Preliminary Examination in Physics

Each of the Papers CP1 - CP4 is a 2½ hour paper in two sections
Section A: Short compulsory questions (total marks 40)
Section B: Answer 3 problems from 4 (total marks 60)

Syllabuses for CP1 CP2, CP3 and CP4.

also **Moderations in Physics and Philosophy**
Syllabuses for CP1, CP3, CP4P (CP4 without optics)
Part A Physics and Philosophy A2P (CP2 without circuit theory)

CP1: Physics 1 *(formerly* Mechanics and Special Relativity Mechanics)

Newton's law of Motion. Mechanics of particles in one dimension. Energy, work and impulse. Conservation of linear momentum including problems where the mass changes, e.g. the motion of a rocket ejecting fuel. Conservation of energy.

Vector formulation of Newton's law of motion. Time-dependent vectors and differentiation of vectors.

Mechanics of particles in two dimensions. Equations of motion in Cartesian and plane polar co-ordinates. Projectiles moving under gravity, including such motion subject to a damping force proportional to velocity. Dimensional Analysis.

Systems of point particles. Centre of mass (or momentum) frame and its uses. Torque and angular momentum. Conservation of angular momentum. Two-body collisions.

Central forces. Importance of conservation of energy and angular momentum. Classification of orbits as bound or unbound (derivation of equation for u=1/r not required; explicit treatment of hyperbolae and ellipses not required). Inverse square central forces. Examples from planetary and satellite motion and motion of charged particles under the Coulomb force. Distance of closest approach and angle of deviation.

Calculus of variations. Principle of stationary action (Hamilton principle). The Euler-Lagrange equation. Constraints. Application to particle motion in one and two dimensions. Conservation laws. Noether's theorem. The Hamiltonian and energy conservation.

Moment of inertia of a system of particles. Use of perpendicular- and parallel-axis theorems. Moment of inertia of simple bodies. Simple problems of rigid body dynamics. Angular impulse, collision and rolling. The concept of principal axes. Angular momentum and total energy in rigid body rotation. Compound pendulum.

Special Relativity

Special theory of relativity restricted throughout to problems in one space dimension. The constancy of the speed of light; simultaneity. The Lorentz transformation (derivation not required). Time dilation and length contraction. The addition of velocities. Invariance of the space-time interval.

Energy, momentum, rest mass and their relationship for a single particle. Conservation of energy and momentum. Elementary kinematics of the scattering and decay of sub-atomic particles, including the photon. Relativistic Doppler effect (longitudinal only).

CP2: Physics 2 *(formerly* Introductory Electromagnetism and Circuits)

The treatment of electromagnetism is restricted to fields in vacuo. Vector operator identities required will be given on the data sheet and complicated manipulations of vector operators will not be set. The treatment of circuits is limited to passive linear circuits.

Electromagnetism

Coulomb's law. The electric field **E** and potential due to a point charge and systems of point charges, including the electric dipole. The couple and force on, and the energy of, a dipole in an external electric field. Energy of a system of point charges; energy stored in an electric field. Gauss' Law; the **E** field and potential due to surface and volume distributions of charge (including simple examples of the method of images), no field inside a closed conductor. Force on a conductor. The capacitance of parallel-plate, cylindrical and spherical capacitors, energy stored in capacitors.

The forces between wires carrying steady currents. The magnetic field **B**, Ampere's law, Gauss' Law ("no magnetic monopoles"), the Biot-Savart Law. The **B** field due to currents in a long straight wire, in a circular loop (on axis only) and in straight and toroidal solenoids. The magnetic dipole; its **B** field. The force and couple on, and the energy of, a dipole in an external **B** field. Energy stored in a **B** field.

The force on a charged particle in **E** and **B** fields. Simple cases of the motion of charged particles in uniform **E** and **B** fields.

Electromagnetic induction, the laws of Faraday and Lenz. Emfs generated by an external, changing magnetic field threading a circuit and due to the motion of a circuit in an external magnetic field, the flux rule. Self and mutual inductance: calculation for simple circuits, energy stored in inductors. The transformer.

Charge conservation, Ampere's law applied to a charging capacitor, Maxwell's addition to Ampere's law ("displacement current").

Maxwell's equations for fields in a vacuum (rectangular co-ordinates only). Plane electromagnetic waves in empty space: their speed; the relationships between **E**, **B** and the direction of propagation.

Circuit Theory

Emf and voltage drop. Resistance, capacitance, inductance and their symbolic representation. Growth and decay of currents in circuits, time constant. The use of complex impedance in steady-state AC circuit analysis, power factor, bandwidth and quality factor (Q) of a resonant circuit, rms, peak and average values.

