Qualification Accredited

OCR
Oxford Cambridge and RSA

A LEVEL

PHYSICS A

H556

For first teach in 2015

Student revision checklist

Version 1

www.ocr.org.uk/physics

Revision checklists

The tables below can be used as a revision checklist.

For more information please see the OCR A Level Physics A specification.

The table headings are explained below:

Assessable learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
Here is a list of the learning outcomes for this qualification and the content you need to cover and work on. You may wish to also have a copy of the data, Formulae and relationships booklet for reference.	You can use the tick boxes to show when you have revised an item and how confident you feel about it. R = **RED** means you are really unsure and lack confidence; you might want to focus your revision here and possibly talk to your teacher for help. A = **AMBER** means you are reasonably confident but need some extra practice. G = **GREEN** means you are very confident. As your revision progresses, you can concentrate on the **RED** and **AMBER** items in order to turn them into **GREEN** items. You might find it helpful to highlight each topic in red, orange or green to help you prioritise.			You can use the comments column to: • add more information about the details for each point • add formulae or notes • include a reference to a useful resource • highlight areas of difficulty or things that you need to talk to your teacher about or look up in a textbook.

Module 1	Development of practical skills in physics				
1.1	Practical skills assessed in a written examination				
1.1.1	Planning				
Learning outcomes You will be required to show and apply knowledge and understanding of:		R	A	G	Comments
(a)	experimental design, including to solve problems set in a practical context Including selection of suitable apparatus, equipment and techniques for the proposed experiment. Learners should be able to apply scientific knowledge based on the content of the specification to the practical context.				
(b)	identification of variables that must be controlled, where appropriate				
(c)	evaluation that an experimental method is appropriate to meet the expected outcomes				

1.1.2 Implementing				
(a) how to use a wide range of practical apparatus and techniques correctly As outlined in the content of the specification and the skills required for the Practical Endorsement.				
(b) appropriate units for measurements				
(c) presenting observations and data in an appropriate format				
1.1.3 Analysis				
(a) processing, analysing and interpreting qualitative and quantitative experimental results Including reaching valid conclusions, where appropriate.				
(b) use of appropriate mathematical skills for analysis of quantitative data Refer to Section 5d for a list of mathematical skills that learners should have acquired competence in as part of their course.				

(c) appropriate use of significant figures				
(d) plotting and interpreting suitable graphs from experimental results, including: (i) selection and labelling of axes with appropriate scales, quantities and units. (ii) measurement of gradients and intercepts				
1.1.4 Evaluation				
(a) how to evaluate results and draw conclusions Learners should be able to evaluate how the scientific community use results to validate new knowledge and ensure integrity.				
(b) the identification of anomalies in experimental measurements				
(c) the limitations in experimental procedures				
(d) precision and accuracy of measurements and data, including margins of error, percentage errors and uncertainties in apparatus				

(e) refining of experimental design by suggestion of improvements to the procedures and apparatus				
1.2 Practical skills assessed in the practical endorsement				
1.2.1 Practical skills				
Learning outcomes Practical work carried out throughout the course will enable learners to develop the following skills:	**R**	**A**	**G**	**Comments**
Independent thinking (a) apply investigative approaches and methods to practical work Including how to solve problems in a practical context.				
Use and application of scientific methods and practices (b) safely and correctly use a range of practical equipment and materials See Section 5g in the specification. Including identification of potential hazards. Learners should understand how to minimise the risks involved.				
(c) follow written instructions				

(d) make and record observations/measurements				
(e) keep appropriate records of experimental activities See Section 5g.				
(f) present information and data in a scientific way				
(g) use appropriate software and tools to process data, carry out research and report findings				
Research and referencing (h) use online and offline research skills including websites, textbooks and other printed scientific sources of information				
(i) correctly cite sources of information The Practical Skills Handbook provides guidance on appropriate methods for citing information.				

Instruments and equipment (j) use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding including in the specification See Section 5g.				
1.2.2 Use of apparatus and techniques				
Learning outcomes Through use of the apparatus and techniques listed below, and the minimum of 12 assessed practicals (see Section 5g), learners should be able to demonstrate all of the practical skills listed within 1.2.1 and CPAC (Section 5g, Table 2) as exemplified through:	**R**	**A**	**G**	**Comments**
(a) use of appropriate analogue apparatus to record a range of measurements (to include length/distance, temperature, pressure, force, angles and volume) and to interpolate between scale marking				
(b) use of appropriate digital instruments, including electrical multimeters, to obtain a range of measurements (to include time, current, voltage, resistance and mass)				
(c) use of methods to increase accuracy of measurements, such as timing over multiple oscillations, or use of fiducial marker, set square or plumb line				

(d) use of a stopwatch or light gates for timing				
(e) use of calipers and micrometers for small distances, using digital or Vernier scales				
(f) correctly constructing circuits from circuit diagrams using DC power supplies, cells, and a range of circuit components, including those where polarity is important				
(g) designing, constructing and checking circuits using DC power supplies, cells, and a range of circuit components				
(h) use of a sign generator and oscilloscope, including volts/division and time-base				
(i) generating and measuring waves, using microphone and loudspeaker, or ripple tank, or vibration transducer, or microwave/radio wave source				
(j) use of a laser or light source to investigate characteristics of light, including reference and diffraction				

(k) use of ICT such as computer modelling, or data logger with a variety of sensors to collect data or use of software to process data				
(l) use of ionising radiation, including detectors				

