NANYANG TECHNOLOGICAL UNIVERSITY
ENTRANCE EXAMINATION SYLLABUS
FOR INTERNATIONAL STUDENTS

PHYSICS

STRUCTURE OF EXAMINATION PAPER

1. There will be one 2-hour paper consisting of 20 multiple choice questions. Candidates will be required to answer all questions.

2. Candidates will have to show working of their answers clearly. Marks will be awarded for the working as well as the answers.

The detailed syllabus is on the next page.

SUBJECT CONTENT

SECTION I MEASUREMENT

1. Measurement

Content

- SI Units
- Errors and uncertainties
- Scalars and vectors

Learning Outcomes

Candidates should be able to:

(a) recall the following base quantities and their units: mass (kg), length (m), time (s), current (A), temperature (K), amount of substance (mol).

(b) express derived units as products or quotients of the base units and use the named units listed in 'Summary of Key Quantities, Symbols and Units' as appropriate.

(c) show an understanding of and use the conventions for labelling graph axes and table columns as set out in the ASE publication *SI Units, Signs, Symbols and Abbreviations*, except where these have been superseded by *Signs, Symbols and Systematics (The ASE Companion to 16–19 Science, 2000).*

(d) use the following prefixes and their symbols to indicate decimal sub-multiples or multiples of both base and derived units: pico (p), nano (n), micro (μ), milli (m), centi (c), deci (d), kilo (k), mega (M), giga (G), tera (T).

(e) make reasonable estimates of physical quantities included within the syllabus.

(f) show an understanding of the distinction between systematic errors (including zero errors) and random errors.

(g) show an understanding of the distinction between precision and accuracy.

(h) assess the uncertainty in a derived quantity by simple addition of actual, fractional or percentage uncertainties (a rigorous statistical treatment is not required).

(i) distinguish between scalar and vector quantities, and give examples of each.

(j) add and subtract coplanar vectors.

(k) represent a vector as two perpendicular components.

SECTION II NEWTONIAN MECHANICS

2. Kinematics

Content

- Rectilinear motion
- Non-linear motion

Learning Outcomes

Candidates should be able to:

(a) define displacement, speed, velocity and acceleration.

(b) use graphical methods to represent distance travelled, displacement, speed, velocity and acceleration.

(c) find displacement from the area under a velocity-time graph.

(d) use the slope of a displacement-time graph to find the velocity.

(e) use the slope of a velocity-time graph to find the acceleration.

(f) derive, from the definitions of velocity and acceleration, equations which represent uniformly accelerated motion in a straight line.

(g) solve problems using equations which represent uniformly accelerated motion in a straight line, including the motion of bodies falling in a uniform gravitational field without air resistance.

(h) describe qualitatively the motion of bodies falling in a uniform gravitational field with air resistance.

(i) describe and explain motion due to a uniform velocity in one direction and a uniform acceleration in a perpendicular direction.

3. Dynamics

Content

- Newton's laws of motion
- Linear momentum and its conservation

Learning Outcomes

Candidates should be able to:

(a) state each of Newton's laws of motion.

(b) show an understanding that mass is the property of a body which resists change in motion.

(c) describe and use the concept of weight as the effect of a gravitational field on a mass.

(d) define linear momentum and impulse.

(e) define force as rate of change of momentum.

(f) recall and solve problems using the relationship $F = ma$, appreciating that force and acceleration are always in the same direction.

(g) state the principle of conservation of momentum.

(h) apply the principle of conservation of momentum to solve simple problems including elastic and inelastic interactions between two bodies in one dimension. (Knowledge of the concept of coefficient of restitution is not required.)

(i) recognise that, for a perfectly elastic collision between two bodies, the relative speed of approach is equal to the relative speed of separation.

(j) show an understanding that, whilst the momentum of a system is always conserved in interactions between bodies, some change in kinetic energy usually takes place.

4. Forces

Content

- Types of force
- Equilibrium of forces
- Centre of gravity
- Turning effects of forces

Learning Outcomes

Candidates should be able to:

(a) recall and apply Hooke's law to new situations or to solve related problems.

(b) deduce the elastic potential energy in a deformed material from the area under the force-extension graph.

(c) describe the forces on mass, charge and current in gravitational, electric and magnetic fields, as appropriate.

(d) solve problems using the equation $p = \rho g h$.

(e) show an understanding of the origin of the upthrust acting on a body in a fluid.

(f) state that an upthrust is provided by the fluid displaced by a submerged or floating object.

(g) calculate the upthrust in terms of the weight of the displaced fluid.

(h) recall and apply the principle that, for an object floating in equilibrium, the upthrust is equal to the weight of the object to new situations or to solve related problems.

(i) show a qualitative understanding of frictional forces and viscous forces including air resistance. (No treatment of the coefficients of friction and viscosity is required.)

