2

Module 2: Foundations of physics

The aim of this module is to introduce important conventions and ideas that permeate the fabric of physics. Understanding of physical quantities, S.I. units, scalars and vectors helps physicists to effectively communicate their ideas within the scientific community (HSW8, 11).

2.1 Physical quantities and units

This section provides knowledge and understanding of physical quantities and units.

2.1.1 Physical quantities

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	physical quantities have a numerical value and a unit	*M0.1*
(b)	making estimates of physical quantities listed in this specification.	*M0.4*

2.1.2 S.I. units

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	Système Internationale (S.I.) base quantities and their units – mass (kg), length (m), time (s), current (A), temperature (K), amount of substance (mol)	HSW8
(b)	derived units of S.I. base units	Examples: momentum $\longrightarrow$ kg m s^{-1} and density $\longrightarrow$ kg m^{-3}
(c)	units listed in this 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)	As set out in the ASE publication *Signs, Symbols and Systematics* (*The ASE Companion to 16–19 Science*, 2000).
(f)	the conventions used for labelling graph axes and table columns.	As set out in above, e.g. speed / m s^{-1}. HSW8

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2.2 Making measurements and analysing data

This section provides knowledge and understanding of physical measurements and treatment of errors and uncertainties.

2.2.1 Measurements and uncertainties

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	systematic errors (including zero errors) and random errors in measurements	
(b)	precision and accuracy	As discussed in *The Language of Measurement* (ASE 2010).
(c)	absolute and percentage uncertainties when data are combined by addition, subtraction, multiplication, division and raising to powers	As set out in the ASE publication *Signs*, *Symbols and Systematics* (*The ASE Companion to 16–19 Science,* 2000). A rigorous statistical treatment is not expected. *M1.5*
(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. HSW5 *M1.5*

2.3 Nature of quantities

This section provides knowledge and understanding of scalars and vectors quantities. Vector quantities add and subtract very differently to scalar quantities; hence it is important to know whether a quantity is a vector or a scalar.

2.3.1 Scalars and vectors

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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 calculation or by scale drawing *M0.6, M4.2, M4.4*
(d)	resolving a vector into two perpendicular components; $F_x = F \cos \theta$; $F_y = F \sin \theta$.	*M0.6, M4.5*

Module 3: Forces and motion

The term *force* is generally used to indicate a push or a pull. It is difficult to give a proper definition for a force, but in physics we can easily describe what a force can do.

A resultant force acting on an object can accelerate the object in a specific direction. The subsequent motion of the object can be analysed using equations of motion. Several forces acting on an object can prevent the object from either moving or rotating. Forces can also change the shape of an object. There are many other things that forces can do.

In this module, learners will learn how to model the motion of objects using mathematics, understand the effect forces have on objects, learn about the important connection between force and energy, appreciate how forces cause deformation and understand the importance of Newton's laws of motion.

3.1 Motion

This section provides knowledge and understanding of key ideas used to describe and analyse the motion of objects in both one-dimension and in two-dimensions. It also provides learners with opportunities to develop their analytical and experimental skills.

The motion of a variety of objects can be analysed using ICT or data-logging techniques (HSW3). Learners also have the opportunity to analyse and interpret experimental data by recognising relationships between physical quantities (HSW5). The analysis of motion gives many opportunities to link to How Science Works. Examples relate to detecting the speed of moving vehicles, stopping distances and freefall (HSW2, 9, 10, 11, 12).

3.1.1 Kinematics

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	displacement, instantaneous speed, average speed, velocity and acceleration	*M0.1, M1.4, M3.7, M3.9* HSW10, 12
(b)	graphical representations of displacement, speed, velocity and acceleration	*M3.6* HSW3 Using data-loggers to analyse motion.
(c)	Displacement–time graphs; velocity is gradient	*M3.4, M3.7*
(d)	Velocity–time graphs; acceleration is gradient; displacement is area under graph.	Learners will also be expected to estimate the area under non-linear graphs. *M3.5, M4.3*

2

3.1.2 Linear motion

		Learning outcomes	Additional guidance
		Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	**(i)**	the equations of motion for constant acceleration in a straight line, including motion of bodies falling in a uniform gravitational field without air resistance $v = u + at$ $s = \frac{1}{2}(u + v)t$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$	*M2.2, M2.4, M3.3* HSW9
	(ii)	techniques and procedures used to investigate the motion and collisions of objects	**PAG1** Apparatus may include trolleys, air-track gliders, ticker timers, light gates, data-loggers and video techniques. HSW4, 9, 10
(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	**PAG1** HSW4, 5, 7 Determining g in the laboratory.
(c)		reaction time and thinking distance; braking distance and stopping distance for a vehicle.	HSW5, 9, 10, 11, 12

3.1.3 Projectile motion

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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.	*M0.6, M4.5*

3.2 Forces in action

This section provides knowledge and understanding of the motion of an object when it experiences several forces and also the equilibrium of an object. Learners will also learn how pressure differences give rise to an *upthrust* on an object in a fluid.

