NANYANG
TECHNOLOGICAL
UNIVERSITY

SINGAPORE

Entrance Examination Syllabus 2021

Physics

updated as at April 2021

SUBJECT CONTENT

SECTION I MEASUREMENT

1. Measurement

Content

- Physical quantities and SI units
- Scalars and vectors
- Errors and uncertainties

Learning Outcomes

Candidates should be able to:

(a) recall the following base quantities and their SI 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) use SI base units to check the homogeneity of physical equations

(d) show an understanding of and use the conventions for labelling graph axes and table columns as set out in the ASE publication ***Signs, Symbols and Systematics (The ASE Companion to 16–19 Science, 2000)***

(e) 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)

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

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

(h) add and subtract coplanar vectors

(i) represent a vector as two perpendicular components

(j) show an understanding of the distinction between systematic errors (including zero error) and random errors

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

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

SECTION II NEWTONIAN MECHANICS

2. Kinematics

Content

- Rectilinear motion
- Non-linear motion

Learning Outcomes

Candidates should be able to:

(a) show an understanding of and use the terms distance, displacement, speed, velocity and acceleration

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

(c) identify and use the physical quantities from the gradients of displacement-time graphs and areas under and gradients of velocity-time graphs, including cases of non-uniform acceleration

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

(e) 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

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

(g) 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 and apply each of Newton's laws of motion

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

(c) describe and use the concept of weight as the force experienced by a mass in a gravitational field

(d) define and use linear momentum as the product of mass and velocity

(e) define and use impulse as the product of force and time of impact

(f) relate resultant force to the rate of change of momentum

(g) recall and solve problems using the relationship $\boldsymbol{F = ma}$, appreciating that resultant force and acceleration are always in the same direction

(h) state the principle of conservation of momentum

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

(j) show an understanding that, for a (perfectly) elastic collision between two bodies, the relative speed of approach is equal to the relative speed of separation

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

4. Forces

Content

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

Learning Outcomes

Candidates should be able to:

(a) recall and apply Hooke's law ($F = kx$, where k is the force constant) to new situations or to solve related problems

(b) describe the forces on a mass, charge and current-carrying conductor in gravitational, electric and magnetic fields, as appropriate

(c) show a qualitative understanding of normal contact forces, frictional forces and viscous forces including air resistance (no treatment of the coefficients of friction and viscosity is required)

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

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

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

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

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

(i) use a vector triangle to represent forces in equilibrium

(j) derive, from the definitions of pressure and density, the equation $p = \rho gh$

(k) solve problems using the equation $p = \rho gh$

(l) show an understanding of the origin of the force of upthrust acting on a body in a fluid

(m) state that upthrust is equal in magnitude and opposite in direction to the weight of the fluid displaced by a submerged or floating object

(n) calculate the upthrust in terms of the weight of the displaced fluid

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

5. Work, Energy and Power

Content

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

Learning Outcomes

Candidates should be able to:

(a) define and use work done by a force as the product of the 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: $\boldsymbol{W = p\Delta V}$

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

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

(e) derive, from the equations for uniformly accelerated motion in a straight line, the equation $E_k = \frac{1}{2}mv^2$

(f) recall and use the equation $E_k = \frac{1}{2}mv^2$

(g) distinguish between gravitational potential energy, electric potential energy and elastic potential energy

(h) deduce that the elastic potential energy in a deformed material is related to the area under the force-extension graph

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

(j) derive, from the definition of work done by a force, the equation $E_p = mgh$ for gravitational potential energy changes near the Earth's surface

(k) recall and use the equation $E_p = mgh$ for gravitational potential energy changes near the Earth's surface

(l) define power as work done per unit time and derive power as the product of a force and velocity in the direction of the force.

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) show an understanding of and use the concept of angular velocity to solve problems

(c) recall and use $\boldsymbol{v} = \boldsymbol{r}\omega$ 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 $\boldsymbol{a} = \boldsymbol{r}\omega^2$, and $\boldsymbol{a} = \boldsymbol{v}^2/\boldsymbol{r}$ to solve problems

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

7. Gravitational Field

Content

- Gravitational field
- Gravitational force between point masses
- Gravitational field of a point mass
- Gravitational field near to the surface of the Earth
- Gravitational potential
- Circular orbits

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 the gravitational field strength at a point as the gravitational force exerted per unit mass placed at that point

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

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

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

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

(f) show an understanding that near the surface of the Earth, gravitational field strength is approximately constant and is equal to the acceleration of free fall

(g) define the gravitational potential at a point as the work done per unit mass in bringing a small test mass from infinity to that point

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

(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.