Note: the above electromagnetism syllabus is also that for the Physics and Philosophy Part A paper A2P (Electromagnetism).

CP3: Mathematical Methods 1 *(formerly* Mathematical Methods)

Elementary ideas of sequences, series, limits and convergence. (Questions on determining the convergence or otherwise of a series will not be set.) Taylor and MacLaurin series and their application to the local approximation of a function of one variable by a polynomial, and to finding limits. (Knowledge of and use of the exact form of the remainder are excluded.) Differentiation of functions of one variable including function of a function and implicit differentiation. Changing variables in a differential equation, Integration of functions of one variable including the methods of integration by parts and by change of variable, though only simple uses of these techniques will be required, such as $\int x \sin x \, dx$ and $\int x \exp(-x^2) \, dx$. The relation between integration and differentiation, i.e. $\int_a^b dx \, (df/dx)$ and $d/dx(\int_a^x f(x') \, dx')$.

Differential calculus of functions of more than one variable. Functions of two variables as surfaces. Partial differentiation, chain rule and differentials and their use to evaluate small changes. Simple transformations of first order coefficients. (Questions on transformations of higher order coefficients are excluded.) Taylor expansion for two variables, maxima, minima and saddle points of functions of two variables.

Differential calculus of functions of more than one variable. Functions of two variables as surfaces. Partial differentiation, chain rule and differentials and their use to evaluate small changes. Simple transformations of first order coefficients. (Questions on transformations of higher order coefficients are excluded.) Taylor expansion for two variables, maxima, minima and saddle points of functions of two variables.

Vector algebra, scalar and vector products, triple products. Elementary vector geometry of lines and planes.

Elementary properties (addition, multiplication, inverse) of two- and three- dimensional matrices. Determinants: minors, cofactors, evaluation by row and column manipulation. Application of matrix methods to the solution of simultaneous linear equations; cases in which solutions are unique, non-unique or do not exist; geometric interpretation of these cases.

Double integrals and their evaluation by repeated integration in Cartesian, plane polar and other specified coordinate systems. Jacobians. Line, surface and volume integrals, evaluation by change of variables (Cartesian, plane polar, spherical polar coordinates and cylindrical coordinates only unless the transformation to be used is specified). Integrals around closed curves and exact differentials. Scalar and vector fields. The operations of grad, div and curl and understanding and use of identities involving these. The statements of the theorems of Gauss and Stokes with simple applications. Conservative fields.

CP4: Mathematical Methods 2 *(formerly* Differential Equations, Waves and Optics)

Differential Equations

Complex numbers, definitions and operations. The Argand diagram; modulus and argument (phase) and their geometric interpretation; curves in the Argand diagram. De Moivre's theorem. Elementary functions (polynomial, trigonometric, exponential, hyperbolic, logarithmic) of a complex variable. (Complex transformations and complex differentiation and integration are excluded.)

Ordinary differential equations: Classification and terminology. Linear homogeneous differential equations and superposition. First-order linear differential equations; integrating factors. Second-order linear differential equations with constant coefficients; complementary functions and particular integrals; applications to damped and forced vibrations. Critical damping. Mechanical resonance and the quality factor Q.

Waves

Coupled undamped oscillations in systems with two degrees of freedom. Normal frequencies, and amplitude ratios in normal modes. General solution (for two coupled oscillators) as a superposition of modes. Total energy, and individual mode energies. Response to a sinusoidal driving term.

Derivation of the one-dimensional wave equation and its application to transverse waves on a stretched string. D'Alembert's solution. Sinusoidal solutions and their complex representation. Characteristics of wave motion in one dimension: amplitude, phase, frequency, wavelength, wavenumber, phase velocity. Energy in a vibrating string. Travelling waves: energy, power, impedance, reflection and transmission at a boundary. Superposition of two waves of different frequencies: beats and elementary discussion of construction of wave packets; qualitative discussion of dispersive media; group velocity. Method of separation of variables for the one-dimensional wave equation; separation constants. Modes of a string with fixed end points (standing waves): superposition of modes, energy as a sum of mode energies.

Optics

Elementary geometrical optics in the paraxial approximation. Refractive index; reflection and refraction at a plane boundary from Huygens' principle; Snell's Law; total internal reflection. Image formation by reflection at a spherical boundary; concave and convex mirrors. Real and virtual images. Magnification. Image formation by refraction at a spherical boundary and by converging and diverging thin lenses. Derivation of the expression for the focal length of a thin lens. (Image formation by systems of two or more lenses or mirrors is excluded.)

