TRIPLE SCIENCE GCSE
PHYSICS PAPER 2
HIGHER

MAJOR FOCUS
NOT MENTIONED
NOT ASSESSED

4.5 Forces

Engineers analyse forces when designing a great variety of machines and instruments, from road bridges and fairground rides to atomic force microscopes. Anything mechanical can be analysed in this way. Recent developments in artificial limbs use the analysis of forces to make movement possible.

4.5.1 Forces and their interactions

4.5.1.1 Scalar and vector quantities

Content	Key opportunities for skills development
Scalar quantities have magnitude only. Vector quantities have magnitude and an associated direction. A vector quantity may be represented by an arrow. The length of the arrow represents the magnitude, and the direction of the arrow the direction of the vector quantity.	

4.5.1.2 Contact and non-contact forces

Content	Key opportunities for skills development
A force is a push or pull that acts on an object due to the interaction with another object. All forces between objects are either: • contact forces – the objects are physically touching • non-contact forces – the objects are physically separated. Examples of contact forces include friction, air resistance, tension and normal contact force. Examples of non-contact forces are gravitational force, electrostatic force and magnetic force. Force is a vector quantity. Students should be able to describe the interaction between pairs of objects which produce a force on each object. The forces to be represented as vectors.	

4.5.1.3 Gravity

Content	Key opportunities for skills development
Weight is the force acting on an object due to gravity. The force of gravity close to the Earth is due to the gravitational field around the Earth. The weight of an object depends on the gravitational field strength at the point where the object is.	

Content	Key opportunities for skills development
The weight of an object can be calculated using the equation: weight = mass × gravitational field strength [$W = m\,g$] weight, *W*, in newtons, N mass, *m*, in kilograms, kg gravitational field strength, *g*, in newtons per kilogram, N/kg (In any calculation the value of the gravitational field strength (*g*) will be given.) The weight of an object may be considered to act at a single point referred to as the object's 'centre of mass'.	MS 3b, c Students should be able to recall and apply this equation.
The weight of an object and the mass of an object are directly proportional. Weight is measured using a calibrated spring-balance (a newtonmeter).	MS 3a Students should recognise and be able to use the symbol for proportionality, ∝

4.5.1.4 Resultant forces

Content	Key opportunities for skills development
A number of forces acting on an object may be replaced by a single force that has the same effect as all the original forces acting together. This single force is called the resultant force. Students should be able to calculate the resultant of two forces that act in a straight line. (HT only) Students should be able to: • describe examples of the forces acting on an isolated object or system	
• use free body diagrams to describe qualitatively examples where several forces lead to a resultant force on an object, including balanced forces when the resultant force is zero. (HT only) A single force can be resolved into two components acting at right angles to each other. The two component forces together have the same effect as the single force.	WS 1.2
(HT only) Students should be able to use vector diagrams to illustrate resolution of forces, equilibrium situations and determine the resultant of two forces, to include both magnitude and direction (scale drawings only).	MS 4a, 5a, b

4.5.2 Work done and energy transfer

Content	Key opportunities for skills development
When a force causes an object to move through a distance work is done on the object. So a force does work on an object when the force causes a displacement of the object.	
The work done by a force on an object can be calculated using the equation: work done = force × distance (moved along the line of action of the force) [$W = F s$] work done, *W*, in joules, J force, *F*, in newtons, N distance, *s*, in metres	MS 3b, c Students should be able to recall and apply this equation.
One joule of work is done when a force of one newton causes a displacement of one metre. 1 joule = 1 newton-metre Students should be able to describe the energy transfer involved when work is done.	WS 4.5
Students should be able to convert between newton-metres and joules. Work done against the frictional forces acting on an object causes a rise in the temperature of the object.	MS 1c WS 4.5

4.5.3 Forces and elasticity

Content	Key opportunities for skills development
Students should be able to: • give examples of the forces involved in stretching, bending or compressing an object • explain why, to change the shape of an object (by stretching, bending or compressing), more than one force has to be applied – this is limited to stationary objects only • describe the difference between elastic deformation and inelastic deformation caused by stretching forces. The extension of an elastic object, such as a spring, is directly proportional to the force applied, provided that the limit of proportionality is not exceeded.	