There are opportunities to consider contemporary applications of terminal velocity, moments, couples, pressure, and Archimedes principle (HSW6, 7, 9, 11, 12).

Experimental work must play a pivotal role in the acquisition of key concepts and skills (HSW4).

3.2.1 Dynamics

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	net force = mass × acceleration; $F = ma$	Learners will also be expected to recall this equation. *M1.1*
(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

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	drag as the frictional force experienced by an object travelling through a fluid	
(b)	factors affecting drag for an object travelling through air	HSW6
(c)	motion of objects falling in a uniform gravitational field in the presence of drag	HSW9
(d)	**(i)** terminal velocity	HSW1, 5
	(ii) techniques and procedures used to determine terminal velocity in fluids.	**PAG1** e.g. ball-bearing in a viscous liquid or cones in air. HSW4 Investigating factors affecting terminal velocity.

2

3.2.3 Equilibrium

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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.	*M4.1, M4.2, M4.4*

3.2.4 Density and pressure

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	density; $\rho = \frac{m}{V}$	*M0.1, M4.3*
(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.	*M2.1* HSW4, 7, 11

3.3 Work, energy and power

Words like *energy*, *power* and *work* have very precise meaning in physics. In this section the important link between work done and energy is explored. Learners have the opportunity to apply the important principle of conservation of energy to a range of situations. The analysis of energy transfers provides the opportunity for calculations of efficiency and the subsequent evaluation of issues relating to the individual and society (HSW2, 5, 8, 9, 10, 11, 12).

2

3.3.1 Work and conservation of energy

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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	HSW2
(d)	energy in different forms; transfer and conservation	
(e)	transfer of energy is equal to work done.	

3.3.2 Kinetic and potential energies

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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. *M0.5*
(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 it from first principles.
(c)	the exchange between gravitational potential energy and kinetic energy.	HSW5, 6

3.3.3 Power

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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; $\text{efficiency} = \frac{\textit{useful output energy}}{\textit{total input energy}} \times 100\%$	*M0.3* HSW9, 10, 12

3.4 Materials

This section examines the physical properties of springs and materials.

Learners can carry out a range of experimental work to enhance their knowledge and skills, including the management of risks and analysis of data to provide evidence for relationships between physical quantities. There are opportunities to consider the selection of appropriate materials for practical applications (HSW5, 6, 8, 9, 12).

2

3.4.1 Springs

		Learning outcomes	Additional guidance
		Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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	*M3.2*
	(ii)	techniques and procedures used to investigate force–extension characteristics for arrangements which may include springs, rubber bands, polythene strips.	**PAG2** HSW5, 6

3.4.2 Mechanical properties of matter

		Learning outcomes	Additional guidance
		Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)		force–extension (or compression) graph; work done is area under graph	*M3.1*
(b)		elastic potential energy; $E = \frac{1}{2}Fx$; $E = \frac{1}{2}kx^2$	*M0.5, M3.12*
(c)		stress, strain and ultimate tensile strength	
(d)	**(i)**	Young modulus = $\frac{\text{tensile stress}}{\text{tensile strain}}$, $E = \frac{\sigma}{\varepsilon}$	*M3.1*
	(ii)	techniques and procedures used to determine the Young modulus for a metal	**PAG2**
(e)		stress–strain graphs for typical ductile, brittle and polymeric materials	*M3.2* HSW8
(f)		elastic and plastic deformations of materials.	HSW4, 5, 9, 12 Investigating the properties of materials **PAG2**

3.5 Newton's laws of motion and momentum

This section provides knowledge and understanding of Newton's laws – fundamental laws that can be used to predict the motion of all colliding or interacting objects in applications such as sport (HSW1, 2). Newton's law can also be used to understand some of the safety features in cars, such as air bags, and to evaluate the benefits and risks of such features (HSW9). Learners should be aware that the introduction of mandatory safety features in cars is a consequence of the scientific community analysing the forces involved in collisions and investigating potential solutions to reduce the likelihood of personal injury (HSW10, 11, 12).

There are many opportunities for learners to carry out experimental work and analyse data using ICT techniques (HSW3).