Module 2 Foundations in physics				
2.1 Physical quantities and units				
2.1.1 Physical quantities				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) physical quantities have a numerical value and a unit				
(b) making estimates of physical quantities listed in this specification				
2.1.2 S.I. units				
(a) Système Internationale (S.I.) base quantities and their units – mass (kg), length (m), time (s), current (A), temperature (K), amount of substance (mol)				

(b) derived units of S.I. base units Examples: momentum → kg m s^{-1} and Density → kg m^{-3}				
(c) units listed in the specification				
(d) checking the homogeneity of physical equations using S.I. base units				
(e) prefixes and their symbols to indicate decimal submultiples or multiples of units – pico (p), nano (n), micro (μ), milli (m), centi (c), deci (d), kilo (k), mega (M), giga (G), tera (T)				
(f) the conventions used for labelling graph axes and table columns e.g. speed / m s^{-1} (see practical skills handbook)				

2.2 Making measurements and analysing data				
2.2.1 Measurements and uncertainties				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) systematic errors (including zero errors) and random errors in measurements				
(b) precision and accuracy				
(c) absolute and percentage uncertainties when data are combined by addition, subtraction, multiplication, division and raising to powers A rigorous statistical treatment is not expected.				
(d) graphical treatment of errors and uncertainties; line of best fit; worst line; absolute and percentage uncertainties; percentage difference An elementary knowledge of error bars is expected at A level.				

2.3 Nature of quantities				
2.3.1 Scalars and vectors				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) Scalar and vector quantities Learners will also be expected to give examples of each.				
(b) vector addition and subtraction				
(c) vector triangle to determine the resultant of any two coplanar vectors To be done by calculations or by scale drawing.				
(d) resolving a vector into two perpendicular components; $F_x = F \cos \theta$; $F_y = F \sin \theta$				

Module 3 Forces and motion				
3.1 Motion				
3.1.1 Kinematics				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) displacement, instantaneous speed, average speed, velocity and acceleration				
(b) graphical representations of displacement, speed, velocity and acceleration Using data-loggers to analyse motion.				
(c) displacement–time graphs, velocity is gradient				
(d) velocity–time graphs, acceleration is gradient; displacement is area under graph Leaners will also be expected to estimate the area under non-linear graphs.				

3.1.2 Linear motion				
(a) (i) the equations of motion for constant acceleration in a straight line, including motion of bodies falling in a uniform gravitational filed without air resistance $v = u + at$ $s = \frac{1}{2}(u + v)t$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$ (ii) techniques and procedures used to investigate the motion and collisions of objects Apparatus may include trolleys, air-track gliders, ticker timers, light gates, data-loggers and video techniques.				
(b) (i) acceleration *g* of free fall (ii) techniques and procedures used to determine the acceleration of free fall using trapdoor and electromagnet arrangement or light gates and timer Determining g in the laboratory.				
(c) reaction time and thinking distance; braking distance and stopping distance for a vehicle				

3.1.3 Projectile motion				
(a) independence of the vertical and horizontal motion of a projectile				
(b) two-dimensional motion of a projectile with constant velocity in one direction and constant acceleration in a perpendicular direction				
3.2 Forces in action				
3.2.1 Dynamics				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) net force = mass × acceleration; $F = ma$ Learners will also be expected to recall this equation.				
(b) the newton as the unit of force				
(c) weight of an object; $W = mg$ Learners will also be expected to recall this equation.				

(d) the terms tension, normal contact force, upthrust and friction				
(e) free-body diagrams				
(f) one- and two-dimensional motion under constant force				
3.2.2 Motion with non-uniform acceleration				
(a) drag as the frictional force experienced by an object travelling through a fluid				
(b) factors affecting drag for an object travelling through air				
(c) motion of objects falling in a uniform gravitational field in the presence of drag				

(d) (i) terminal velocity (ii) techniques and procedures used to determine terminal velocity in fluids. E.g. ball-bearing in a viscous liquid or cones in air. Investigating factors affecting terminal velocity.				
3.2.3 Equilibrium				
(a) moment of force				
(b) couple; torque of a couple				
(c) the principle of moments				
(d) centre of mass; centre of gravity; experimental determination of centre of gravity				
(e) equilibrium of an object under the action of forces and torques				
(f) condition for equilibrium of three coplanar forces; triangle of forces				

3.2.4 Density and pressure				
(a) density; $\rho = \frac{m}{V}$				
(b) pressure; $p = \frac{F}{A}$ for solids, liquids and gases				
(c) $p = h\rho g$; upthrust on an object in a fluid; Archimedes' principle				

3.3 Work, energy and power				
3.3.1 Work and conservation of energy				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) work done by a force; the unit joule				
(b) $W = Fx \cos \theta$ for work done by a force				

(c) the principle of conservation of energy				
(d) energy in different forms; transfer and conservation				
(e) transfer of energy is equal to work done				
3.3.2 Kinetic and potential energies				
(a) kinetic energy of an object; $E_k = \frac{1}{2}mv^2$ Learners will also be expected to recall this equation and derive it from first principles.				
(b) gravitational potential energy of an object in a uniform gravitational field; $E_p = mgh$ Learners will also be expected to recall this equation and derive if from first principles.				
(c) the exchange between gravitational potential energy and kinetic energy				