SECTION III THERMAL PHYSICS

8. Temperature and Ideal Gases

Content

- Thermal equilibrium
- Temperature scales
- Equation of state
- Kinetic theory of gases
- Kinetic energy of a molecule

Learning Outcomes

Candidates should be able to:

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

(b) explain how empirical evidence leads to the gas laws and to the idea of an absolute scale of temperature (i.e. the thermodynamic scale that is independent of the property of any particular substance and has an absolute zero)

(c) convert temperatures measured in degrees Celsius to kelvin: $T / \mathrm{K} = T / {}^\circ\mathrm{C} + 273.15$

(d) recall and use the equation of state for an ideal gas expressed as $pV = nRT$, where n is the amount of gas in moles

(e) state that one mole of any substance contains $6.02 \cdot 10^{23}$ particles and use the Avogadro number $N_A = 6.02 \cdot 10^{23}\ \mathrm{mol}^{-1}$

(f) state the basic assumptions of the kinetic theory of gases

(g) explain how molecular movement causes the pressure exerted by a gas and hence derive the relationship $pV = \frac{1}{3} Nm\langle c^2\rangle$, where N is the number of gas molecules (a simple model considering one-dimensional collisions and then extending to three dimensions using $\frac{1}{3}\langle c^2\rangle = \langle c_x^2\rangle$ is sufficient)

(h) recall and apply the relationship that the mean kinetic energy of a molecule of an ideal gas is proportional to the thermodynamic temperature (i.e. $\frac{1}{2} m\langle c^2\rangle = \frac{3}{2} kT$) to new situations or to solve related problems.

9. First Law of Thermodynamics

Content

- Specific heat capacity and specific latent heat
- Internal energy
- First law of thermodynamics

Learning Outcomes

Candidates should be able to:

(a) define and use the concepts of specific heat capacity and specific latent heat

(b) 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

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

(d) recall and use the first law of thermodynamics expressed in terms of the increase in internal energy, the heat supplied to the system and the work done on the system.

SECTION IV OSCILLATION AND WAVES

10. 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) show an understanding of 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) recall and use the equation $\boldsymbol{a} = -\omega^2\boldsymbol{x}$ as the defining equation of simple harmonic motion

(e) recognise and use $\boldsymbol{x} = \boldsymbol{x}_0 \sin \omega \boldsymbol{t}$ as a solution to the equation $\boldsymbol{a} = -\omega^2\boldsymbol{x}$

(f) recognise and use the equations $\boldsymbol{v} = \boldsymbol{v}_0 \cos \omega \boldsymbol{t}$ and $\boldsymbol{v} = \pm\,\omega\sqrt{\left(\boldsymbol{x}_0^2 - \boldsymbol{x}^2\right)}$

(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 to the importance of critical damping in applications 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 driving 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.

11. Wave Motion

Content

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

Learning Outcomes

Candidates should be able to:

(a) show an understanding of and use the terms displacement, amplitude, period, frequency, phase difference, 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) show an understanding of and apply the concept that a wave from a point source and travelling without loss of energy obeys an inverse square law to solve problems

(g) analyse and interpret graphical representations of transverse and longitudinal waves

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

(i) recall and use Malus' law ($intensity \propto \cos^2\theta$) to calculate the amplitude and intensity of a plane polarised electromagnetic wave after transmission through a polarising filter

(j) determine the frequency of sound using a calibrated oscilloscope

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

12. Superposition

Content

- Principle of superposition
- Stationary waves
- Diffraction
- Two-source interference
- Single slit and multiple slit diffraction

Learning Outcomes

Candidates should be able to:

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

(b) show an understanding of the terms interference, coherence, phase difference and path difference

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

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

(e) explain the meaning of the term diffraction

(f) 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

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

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

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

(j) recall and use the equation $\sin\theta = \lambda/b$ to locate the position of the first minima for single slit diffraction

(k) recall and use the Rayleigh criterion $\theta \approx \lambda/b$ for the resolving power of a single aperture

(l) recall and use the equation $d\sin\theta = n\lambda$ to locate the positions of the principal maxima produced by a diffraction grating

(m) describe the use of a diffraction grating to determine the wavelength of light (the structure and use of a spectrometer are not required).