Content	Key opportunities for skills development
$force = spring\ constant \times extension$ [$F = k e$] force, *F*, in newtons, N spring constant, *k*, in newtons per metre, N/m extension, *e*, in metres, m	MS 3b, c, 4a Students should be able to recall and apply this equation.
This relationship also applies to the compression of an elastic object, where '*e*' would be the compression of the object. A force that stretches (or compresses) a spring does work and elastic potential energy is stored in the spring. Provided the spring is not inelastically deformed, the work done on the spring and the elastic potential energy stored are equal. Students should be able to: • describe the difference between a linear and non-linear relationship between force and extension • calculate a spring constant in linear cases	MS 3b, c, 4a
• interpret data from an investigation of the relationship between force and extension	WS 3.5
• calculate work done in stretching (or compressing) a spring (up to the limit of proportionality) using the equation: $elastic\ potential\ energy = 0.5 \times spring\ constant \times (extension)^2$ [$E_e = \frac{1}{2} k e^2$]	MS 3c Students should be able to apply this equation which is given on the Physics equation sheet. This equation is also given in Changes in energy (page 18).
Students should be able to calculate relevant values of stored energy and energy transfers.	MS 3c

Required practical activity 6: investigate the relationship between force and extension for a spring.

4.5.4 Moments, levers and gears (physics only)

Content	Key opportunities for skills development
A force or a system of forces may cause an object to rotate. Students should be able to describe examples in which forces cause rotation. The turning effect of a force is called the moment of the force. The size of the moment is defined by the equation:	
$moment\ of\ a\ force = force \times distance$ [$M = F d$] moment of a force, *M*, in newton-metres, Nm force, *F*, in newtons, N distance, *d*, is the perpendicular distance from the pivot to the line of action of the force, in metres, m. If an object is balanced, the total clockwise moment about a pivot equals the total anticlockwise moment about that pivot. Students should be able to calculate the size of a force, or its distance from a pivot, acting on an object that is balanced. A simple lever and a simple gear system can both be used to transmit the rotational effects of forces. Students should be able to explain how levers and gears transmit the rotational effects of forces.	MS 3c Students should be able to recall and apply this equation.

4.5.5 Pressure and pressure differences in fluids (physics only)

4.5.5.1 Pressure in a fluid

4.5.5.1.1 Pressure in a fluid 1

Content	Key opportunities for skills development
A fluid can be either a liquid or a gas. The pressure in fluids causes a force normal (at right angles) to any surface. The pressure at the surface of a fluid can be calculated using the equation:	

Content	Key opportunities for skills development
pressure = $\frac{\text{force normal to a surface}}{\text{area of that surface}}$ [$p = \frac{F}{A}$] pressure, *p*, in pascals, Pa force, *F*, in newtons, N area, *A*, in metres squared, m^2	MS 3b, c WS 4.3, 4.4, 4.5, 4.6 Students should be able to recall and apply this equation.

4.5.5.1.2 Pressure in a fluid 2 (HT only)

Content	Key opportunities for skills development
The pressure due to a column of liquid can be calculated using the equation:	
pressure = height of the column × density of the liquid × gravitational field strength [$p = h \rho g$] pressure, *p*, in pascals, Pa height of the column, *h*, in metres, m density, *ρ*, in kilograms per metre cubed, kg/m^3 gravitational field strength, g, in newtons per kilogram, N/kg (In any calculation the value of the gravitational field strength (*g*) will be given.) Students should be able to explain why, in a liquid, pressure at a point increases with the height of the column of liquid above that point and with the density of the liquid.	MS 3b, 3c WS 4.3, 4.4, 4.5, 4.6 Students should be able to apply this equation which is given on the Physics equation sheet.
Students should be able to calculate the differences in pressure at different depths in a liquid. A partially (or totally) submerged object experiences a greater pressure on the bottom surface than on the top surface. This creates a resultant force upwards. This force is called the upthrust. Students should be able to describe the factors which influence floating and sinking.	MS 1c, 3c