3.3.3 Power				
(a) power; the unit watt; $P = \frac{W}{t}$				
(b) $P = Fv$ Learners will also be expected to derive this equation from first principles.				
(c) efficiency of a mechanical system; $\text{efficiency} = \frac{\text{useful output energy}}{\text{total input energy}} \times 100\%$				

3.4 Materials				
3.4.1 Springs				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) tensile and compressive deformation; extension and compression				
(b) Hooke's law				

(c) force constant k of a spring or wire; $F = kx$				
(d) (i) force-extension (or compression) graphs for springs and wires (ii) techniques and procedures used to investigate force-extension characteristics for arrangements which may include springs, rubber bands, polythene strips.				
3.4.2 Mechanical properties of matter				
(a) force-extension (or compression) graph; work done is area under graph				
(b) elastic potential energy; $E = \frac{1}{2} Fx$; $E = \frac{1}{2} kx^2$				
(c) stress, strain and ultimate tensile strength				
(d) (i) Young modulus = $\frac{\text{tensile stress}}{\text{tensile strain}}$, $E = \frac{\sigma}{\varepsilon}$ (ii) techniques and procedures used to determine the Young modulus for a metal.				
(e) stress-strain graphs for typical ductile, brittle and polymeric materials				

(f) elastic and plastic deformations of materials Investigating the properties of materials.				
3.5 Newton's laws of motion and momentum				
3.5.1 Newton's laws of motion				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) Newton's three laws of motion				
(b) linear momentum; $p = mv$; vector nature of momentum				
(c) net force = rate of change of momentum; $F = \frac{\Delta p}{\Delta t}$ Learners are expected to know that $F = ma$ is a special case of this equation.				
(d) impulse of a force; impulse = $F\Delta t$				

(e) impulse is equal to the area under a force-time graph Learners will also be expected to estimate the area under non-linear graphs. Using a spreadsheet to determine impulse from *F-t* graph.				
3.5.2 Collisions				
(a) the principle of conservation of momentum				
(b) collisions and interaction of bodies in one dimension and in two dimensions Two-dimensional problems will only be assessed at A level.				
(c) perfectly elastic collision and inelastic collision				

Module 4 Electrons, waves and photons				
4.1 Charge and current				
4.1.1 Charge				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) electric current as rate of flow of charge; $I = \frac{\Delta Q}{\Delta t}$				
(b) the coulomb as the unit of charge				
(c) the elementary charge *e* equals 1.6×10^{-19} C Learners will be expected to know that an electron has charge –*e* and a proton +*e*.				
(d) net charge on a particle or an object is quantised and a multiple of *e*				
(e) current as the movement of electrons in metals and movement of ions in electrolytes				
(f) conventional current and electron flow				
(g) Kirchhoff's first law; conservation of charge				

4.1.2 Mean drift velocity				
(a) mean drift velocity of charge carriers				
(b) *I* = *Anev,* where *n* is the number density of charge carriers				
(c) distinction between conductors, semiconductors and insulators in term of *n*				
4.2 Energy, power and resistance				
4.2.1 Circuit symbols				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) circuit symbols As set out in ASE publication *Signs, Symbols and Systematics (The ASE Companion to 16-19 Science, 2000).*				
(b) circuit diagrams using these symbols				
4.2.2 E.m.f and p.d				
(a) potential difference (p.d.); the unit volt				

(b) electromotive force (e.m.f.) of a source such as a cell or a power supply Epsilon is used as the symbol for e.m.f. to avoid confusion with E which is used for energy and electric field. The ASE guide 'Signs, symbols and systematics' details E as the correct symbol for e.m.f. and this will be credited in all examinations.				
(c) distinction between e.m.f. and p.d. in terms of energy transfer				
(d) energy transfer; $W = VQ$; $W = \mathcal{E}Q$				
(e) energy transfer $eV = \frac{1}{2}mv^2$ for electrons and other charged particles				
4.2.3 Resistance				
(a) resistance; $R = \frac{V}{I}$; the unit ohm Learners will also be expected to recall this equation.				
(b) Ohm's law				

(c) (i) I–V; characteristics of resistor, filament lamp, thermistor, diode and light-emitting diode (LED) (ii) techniques and procedures used to investigate the electrical characteristics for a range of ohmic and non-ohmic components. Investigating components and analysing data using spreadsheet.				
(d) light-dependent resistor (LDR); variation of resistance with light intensity				
4.2.4 Resistivity				
(a) (i) resistivity of a material; the equation $R = \frac{\rho L}{A}$; the unit ohm (ii) techniques and procedures used to determine the resistivity of a metal.				
(b) the variation of resistivity of metals and semiconductors with temperature				
(c) negative temperature coefficient (NTC) thermistor; variation of resistance with temperature				

4.3 Electrical circuits				
4.3.1 Series and parallel circuits				
Learning outcomes You will be required to show and apply knowledge and understanding of:	R	A	G	Comments
(a) Kirchhoff's second law; the conservation of energy				
(b) Kirchhoff's first and second laws applied to electrical circuits				
(c) total resistance of two or more resistors in series; $R = R_1 + R_2 +$				
(d) total resistance of two or more resistors in parallel; $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots.$				
(e) analysis of circuits with components, including both series and parallel				
(f) analysis of circuits with more than one source of e.m.f.				