(j) use a vector triangle to represent forces in equilibrium.

(k) show an understanding that the weight of a body may be taken as acting at a single point known as its centre of gravity.

(l) show an understanding that a couple is a pair of forces which tends to produce rotation only.

(m) define and apply the moment of a force and the torque of a couple.

(n) show an understanding that, when there is no resultant force and no resultant torque, a system is in equilibrium.

(o) apply the principle of moments to new situations or to solve related problems.

5. Work, Energy and Power

Content

- Work
- Energy conversion and conservation
- Potential energy and kinetic energy
- Power

Learning Outcomes

Candidates should be able to:

(a) show an understanding of the concept of work in terms of the product of a force and displacement in the direction of the force.

(b) calculate the work done in a number of situations including the work done by a gas which is expanding against a constant external pressure: $W = p\Delta V$.

(c) give examples of energy in different forms, its conversion and conservation, and apply the principle of energy conservation to simple examples.

(d) derive, from the equations of motion, the formula $E_k = ½mv^2$.

(e) recall and apply the formula $E_k = ½mv^2$.

(f) distinguish between gravitational potential energy, electric potential energy and elastic potential energy.

(g) show an understanding of and use the relationship between force and potential energy in a uniform field to solve problems.

(h) derive, from the defining equation $W = Fs$, the formula $E_p = mgh$ for potential energy changes near the Earth's surface.

(i) recall and use the formula $E_p = mgh$ for potential energy changes near the Earth's surface.

(j) show an appreciation for the implications of energy losses in practical devices and use the concept of efficiency to solve problems.

(k) define power as work done per unit time and derive power as the product of force and velocity.

6. Motion in a Circle

Content

- Kinematics of uniform circular motion
- Centripetal acceleration
- Centripetal force

Learning Outcomes

Candidates should be able to:

(a) express angular displacement in radians.

(b) understand and use the concept of angular velocity to solve problems.

(c) recall and use $v = r\omega$ to solve problems.

(d) describe qualitatively motion in a curved path due to a perpendicular force, and understand the centripetal acceleration in the case of uniform motion in a circle.

(e) recall and use centripetal acceleration $a = r\omega^2$, $a = v^2/r$ to solve problems.

(f) recall and use centripetal force $F = mr\omega^2$, $F = mv^2/r$ to solve problems.

7. Gravitational Field

Content

- Gravitational field
- Force between point masses
- Field of a point mass
- Field near to the surface of the Earth
- Gravitational potential

Learning Outcomes

Candidates should be able to:

(a) show an understanding of the concept of a gravitational field as an example of field of force and define gravitational field strength as force per unit mass.

(b) recall and use Newton's law of gravitation in the form $F = \dfrac{Gm_1m_2}{r^2}$.

(c) derive, from Newton's law of gravitation and the definition of gravitational field strength, the equation $g = \dfrac{GM}{r^2}$ for the gravitational field strength of a point mass.

(d) recall and apply the equation $g = \dfrac{GM}{r^2}$ for the gravitational field strength of a point mass to new situations or to solve related problems

(e) show an appreciation that on the surface of the Earth g is approximately constant and equal to the acceleration of free fall.

(f) define potential at a point as the work done in bringing unit mass from infinity to the point.

(g) solve problems using the equation $\phi = -\dfrac{GM}{r}$ for the potential in the field of a point mass.

(h) recognise the analogy between certain qualitative and quantitative aspects of gravitational and electric fields.

(i) analyse circular orbits in inverse square law fields by relating the gravitational force to the centripetal acceleration it causes.

(j) show an understanding of geostationary orbits and their application.

8. Oscillations

Content

- Simple harmonic motion
- Energy in simple harmonic motion
- Damped and forced oscillations: resonance

Learning Outcomes

Candidates should be able to:

(a) describe simple examples of free oscillations.

(b) investigate the motion of an oscillator using experimental and graphical methods.

(c) understand and use the terms amplitude, period, frequency, angular frequency and phase difference and express the period in terms of both frequency and angular frequency.

(d) recognise and use the equation $a = -\omega^2 x$ as the defining equation of simple harmonic motion.

(e) recall and use $x = x_o \sin\omega t$ as a solution to the equation $a = -\omega^2 x$.

(f) recognise and use
$v = v_o \cos\omega t$
$v = \pm\omega\sqrt{(x_o^2 - x^2)}$.

(g) describe, with graphical illustrations, the changes in displacement, velocity and acceleration during simple harmonic motion.

(h) describe the interchange between kinetic and potential energy during simple harmonic motion.

(i) describe practical examples of damped oscillations with particular reference to the effects of the degree of damping and the importance of critical damping in cases such as a car suspension system.

(j) describe practical examples of forced oscillations and resonance.