Simple two-slit interference (restricted to slits of negligible width). The diffraction grating, its experimental arrangement; conditions for proper illumination. The dispersion of a diffraction grating. (The multiple-slit interference pattern and the resolution of a diffraction grating are excluded.) Fraunhofer diffraction by a single slit. The resolution of a simple lens.

Note: the above syllabus, without the optics section is also that for the Physics and Philosophy Mods paper CP4P (Differential Equations and Waves).

Final Honour School - Part A

A knowledge of the topics in the syllabuses for the four compulsory physics Prelims papers will be assumed. Emphasis will be placed on testing a candidate's conceptual and experimental understanding of the subjects, apart from explicitly mathematical questions.

Non-examinable topics. *Material under this heading will be covered in the lectures (with associated problems sets). Questions on these topics will not be set in part A, but general knowledge of the material will be assumed by the 3rd year lectures. Only if these topics appear in the part B syllabus may explicit questions be set on them in that examination.*

Each of the three A Papers is a 3-hour paper in two sections
Section A: Short compulsory questions (total marks 40)
Section B: Answer 3 problems from 4 (total marks 60)

Mathematical Methods

Matrices and linear transformations, including translations and rotations in three dimensions and Lorentz transformations in four dimensions. Eigenvalues and eigenvectors of real symmetric matrices and of Hermitian matrices. Diagonalization of real symmetric matrices; *diagonalization of Hermitian matrices (non-examinable).* The method of separation of variables in linear partial differential equations in two, three and four variables. Use of Cartesian, spherical polar and cylindrical polar coordinates (proofs of the form of ∇^2 will not be required). Eigenvalues and eigenfunctions of second-order linear ordinary differential equations of the Sturm–Liouville type; orthogonality of eigenfunctions belonging to different eigenvalues; simple eigenfunction expansions including Fourier series. Fourier transform, its inverse, and the convolution theorem. Concept and use of the delta function.

The above material on mathematical methods is not attributed to a specific paper.

Short questions on mathematical methods will be set in one or more of papers A1, A2 and A3. It is expected that the total credit for these short questions will amount to about 15% of the total credit for short questions, as this is roughly the length of the mathematical methods course as a fraction of all courses for papers A1, A2 and A3. One long question on mathematical methods may be set in one of papers A1, A2 or A3.

A1: Thermal Physics

Kinetic Theory

Maxwell distribution of velocities: derivation assuming the Boltzmann factor, calculation of averages, experimental verification. Derivation of pressure and effusion formulae, distribution of velocities in an effusing beam, simple kinetic theory expressions for mean free path, thermal conductivity and viscosity; dependence on temperature and pressure, limits of validity. Practical applications of kinetic theory.

Heat transport

Conduction, radiation and convection as heat-transport mechanisms. The approximation that heat flux is proportional to the temperature gradient. Derivation of the heat diffusion equation. Generalization to systems in which heat is generated at a steady rate per unit volume. Solution by separation of variables for problems with spherical and planar symmetry. Steady-state problems, initial-value problems, and problems involving sinusoidally varying surface temperatures.

Thermodynamics

Zeroth & First laws. Heat, work and internal energy: the concept of a function of state. Slow changes and the connection with statistical mechanics: entropy and pressure as functions of state. Heat engines: Kelvin's statement of the second law of thermodynamics and the equivalence and superiority of reversible engines. The significance of $\oint dQ/T=0$ and the fact that entropy is a function of state. Practical realization of the thermodynamic temperature scale. Entropy as dQ (reversible)/T. Enthalpy, Helmholtz energy and Gibbs energy as functions of state. Maxwell relations. Concept of the equation of state; thermodynamic implications. Ideal gas, van der Waals gas. Reversible and free expansion of gas; changes in internal energy and entropy in ideal and non-ideal cases. Joule–Kelvin expansion; inversion temperature and microscopic reason for cooling. Impossibility of global entropy decreasing: connection to latent heat in phase changes. *Constancy of global entropy during fluctuations around equilibrium (non-examinable)*. Chemical potential and its relation to Gibbs energy. Equality of chemical potential between phases in equilibrium. Latent heat and the concepts of first-order and continuous phase changes. Clausius–Clapeyron equation and simple applications. Simple practical examples of the use of thermodynamics.

