion in rectangular, normal-tangential, and polar coordinates; relative motion (translating, not rotating, axes). Plane kinematics of rigid bodies: translation, rotation, and general plane motion; relative motion; rotation about a fixed axis. Dynamics of particles: Newton’s second law; work, energy, power; impulse and momentum (linear and angular); conservation of energy and momentum (linear and angular); impact; central-force motion. Dynamics of rigid bodies: equations of motion for translation and fixed-axis rotation; moment of inertia; work and energy; impulse and momentum (linear and angular). Simple variable mass problems, i.e. rockets.

Learning Outcomes:

1. Express motion of particles (displacement, velocity, acceleration) in Cartesian or plane polar coordinates
2. Solve particle dynamics problems using Newton's 2^{nd} Law, impulse-momentum relations or energy conservation
3. Understand that all these formulations, familiar in translational motion, have an equivalent form for rotational motion
4. Recognize situations in which energy is or is not conserved
5. Use momentum flux to determine rocket thrusts etc
6. Understand the concept of moment of momentum
7. Analyze simple elliptical and circular satellite orbits
8. Describe the motion of rigid bodies that are rotating about a fixed axis or rolling along a surface
9. Calculate moments of inertia for simple geometric shapes
10. Solve 2D rigid body mechanics problems using Newton's 2^{nd} Law, impulse-momentum relations and kinetic energy

<u>p303: Materials and Solid Mechanics; Matric 2021, Y 1; Paper P3: 12 Lectures, 3 Tutorial Sheets</u>

Classes of materials (e.g. metals, polymers, ceramics, glasses and composites): engineering properties and selection of materials for engineering applications. Elastic properties and their relation to interatomic bonding and structure. Crystalline and amorphous materials. Stress and strain under multi-axial loading. Hooke's law in 3D. Plane stress and plane strain. Transformation of stress and strain – Mohr's circle. Relationship between elastic constants for isotropic materials. Yield stress, yield as a shear phenomenon. Microscopic aspects of yield: theoretical yield stress and dislocations. Tresca yield criterion under multi-axial loading. Post yield behaviour under uniaxial loading: True stress and natural strain. Plastic instability and tensile strength. Griffith Theory of fracture. Materials selection on the basis of weight, stiffness, strength, toughness, and cost.

Learning Outcomes:

1. Have an appreciation of the different classes of engineering materials and typical properties for each class.
2. Understand the origins of atomic bonding.
3. Understand the differences between ionic, covalent, metallic, hydrogen and van der Waals bonds.
4. Be able to determine the stiffness and strength of a bond from a knowledge of the interatomic potential.
5. Understand the different ways that atoms can pack together to form a solid body and the difference between crystalline and amorphous materials.
6. Know the difference between body centred cubic, face centred cubic and hexagonal close packed crystalline structures.
7. Understand the different ways that monomer units can be combined to form a polymer and the difference between thermoplastics, thermosets and elastomers.
8. Understand the importance of the glass transition temperature in determining the engineering properties of polymers and glasses.

9. Understand the relationship between bond stiffness, atomic packing and Young's modulus.
10. Understand how Young's modulus and density can be changed by forming a composite, foam, lattice material or hybrid structure.
11. Be able to construct merit indices for simple design situations and use material selection charts to select a material for an engineering application.
12. Know Hooke's law under general multiaxial stress states for isotropic materials.
13. Understand the relationship between Young's modulus, shear modulus, bulk modulus and Poisson's ratio for an isotropic material.
14. Be able to use Mohr's circle to transform stresses and strains in 2D and determine the principal stresses (strains) and maximum shear stress (strain).
15. Be able to determine the components of strain at the surface of a component using strain gauge rosettes.
16. Understand how the motion of dislocations results in the plastic deformation of crystalline materials.

p304: Statics; Matric 2021, Y 1; Paper P3: 8 Lectures, 2 Tutorial Sheets

Equilibrium of force systems. Internal and external forces. Forces in pin-jointed frames. Method of sections. Method of joints. Equilibrium matrix methods. Cables and arches. Stresses in thin walled cylindrical and spherical shells. One-dimensional stress and strain. Displacements of simple pin-jointed frames. Simple redundant systems.

Learning Outcomes:

1. Have a good grasp of the principles of equilibrium, which are fundamental to the understanding of all mechanical problems.
2. Appreciate the importance of sign conventions.
3. Be familiar with the concepts of force, moment and reaction.
4. Know the difference between internal and external forces.
5. Appreciate how to idealise external loading and support conditions.
6. Be able to draw free-body diagrams.
7. Be able to calculate forces in simple planar assemblies.
8. Be able to classify frameworks as statically determinate, indeterminate or mechanisms.
9. Be able to determine forces in statically determinate pin-jointed frames.
10. Be familiar with some simple analysis methods for cables and arches.
11. Understand the concepts of one-dimensional stress and strain.
12. Be able to determine the stresses in thin walled cylindrical and spherical shells.
13. Understand and be able to use the principle of displacement compatibility.
14. Be able to draw displacement diagrams to calculate deflections of simple pin-jointed frames.