4.3.2 Internal resistance				
(a) source of e.m.f.; internal resistance				
(b) terminal p.d.; 'lost volts'				
(c) (i) the equations $\mathcal{E} = I(R + r)$ and $\mathcal{E} = V + Ir$ (ii) techniques and procedures used to determine the internal resistance of a chemical cell or other source of e.m.f. Investigating the internal resistance of a power supply.				
4.3.3 Potential dividers				
(a) potential divider circuit with components				
(b) potential divider circuits with variable components e.g. LDR and thermistor				

	R	A	G	Comments
(c) (i) potential divider equations e.g. $V_{out} = \frac{R_2}{R_1 + R_2} \times V_{in}$ and $\frac{V_1}{V_2} = \frac{R_1}{R_2}$ (ii) techniques and procedures used to investigate potential divider circuits which may include a sensor such as a thermistor or an LDR. Designing temperature and light sensing circuits.				
4.4 Waves				
4.4.1 Wave motion				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) progressive waves; longitudinal and transverse waves				
(b) (i) displacement, amplitude, wavelength, period, phase difference, frequency and speed of a wave (ii) techniques and procedures used to use an oscilloscope to determine frequency.				
(c) the equation $f = \frac{1}{T}$				

(d) the wave equation $v = f\lambda$				
(e) Graphical representations of transverse and longitudinal waves				
(f) (i) reflection, refraction, polarisation and diffraction of all waves (ii) techniques and procedures used to demonstrate wave effects using a ripple tank (iii) Techniques and procedures used to observe polarising effecting using microwaves and light.				
(g) intensity of a progressive wave; $I = \frac{P}{A}$; intensity $\propto$ (amplitude)^2				
4.4.2 Electromagnetic waves				
(a) electromagnetic spectrum; properties of electromagnetic waves				
(b) orders of magnitude of wavelengths of the principal radiations from radio waves to gamma rays				

(c) plain polarised waves, polarisation of electromagnetic waves Learners will be expected to know about polarising filters for light and metal grilles for microwaves in demonstrating polarisation.				
(d) (i) refraction of light; refractive index; $n = \frac{c}{v}$; $n \sin \theta$ = constant at a boundary where θ is the angle to the normal (ii) techniques and procedures used to investigate refraction and total internal reflection of light using ray boxes, including transparent rectangular and semi-circular block.				
(e) critical angle; $\sin c = \frac{1}{n}$; total internal reflection for light				
4.4.3 Superposition				
(a) (i) the principle of superposition of waves (ii) techniques and procedures used for superposition experiments using sound, light and microwaves.				
(b) graphical methods to illustrate the principle of superposition				

(c) interference, coherence, path difference and phase difference				
(d) constructive interference and destructive interference in terms of path difference and phase difference				
(e) two-source interference with sound and microwaves				
(f) Young double-slit experiment using visible light Learners should understand that this experiment gave a classical confirmation of the wave-nature of light. Internet research on the ideas of Newton and Huygens about the nature of light.				
4.4.4 Stationary waves				
(a) stationary (standing) waves using microwaves, stretched strings and air columns				
(b) graphical representations of a stationary wave				
(c) similarities and the differences between stationary and progressive waves				

(d) nodes and antinodes				
(e) (i) stationary wave patterns for a stretched string and air columns in closed and open tubes (ii) techniques and procedures used to determine the speed of sound in air by formation of stationary waves in a resonance tube.				
(f) the idea that the separation between adjacent nodes (or antinodes) is equal to $\lambda/2$, where λ is the wavelength of the progressive wave				
(g) fundamental mode of vibration (1st harmonic) harmonics				
4.5 Quantum Physics				
4.5.1 Photons				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) the particulate nature (photon model) of electromagnetic radiation				
(b) photon as a quantum of energy of electromagnetic radiation				

(c) energy of photon; $E = hf$ and $E = \frac{hc}{\lambda}$				
(d) the electronvolt (eV) as a unit of energy				
(e) (i) using LEDs and the equation $eV = \frac{hc}{\lambda}$ estimate the value of Planck constant h (ii) Determine the Planck constant using different coloured LEDs. No knowledge of semiconductor theory is required.				
4.5.2 The photoelectric effect				
(a) (i) photoelectric effect, including a simple experiment to demonstrate this effect (ii) demonstration of the photoelectric effect using, e.g. gold-leaf electroscope and zinc plate. Learners should understand that the photoelectric effect provides evidence for particulate nature of electromagnetic radiation. Internet research on the development of quantum physics.				

(b) a one-to-one interaction between a photon and a surface electron				
(c) Einstein's photoelectric equation $hf = \phi + KE_{max}$				
(d) work function; threshold frequency				
(e) the idea that the maximum kinetic energy of the photoelectrons is independent of the intensity of the incident radiation				
(f) the idea that rate of emission of photoelectrons above the threshold frequency is directly proportional to the intensity of the incident radiation				
4.5.3 Wave-particle duality				
(a) electron diffraction, including experimental evidence of this effect Learners should understand that electron diffraction providers evidence for wave-like behaviour of particles.				
(b) diffraction of electrons travelling through a thin slice of polycrystalline graphite by the atoms of graphite and the spacing between the atoms				

(c) the de Broglie equation $\lambda = \frac{h}{p}$				

Module 5 Newtonian world and astrophysics				
5.1 Thermal Physics				
5.1.1 Temperature				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) thermal equilibrium				
(b) absolute scale of temperature (i.e. the thermodynamic scale) that does not depend on property of any particular substance				
(c) temperature measurements both in degrees Celsius (°C) and in kelvin (K)				
(d) $T(\text{K}) \approx \theta(°\text{C}) + 273$				
5.1.2 Solid, liquid and gas				
(a) solids, liquids and gases in terms of the spacing, ordering and motion of atoms or molecules				