3.5.1 Newton's laws of motion

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	Newton's three laws of motion	HSW7
(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. HSW9, 10 *M2.1, M3.9*
(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. HSW3 Using a spreadsheet to determine impulse from F–t graph. *M3.8, M4.3*

3.5.2 Collisions

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the principle of conservation of momentum	HSW7
(b)	collisions and interaction of bodies in one dimension and in two dimensions	Two-dimensional problems will only be assessed at A level. HSW11, 12
(c)	perfectly elastic collision and inelastic collision.	HSW1, 2, 6

2

Module 4: Electrons, waves and photons

The aim of this module is to ultimately introduce key ideas of quantum physics. Electromagnetic waves (e.g. light) have a dual nature. They exhibit both wave and particle-like behaviour. The wave–particle dual nature is also found to be characteristic of all particles (e.g. electrons).

Before any sophisticated work can be done on quantum physics, learners need to appreciate what electrons are and how they behave in electrical circuits. A basic understanding of wave properties is also required.

In this module, learners will learn about electrons, electric current, electrical circuits, wave properties, electromagnetic waves and, of course, quantum physics.

Learners have the opportunity to appreciate how scientific ideas of quantum physics developed over time (HSW7) and their validity rested on the foundations of experimental work (HSW1 and HSW2).

4.1 Charge and current

This short section introduces the ideas of charge and current. Understanding electric current is essential when dealing with electrical circuits. This section does not lend itself to practical work but to introducing important ideas. The continuity equation ($I = Anev$) is developed using these key ideas. This section concludes with categorising all materials in terms of their ability to conduct.

4.1.1 Charge

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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 a charge +*e*. HSW7
(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	HSW7
(f)	conventional current and electron flow	HSW7
(g)	Kirchhoff’s first law; conservation of charge.	

4.1.2 Mean drift velocity

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	mean drift velocity of charge carriers	
(b)	$I = Anev$, where n is the number density of charge carriers	*M0.2*
(c)	distinction between conductors, semiconductors and insulators in terms of *n.*	HSW1, 2

4.2 Energy, power and resistance

This section provides knowledge and understanding of electrical symbols, electromotive force, potential difference, resistivity and power. The scientific vocabulary developed here is a prerequisite for understanding electrical circuits in **4.3**.

There is a desire to use energy saving devices, such as LED lamps, in homes. Learners have the opportunity to understand the link between environmental damage from power stations and the impetus to use energy saving devices in the home (HSW10) and how customers can make informed decisions when buying domestic appliances (HSW12).

There are many opportunities for learners to use spreadsheets in the analysis and presentation of data (HSW3), to carry out practical activities to understand concepts (HSW4) and to analyse data to find relationships between physical quantities (HSW5).

4.2.1 Circuit symbols

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	circuit symbols	As set out in ASE publication *Signs, Symbols and Systematics (The ASE Companion to 16–19 Science, 2000).* HSW8
(b)	circuit diagrams using these symbols.	

4.2.2 E.m.f. and p.d

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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)	*M3.12* HSW5, 8, 9
	(ii) techniques and procedures used to investigate the electrical characteristics for a range of ohmic and non-ohmic components.	**PAG3** HSW3, 4, 5 Investigating components and analysing data using spreadsheet.
(d)	light-dependent resistor (LDR); variation of resistance with light intensity.	

4.2.4 Resistivity

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	**(i)** resistivity of a material; the equation $R = \frac{\rho L}{A}$	
	(ii) techniques and procedures used to determine the resistivity of a metal.	**PAG3**
(b)	the variation of resistivity of metals and semiconductors with temperature	HSW2
(c)	negative temperature coefficient (NTC) thermistor; variation of resistance with temperature.	HSW5

4.2.5 Power

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the equations $P = VI$, $P = I^2R$ and $P = \frac{V^2}{R}$	*M2.2*
(b)	energy transfer; $W = VIt$	

(c)	the kilowatt-hour (kW h) as a unit of energy; calculating the cost of energy.	Learners will be expected to link this with 3.3.3(c) HSW10,12

4.3 Electrical circuits

This section provides knowledge and understanding of electrical circuits, internal resistance and potential dividers. LDRs and thermistors are used to show how changes in light intensity and temperature respectively can be monitored using potential dividers.

Setting up electrical circuits, including potential divider circuits, provides an ideal way of enhancing experimental skills, understanding electrical concepts and managing risks when using power supplies (HSW4). Learners are encouraged to communicate scientific ideas using appropriate terminology (HSW8). This section provides ample opportunities for learners to design circuits and carry out appropriate testing for faults and there are opportunities to study the many applications of electrical circuits (HSW1, 2, 3, 5, 6, 9, 12).