Paper P4: Energy

p401: Heat and Mass Transfer; Matric 2021, Y 1; Paper P4: 6 Lectures, 2 Tutorial Sheets

Overview of heat transfer mechanisms. Conduction in solids. Convection in laminar and turbulent flows. Determination of heat transfer coefficients. Thermal radiation. Mass diffusion and Fick's law. Mass transfer coefficients. Analogies between heat, mass and momentum transfer. Correlations for convection of heat and mass using dimensional analysis.

Learning Outcomes:

1. Ability to solve one dimensional conduction problems.
2. Familiarity with thermal to electrical analogue.
3. Understanding of convection processes.
4. Correlations for dimensionless heat transfer coefficients.
5. Understanding of the basis of thermal radiation and application of Stefan Boltzmann's equation and view factors.
6. Ability to solve mass transfer forced convection problems.
7. Prediction of osmotic pressure from Morse equation.

p402: Fluid Mechanics; Matric 2021, Y 1; Paper P4: 14 Lectures, 3 Tutorial Sheets

Hydrostatics, forces on immersed bodies. Stationary control volumes, continuity, momentum, Euler equations, streamline analysis in steady flow. Conservation of energy and application of Bernoulli's equation in simple inviscid incompressible flows. Introduction to stream functions.

Definition of viscosity. Simple laminar Couette and Poiseuille flow. Introduction to boundary layers, laminar and turbulent flow. Characterising flow through Reynolds number. Loss of total pressure in pipe flows. The integral momentum equation, displacement and momentum thickness. Friction and form drag; flow separation.

Learning Outcomes:

This course will enable the students to understand the basics of viscous and inviscid flow, and apply a series of analysis procedures to solve a range of problems. The difference between laminar and turbulent flow should be understood and the application of control volume analysis and the open system version of Newton's second law of motion demonstrated.

p403: Thermodynamics; Matric 2021, Y 1; Paper P4: 12 Lectures, 3 Tutorial Sheets

Compressibility, temperature coefficient of expansion, specific heat, conductivity, viscosity, diffusion. One-dimensional heat conduction, use of heat transfer coefficients. Properties of ideal gases. Properties of mixtures. Use of tabulated data for steam and other fluids involving liquid and vapour phases. Properties of real gases.

Basic concepts and terminology of thermodynamics. Heat, work and the First law. Definition of internal energy. Applications and examples. First law applied to open systems. Definition of enthalpy, mass and energy balance. Chemical balance equations, examples to include combustion and fuel production (e.g. biodiesel and bioethanol). Formal definitions of imep, bmep, volumetric efficiency; the effect of AFR in SI engines on efficiency and bmep.

Simple cycle analysis to cover Rankine, Joule, Otto and Diesel cycles.

Learning Outcomes:

1. Have a good understanding of the meaning of the common physical properties used to describe solids, liquids and gases.
2. Appreciate the importance of correct units.
3. Be familiar with the process of heat conduction and understand the use of heat transfer coefficients.
4. Know the ideal gas law and understand how real gases differ from this behaviour and be able to use the compressibility diagram.
5. Understand how to analyse mixtures of gases.
6. Be familiar with the use of steam tables and other tabulated information about liquid-vapour states of other substances.
7. Understand the concepts of heat, work and internal energy and the first law of thermodynamics.
8. Appreciate the importance of sign convention.
9. Understand the concept of systems and control volumes.
10. Be able to apply the first law to closed systems and simple open systems (with steady flow and unsteady flow).
11. Understand the definition of enthalpy.
12. Be able to perform enthalpy, mass and energy balances.
13. Be able to balance chemical equations.
14. Understand the application of chemical balance equations to combustion and fuel production processes.
15. Be able to analyse combustion and fuel production processes.

<u>p404: Dimensional Analysis; Matric 2021, Y 1; Paper P4: 4 Lectures, 1 Tutorial Sheet</u>

Dimensional homogeneity, dimensional parameters, dimensional analysis of governing equations, geometric and dynamic similarity, Buckingham pi theorem, worked examples in energy systems, limitations of dimensional analysis.

Learning Outcomes:

1. Determine the dimension of engineering variables.
2. Be able to explain the benefits of dimensional analysis in experimental testing.
3. Be familiar with the dimensionless groups relevant to heat transfer and fluid mechanics.
4. Be able to describe the role and benefits of dimensional analysis in engineering design.
5. Be able to apply the Buckingham p theorem to determine the relevant dimensionless parameters for engineering problems.
6. Understand the concept of similitude and apply it to design of experiments with scaled models and prototypes.
7. Be able to transform the dimensional governing equations to their dimensionless form and apply the dimensionless equation to problems.