(b) simple kinetic model for solids, liquids and gases				
(c) Brownian motion in terms of the kinetic model of matter and a simple demonstration using smoke particles suspended in air				
(d) internal energy as the sum of the random distribution of kinetic and potential energies associated with the molecules of a system				
(e) absolute zero (0 K) as the lowest limit for temperature; the temperature at which a substance has minimum internal energy				
(f) increase in the internal energy of a body as its temperature rises				
(g) changes in the internal energy of a substance during change of phase; constant temperature during change of phase				
5.1.3 Thermal properties of materials				
(a) specific heat capacity of a substance; the equation $E = mc\Delta\theta$ Estimating specific heat capacity, using method of mixture.				

(b) (i) an electrical experiment to determine the specific heat capacity of a metal or a liquid (ii) techniques and procedures used for an electrical method to determine the specific heat capacity of a metal block and a liquid.				
(c) specific latent heat of fusion and specific latent heat of vaporisation; $E = mL$				
(d) (i) an electrical experiment to determine the specific latent heat of fusion and vaporisation (ii) techniques and procedures used for an electrical method to determine the specific latent heat of a solid and a liquid.				
5.1.4 Ideal gases				
(a) amount of substance in moles; Avogadro constant N_A equals 6.02×10^{23} mol^{-1}				
(b) model of kinetic theory of gases assumptions for the model: large number of molecules in random, rapid motion particles (atoms or molecules) occupy negligible volume compared to the volume of				

gas all collisions are perfectly elastic and the time of the collisions is negligible compared to the time between collisions negligible forces between particles except during collision				
(c) pressure in terms of this model Explanation of pressure in terms of Newtonian theory.				
(d) (i) the equation of state of an ideal gas $pV = nRT$, where n is the number of moles (ii) techniques and procedures used to investigate PV = constant (Boyle's law) and $\frac{P}{T}$ = constant				
(e) the equation $pV = \frac{1}{3}Nm\overline{c^2}$ where N is the number of particles (atoms or molecules) and $\overline{c^2}$ is the mean square speed Derivation of this equation is not required.				

(f) root mean square (r.m.s.) speed; mean square speed Learners should know about the general characteristics of the Maxwell-Boltzmann distribution.				
(g) the Boltzmann constant; $k = \frac{R}{N_A}$				
(h) $pV = NkT$; $\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$ Learners will also be expected to know the derivation of the equation $\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$ from $pV = \frac{1}{3}Nm\overline{c^2}$ and $pV = NkT$.				
(i) internal energy of an ideal gas				
5.2 Circular motion				
5.2.1 Kinematics of circular motion				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) the radian as a measure of angle				

(b) period and frequency of an object in circular motion				
(c) angular velocity ω; $\omega = \frac{2\pi}{T}$ or $\omega = 2\pi f$				
5.2.2 Centripetal force				
(a) a constant net force perpendicular to the velocity of an object causes it to travel in a circular path				
(b) constant speed in a circle; $v = \omega r$				
(c) centripetal acceleration; $a = \frac{v^2}{r}$; $a = \omega^2 r$				
(d) (i) centripetal force; $F = \frac{mv^2}{r}$; $F = m\omega^2 r$ (ii) techniques and procedures used to investigate circular motion using a whirling bung				

5.3 Oscillations				
5.3.1 Simple harmonic oscillations				
Learning outcomes You will be required to show and apply knowledge and understanding of:	R	A	G	**Comments**
(a) displacement, amplitude, period, frequency, angular frequency and phase difference				
(b) angular frequency ω; $\omega = \frac{2\pi}{T}$ or $\omega = 2\pi f$				
(c) (i) simple harmonic motion; defining equation $a = -\omega^2 x$ (ii) techniques and procedures used to determine the period/frequency of simple harmonic oscillations e.g. mass on a spring, pendulum				
(d) solutions to the equation $a = -\omega^2 x$ e.g. $x = A \cos \omega t$ or $x = A \sin \omega t$				
(e) $v = \pm\omega\sqrt{A^2 - x^2}$ hence $v_{max} = \omega A$				
(f) the period of a simple harmonic oscillator is independent of its amplitude (isochronous oscillator)				

(g) graphical methods to relate the changes in displacement, velocity and acceleration during simple harmonic motion				
5.3.2 Energy of a simple harmonic oscillator				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) interchange between kinetic and potential energy during simple harmonic motion				
(b) energy-displacement graphs for a simple harmonic oscillator				
5.3.3 Damping				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) free and forced oscillations				
(b) (i) the effects of damping on an oscillatory system (ii) observe forced and damped oscillations for a range of systems.				
(c) resonance; natural frequency				

(d) amplitude-driving frequency graphs for forced oscillators				
(e) practical examples of forced oscillations and resonance				
5.4 Gravitational fields				
5.4.1 Point and spherical masses				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) gravitational fields are due to objects having mass				
(b) modelling the mass of a spherical object as a point mass at its centre				
(c) gravitational field lines to map gravitational fields				
(d) gravitational field strength; $g = \frac{F}{m}$				
(e) the concept of gravitational fields as being one of a number of forms of field giving rise to a force Learners will be expected to link this with section 6.2.				