(k) describe graphically how the amplitude of a forced oscillation changes with frequency near to the natural frequency of the system, and understand qualitatively the factors which determine the frequency response and sharpness of the resonance.

(l) show an appreciation that there are some circumstances in which resonance is useful and other circumstances in which resonance should be avoided.

SECTION III THERMAL PHYSICS

9. Thermal Physics

Content

- Internal energy
- Temperature scales
- Specific heat capacity
- Specific latent heat
- First law of thermodynamics
- The ideal gas equation
- Kinetic energy of a molecule

Learning Outcomes

Candidates should be able to:

(a) show an understanding that internal energy is determined by the state of the system and that it can be expressed as the sum of a random distribution of kinetic and potential energies associated with the molecules of a system.

(b) relate a rise in temperature of a body to an increase in its internal energy.

(c) show an understanding that regions of equal temperature are in thermal equilibrium.

(d) show an understanding that there is an absolute scale of temperature which does not depend on the property of any particular substance, i.e. the thermodynamic scale.

(e) apply the concept that, on the thermodynamic (Kelvin) scale, absolute zero is the temperature at which all substances have a minimum internal energy.

(f) convert temperatures measured in Kelvin to degrees Celsius: $T / K = T / °C + 273.15$.

(g) define and use the concept of specific heat capacity, and identify the main principles of its determination by electrical methods.

(h) define and use the concept of specific latent heat, and identify the main principles of its determination by electrical methods.

(i) explain using a simple kinetic model for matter why
   i. melting and boiling take place without a change in temperature,
   ii. the specific latent heat of vaporisation is higher than specific latent heat of fusion for the same substance,
   iii. cooling effect accompanies evaporation.

(j) recall and use the first law of thermodynamics expressed in terms of the change in internal energy, the heating of the system and the work done on the system.

(k) recall and use the ideal gas equation $pV = nRT$, where n is the amount of gas in moles.

(l) show an understanding of the significance of the Avogadro constant as the number of atoms in 0.012 kg of carbon-12.

(m) use molar quantities where one mole of any substance is the amount containing a number of particles equal to the Avogadro constant.

(n) recall and apply the relationship that the mean kinetic energy of a molecule of an ideal gas is proportional to the thermodynamic temperature to new situations or to solve related problems.

SECTION IV WAVES

10. Wave Motion

Content

- Progressive waves
- Transverse and longitudinal waves
- Polarisation
- Determination of frequency and wavelength

Learning Outcomes

Candidates should be able to:

(a) show an understanding and use the terms displacement, amplitude, phase difference, period, frequency, wavelength and speed.

(b) deduce, from the definitions of speed, frequency and wavelength, the equation $v = f\lambda$.

(c) recall and use the equation $v = f\lambda$.

(d) show an understanding that energy is transferred due to a progressive wave.

(e) recall and use the relationship, *intensity* $\propto$ *(amplitude)*^{2}.

(f) analyse and interpret graphical representations of transverse and longitudinal waves.

(g) show an understanding that polarisation is a phenomenon associated with transverse waves.

(h) determine the frequency of sound using a calibrated c.r.o.

(i) determine the wavelength of sound using stationary waves.

11. Superposition

Content

- Stationary waves
- Diffraction
- Interference
- Two-source interference patterns
- Diffraction grating

Learning Outcomes

Candidates should be able to:

(a) explain and use the principle of superposition in simple applications.

(b) show an understanding of experiments which demonstrate stationary waves using microwaves, stretched strings and air columns.

(c) explain the formation of a stationary wave using a graphical method, and identify nodes and antinodes.

(d) explain the meaning of the term diffraction.

(e) show an understanding of experiments which demonstrate diffraction including the diffraction of water waves in a ripple tank with both a wide gap and a narrow gap.

(f) show an understanding of the terms interference and coherence.

(g) show an understanding of experiments which demonstrate two-source interference using water, light and microwaves.

(h) show an understanding of the conditions required if two-source interference fringes are to be observed.

(i) recall and solve problems using the equation $\lambda = ax/D$ for double-slit interference using light.

(j) recall and solve problems by using the formula $d\sin\theta = n\lambda$ and describe the use of a diffraction grating to determine the wavelength of light. (The structure and use of the spectrometer is not required.)

SECTION V ELECTRICITY AND MAGNETISM

12. Electric Fields

Content

- Concept of an electric field
- Force between point charges
- Electric field of a point charge
- Uniform electric fields
- Electric potential

Learning Outcomes

Candidates should be able to:

(a) show an understanding of the concept of an electric field as an example of a field of force and define electric field strength as force per unit positive charge.

(b) represent an electric field by means of field lines.

(c) recall and use Coulomb's law in the form $F = Q_1Q_2/4\pi\varepsilon_o r^2$ for the force between two point charges in free space or air.