SECTION V ELECTRICITY AND MAGNETISM

13. Electric Fields

Content

- Concept of an electric field
- Electric 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 at a point as the electric force exerted per unit positive charge placed at that point

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

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

(d) recall and use Coulomb's law in the form $F = Q_1Q_2 / 4\pi\varepsilon_0 r^2$ for the electric force between two point charges in free space or air

(e) recall and use $E = Q / 4\pi\varepsilon_0 r^2$ for the electric field strength of a point charge in free space or air

(f) calculate the electric field strength of the uniform field between charged parallel plates in terms of the potential difference and plate separation

(g) calculate the forces on charges in uniform electric fields

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

(i) define the electric potential at a point as the work done per unit positive charge in bringing a small test charge from infinity to that point

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

(k) use the equation $V = Q / 4\pi\varepsilon_0 r$ for the electric potential in the field of a point charge, in free space or air.

14. Current of Electricity

Content

- Electric current
- Potential difference
- Resistance and resistivity
- Electromotive force

Learning Outcomes

Candidates should be able to:

(a) show an understanding that electric current is the rate of flow of charge

(b) derive and use the equation $\boldsymbol{I = nAvq}$ for a current-carrying conductor, where $\boldsymbol{n}$ is the number density of charge carriers and $\boldsymbol{v}$ is the drift velocity

(c) recall and solve problems using the equation $\boldsymbol{Q = It}$

(d) recall and solve problems using the equation $\boldsymbol{V = W/Q}$

(e) recall and solve problems using the equations $\boldsymbol{P = VI}$, $\boldsymbol{P = I^2R}$ and $\boldsymbol{P} = \boldsymbol{V}^2 / R$

(f) define the resistance of a circuit component as the ratio of the potential difference across the component to the current passing through it and solve problems using the equation $\boldsymbol{V = IR}$

(g) sketch and explain the ***I–V*** characteristics of various electrical components such as an ohmic resistor, a semiconductor diode, a filament lamp and a negative temperature coefficient (NTC) thermistor

(h) sketch the resistance-temperature characteristic of an NTC thermistor

(i) recall and solve problems using the equation $\boldsymbol{R = \rho l / A}$

(j) distinguish between electromotive force (e.m.f.) and potential difference (p.d.) using energy considerations

(k) 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.

15. D.C. Circuits

Content

- Circuit symbols and diagrams
- 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 the ASE publication ***Signs, Symbols and Systematics (The ASE Companion to 16–19 Science, 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 divider circuits 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.

16. Electromagnetism

Content

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

Learning Outcomes

Candidates should be able to:

(a) show an understanding that a magnetic field is an example of a field of force produced either by current-carrying conductors or by permanent magnets

(b) sketch flux patterns due to currents in a long straight wire, a flat circular coil and a long solenoid

(c) use $\boldsymbol{B} = \propto_0 \boldsymbol{I} / 2\pi \boldsymbol{d}$, $\boldsymbol{B} = \propto_0 \boldsymbol{NI} / 2\boldsymbol{r}$ and $\boldsymbol{B} = \propto_0 \boldsymbol{nI}$ for the flux densities of the fields due to currents in a long straight wire, a flat circular coil and a long solenoid respectively

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

(e) show an understanding that a current-carrying conductor placed in a magnetic field might experience a force

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

(g) define magnetic flux density

(h) 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

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

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

(k) recall and solve problems using the equation $\boldsymbol{F} = \boldsymbol{BQv} \sin \theta$

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

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

17. Electromagnetic Induction

Content

- Magnetic flux
- Laws of electromagnetic induction

Learning Outcomes

Candidates should be able to:

(a) define magnetic flux as the product of an area and the component of the magnetic flux density perpendicular to that area

(b) recall and solve problems using $\Phi = \boldsymbol{BA}$

(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.
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.