2

4.3.1 Series and parallel circuits

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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; $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + ...$	
(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

		Learning outcomes	Additional guidance
		Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)		source of e.m.f.; internal resistance	HSW9, 12
(b)		terminal p.d.; 'lost volts'	
(c)	**(i)**	the equations $\mathcal{E} = I(R + r)$ and $\mathcal{E} = V + Ir$	HSW5, 6
	(ii)	techniques and procedures used to determine the internal resistance of a chemical cell or other source of e.m.f.	**PAG4** HSW4, HSW8 Investigating the internal resistance of a power supply.

4.3.3 Potential dividers

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	potential divider circuit with components	Learners will also be expected to know about a potentiometer as a potential divider.
(b)	potential divider circuits with variable components e.g. LDR and thermistor	
(c)	**(i)** potential divider equations e.g. $V_{out} = \frac{R_2}{R_1 + R_2} \times V_{in}$ and $\frac{V_1}{V_2} = \frac{R_1}{R_2}$	*M2.3*
	(ii) techniques and procedures used to investigate potential divider circuits which may include a sensor such as a thermistor or an LDR.	**PAG4** HSW4 Designing temperature and light sensing circuits.

4.4 Waves

This section provides knowledge and understanding of wave properties, electromagnetic waves, superposition and stationary waves. The wavelength of visible light is too small to be measured directly using a ruler. However, superposition experiments can be done in the laboratory to determine wavelength of visible light using a laser and a double slit.

There are opportunities to discuss how the double-slit experiment demonstrated the wave-like behaviour of light (HSW7).

The breadth of the topic covering sound waves and the electromagnetic spectrum provides scope for learners to appreciate the wide ranging applications of waves and their properties. (HSW1, 2, 5, 8, 9, 12)

4.4.1 Wave motion

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	progressive waves; longitudinal and transverse waves	HSW8
(b)	**(i)** displacement, amplitude, wavelength, period, phase difference, frequency and speed of a wave	HSW8
	(ii) techniques and procedures used to use an oscilloscope to determine frequency	**PAG5**
(c)	the equation $f = \frac{1}{T}$	
(d)	the wave equation $v = f\lambda$	

(e)	graphical representations of transverse and longitudinal waves		HSW5
(f)	**(i)**	reflection, refraction, polarisation and diffraction of all waves	Learners will be expected to know that diffraction effects become significant when the wavelength is comparable to the gap width.
	(ii)	techniques and procedures used to demonstrate wave effects using a ripple tank	HSW1, 4
	(iii)	techniques and procedures used to observe polarising effects using microwaves and light	**PAG5**
(g)	intensity of a progressive wave; $I = \frac{P}{A}$; intensity ∝ (amplitude)^2.		

4.4.2 Electromagnetic waves

	Learning outcomes		Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:		
(a)	electromagnetic spectrum; properties of electromagnetic waves		
(b)	orders of magnitude of wavelengths of the principal radiations from radio waves to gamma rays		
(c)	plane 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. HSW9
(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 blocks	**PAG6**
(e)	critical angle; $\sin C = \frac{1}{n}$; total internal reflection for light.		

2

4.4.3 Superposition

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	**(i)** the principle of superposition of waves	
	(ii) techniques and procedures used for superposition experiments using sound, light and microwaves	**PAG5**
(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. HSW7 Internet research on the ideas of Newton and Huygens about the nature of light.
(g)	**(i)** $\lambda = \frac{ax}{D}$ for all waves where $a << D$	*M4.6*
	(ii) techniques and procedures used to determine the wavelength of light using (1) a double-slit, and (2) a diffraction grating.	**PAG5** $d \sin\theta = n\lambda$ and diffraction gratings will only be assessed at A level

4.4.4 Stationary waves

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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	**PAG5**
(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

This section provides knowledge and understanding of photons, the photoelectric effect, de Broglie waves and wave–particle duality.

In the photoelectric effect experiment, electromagnetic waves are used to eject surface electrons from metals. The electrons are ejected instantaneously and their energy is independent of the intensity of the radiation. The wave model is unable to explain the interaction of these waves with matter. This single experiment led to the development of the photon model and was the cornerstone of quantum physics. Learners have the opportunity to carry out internet research into how the ideas of quantum physics developed (HSW1, 2, 7) and how scientific community validates the integrity of new knowledge before its acceptance (HSW11).