Statistical mechanics

Boltzmann factor. Partition function and its relation to internal energy, entropy, Helmholtz energy, heat capacities and equations of state. *Quantum states and the Gibbs hypothesis (non-examinable).* Density of states. Application to: the spin-half paramagnet; simple harmonic oscillator (Einstein model of a solid); perfect gas; vibrational excitations of a diatomic gas; rotational excitations of a heteronuclear diatomic gas. Equipartition of energy. Bosons and fermions: Fermi–Dirac and Bose–Einstein distribution functions for non-interacting, indistinguishable particles. *Partition function for bosons and fermions when the particle number is not restricted and when it is: microcanonical, canonical and grand canonical ensemble (non-examinable).* Chemical potential. High-temperature limit and the Maxwell–Boltzmann distribution. *Simple treatment of fluctuations (non-examinable).* Low-temperature limit for fermions: Fermi energy and low-temperature limit of the heat capacity; application to electrons in metals and degenerate stars. Low-temperature limit for boson gas: Bose–Einstein condensation: calculation of the critical temperature of the phase transition; heat capacity; relevance to superfluidity in helium. The photon gas: Planck distribution, Stefan–Boltzmann law. *Kirchhoff's law (non-examinable).*

A2: Electromagnetism and Optics

Electromagnetism

Dielectric media, polarisation density and the electric displacement **D**. Dielectric permittivity and susceptibility. Boundary conditions on **E** and **D** at an interface between two dielectrics. Magnetic media, magnetisation density and the magnetic field strength **H**. Magnetic permeability and susceptibility; properties of magnetic materials as represented by hysteresis curves. Boundary conditions on **B** and **H** at an interface between two magnetic media. Maxwell's equations in the presence of dielectric and magnetic media.

Treatment of electrostatic problems by solution of Poisson's equation using separation of variables in Cartesian, cylindrical or spherical coordinate systems. Representation of curl-free magnetic fields by a magnetic scalar potential and applications.

Electromagnetic waves in free space. Derivation of expressions for the energy density and energy flux (Poynting vector) in an electromagnetic field. Radiation pressure. *(Non-examinable) Magnetic vector potential. Description of radiation fields from an electric dipole aerial and a magnetic dipole aerial.*

Electromagnetic wave equation in dielectrics: refractive index and impedance of the medium. Reflection and transmission of light at a plane interface between two dielectric media: derivation of the Fresnel equations for the reflection and transmission coefficients from Maxwell's equations. The Brewster angle. Total internal reflection, the evanescent wave and its demonstration. The electromagnetic wave equation in a conductor: skin depth. Electromagnetic waves in a plasma; the plasma frequency. *(Non-examinable) Scattering , dispersion and absorption of electromagnetic waves, treated in terms of the response of a damped classical harmonic oscillator.*

Theory of a loss-free transmission line: characteristic impedance and wave speed. Reflection and transmission of signals at connections between transmission lines and at loads; impedance matching using a quarter-wavelength transmission line. *Non-examinable: Rectangular loss-less waveguides and resonators.*

Optics

Image formation by systems of thin lenses as illustrated by: a simple astronomical telescope consisting of two convex lenses, a simple reflecting telescope, a simple microscope.

Diffraction, and interference by division of wave front (quasi-monochromatic light). Questions on diffraction will be limited to the Fraunhofer case. Statement of the Fraunhofer condition. Practical importance of Fraunhofer diffraction and experimental arrangements for its observation. Derivation of patterns for multiple slits and the rectangular aperture using Huygens Fresnel theory with a scalar amplitude and neglecting obliquity factors. (The assumptions involved in this theory will not be asked for.) The resolving power of a telescope. Fourier transforms in Fraunhofer diffraction: the decomposition of a screen transmission function with simple periodic structure into its spatial frequency components. Spatial filtering. *(Non-examinable) The Gaussian function and apodization*. The resolving power of a microscope with coherent illumination.

Interference by division of amplitude (quasi-monochromatic light). Two-beam interference, restricted to the limiting cases of fringes of equal thickness and of equal inclination. Importance in modern optical and photonic devices as illustrated by: the Michelson interferometer (including its use as a Fourier-transform spectrometer); the Fabry–Perot etalon (derivation of the pattern, definition of finesse). Single and multiple $\lambda/4$ coatings for normally incident light: high-reflectors and anti-reflection coatings.

Distinction between completely polarized, partially polarized and unpolarized light. Phenomenological understanding of birefringence; principles of the use of uniaxial crystals in practical polarizers, compensators and wave plates (detailed knowledge of individual devices will not be required). Production and analysis of completely polarized light. Practical applications of polarized light. The interference of polarized light; conditions for observation.

(Non-examinable) Properties of laser radiation. Brightness compared to conventional sources; coherence length measured using the Michelson Interferometer. Measurement and use of transverse coherence. Propagation of laser light in optical fibres.