18. Alternating Current

Content

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

Learning Outcomes

Candidates should be able to:

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

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

(c) represent an alternating current or an alternating voltage by an equation of the form $\boldsymbol{x} = \boldsymbol{x}_0 \sin \omega \boldsymbol{t}$

(d) distinguish between r.m.s. and peak values and recall and solve problems using the relationship $\boldsymbol{I}_{\text{rms}} = \boldsymbol{I}_0/\sqrt{2}$ for the sinusoidal case

(e) show an understanding of the principle of operation of a simple iron-core transformer and recall and solve problems using $\boldsymbol{N}_s/\boldsymbol{N}_p = \boldsymbol{V}_s/\boldsymbol{V}_p = \boldsymbol{I}_p/\boldsymbol{I}_s$ 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

19. 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

Learning Outcomes

Candidates should be able to:

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

(b) recall and use the equation $E = hf$ for the energy of a photon

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

(d) recall the significance of threshold frequency

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

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

(g) explain why the stopping potential is independent of intensity whereas the photoelectric current is proportional to intensity at constant frequency

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

(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 electronic energy levels in isolated atoms (e.g. atomic hydrogen) and deduce how this leads to the observation of spectral lines

(l) distinguish between emission and absorption line spectra

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

(n) explain the origins of the features of a typical X-ray spectrum

(o) show an understanding of and apply $\Delta p \Delta x \gtrsim h$ as a form of the Heisenberg position-momentum uncertainty principle to new situations or to solve related problems.

20. Nuclear Physics

Content

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

Learning Outcomes

Candidates should be able to:

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

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

(f) show an understanding of the concept of mass defect

(g) recall and apply the equivalence between energy and mass as represented by $\boldsymbol{E = mc^2}$ to solve problems

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

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

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

(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 (knowledge of positron emission is not required)

(o) show an understanding of how the conservation laws for energy and momentum in β decay were used to predict the existence of the neutrino (knowledge of antineutrino and antiparticles is not required)

(p) define the terms activity and decay constant and recall and solve problems using the equation $\boldsymbol{A = \lambda N}$

(q) infer and sketch the exponential nature of radioactive decay and solve problems using the relationship $\boldsymbol{x = x_0} \exp(-\lambda \boldsymbol{t})$ where $\boldsymbol{x}$ could represent activity, number of undecayed particles or received count rate

(r) define and use half-life as the time taken for a quantity $\boldsymbol{x}$ to reduce to half its initial value

(s) solve problems using the relation $\lambda = \dfrac{\ln 2}{t_{\frac{1}{2}}}$

(t) 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. $\pi^2 \approx 10$) 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 $\boldsymbol{ab}$, $\boldsymbol{a}/\boldsymbol{b}$, $\boldsymbol{x}^{\boldsymbol{n}}$, $e^{\boldsymbol{kx}}$; 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 $<$, $>$, $\ll$, $\gg$, $\approx$, /, $\propto$, $\langle x \rangle$ ($= \bar{x}$), Σ, $\Delta \boldsymbol{x}$, $\delta \boldsymbol{x}$, $\surd$.

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:

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

(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 line of best fit through a set of data points presented graphically

(e) recall standard linear form $y = \boldsymbol{mx + c}$ and rearrange relationships into linear form where appropriate

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

(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 $\mathrm{d}\boldsymbol{y} / \mathrm{d}\boldsymbol{x}$ for a rate of change

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

GLOSSARY OF TERMS

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.

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 AND REFERENCES

Teachers may find reference to the following books helpful.

Practice in Physics (4th Edition), by Akrill et al., published by Hodder Education, ISBN 1-444-12125-1

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

Advanced Physics (5th Edition), by T Duncan, published by Hodder Education, ISBN 0-719-57669-5

Physics for Scientists and Engineers with Modern Physics (9th Edition), by R Serway and J Jewett, published by Brooks/Cole, ISBN 1-133-95399-9

Fundamental of Physics (10th Edition), by R Resnick, D Halliday & J Walker, published by Wiley, ISBN 1-118-23071-X

Physics: Principles with Applications (7th Edition), by DC Giancoli, published by Addison-Wesley, ISBN 0-321-62592-2

College Physics, by PP Urone, published by Brooks/Cole, ISBN 0-534-37688-6

AS/A-Level Physics – Essential Word Dictionary by Mike Crundell, ISBN: 0860033775

Advanced Physics by Steve Adams and Jonathan Allday, Oxford University Press, ISBN: 978-0-19-914680-2

Cambridge International AS and A Level Physics Coursebook by Sang, Janoes, Woodside and Chandha, Cambridge University Press, ISBN: 9781107697690

The Language of Mathematics in Science: A Guide for Teachers of 11–16 Science, by R Boohan, published by Association for Science Education, ISBN 9780863574559

Teachers are encouraged to choose texts for class use that they feel will be of interest to their students and will support their own teaching style.