(d) recall and use $E = Q/4\pi\varepsilon_o r^2$ for the field strength of a point charge in free space or air.

(e) calculate the field strength of the uniform field between charged parallel plates in terms of potential difference and separation.

(f) calculate the forces on charges in uniform electric fields.

(g) describe the effect of a uniform electric field on the motion of charged particles.

(h) define potential at a point in terms of the work done in bringing unit positive charge from infinity to the point.

(i) state that the field strength of the field at a point is numerically equal to the potential gradient at that point.

(j) use the equation $V = Q/4\pi\varepsilon_o r$ for the potential in the field of a point charge.

(k) recognise the analogy between certain qualitative and quantitative aspects of electric field and gravitational fields.

13. Current of Electricity

Content

- Electric current
- Potential difference
- Resistance and resistivity
- Sources of electromotive force

Learning Outcomes

Candidates should be able to:

(a) show an understanding that electric current is the rate of flow of charged particles.

(b) define charge and the coulomb.

(c) recall and solve problems using the equation $Q = It$.

(d) define potential difference and the volt.

(e) recall and solve problems using $V = W/Q$.

(f) recall and solve problems using $P = VI$, $P = I^2R$.

(g) define resistance and the ohm.

(h) recall and solve problems using $V = IR$.

(i) sketch and explain the I-V characteristics of a metallic conductor at constant temperature, a semiconductor diode and a filament lamp.

(j) sketch the temperature characteristic of a thermistor.

(k) recall and solve problems using $R = \rho l/A$.

(l) define e.m.f. in terms of the energy transferred by a source in driving unit charge round a complete circuit.

(m) distinguish between e.m.f. and p.d. in terms of energy considerations.

(n) show an understanding of the effects of the internal resistance of a source of e.m.f. on the terminal potential difference and output power.

14. D.C. Circuits

Content

- Practical circuits
- Series and parallel arrangements
- Potential divider
- Balanced potentials

Learning Outcomes

Candidates should be able to:

(a) recall and use appropriate circuit symbols as set out in *SI Units, Signs, Symbols and Abbreviations* (ASE, 1981) and *Signs, Symbols and Systematics* (ASE, 2000).

(b) draw and interpret circuit diagrams containing sources, switches, resistors, ammeters, voltmeters, and/or any other type of component referred to in the syllabus.

(c) solve problems using the formula for the combined resistance of two or more resistors in series.

(d) solve problems using the formula for the combined resistance of two or more resistors in parallel.

(e) solve problems involving series and parallel circuits for one source of e.m.f.

(f) show an understanding of the use of a potential divider circuit as a source of variable p.d.

(g) explain the use of thermistors and light-dependent resistors in potential dividers to provide a potential difference which is dependent on temperature and illumination respectively.

(h) recall and solve problems by using the principle of the potentiometer as a means of comparing potential differences.

15. Electromagnetism

Content

- Force on a current-carrying conductor
- Force on a moving charge
- Magnetic fields due to currents
- Force between current-carrying conductors

Learning Outcomes

Candidates should be able to:

(a) show an appreciation that a force might act on a current-carrying conductor placed in a magnetic field.

(b) recall and solve problems using the equation $F = BIl\sin\theta$, with directions as interpreted by Fleming's left-hand rule.

(c) define magnetic flux density and the tesla.

(d) show an understanding of how the force on a current-carrying conductor can be used to measure the flux density of a magnetic field using a current balance.

(e) predict the direction of the force on a charge moving in a magnetic field.

(f) recall and solve problems using $F = BQv\sin\theta$.

(g) describe and analyse deflections of beams of charged particles by uniform electric and uniform magnetic fields.

(h) explain how electric and magnetic fields can be used in velocity selection for charged particles.

(i) sketch flux patterns due to a long straight wire, a flat circular coil and a long solenoid.

(j) show an understanding that the field due to a solenoid may be influenced by the presence of ferrous core.

(k) explain the forces between current-carrying conductors and predict the direction of the forces.

16. Electromagnetic Induction

Content

- Magnetic flux
- Laws of electromagnetic induction

Learning Outcomes

Candidates should be able to:

(a) define magnetic flux and the weber.

(b) recall and solve problems using $\Phi = BA$.

(c) define magnetic flux linkage.

(d) infer from appropriate experiments on electromagnetic induction:
i. that a changing magnetic flux can induce an e.m.f. in a circuit,
ii. that the direction of the induced e.m.f. opposes the change producing it,
iii. the factors affecting the magnitude of the induced e.m.f.

(e) recall and solve problems using Faraday's law of electromagnetic induction and Lenz's law.

(f) explain simple applications of electromagnetic induction.