5.4.2 Newton's law of gravitation				
(a) Newton's law of gravitation; $F = -\frac{GM}{r^2}$ for the force between two point masses				
(b) gravitational field strength $g = -\frac{GM}{r^2}$ for a point mass				
c) gravitational field strength is uniform close to the surface of the Earth and numerically equal to the acceleration of free fall				
5.4.3 Planetary motion				
(a) Kepler's three laws of planetary motion				
(b) the centripetal force on a planet is provided by the gravitational force between it and the Sun				
(c) the equation $T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$ Learners will also be expected to derive this equation from first principles.				
(d) the relationship for Kepler's third law $T^2 \propto r^3$ applied to systems other than our solar system				

(e) geostationary orbit; uses of geostationary satellites Predicting geostationary orbit using Newtonian laws.				
5.4.4 Gravitational potential and energy				
(a) gravitational potential at a point as the work done in bringing unit mass from infinity to the point; gravitational potential is zero at infinity				
(b) gravitational potential $V_g = -\frac{GM}{r}$ at a distance r from a point mass M; changes in gravitational potential				
(c) force-distance graph for a point or spherical mass; work done is area under graph				
(d) gravitational potential energy $E = mV_g = -\frac{GMm}{r}$ at a distance r from a point mass M				
(e) escape velocity Predicting the escape velocity of atoms from the atmosphere of planets.				

5.5 Astrophysics and cosmology				
5.5.1 Stars				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) the terms planets, planetary satellites, comets, solar systems, galaxies and the universe				
(b) formation of a star from interstellar dust and gas in terms of gravitational collapse, fusion of hydrogen into helium, radiation and gas pressure Learners are not expected to know the details of fusion in terms of Einstein's mass-energy equation.				
(c) evolution of a low-mass star like our Sun into a red giant and white dwarf; planetary nebula				
(d) characteristics of a white dwarf; electron degeneracy pressure; Chandrasekhar limit				
(e) evolution of a massive star into a red super giant and then either a neutron star or black hole; supernova				
(f) characteristics of a neutron star and a black hole				

(g) Hertzsprung–Russell (HR) diagram as luminosity-temperature plot; main sequence; red giants; super red giants; white dwarf				
5.5.2 Electromagnetic radiation from stars				
(a) energy levels of electrons in isolated gas atoms				
(b) the idea that energy levels have negative values				
(c) emission spectral lines from hot gases in terms of emission of photons and transition of electrons between discrete energy levels				
(d) the equations $hf = \Delta E$ *and* $\frac{hc}{\lambda} = \Delta E$ Learners will also require knowledge of section 4.5.				
(e) different atoms have different spectral lines which can be used to identify elements within stars				
(f) continuous spectrum, emission line spectrum and absorption line spectrum				

(g) transmission diffraction grating used to determine the wavelength of light The structure and use of an optical spectrometer are not required.				
(h) the condition for maxima $d \sin\theta = n\lambda$, where d is the grating spacing Proof of this equation is not required.				
(i) use of Wien's displacement law $\lambda_{max} \propto \frac{1}{T}$ to estimate the peak surface temperature (of a star)				
(j) luminosity L of a star; Stefan's law $L = 4\pi r^2 \sigma T^4$ where σ is the Stefan constant Learners will also require knowledge of 4.4.1				
(k) use of Wien's displacement law and Stefan's law to estimate the radius of a star				
5.5.3 Cosmology				
(a) distances measured in astronomical unit (AU), light-year (ly) and parsec (pc)				
(b) stellar parallax; distances the parsec (pc)				

(c) the equation $p = \frac{1}{d}$, where *p* is the parallax in seconds of arc and *d* is the distance in parsec				
(d) the Cosmological principle; universe is homogeneous, isotropic and the laws of physics are universal				
(e) Doppler effect; Doppler shift of electromagnetic radiation				
(f) Doppler equation $\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$ for a source of electromagnetic radiation moving relative to an observer				
(g) Hubble's law; $v \approx H_0 d$ for receding galaxies, where H_0 is the Hubble constant				
(h) model of an expanding universe supported by galactic red shift				
(i) Hubble constant H_0 in both km $s^{-1}Mpc^{-1}$ and s^{-1} units				
(j) the Big Bang theory				

(k) experimental evidence for the Big Bang theory from microwave background radiation at a temperature of 2.7 K The development and acceptance of Big Bang theory by the scientific community.				
(l) the idea that the Big Bang gave rise to the expansion of space-time				
(m) estimation for the age of the universe; $t \approx H_0^{-1}$				
(n) evolution of the universe after the Big Bang to the present				
(o) current ideas; universe is made up of dark energy, dark matter, and a small percentage of ordinary matter				

Module 6 Particles and medical physics				
6.1 Capacitors				
6.1.1 Capacitors				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) capacitance; $C = \frac{Q}{V}$; the unit farad				
(b) charging and discharging of a capacitor or capacitor plates with reference to the flow of electrons				
(c) total capacitance of two of more capacitors in series; $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$.				
(d) total capacitance of two or more capacitors in parallel; $C = C_1 + C_2 + \ldots$.				
(e) (i) analysis of circuits containing capacitors, including resistors (ii) techniques and procedures used to investigate capacitors in both series and parallel combinations using ammeters and voltmeters.				