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_0	$F\,m^{-1}$
magnetic flux	Φ	Wb
magnetic flux density	B	T
permeability of free space	∞_0	$H\,m^{-1}$
force constant	k	$N\,m^{-1}$

Quantity	***Usual symbols***	***Usual unit***
Celsius temperature	θ	°C
specific heat capacity	c	$\mathrm{J\,K^{-1}\,kg^{-1}}$
molar gas constant	R	$\mathrm{J\,K^{-1}\,mol^{-1}}$
Boltzmann constant	k	$\mathrm{J\,K^{-1}}$
Avogadro constant	N_A	$\mathrm{mol^{-1}}$
number	N, n, m	
number density (number per unit volume)	n	$\mathrm{m^{-3}}$
Planck constant	h	J s
work function energy	Φ	J
activity of radioactive source	A	Bq
decay constant	λ	$\mathrm{s^{-1}}$
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	=	$3.00 \cdot 10^{8}\ \mathrm{m\ s^{-1}}$
permeability of free space	$\propto_0$	=	$4\pi \cdot 10^{-7}\ \mathrm{H\ m^{-1}}$
permittivity of free space	ε_0	=	$8.85 \cdot 10^{-12}\ \mathrm{F\ m^{-1}}$
			$(1/(36\pi)) \cdot 10^{-9}\ \mathrm{F\ m^{-1}}$
elementary charge	e	=	$1.60 \cdot 10^{-19}\ \mathrm{C}$
the Planck constant	h	=	$6.63 \cdot 10^{-34}\ \mathrm{J\ s}$
unified atomic mass constant	u	=	$1.66 \cdot 10^{-27}\ \mathrm{kg}$
rest mass of electron	m_e	=	$9.11 \cdot 10^{-31}\ \mathrm{kg}$
rest mass of proton	m_p	=	$1.67 \cdot 10^{-27}\ \mathrm{kg}$
molar gas constant	R	=	$8.31\ \mathrm{J\ K^{-1}\ mol^{-1}}$
the Avogadro constant	N_A	=	$6.02 \cdot 10^{23}\ \mathrm{mol^{-1}}$
the Boltzmann constant	k	=	$1.38 \cdot 10^{-23}\ \mathrm{J\ K^{-1}}$
gravitational constant	G	=	$6.67 \cdot 10^{-11}\ \mathrm{N\ m^2\ kg^{-2}}$
acceleration of free fall	g	=	$9.81\ \mathrm{m\ s^{-2}}$

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	=	$-\frac{Gm}{r}$
temperature	T/K	=	$T/{}^\circ\mathrm{C} + 273.15$
pressure of an ideal gas	p	=	$\frac{1}{3}\frac{Nm}{V}\langle c^2\rangle$
mean translational kinetic energy of an ideal gas molecule	E	=	$\frac{3}{2}kT$
displacement of particle in s.h.m.	x	=	$x_0 \sin \omega t$
velocity of particle in s.h.m.	v	=	$v_0 \cos \omega t$
		=	$\pm\omega\sqrt{\left(x_0^2 - x^2\right)}$
electric current	I	=	$Anvq$
resistors in series	R	=	$R_1 + R_2 + \ldots.$
resistors in parallel	$1/R$	=	$1/R_1 + 1/R_2 + \ldots.$
electric potential	V	=	$\frac{Q}{4\pi\varepsilon_0 r}$
alternating current/voltage	x	=	$x_0 \sin\omega t$
magnetic flux density due to a long straight wire	B	=	$\frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	B	=	$\frac{\propto_0 NI}{2r}$
magnetic flux density due to a long solenoid	B	=	$\propto_0 nI$

radioactive decay	$\boldsymbol{x}$	=	$\boldsymbol{x}_0 \exp(-\lambda \boldsymbol{t})$
decay constant	λ	=	$\dfrac{\ln 2}{\boldsymbol{t}_{\frac{1}{2}}}$