17. Alternating Currents

Content

- Characteristics of alternating currents
- The transformer
- Rectification with a diode

Learning Outcomes

Candidates should be able to:

(a) show an understanding and use the terms period, frequency, peak value and root-mean-square value as applied to an alternating current or voltage.

(b) deduce that the mean power in a resistive load is half the maximum power for a sinusoidal alternating current.

(c) represent an alternating current or an alternating voltage by an equation of the form
$x = x_o \sin\omega t$.

(d) distinguish between r.m.s. and peak values and recall and solve problems using the relationship $I_{rms} = I_o/\sqrt{2}$ for the sinusoidal case.

(e) show an understanding of the principle of operation of a simple iron-cored transformer and recall and solve problems using $N_s/N_p = V_s/V_p = I_p/I_s$ for an ideal transformer.

(f) explain the use of a single diode for the half-wave rectification of an alternating current.

SECTION VI MODERN PHYSICS

18. Quantum Physics

Content

- Energy of a photon
- The photoelectric effect
- Wave-particle duality
- Energy levels in atoms
- Line spectra
- X-ray spectra
- The uncertainty principle
- Schrödinger model
- Barrier tunnelling

Learning Outcomes

Candidates should be able to:

(a) show an appreciation of the particulate nature of electromagnetic radiation.

(b) recall and use $E = hf$.

(c) show an understanding that the photoelectric effect provides evidence for a particulate nature of electromagnetic radiation while phenomena such as interference and diffraction provide evidence for a wave nature.

(d) recall the significance of threshold frequency.

(e) recall and use the equation $\frac{1}{2}mv_{max}^2 = eV_s$, where V_s is the stopping potential.

(f) explain photoelectric phenomena in terms of photon energy and work function energy.

(g) explain why the maximum photoelectric energy is independent of intensity whereas the photoelectric current is proportional to intensity.

(h) recall, use and explain the significance of $hf = \Phi + \frac{1}{2}mv_{max}^2$.

(i) describe and interpret qualitatively the evidence provided by electron diffraction for the wave nature of particles.

(j) recall and use the relation for the de Broglie wavelength $\lambda = h/p$.

(k) show an understanding of the existence of discrete electron energy levels in isolated atoms (e.g. atomic hydrogen) and deduce how this leads to spectral lines.

(l) distinguish between emission and absorption line spectra.

(m) recall and solve problems using the relation $hf = E_1 - E_2$.

(n) explain the origins of the features of a typical X-ray spectrum using quantum theory.

(o) show an understanding of and apply the Heisenberg position-momentum and time-energy uncertainty principles in new situations or to solve related problems.

(p) show an understanding that an electron can be described by a wave function Ψ where the square of the amplitude of wave function $|\Psi|^2$ gives the probability of finding the electron at a point. (No mathematical treatment is required.)

(q) show an understanding of the concept of a potential barrier and explain qualitatively the phenomenon of quantum tunnelling of an electron across such a barrier.

(r) describe the application of quantum tunnelling to the probing tip of a scanning tunnelling microscope (STM) and how this is used to obtain atomic-scale images of surfaces. (Details of the structure and operation of a scanning tunnelling microscope are not required.)

(s) apply the relationship transmission coefficient $T = exp(-2kd)$ for the STM in related situations or to solve problems. (Recall of the equation is not required.)

(t) recall and use the relationship $R + T = 1$, where R is the reflection coefficient and T is the transmission coefficient, in related situations or to solve problems.

19. Lasers and Semiconductors

Content

- Basic principles of lasers
- Energy bands, conductors and insulators
- Semiconductors
- Depletion region of a p-n junction

Learning Outcomes

Candidates should be able to:

(a) recall and use the terms spontaneous emission, stimulated emission and population inversion in related situations.

(b) explain the action of a laser in terms of population inversion and stimulated emission. (Details of the structure and operation of a laser are not required.)

(c) describe the formation of energy bands in a solid, with reference to conduction electrons and holes.

(d) distinguish between conduction band and valence band.

(e) use band theory to account for the electrical properties of metals, insulators and intrinsic semiconductors.

(f) analyse qualitatively how n- and p-type doping change the conduction properties of semiconductors.

(g) discuss qualitatively the origin of the depletion region at a p-n junction and use this to explain how a p-n junction can act as a rectifier.

20. Nuclear Physics

Content

- The nucleus
- Isotopes
- Mass defect and nuclear binding energy
- Nuclear processes
- Radioactive decay
- Biological effect of radiation

Learning Outcomes

Candidates should be able to:

(a) infer from the results of the α-particle scattering experiment the existence and small size of the nucleus.

(b) distinguish between nucleon number (mass number) and proton number (atomic number).

(c) show an understanding that an element can exist in various isotopic forms each with a different number of neutrons.