6.1.2 Energy				
(a) p.d. – charge graph for a capacitor; energy stored is area under graph				
(b) energy stored by capacitor; $W = \frac{1}{2}QV$, $W = \frac{1}{2}\frac{Q^2}{C}$ and $W = \frac{1}{2}V^2C$				
(c) uses of capacitors as storage of energy				
6.1.3 Charging and discharging capacitors				
(a) (i) charging and discharging capacitor through a resistor (ii) techniques and procedures to investigate the charge and discharge of a capacitor using both meters and data-loggers. Investigating the charge and discharge of capacitors in the laboratory.				
(b) time constant of a capacitor-resistor circuit; $\tau = CR$				

(c) equations of the form $x = x_0 e^{-\frac{t}{CR}}$ for capacitor-resistor circuits $x = x_0(1 - e^{-\frac{t}{CR}})$ Learners will be expected to know how ln*x*–*t* graphs can be used to determine *CR*.				
(d) graphical methods and spreadsheet modelling of the equation $\frac{\Delta Q}{\Delta t} = -\frac{Q}{CR}$ for a discharging capacitor Using spreadsheets to model the discharge of a capacitor.				
(e) exponential decay graph; constant-ratio property of such a graph				
6.2 Electric Fields				
6.2.1 Point and spherical charges				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) electric fields are due to charges				
(b) modelling a uniformly charged sphere as a point charge at its centre				

(c) electric field lines to map electric fields				
(d) electric field strength; $E = \frac{F}{Q}$				
6.2.2 Coulomb's law				
(a) Coulomb's law; $F = \frac{Qq}{4\pi\varepsilon_0 r^2}$ for the force between two point charges Learners will also require knowledge of section 3.2.				
(b) electric field strength $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ for a point charge				
(c) similarities and differences between the gravitational field of a point mass and the electric field of a point charge Learners will also require knowledge of 5.4.				
(d) the concept of electric fields as being one of a number of forms of field giving rise to a force Learners will be expected to link this with 5.4.				

6.2.3	**Uniform electric field**			
(a) uniform electric field strength; $E = \frac{V}{d}$				
(b) electric field strength $C = \frac{\varepsilon_0 A}{d}$; $C = \frac{\varepsilon A}{d}$; $\varepsilon = \varepsilon_r \varepsilon_0$ Learners are not expected to know why the relative permittivity $\varepsilon_r \geqslant 1$.				
(c) motion of charged particles in a uniform electric field Learners will also require knowledge of 3.1, 3.2 and 3.3.				
6.2.4	**Electric potential and energy**			
(a) electric potential at a point as the work done in bringing unit positive charge from infinity to the point; electric potential is zero at infinity				
(b) electric potential $V = \frac{Q}{4\pi\varepsilon_0 r}$ at a distance r from a point charge; changes in electric potential				

(c) capacitance $C = 4\pi\varepsilon_0 R$ for an isolated sphere Derivation expected from equation for electric potential and $Q = VC$.				
(d) force–distance graph for a point or spherical charge; work done is area under graph				
(e) electric potential energy = $Vq = \frac{Qq}{4\pi\varepsilon_0 r}$ at a distance *r* from a point charge *Q*				
6.3 Electromagnetism				
6.3.1 Magnetic fields				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) magnetic fields are due to moving charges or permanent magnets				
(b) magnetic field lines to map magnetic fields				
(c) magnetic field patterns for a long straight current-carrying conductor, a flat coil and a long solenoid				
(d) Fleming's left-hand rule				

(e) (i) force on a current-carrying conductor; $F = BIL \sin \theta$ (ii) techniques and procedures used to determine the uniform magnetic flux density between the poles of a magnet using a current-carrying wire and digital balance.				
(f) magnetic flux density; the unit tesla				
6.3.2 Motion of charged particles				
(a) force on a charged particle travelling at right angles to a uniform magnetic field; $F = BQv$				
(b) charged particles moving in a uniform magnetic field; circular orbits of charged particles in a uniform magnetic field Learners will also require knowledge of 3.2, 3.3 and 5.2.				
(c) charged particles moving in a region occupied by both electric and magnetic fields; velocity selector				

6.3.3 Electromagnetism				
(a) magnetic flux ϕ; the unit weber $\phi = BAcos\theta$				
(b) magnetic flux linkage				
(c) Faraday's law of electromagnetic induction and Lenz's law				
(d) (i) e.m.f. = – rate of change of magnetic flux linkage; $\mathcal{E} = -\frac{\Delta(N\phi)}{\Delta t}$ (ii) techniques and procedures used to investigate magnetic flux using search coils.				
(e) simple a.c. generator				
(f) (i) simple laminated iron-cored transformer; $\frac{n_s}{n_p} = \frac{V_s}{V_p} = \frac{I_p}{I_s}$ for an ideal transformer (ii) techniques and procedures used to investigate transformers.				