4.5.1 Photons

		Learning outcomes	Additional guidance
		Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)		the particulate nature (photon model) of electromagnetic radiation	
(b)		photon as a quantum of energy of electromagnetic radiation	
(c)		energy of a photon; $E = hf$ and $E = \frac{hc}{\lambda}$	
(d)		the electronvolt (eV) as a unit of energy	
(e)	**(i)**	using LEDs and the equation $eV = \frac{hc}{\lambda}$ to estimate the value of Planck constant h	No knowledge of semiconductor theory is required. HSW11
	(ii)	Determine the Planck constant using different coloured LEDs.	**PAG6**

2

4.5.2 The photoelectric effect

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	**(i)** photoelectric effect, including a simple experiment to demonstrate this effect	Learners should understand that the photoelectric effect provides evidence for particulate nature of electromagnetic radiation. HSW1, 2, 3, 7, 11 Internet research on the development of quantum physics.
	(ii) demonstration of the photoelectric effect using, e.g. gold-leaf electroscope and zinc plate	
(b)	a one-to-one interaction between a photon and a surface electron	
(c)	Einstein's photoelectric equation $hf = \phi + KE_{\text{max}}$	*M2.3*
(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

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	electron diffraction, including experimental evidence of this effect	Learners should understand that electron diffraction provides 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

The aim of this module is to show the impact Newtonian mechanics has on physics. The microscopic motion of atoms can be modelled using Newton's laws and hence provide us with an understanding of macroscopic quantities such as pressure and temperature. Newton's law of gravitation can be used to predict the motion of planets and distant galaxies. In the final section we explore the intricacies of stars and the expansion of the Universe by analysing the electromagnetic radiation from space. As such, it lends itself to the consideration of how the development of the scientific model is improved based on the advances in the means of observation (HSW1, 2, 5, 6, 7, 8, 9, 11).

In this module, learners will learn about thermal physics, circular motion, oscillations, gravitational field, astrophysics and cosmology.

5.1 Thermal physics

This section provides knowledge and understanding of temperature, matter, specific heat capacity and specific latent heat with contexts involving heat transfer and change of phase (HSW1, 2, 5, 7).

Experimental work can be carried out to safely investigate specific heat capacity of materials (HSW4).

It also provides an opportunity to discuss how Newton's laws can be used to model the behaviour of gases (HSW1) and significant opportunities for the analysis and interpretation of data (HSW5).

5.1.1 Temperature

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	thermal equilibrium	
(b)	absolute scale of temperature (i.e. the thermodynamic scale) that does not depend on property of any particular substance	HSW7
(c)	temperature measurements both in degrees Celsius (°C) and in kelvin (K)	HSW7
(d)	$T(K) \approx \theta(°C) + 273$.	

5.1.2 Solid, liquid and gas

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	solids, liquids and gases in terms of the spacing, ordering and motion of atoms or molecules	HSW1
(b)	simple kinetic model for solids, liquids and gases	HSW1
(c)	Brownian motion in terms of the kinetic model of matter and a simple demonstration using smoke particles suspended in air	HSW2

(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.

2

5.1.3 Thermal properties of materials

			Additional guidance
	Learning outcomes		**Additional guidance**
	Learners should be able to demonstrate and apply their knowledge and understanding of:		
(a)	specific heat capacity of a substance; the equation $E = mc\Delta\theta$		HSW4 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	HSW5
	(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

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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 HSW1
(c)	pressure in terms of this model	HSW1, 2 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	**PAG8**
	(iii) an estimation of absolute zero using variation of gas temperature with pressure	**PAG8**
(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. HSW2
(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* $pV = NkT$. HSW2
(i)	internal energy of an ideal gas.	

5.2 Circular motion

There are many examples of objects travelling at constant speed in circles, e.g. planets, artificial satellites, charged particles in a magnetic field, etc. The physics in all these cases can be described and analysed using the ideas developed by Newton. The concepts in this section have applications in many contexts present in other sections of this specification, such as planetary motion in section 5.4.3 (HSW1, 2, 5, 9).

This section provides knowledge and understanding of circular motion and important concepts such as centripetal force and acceleration.

2

5.2.1 Kinematics of circular motion

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the radian as a measure of angle	*M4.7*
(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

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	a constant net force perpendicular to the velocity of an object causes it to travel in a circular path	HSW1, 2, 5, 9
(b)	constant speed in a circle; $v = \omega r$	
(c)	centripetal acceleration; $a = \frac{v^2}{r}$; $a = \omega^2 r$	*M2.4*
(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

Oscillatory motion is all around us, with examples including atoms vibrating in a solid, a bridge swaying in the wind, the motion of pistons of a car and the motion of tides. (HSW1, 2, 3, 5, 6, 8, 9, 10, 12)

This section provides knowledge and understanding of simple harmonic motion, forced oscillations and resonance.