(d) use the usual notation for the representation of nuclides and represent simple nuclear reactions by nuclear equations of the form ${}^{14}_{7}\mathrm{N} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{17}_{8}\mathrm{O} + {}^{1}_{1}\mathrm{H}$.

(e) show an understanding of the concept of mass defect.

(f) recall and apply the equivalence relationship between energy and mass as represented by $E = mc^2$ in problem solving.

(g) show an understanding of the concept of binding energy and its relation to mass defect.

(h) sketch the variation of binding energy per nucleon with nucleon number.

(i) explain the relevance of binding energy per nucleon to nuclear fusion and to nuclear fission.

(j) state and apply to problem solving the concept that nucleon number, proton number, energy and mass are all conserved in nuclear processes.

(k) show an understanding of the spontaneous and random nature of nuclear decay.

(l) infer the random nature of radioactive decay from the fluctuations in count rate.

(m) show an understanding of the origin and significance of background radiation.

(n) show an understanding of the nature of α, β and γ radiations.

(o) define the terms activity and decay constant and recall and solve problems using $A = \lambda N$.

(p) infer and sketch the exponential nature of radioactive decay and solve problems using the relationship $x = x_o exp(-\lambda t)$ where x could represent activity, number of undecayed particles and received count rate.

(q) define half-life.

(r) solve problems using the relation $\lambda = \dfrac{0.693}{t_{\frac{1}{2}}}$.

(s) discuss qualitatively the effects, both direct and indirect, of ionising radiation on living tissues and cells.

MATHEMATICAL REQUIREMENTS

Arithmetic

Candidates should be able to:

(a) recognise and use expressions in decimal and standard form (scientific) notation.

(b) use appropriate calculating aids (electronic calculator or tables) for addition, subtraction, multiplication and division. Find arithmetic means, powers (including reciprocals and square roots), sines, cosines, tangents (and the inverse functions), exponentials and logarithms (lg and ln).

(c) take account of accuracy in numerical work and handle calculations so that significant figures are neither lost unnecessarily nor carried beyond what is justified.

(d) make approximate evaluations of numerical expressions (e.g. $\pi^2 = 10$) and use such approximations to check the magnitude of machine calculations.

Algebra

Candidates should be able to:

(a) change the subject of an equation. Most relevant equations involve only the simpler operations but may include positive and negative indices and square roots.

(b) solve simple algebraic equations. Most relevant equations are linear but some may involve inverse and inverse square relationships. Linear simultaneous equations and the use of the formula to obtain the solutions of quadratic equations are included.

(c) substitute physical quantities into physical equations using consistent units and check the dimensional consistency of such equations.

(d) formulate simple algebraic equations as mathematical models of physical situations, and identify inadequacies of such models.

(e) recognise and use the logarithmic forms of expressions like ab, a/b, x^n, e^{kx}; understand the use of logarithms in relation to quantities with values that range over several orders of magnitude.

(f) manipulate and solve equations involving logarithmic and exponential functions.

(g) express small changes or errors as percentages and *vice versa.*

(h) comprehend and use the symbols $<$, $>$, «, », $\approx$, /, $\propto$, <*x*> (= $\bar{x}$), Σ, Δx, δx, $\surd$.

Geometry and trigonometry

Candidates should be able to:

(a) calculate areas of right-angled and isosceles triangles, circumference and area of circles, areas and volumes of rectangular blocks, cylinders and spheres.

(b) use Pythagoras' theorem, similarity of triangles, the angle sum of a triangle.

(c) use sines, cosines and tangents (especially for 0°, 30°, 45°, 60°, 90°). Use the trigonometric relationships for triangles:

$$\frac{a}{\sin A} \quad \frac{b}{\sin B} \quad \frac{c}{\sin C}; \qquad a^2 \quad b^2 + c^2 \quad 2bc\cos A$$

(d) use $\sin\theta \approx \tan\theta \approx \theta$ and $\cos\theta \approx 1$ for small θ; $\sin^2\theta + \cos^2\theta = 1$.

(e) understand the relationship between degrees and radians (defined as arc/radius), translate from one to the other and use the appropriate system in context.

Vectors

Candidates should be able to:

(a) find the resultant of two coplanar vectors, recognising situations where vector addition is appropriate.

(b) obtain expressions for components of a vector in perpendicular directions, recognising situations where vector resolution is appropriate.

Graphs

Candidates should be able to:

(a) translate information between graphical, numerical, algebraic and verbal forms.

(b) select appropriate variables and scales for graph plotting.

(c) for linear graphs, determine the slope, intercept and intersection.

(d) choose, by inspection, a straight line which will serve as the best straight line through a set of data points presented graphically.

(e) recall standard linear form $y = mx + c$ and rearrange relationships into linear form where appropriate.

(f) sketch and recognise the forms of plots of common simple expressions like $1/x$, x^2, $1/x^2$, $\sin x$, $\cos x$, e^{-x}.