P5: Laboratory Coursework

p501: Computing Laboratory: Matric 2021, Y1: 5 Labs

The objective of the Laboratory is to give students the programming skills and computer competence they will need as an engineer.

The course consists of five 5 hour laboratories and 4 lectures spread throughout the academic year.

Learning Outcomes:

By the end of the course, students should be able to:

1. Identify advantages and limitations of using computing as a tool to support problem solving in engineering.
2. Understand and use basic programming constructs such as variables, statements, loops and functions to carry out engineering tasks
3. Ability to select appropriate programming approaches when problem solving. For example using a loop for a repetitive task.
4. Use the MATLAB environment to write and debug basic computer programs
5. Develop good programming practice relevant to the professional world, such as ability to document programs with clear and concise language and use sensible variable names.
6. Be able to plan complex computer programs, by using top down design to decompose problems into small, manageable steps
7. Develop and revise programs using the design cycle, and use version control to manage files

p502: Drawing and Design; Matric 2021, Y1: 2 Labs

The course consists of a 1 hour introductory lecture and two 5-hour practical sessions in the Design Office, ETB.

The first lab session requires students to do the following:

- A freehand sketch showing three views of a simple object.
- Using the SolidWorks Computer Aided Design (CAD) software, create a solid model of a simple object.
- Produce a 2D CAD drawing from the solid model.

The second session requires satisfactory completion of the following:

- Using detailed instructions, create a Solid Model of a complex object using SolidWorks.
- Create an assembly using this, and other components.

- Animate the assembly.
- Design and produce a Solid Model of a new component to a given specification.
- Produce a 2D drawing of this new component.

Learning Outcomes:

1. Understand the different functions of engineering drawings.
2. Understand the principles of orthogonal and isometric projections.
3. Understand the common symbols and notation used in engineering drawings.
4. Understand how to depict three dimensional objects using different views.
5. Understand how to show internal features of a component using sections and/or hidden detail.
6. Understand how to dimension and apply simple tolerances to components.
7. Understand the application of standards to engineering components.
8. Be able to produce an engineering sketch of an object.
9. Be able to use Solid Modelling techniques to create three-dimensional models of objects.
10. Be able to create two-dimensional engineering drawings of a simple object using CAD techniques.
11. Be able to create assemblies of components from solid models.
12. Be able to create 2D drawings from 3D solid models.

<u>p503: Electrical Laboratory; Matric 2021, Y1: 5 Labs</u>

The laboratory consists of five sessions which take place in Michaelmas and Hilary terms and the first half of Trinity term. The first session, in the first half of Michaelmas term, teaches basic measurement techniques, particularly the use of the oscilloscope as a measurement tool, and the use of a signal generator. The importance of accurate record-keeping is emphasized. The remaining four sessions, which are spread out over the rest of the year, form an extended exercise, in which each undergraduate considers the design and implementation of a simple electronic "musical box". The musical box is based on a programmable microcontroller development board which is controlled by external signals. It has three modes of operation, one in which it plays back a pre-programmed sequence of notes, and one in which pitch and volume are varied via analogue inputs (e.g. the light intensity on a photo-diode and LDR respectively) and one where the output frequency is determined by a digital input. The waveform which is output (square, ramp or sampled sine) can be selected.

The exercises will demonstrate digital and analogue inputs (e.g. switches, voltage levels) and digital and analogue outputs (e.g. LED indicators, waveform). To understand the driving of a loudspeaker, an audio amplifier based on an operational amplifier circuit will be considered. Each laboratory will have pre-written code to be downloaded onto the microcontroller. Some guided editing of the code will be required to complete the exercises. The emphasis will be on understanding how the microcontroller can be used.

Laboratory (1) Introduction to laboratory techniques

Learning objectives

Students should be able to:
• Operate a signal generator so that they can select wave shape, frequency and amplitude,
• Operate an oscilloscope to observe waveforms and take measurements from them,
• Be able to explain the trigger function on the oscilloscope,
• Be able to explain sources of error in measurements and be aware of the magnitudes of these and how to minimise them.