2

5.3.1 Simple harmonic oscillations

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	displacement, amplitude, period, frequency, angular frequency and phase difference	*M4.7* HSW8
(b)	angular frequency ω; $\omega = \frac{2\pi}{T}$ or $\omega = 2\pi f$	
(c)	**(i)** simple harmonic motion; defining equation $a = -\omega^2 x$	HSW5
	(ii) techniques and procedures used to determine the period/frequency of simple harmonic oscillations	**PAG10** e.g. mass on a spring, pendulum
(d)	solutions to the equation $a = -\omega^2 x$ e.g. $x = A\cos\omega t$ or $x = A\sin\omega t$	*M3.9, M3.12*
(e)	velocity $v = \pm\omega\sqrt{A^2 - x^2}$ hence $v_{max} = \omega A$	*M2.2*
(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.	HSW1

5.3.2 Energy of a simple harmonic oscillator

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	interchange between kinetic and potential energy during simple harmonic motion	HSW2
(b)	energy-displacement graphs for a simple harmonic oscillator	HSW6

2

5.3.3 Damping

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	free and forced oscillations	
(b)	**(i)** the effects of damping on an oscillatory system	HSW9, 12
	(ii) observe forced and damped oscillations for a range of systems	
(c)	resonance; natural frequency	HSW9, 12
(d)	amplitude-driving frequency graphs for forced oscillators	
(e)	practical examples of forced oscillations and resonance.	HSW9, 12

5.4 Gravitational fields

This section provides knowledge and understanding of Newton's law of gravitation, planetary motion and gravitational potential and energy.

Newton's law of gravitation can be used to predict the motion of orbiting satellites, planets and even why some objects in our Solar system have very little atmosphere with the opportunity to analyse evidence and look at causal relationships (HSW1, 2, 5, 7).

Geostationary satellites have done much to improve telecommunications around the world. They are expensive; governments and industry have to make difficult decisions when building new ones. Learners have the opportunity to discuss the societal benefits of satellites and the risks they pose when accidents do occur (HSW9, 10).

5.4.1 Point and spherical masses

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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	HSW1
(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

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	Newton's law of gravitation; $F = -\frac{GMm}{r^2}$ for the force between two point masses	*M2.3*
(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

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	Kepler's three laws of planetary motion	HSW7
(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. HSW1
(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.	HSW1, 2, 9, 10 Predicting geostationary orbit using Newtonian laws.

5.4.4 Gravitational potential and energy

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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	HSW5
(d)	gravitational potential energy $E = mV_g = -\frac{GMm}{r}$ at a distance r from a point mass M	
(e)	escape velocity.	HSW1, HSW2 Predicting the escape velocity of atoms from the atmosphere of planets.

2

5.5 Astrophysics and cosmology

This section provides knowledge and understanding of stars, Wien's displacement law, Stefan's law, Hubble's law and the Big Bang.

Learners have the opportunity to appreciate how scientific ideas of the Big Bang developed over time and how its validity is supported by research and experimental work carried out by the scientific community (HSW2, 7, 8, 11).

5.5.1 Stars

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the terms planets, planetary satellites, comets, solar systems, galaxies and the universe	HSW7
(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	HSW8
(d)	characteristics of a white dwarf; electron degeneracy pressure; Chandrasekhar limit	HSW8
(e)	evolution of a massive star into a red super giant and then either a neutron star or black hole; supernova	HSW8
(f)	characteristics of a neutron star and a black hole	HSW8
(g)	Hertzsprung–Russell (HR) diagram as luminosity-temperature plot; main sequence; red giants; super red giants; white dwarfs.	HSW8

5.5.2 Electromagnetic radiation from stars

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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	HSW2, 8
(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; **PAG5**
(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)	*M0.4* HSW5
(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.	*M0.4* HSW5

2

5.5.3 Cosmology

	Learning outcomes	**Additional guidance**
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	distances measured in astronomical unit (AU), light-year (ly) and parsec (pc)	*M4.6*
(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	HSW7
(h)	model of an expanding universe supported by galactic red shift	HSW2, 7, 8, 11
(i)	Hubble constant H_0 in both $\mathrm{km\,s^{-1}\,Mpc^{-1}}$ and $\mathrm{s^{-1}}$ units	
(j)	the Big Bang theory	HSW7, 9, 10, 12

(k)	experimental evidence for the Big Bang theory from microwave background radiation at a temperature of 2.7 K	HSW7, HSW11 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; $t \approx H_0^{-1}$	*M1.4* HSW7
(n)	evolution of the universe after the Big Bang to the present	HSW1, 2, 5, 6, 7, 8, 9, 10, 11
(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

In this module, learners will learn about capacitors, electric field, electromagnetism, nuclear physics, particle physics and medical imaging.