6.4	Nuclear and particle physics				
6.4.1	**The nuclear atom**				
Learning outcomes You will be required to show and apply knowledge and understanding of:		**R**	**A**	**G**	**Comments**
(a)	alpha-particle scattering experiment; evidence of a small charged nucleus				
(b)	simple nuclear model of the atom; protons; neutrons and electrons				
(c)	relative sizes of atom and nucleus				
(d)	proton number; nucleon number; isotopes; notation ${}^{A}_{Z}X$ for the representation of nuclei.				
(e)	strong nuclear force; short-range nature of the force; attractive to about 3 fm and repulsive below about 0.5 fm 1 fm = 10^{-15} m				
(f)	radius of nuclei; $R = r_0 A^{\frac{1}{3}}$ where r_0 is a constant and A is the nucleon number				
(g)	mean densities of atoms and nuclei				

6.4.2 Fundamental particles				
(a) particles and antiparticles; electron–positron, proton-antiproton, neutron-antineutron and neutrino-antineutrino				
(b) particle and its corresponding antiparticle have same mass; electron and positron have opposite charge; proton and antiproton have opposite charge				
(c) classification of hadrons; proton and neutron as examples of hadrons; all hadrons are subject to both the strong nuclear force and the weak nuclear force				
(d) classification of leptons; electron and neutrino as examples of leptons; all leptons are subject to the weak nuclear force but not the strong nuclear force				
(e) simple quark model of hadrons in terms of up (u), down (d) and strange (s) quarks and their respective anti-quarks				
(f) quark model of the proton (uud) and the neutron (udd)				

(g) charges of the up (u), down (d), strange (s), anti-up ($\bar{u}$), anti-down ($\bar{d}$) and the anti-strange ($\bar{s}$) quarks as fractions of the elementary charge *e*				
(h) beta-minus (β^-) decay; beta-plus (β^+) decay. plus (β^+) decay				
(i) β^- decay in terms of a quark model; $d \rightarrow u + {}^{0}_{-1}e + \bar{\nu}$				
(j) β^+) decay in terms of a quark model; $u \rightarrow d + {}^{0}_{1}e + \nu$				
(k) balancing of quark transformation equations in terms of charge				
(l) decay of particles in terms of the quark model				
6.4.3 Radioactivity				
(a) radioactive decay; spontaneous and random nature of decay				
(b) (i) α-particles, β-particles and γ-rays; nature, penetration and range of these radiations				

(b) (ii) techniques and procedures used to investigate the absorption of α-particles, β-particles and γ-rays by appropriate materials				
(c) nuclear decay equations for alpha, beta-minus and beta-plus decays; balancing nuclear transformation equations				
(d) activity of a source; decay constant λ of an isotope; $A = \lambda N$ Learners will also require knowledge of 5.1.4(a).				
(e) (i) half-life of an isotope; $\lambda t_{\frac{1}{2}} = \ln(2)$ (ii) techniques and procedures used to determine the half-life of an isotope such as protactinium.				
(f) (i) the equations $A = A_0e^{-\lambda t}$ and $N = N_0e^{-\lambda t}$ where A is the activity and N is the number of undecayed nuclei (ii) simulation of radioactive decay using dice.				

(g) graphical methods and spreadsheet modelling of the equation $\frac{\Delta N}{\Delta t} = -\lambda N$ for radioactive decay Using spreadsheets to model the radioactive decay of nuclei.				
(h) radioactive dating e.g. carbon-dating				
6.4.4 Nuclear fission and fusion				
(a) Einstein's mass-energy equation; $\Delta E = \Delta mc^2$				
(b) energy released (or absorbed) in simple nuclear reactions				
(c) creation and annihilation of particle-antiparticle pairs				
(d) mass defect; binding energy; binding energy per nucleon				
(e) binding energy per nucleon against nucleon number curve; energy changes in reactions				
(f) binding energy of nuclei using $\Delta E = \Delta mc^2$ and masses of nuclei				

(g) induced nuclear fission; chain reaction				
(h) basic structure of a fission reactor; components – fuel rods, control rods and moderator				
(i) environmental impact of nuclear waste Decision making process when building new nuclear power stations.				
(j) nuclear fusion; fusion reactions and temperature Learners will also require knowledge of 5.1.4.				
(k) balancing nuclear transformation equations				
6.5.1 Medical imaging				
6.5.1 Using X-rays				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) basic structure of an X-ray tube; components – heater (cathode), anode, target metal and high voltage supply				
(b) production of X-ray photons from an X-ray tube				

(c) X-ray attenuation mechanisms; simple scatter, photoelectric effect, Compton effect and pair production				
(d) attenuation of X-rays; $I = I_0 e^{-\mu x}$, where μ is the attenuation (absorption) coefficient				
(e) X-ray imaging with contrast media; barium and iodine				
(f) computerised axial tomography (CAT) scanning; components – rotating X-tube producing a thin fan-shaped X-ray beam, ring of detectors, computer software and display				
(g) advantages of a CAT scan over an X-ray image				
6.5.2 Diagnostic methods in medicine				
Learning outcomes You will be required to show and apply knowledge and understanding of:	**R**	**A**	**G**	**Comments**
(a) medical tracers; technetium–99m and fluorine–18				
(b) gamma camera; components – collimator, scintillator, photomultiplier tubes, computer and display; formation of image				

(c) diagnosis using gamma camera				
(d) positron emission tomography (PET) scanner; annihilation of positron–electron pairs; formation of image				
(e) diagnosis using PET scanning Issues raised when equipping a hospital with an expensive scanner.				
6.5.3 Using ultrasound				
(a) ultrasound; longitudinal wave with frequency greater than 20 kHz				
(b) piezoelectric effect; ultrasound transducer as a device that emits and receives ultrasound				
(c) ultrasound A-scan and B-scan				
(d) acoustic impedance of a medium; $Z = \rho c$				
(e) reflection of ultrasound at a boundary; $\frac{I_r}{I_0} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$				

(f) impedance (acoustic) matching; special gel used in ultrasound scanning				
(g) Doppler effect in ultrasound; speed of blood in the patient; $\frac{\Delta f}{f} = \frac{2v\cos\theta}{c}$ for determining the speed v of blood				

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