Laboratory (2,3,4 & 5)
Learning objectives
Students should be able to describe and/or carry out basic measurements demonstrating:
• Frequency dependent behaviour and the frequency-filtering property of a resistor-capacitor (RC) circuit,
• Resonance in inductor-capacitor circuits,
• Automated data collection (using Keysight BenchVue software),
• Introductory Fourier series & the concept that waves can be thought of as sums of sine and cosine waves.
• RC circuits for smoothing,
• Simple binary & truth tables,
• Structure of development board: processor, memory, inputs & outputs,
• Structure of a simple C program,
• Digital inputs represented inside the microcontroller,
• Digital outputs,
• LEDs: current voltage characteristics, need for a current limiting resistor,
• Introductory digital to analogue conversion and the concept of quantisation in the output of the process,
• Introductory analogue to digital conversion,
• Introduction to the structure of more complex C programs (e.g. the use of functions),
• Behaviour of Photodiodes,
• Use of photodiodes and light-dependent resistors in practical circuits,
• Operational amplifiers (introduction to feedback circuit configurations).
• The operational amplifier to give voltage gain (and current to drive loudspeaker), understanding how the gain and bandwidth can be controlled using the external components (capacitors in the feedback loop to give frequency dependence).

p504: Mechanical Laboratory; Matric 2021, Y1: 5 Labs

The objective is to explore aspects of design, build and test of a pin jointed framework, using data gained from lab tests of materials and riveted jointing methods. The exercise supports the theory given in lectures and tutorials, and is split into five sessions with a lecture to introduce a software design tool.

The lab sessions are :
1. Riveted joint fabrication, materials tensile testing, and a buckling experiment.
2. Practical analysis of a simple pin jointed structure using a strain gauged specimen. Exploring frame design using the ‘frame2d’ design tool. 3D Print exercise (possibly in session 3).
3 & 4. Frame design work and Bridge manufacture.
5. Test structure and conclude.

Learning Outcomes:

1. Use various measurement techniques, some of which are provided as electrical signals suitable for logging and subsequent processing. You will learn that it is difficult, and often expensive, to measure anything accurately.
2. Understand concepts, which will be explained more fully later in lectures and the Design-Build-Test exercise, e.g. stress, strain, buckling, and compression.
3. See that acquired skills are necessary to handle unfamiliar equipment and make deductions from them, and the experimental results, efficiently within a limited time.
4. Experience a practical application of strain gauges.
5. Develop a design for a simple model structure to satisfy a written specification, which includes strength, and weight criteria.
6. Build a simple riveted model structure.
7. Solve construction issues that may not have been obvious at the concept stage of design. In addition, by observing the behaviour of structures as they are tested, you will begin to appreciate that structures fail in ways that may not have been anticipated during the design process.
8. Introduction to 3D printing and the 3D Print Lab.

p505: Thermodynamics Laboratory; Matric 2021, Y1: 1 Lab

This laboratory teaching consists of two parts which students, typically in groups of two or three, undertaken in the morning and afternoon of the same day. The two parts are the calibration of three types of transducers and the characterisation of an instrumented internal combustion engine. The calibrated transducers are:

1. Pressure Transducer: A piezo-electric transducer which is used to measure cylinder pressures in internal combustion engines is calibrated against a dead weight tester.
2. Temperature Transducer: A thermocouple transducer is calibrated against a liquid-in-glass thermometer, and thermistors are also demonstrated. Thermocouples and platinum resistance thermometers are used to measure temperatures in the engine, and their operation is explained.
3. Rotational speed transducer. An analogue pulse-counting “rev counter” is calibrated against an accurate quartz crystal frequency meter.

These three types of transducers, and others, are then used to measure variables from an operating four stroke internal combustion engine in a test cell. This enables the students to calculate key engine performance metrics such as power output, efficiency and heat flows, and to evaluate the importance of calibration when undertaking measurements.

Learning Outcomes**:**

- Students will be able to explain the need for instrumentation calibration and discuss how to plan a calibration experiment for a transducer.
- Students will be able to design and perform laboratory experiments to calibrate transducers against a provided reference transducer and interpret the accuracy.
- Students will be able to describe the operation of a four stroke engine and explain the principles of the instrumentation used to evaluate engine performance.
- Students will be able to perform an energy balance using their recorded engine data and calculate key engine performance metrics, including power output and efficiency, for a range of operating conditions.
- Students will be able to recognize and estimate how the accuracy of transducers impacts the accuracy of the variables of interest.

<u>p506: Workshop Practice; Matric 2021, Y1: 1 Lab</u>

Students attend one 2 hour lab session in the Staff/Student Workshop (DBT Lab) in the Thom building. Students manufacture a steel bush and mating brass pin to close tolerances, using a centre lathe. The lab session is preceded by a safety video.

Learning Outcomes:

1. Understand how to use a lathe safely for simple turning operations.
2. Understand how to use micrometres and bore gauges.
3. Understand how parts can be machined to high precision.
4. Understand the use of limits and fits and how the definition of these on a drawing relates to how the part is made.
5. Understand how the basic features and geometry of a lathe enable it to produce flat and cylindrical surfaces.