6.1 Capacitors

2

This section introduces the basic properties of capacitors and how they are used in electrical circuits. The use of capacitors as a source of electrical energy is then developed. This section introduces the mathematics of exponential decay, which is also required for the decay of radioactive nuclei in **6.4**.

This section provides knowledge and understanding of capacitors and exponential decay.

Experimental work provides an excellent way to understand the behaviour of capacitors in electrical circuits and the management of safety and risks when using power supplies (HSW4). There are many opportunities for learners to use spreadsheets in the analysis and presentation of data (HSW3). The varied uses of capacitors give the opportunity for the consideration of their use in many practical applications (HSW2, 5, 6, 9)

6.1.1 Capacitors

		Learning outcomes	Additional guidance
		Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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	HSW2
(c)		total capacitance of two or more capacitors in series; $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + ...$	
(d)		total capacitance of two or more capacitors in parallel; $C = C_1 + C_2 + ...$	
(e)	**(i)**	analysis of circuits containing capacitors, including resistors	HSW5
	(ii)	techniques and procedures used to investigate capacitors in both series and parallel combinations using ammeters and voltmeters.	**PAG9**

6.1.2 Energy

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	p.d. – charge graph for a capacitor; energy stored is area under graph	*M3.8* HSW5
(b)	energy stored by capacitor; $W = \frac{1}{2}QV$, $W = \frac{1}{2}\frac{Q^2}{C}$ and $W = \frac{1}{2}V^2C$	HSW6
(c)	uses of capacitors as storage of energy.	HSW9

6.1.3 Charging and discharging capacitors

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	**(i)** charging and discharging capacitor through a resistor	
	(ii) techniques and procedures to investigate the charge and the discharge of a capacitor using both meters and data-loggers	**PAG9** HSW4 Investigating the charge and discharge of capacitors in the laboratory.
(b)	time constant of a capacitor–resistor circuit; $\tau = CR$	HSW9
(c)	equations of the form $x = x_0 e^{-\frac{t}{CR}}$ and $x = x_0(1 - e^{-\frac{t}{CR}})$ for capacitor–resistor circuits	Learners will be expected to know how ln*x*–*t* graphs can be used to determine *CR*. *M0.5, M2.5, M3.10, M3.12*
(d)	graphical methods and spreadsheet modelling of the equation $\frac{\Delta Q}{\Delta t} = -\frac{Q}{CR}$ for a discharging capacitor	HSW3 Using spreadsheets to model the discharge of a capacitor. *M3.9*
(e)	exponential decay graph; constant-ratio property of such a graph.	*M3.11*

6.2 Electric fields

This section provides knowledge and understanding of Coulomb's law, uniform electric fields, electric potential and energy.

6.2.1 Point and spherical charges

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	electric fields are due to charges	
(b)	modelling a uniformly charged sphere as a point charge at its centre	HSW1
(c)	electric field lines to map electric fields	
(d)	electric field strength; $E = \frac{F}{Q}$.	

6.2.2 Coulomb's law

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	uniform electric field strength; $E = \frac{V}{d}$	
(b)	parallel plate capacitor; permittivity; $C = \frac{\varepsilon_0 A}{d}$; $C = \frac{\varepsilon A}{d}$; $\varepsilon = \varepsilon_r \varepsilon_0$	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 HSW2

6.2.4 Electric potential and energy

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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	HSW5
(e)	electric potential energy $= Qq/4\pi\varepsilon r = \frac{Qq}{4\pi\varepsilon_0 r}$ of a distance r from a point charge Q.	

6.3 Electromagnetism

This section provides knowledge and understanding of magnetic fields, motion of charged particles in magnetic fields, Lenz's law and Faraday's law. The application of Faraday's law may be used to demonstrate how science has benefited society with important devices such as generators and transformers. Transformers are used in the transmission of electrical energy using the national grid and are an integral part of many electrical devices in our homes. The application of Lenz's law allows discussion of the use of scientific knowledge to present a scientific argument (HSW1, 2, 3, 5, 6, 7, 8, 9, 11, 12).

6.3.1 Magnetic fields

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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	HSW7
(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.	