(g) use logarithmic plots to test exponential and power law variations.

(h) understand, draw and use the slope of a tangent to a curve as a means to obtain the gradient, and use notation in the form dy/dx for a rate of change.

(i) understand and use the area below a curve where the area has physical significance.

GLOSSARY OF TERMS USED IN PHYSICS PAPERS

It is hoped that the glossary will prove helpful to candidates as a guide, although it is not exhaustive. The glossary has been deliberately kept brief not only with respect to the number of terms included but also to the descriptions of their meanings. Candidates should appreciate that the meaning of a term must depend in part on its context. They should also note that the number of marks allocated for any part of a question is a guide to the depth of treatment required for the answer.

1. *Define* (*the term(s)* ...) is intended literally. Only a formal statement or equivalent paraphrase, such as the defining equation with symbols identified, being required.

2. *What is meant by ...* normally implies that a definition should be given, together with some relevant comment on the significance or context of the term(s) concerned, especially where two or more terms are included in the question. The amount of supplementary comment intended should be interpreted in the light of the indicated mark value.

3. *Explain* may imply reasoning or some reference to theory, depending on the context.

4. *State* implies a concise answer with little or no supporting argument, e.g. a numerical answer that can be obtained 'by inspection'.

5. *List* requires a number of points with no elaboration. Where a given number of points is specified, this should not be exceeded.

6. *Describe* requires candidates to state in words (using diagrams where appropriate) the main points of the topic. It is often used with reference either to particular phenomena or to particular experiments. In the former instance, the term usually implies that the answer should include reference to (visual) observations associated with the phenomena. The amount of description intended should be interpreted in the light of the indicated mark value.

7. *Discuss* requires candidates to give a critical account of the points involved in the topic.

8. *Deduce/Predict* implies that candidates are not expected to produce the required answer by recall but by making a logical connection between other pieces of information. Such information may be wholly given in the question or may depend on answers extracted in an earlier part of the question.

9. *Suggest* is used in two main contexts. It may either imply that there is no unique answer or that candidates are expected to apply their general knowledge to a 'novel' situation, one that formally may not be 'in the syllabus'.

10. *Calculate* is used when a numerical answer is required. In general, working should be shown.

11. *Measure* implies that the quantity concerned can be directly obtained from a suitable measuring instrument, e.g. length, using a rule, or angle, using a protractor.

12. *Determine* often implies that the quantity concerned cannot be measured directly but is obtained by calculation, substituting measured or known values of other quantities into a standard formula, e.g. the Young modulus, relative molecular mass.

13. *Show* is used when an algebraic deduction has to be made to prove a given equation. It is important that the terms being used by candidates are stated explicitly.

14. *Estimate* implies a reasoned order of magnitude statement or calculation of the quantity concerned. Candidates should make such simplifying assumptions as may be necessary about points of principle and about the values of quantities not otherwise included in the question.

15. *Sketch,* when applied to graph work, implies that the shape and/or position of the curve need only be qualitatively correct. However, candidates should be aware that, depending on the context, some quantitative aspects may be looked for, e.g. passing through the origin, having an intercept, asymptote or discontinuity at a particular value. On a sketch graph it is essential that candidates clearly indicate what is being plotted on each axis.

16. *Sketch,* when applied to diagrams, implies that a simple, freehand drawing is acceptable: nevertheless, care should be taken over proportions and the clear exposition of important details.

17. *Compare* requires candidates to provide both similarities and differences between things or concepts.

TEXTBOOKS

Practice in Physics (3rd Edition), by Akrill et al, published by Hodder & Stoughton, ISBN 0-340-75813-9

New Understanding Physics for Advanced Level (4th Edition), by J. Breithaupt, published by Nelson Thornes, ISBN 0-748-74314-6

Advanced Physics (4th Edition), by T. Duncan, published by John Murray, ISBN 0-719-57669-5

Advanced Physics (2nd Edition), by K. Gibbs, published by Cambridge University Press,
ISBN 0-521-56701-7

Bath Advanced Science: Physics (2nd Edition), by R. Hutchings, published by Nelson Thornes, ISBN 0-174-38731-8

Physics for Scientists and Engineers with Modern Physics (5th Edition), by R. Serway, published by Saunders, ISBN 0-030-20974-9

Fundamental of Physics (Extended – 6th Edition), by R. Resnick, D. Halliday & J. Walker, published by Wiley, ISBN 0-471-22863-X

Physics: Principles with Applications (5th Edition), by D.C. Giancoli, published by Prentice Hall, ISBN 0-13611-971-9

SUMMARY OF KEY QUANTITIES, SYMBOLS AND UNITS

The following list illustrates the symbols and units that will be used in question papers.

