PH2011 - Physics 2A

Credits:	30.0	**Semester:**	1
Number of Lectures:	46	**Lecturer:**	Dr Paul Cruickshank (module co-ordinator), Prof Graham Smith, Prof Steve Lee, Dr Charles Baily, Dr Irina Leonhardt and Dr Cameron Rae (lab co-ordinator)
Academic Year:	2018-19		

Overview
This module covers the subjects of mechanics, oscillations in physics, thermal physics and special relativity. It is suitable for those who have taken the specified first year modules in physics and mathematics, or have good Advanced Higher or A-level passes or equivalent in physics and mathematics. It includes lectures on the dynamics of particles, rigid bodies, gravitation, the laws of thermodynamics, Einstein's special theory of relativity, and undamped, damped, forced and coupled oscillations.

Aims & Objectives
To present a broad and mathematically founded introductory account of mechanics, thermal physics, oscillations and special relativity, in particular:

- The ability to reason through scientific concepts, to relate different concepts to one another and to solve qualitative and quantitative problems in the areas covered in the courses with a toolkit of problem-solving techniques.
- Laboratory skills, including the planning of experimental investigations, the use of modern test equipment, and the construction of electronic circuits.
- An appreciation of the value of learning of physics as a transformative experience in terms of motivated use (using physics beyond the course e.g. in everyday situations) and expansion of perception (seeing the world through the lens of physics).
- To develop basic concepts in classical mechanics and Newtonian gravity including kinematics and dynamics of a single particle and rigid bodies, and to apply these concepts to analyse mechanical systems and describe their behaviour.
- To develop a conceptual and mathematical understanding of simple harmonic motion, damped, forced and coupled oscillations, to apply Newton's second law to determine the equations of motion of a range of oscillatory systems and to find solutions using trial functions.
- To present the fundamental laws of thermodynamics, and to apply them to simple thermodynamic systems, including heat engines and the Carnot cycle.
- To develop an understanding of the distinction between reversible and irreversible processes and their relation to entropy.
- To place the development of special relativity in historical context, and establish the consequences of Einstein's postulates
- To develop a conceptual and mathematical understanding of kinematics and dynamics in special relativity.
- The practical work of the module will develop a competence in using some of the standard equipment in physics laboratories, the analysis of experimental uncertainties and the presentation of experimental data in scientific reports.
- The module will develop the ability to reason through scientific concepts and to solve quantitative problems in the areas of classical mechanics, thermal physics, oscillations in physics and special relativity with a toolkit of problem-solving techniques.

Learning Outcomes
By the end of the module, students should be able to:

- Identify a hierarchy of physical concepts and mathematical equations pertinent to mechanics, understanding which are the most fundamental and which follow from the fundamental laws.
- Embed previously acquired knowledge correctly within the more general framework of mechanics presented in the course and to be aware of the limits of applicability and connectivity of that previous knowledge and its relation to newly acquired knowledge.

- Solve elementary problems in mechanics, being confident in correctly identifying concepts that are applicable to each problem and to correctly visualise and analyse the problem in order to allow a solution to be formulated.
- Be confident in the use of vectors, their manipulation, their transformation to different coordinate systems, and to be clear about why vectors are necessary to properly understand some problems. This includes being able to visualise a problem in mechanics and then to correctly formulate the problem in vector notation in order to allow a solution to be arrived at. To be clear about when the reduction of a vector problem to a scalar one is possible or advantageous.
- Be confident in the use of Cartesian and polar coordinates, transformations between them, and to recognise which might be the most appropriate system to work in or which system might facilitate better insight into a problem or provide greater ease of solution.
- Apply concepts of classical mechanics to derive equations of motion for oscillatory systems.
- For undamped and simple cases of damped, forced and coupled oscillations, solve the resulting equations of motion and distinguish between general and specific solutions.
- Represent oscillatory motion physically, mathematically and graphically and explain the connections between these representations.
- Give numerous real-world examples of oscillatory systems and be able to model these systems using different representations.
- State the postulates of special relativity, and use them to derive the formulas for length contraction and time dilation.
- Use the Lorentz transformations to find the spacetime coordinates of events in different reference frames.
- Draw and interpret spacetime diagrams.
- Derive and apply the relativistic velocity addition formula.
- Give multiple examples of experimental evidence that supports the theory of special relativity.
- Use the relativistic definitions of energy and momentum, and transform these quantities between different reference frames.
- Identify invariant quantities in special relativity, distinguish invariants from conserved quantities, and use both concepts to determine the outcome of relativistic collisions.
- State the zeroth, first and second laws of thermodynamics, explain their physical meaning and relate them to the thermodynamic identity.
- Solve problems involving thermal expansion, heat capacity and the transport of energy by heating in terms of the thermal properties of materials.
- Appreciate the differences between reversible and irreversible processes.
- State the ideal gas law and equipartition theorem and apply them to a variety of different thermodynamic problems.
- Distinguish between the concepts of heat and work and perform and explain basic calculations for these quantities for ideal gases under various conditions.
- Describe the essential assumptions and conclusions of the kinetic theory of ideal gases and apply these to problems involving ideal gases, including the Maxwell-Boltzmann speed distribution and its behaviour.
- Describe the difference between a macrostate and a microstate of a system and explain the links between multiplicity and the likelihood of a macrostate.
- State the thermodynamic and statistical definitions of entropy and explain the link between them, and relate changes in entropy to the reversibility of a process.
- Explain selected thermodynamic cycles, including the Carnot cycle and state an expression for the Carnot efficiency and the link between entropy and heat engines and refrigerators.
- Describe and demonstrate appropriate data gathering procedures.
- Clearly record experimental data with an associated uncertainty.
- Perform calculations on data with a correctly propagated uncertainty for single- or multi-variable problems as required.
- Clearly report results through appropriate means: stated value, tabulated and graphical representation.
- Critically analyse results against accepted literature values.
- Communicate observations through a structured laboratory notebook.