2

6.3.2 Motion of charged particles

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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 HSW1
(c)	charged particles moving in a region occupied by both electric and magnetic fields; velocity selector.	HSW1, 2, 6

6.3.3 Electromagnetism

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	magnetic flux ϕ; the unit weber; $\phi = BA\cos\theta$	
(b)	magnetic flux linkage	
(c)	Faraday's law of electromagnetic induction and Lenz's law	HSW2, 7
(d)	**(i)** e.m.f. = − rate of change of magnetic flux linkage; $\mathcal{E} = -\frac{\Delta(N\phi)}{\Delta t}$	*M3.9* HSW2, 8
	(ii) techniques and procedures used to investigate magnetic flux using search coils	
(e)	simple a.c. generator	HSW8
(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	*M0.3* HSW9
	(ii) techniques and procedures used to investigate transformers.	HSW3, 9

6.4 Nuclear and particle physics

This section provides knowledge and understanding of the atom, nucleus, fundamental particles, radioactivity, fission and fusion.

Nuclear power stations provide a significant fraction of the energy needs of many countries. They are expensive; governments have to make difficult decisions when building new ones. The building of nuclear power stations can be used to evaluate the benefits and risks to society (HSW9). Ethical, environmental and decision making issues may also be discussed (HSW10 and HSW12). The development of the atomic model also addresses issues of scientific development and validation (HSW7, 11).

2

6.4.1 The nuclear atom

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	alpha-particle scattering experiment; evidence of a small charged nucleus	HSW7
(b)	simple nuclear model of the atom; protons, neutrons and electrons	
(c)	relative sizes of atom and nucleus	*M0.4, M1.4*
(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; $R = r_0 A^{1/3}$ where r_0 is a constant and A is the nucleon number	
(g)	mean densities of atoms and nuclei.	HSW7

6.4.2 Fundamental particles

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	particles and antiparticles; electron–positron, proton-antiproton, neutron-antineutron and neutrino-antineutrino	HSW7, 9
(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 the strong nuclear force	
(d)	classification of leptons; electron and neutrino as examples of leptons; all leptons are subject to the weak nuclear force	HSW7, 9

(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 ($\overline{u}$), anti-down ($\overline{d}$) and the anti-strange ($\overline{s}$) quarks as fractions of the elementary charge *e*	
(h)	beta-minus (β^-) decay; beta-plus (β^+) decay	
(i)	β^- decay in terms of a quark model; $d \rightarrow u + {}^{0}_{-1}e + \overline{\nu}$	
(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.	

2

6.4.3 Radioactivity

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	radioactive decay; spontaneous and random nature of decay	*M1.3*
(b)	**(i)** α-particles, β-particles and γ-rays; nature, penetration and range of these radiations	
	(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; $\lambda t_{1/2} = \ln(2)$	
	(ii) techniques and procedures used to determine the half-life of an isotope such as protactinium	**PAG7**
(f)	**(i)** the equations $A = A_0 e^{-\lambda t}$ and $N = N_0 e^{-\lambda t}$, where *A* is the activity and *N* is the number of undecayed nuclei	*M3.12*
	(ii) simulation of radioactive decay using dice	*M1.3*

(g)	graphical methods and spreadsheet modelling of the equation $\frac{\Delta N}{\Delta t} = -\lambda N$ for radioactive decay	HSW3 Using spreadsheets to model the radioactive decay of nuclei. *M0.5, M2.5, M3.9*
(h)	radioactive dating, e.g. carbon-dating.	

6.4.4 Nuclear fission and fusion

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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	HSW9, HSW10, HSW12 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 Medical imaging

This section provides knowledge and understanding of X-rays, CAT scans, PET scans and ultrasound scans. This section shows how the developments in medical imaging have led to a number of valuable non-invasive techniques used in hospitals.

Not all hospitals in this country are equipped with complex scanners. Learners have the chance to discuss the ethical issues in the treatment of humans and the ways in which society uses science to inform decision making (HSW10 and 12).

6.5.1 Using X-rays

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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	*M0.5, M3.11*
(e)	X-ray imaging with contrast media; barium and iodine	HSW9, 10, 12
(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.	HSW9, 10, 12

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6.5.2 Diagnostic methods in medicine

	Learning outcomes	**Additional guidance**
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	medical tracers; technetium–99m and fluorine–18	HSW9, 10
(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	HSW9, 10, 12
(e)	diagnosis using PET scanning.	HSW10, HSW12 Issues raised when equipping a hospital with an expensive scanner.

6.5.3 Using ultrasound

	Learning outcomes	**Additional guidance**
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(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	HSW9, 10, 12
(d)	acoustic impedance of a medium; $Z = \rho c$	
(e)	reflection of ultrasound at a boundary; $\frac{I_r}{I_0} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$	*M0.3*

(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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