Quantity	***Usual symbols***	***Usual unit***
Base Quantities		
mass	m	kg
length	l	m
time	t	s
electric current	I	A
thermodynamic temperature	T	K
amount of substance	n	mol
Other Quantities		
distance	d	m
displacement	s, x	m
area	A	m^2
volume	V, v	m^3
density	ρ	$kg\ m^{-3}$
speed	u, v, w, c	$m\ s^{-1}$
velocity	u, v, w, c	$m\ s^{-1}$
acceleration	a	$m\ s^{-2}$
acceleration of free fall	g	$m\ s^{-2}$
force	F	N
weight	W	N
momentum	p	N s
work	w, W	J
energy	E,U,W	J
potential energy	E_p	J
kinetic energy	E_k	J
heating	Q	J
change of internal energy	ΔU	J
power	P	W
pressure	p	Pa
torque	T	N m
gravitational constant	G	$N\ kg^{-2}\ m^2$
gravitational field strength	g	$N\ kg^{-1}$
gravitational potential	ϕ	$J\ kg^{-1}$
angle	θ	°, rad
angular displacement	θ	°, rad
angular speed	ω	$rad\ s^{-1}$
angular velocity	ω	$rad\ s^{-1}$
period	T	s
frequency	f	Hz
angular frequency	ω	$rad\ s^{-1}$
wavelength	λ	m
speed of electromagnetic waves	c	$m\ s^{-1}$
electric charge	Q	C
elementary charge	e	C
electric potential	V	V
electric potential difference	V	V
electromotive force	E	V
resistance	R	Ω
resistivity	ρ	Ω m
electric field strength	E	$N\ C^{-1}$, $V\ m^{-1}$
permittivity of free space	ε_o	$F\ m^{-1}$
magnetic flux	Φ	Wb

Quantity	*Usual symbols*	*Usual unit*
magnetic flux density	B	T
permeability of free space	μ_o	H m^{-1}
force constant	k	N m^{-1}
Celsius temperature	θ	°C
specific heat capacity	c	J K^{-1} kg^{-1}
molar gas constant	R	J K^{-1} mol^{-1}
Boltzmann constant	k	J K^{-1}
Avogadro constant	N_A	mol^{-1}
number	N, n, m	
number density (number per unit volume)	n	m^{-3}
Planck constant	h	J s
work function energy	Φ	J
activity of radioactive source	A	Bq
decay constant	λ	s^{-1}
half-life	$t_{1/2}$	s
relative atomic mass	A_r	
relative molecular mass	M_r	
atomic mass	m_a	kg, u
electron mass	m_e	kg, u
neutron mass	m_n	kg, u
proton mass	m_p	kg, u
molar mass	M	kg
proton number	Z	
nucleon number	A	
neutron number	N	

DATA AND FORMULAE

Data

speed of light in free space	c	=	3.00×10^{8} m s^{-1}
permeability of free space	μ_o	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_o	=	8.85×10^{-12} F m^{-1}
			$(1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	e	=	1.60×10^{-19} C
the Planck constant	h	=	6.63×10^{-34} Js
unified atomic mass constant	u	=	1.66×10^{-27} kg
rest mass of electron	m_e	=	9.11×10^{-31} kg
rest mass of proton	m_p	=	1.67×10^{-27} kg
molar gas constant	R	=	8.31 J K^{-1} mo^{-1}
the Avogadro constant	N_A	=	6.02×10^{23} mol^{-1}
the Boltzmann constant	k	=	1.38×10^{-23} J K^{-1}
gravitational constant	G	=	6.67×10^{-11} N m^{2} kg^{-2}
acceleration of free fall	g	=	9.81 m s^{-2}

Formulae

uniformly accelerated motion	s	=	$ut + \frac{1}{2}at^2$
	v^2	=	$u^2 + 2as$
work done on/by a gas	W	=	$p\Delta V$
hydrostatic pressure	p	=	ρgh
gravitational potential	ϕ	=	$-Gm/r$
displacement of particle in s.h.m.	x	=	$x_o \sin\omega t$
velocity of particle in s.h.m.	v	=	$v_o \cos\omega t$
		=	$\pm\,\omega\sqrt{\left(x_o^2 - x^2\right)}$
resistors in series	R	=	$R_1 + R_2 + ...$
resistors in parallel	$1/R$	=	$1/R_1 + 1/R_2 + ...$
electric potential	V	=	$Q/4\pi\varepsilon_o r$
alternating current/voltage	x	=	$x_o \sin\omega t$
transmission coefficient	T	=	$exp(-2kd)$
	where k	=	$\sqrt{\frac{8\pi^2 m(U-E)}{h^2}}$
radioactive decay	x	=	$x_o\, exp(-\lambda t)$
decay constant	λ	=	$\frac{0.693}{t_{\frac{1}{2}}}$