Synopsis
Mathematics Revision
Trigonometry, dimensional analysis, complex vectors, functions, graphs, differentiation, integration, differential equations, Taylor series.

Mechanics

- Dynamics of a single particle: Newton's laws of motion, inertial reference frames. Momentum, conservation of momentum in absence of external forces. Central force problems: velocity and acceleration of particles in plane polar coordinates. Work, energy and power. Conservative forces, relation between force and potential energy. Friction. Torque. Conservation of angular momentum.
- Gravitation: Newton's gravitational force law, potential energy for point source.
- Dynamics of a system of particles: Centre of mass. Internal and external forces. Translational equation of motion. Torque. Angular momentum and kinetic energy of a rotating system. Rotational equation of motion. Rigid bodies. Moments of inertia. Parallel and perpendicular axis theorems.

Oscillations in Physics

- Introduction to oscillations. Mathematical description of oscillations. Circular motion and simple harmonic motion (SHM). Energy in SHM. Examples of SHM: spring-mass systems, pendulums, other oscillating systems. Damped oscillations. Types of damping, Q factor. Forced oscillations. Resonance. Examples of resonant systems. Coupled oscillations and normal modes.

Thermal Physics

- Temperature, pressure and translational kinetic energy. The thermodynamic temperature scale. The notion of thermal equilibrium. Degrees of freedom. Reversible and irreversible processes. The zero'th law. Ideal gases. Mean Free Path and Maxwell Speed Distribution. Types of thermometer. Thermal expansion (linear, area and volume), interatomic forces and crystal structures elasticity. Equations of state.
- Work, heat and the First law of thermodynamics. Heat capacity and phonons. Heat transport, conduction, convection and radiation. Phase changes and latent heat. Adiabatic processes, free expansion of a gas.
- Entropy and the second law of thermodynamics. Direction of time. Heat engines, heat pumps, refrigerators, efficiency. Entropy from a statistical viewpoint.

Special Relativity
Inertial reference frames and Galilean relativity. The postulates of special relativity. Clock synchronisation and the relativity of simultaneity. Length contraction, time dilation and the Lorentz transformations. Proper time, invariants and spacetime diagrams. Transformation of velocity. Relativistic Doppler effect. Relativistic momentum and energy. Conservation principles and relativistic collisions.

Laboratory Work
As a direct entrant student, follow a focused laboratory skills development programme that includes: precision and accuracy, error propagation, data analysis and graphical representation, experimental technique and laboratory notebook keeping. All students; explore aspects of physics in a practical manner, broaden competence in various forms of experimental and diagnostic instrumentation.

Pre-requisites
PH1011, PH1012 and MT1002; alternatively passes in Advanced Higher Physics and Mathematics or A-level Physics and Mathematics both normally at grade A, or equivalent.

Anti-requisites
AS1002

Assessment

3 Hour Examination = 60%, Class Test = 10%, Laboratory work = 25%, Meaningful participation in pre-lecture quizzes and in-lecture clicker questions = 5%

Additional information on continuous assessment etc.

Accreditation Matters
This module contains some material that is or may be part of the IOP "Core of Physics". This includes

Revision of Taylor series
Revision of calculus including multiple integrals, solution of linear ordinary and differential equations
Revision of three dimensional trigonometry
Newton's laws, conservation laws including rotation
Newtonian gravitation, Kepler's laws
Lorentz Transformations and energy momentum relationship
Thermal expansion
Inter-atomic forces and bonding
Phonons and heat capacity
Crystal structure
Free, damped, forced and coupled oscillations to include resonance and normal modes
Temperature scales, work, internal energy, and heat capacity
Entropy and the Carnot cycle
Changes of state
Statistical basis of entropy
Maxwell-Boltzmann distribution
Ability to work independently, to use their initiative and to organize themselves to meet deadlines
In Lab
How to plan, execute and report the results of an experiment or investigation
How to compare results critically with predictions from theory

Recommended Books
Please view University online record:
http://resourcelists.st-andrews.ac.uk/modules/ph2011.html

General Information
Please also read the additional information in the School's pre-honours handbook.