4.5.5.2 Atmospheric pressure

Content	Key opportunities for skills development
The atmosphere is a thin layer (relative to the size of the Earth) of air round the Earth. The atmosphere gets less dense with increasing altitude. Air molecules colliding with a surface create atmospheric pressure. The number of air molecules (and so the weight of air) above a surface decreases as the height of the surface above ground level increases. So as height increases there is always less air above a surface than there is at a lower height. So atmospheric pressure decreases with an increase in height. Students should be able to:	
• describe a simple model of the Earth's atmosphere and of atmospheric pressure • explain why atmospheric pressure varies with height above a surface.	WS 1.2

4.5.6 Forces and motion

4.5.6.1 Describing motion along a line

4.5.6.1.1 Distance and displacement

Content	Key opportunities for skills development
Distance is how far an object moves. Distance does not involve direction. Distance is a scalar quantity. Displacement includes both the distance an object moves, measured in a straight line from the start point to the finish point and the direction of that straight line. Displacement is a vector quantity. Students should be able to express a displacement in terms of both the magnitude and direction.	MS 1, 3c Throughout this section (Forces and motion), students should be able to use ratios and proportional reasoning to convert units and to compute rates.

4.5.6.1.2 Speed

Content	Key opportunities for skills development
Speed does not involve direction. Speed is a scalar quantity. The speed of a moving object is rarely constant. When people walk, run or travel in a car their speed is constantly changing. The speed at which a person can walk, run or cycle depends on many factors including: age, terrain, fitness and distance travelled. Typical values may be taken as: walking ~ 1.5 m/s running ~ 3 m/s cycling ~ 6 m/s. Students should be able to recall typical values of speed for a person walking, running and cycling as well as the typical values of speed for different types of transportation systems. It is not only moving objects that have varying speed. The speed of sound and the speed of the wind also vary. A typical value for the speed of sound in air is 330 m/s.	
Students should be able to make measurements of distance and time and then calculate speeds of objects. For an object moving at constant speed the distance travelled in a specific time can be calculated using the equation:	MS 1a, c, 2f
$distance\ travelled = speed \times time$ [$s = v\,t$] distance, *s*, in metres, m speed, *v*, in metres per second, m/s time, *t*, in seconds, s	MS 3b, 3c Students should be able to recall and apply this equation.
Students should be able to calculate average speed for non-uniform motion.	MS 3b, 3c

4.5.6.1.3 Velocity

Content	Key opportunities for skills development
The velocity of an object is its speed in a given direction. Velocity is a vector quantity. Students should be able to explain the vector–scalar distinction as it applies to displacement, distance, velocity and speed. (HT only) Students should be able to explain qualitatively, with examples, that motion in a circle involves constant speed but changing velocity.	

4.5.6.1.4 The distance–time relationship

Content	Key opportunities for skills development
If an object moves along a straight line, the distance travelled can be represented by a distance–time graph. The speed of an object can be calculated from the gradient of its distance–time graph. (HT only) If an object is accelerating, its speed at any particular time can be determined by drawing a tangent and measuring the gradient of the distance–time graph at that time. Students should be able to draw distance–time graphs from measurements and extract and interpret lines and slopes of distance–time graphs, translating information between graphical and numerical form. Students should be able to determine speed from a distance–time graph.	MS 4a, b, c, d, f

4.5.6.1.5 Acceleration

Content	Key opportunities for skills development
The average acceleration of an object can be calculated using the equation:	

Content	Key opportunities for skills development
$acceleration = \frac{change\ in\ velocity}{time\ taken}$ [$a = \frac{\Delta v}{t}$] acceleration, a, in metres per second squared, m/s^2 change in velocity, Δv, in metres per second, m/s time, t, in seconds, s An object that slows down is decelerating. Students should be able to estimate the magnitude of everyday accelerations.	MS 1d, 3b, 3c Students should be able to recall and apply this equation.
The acceleration of an object can be calculated from the gradient of a velocity–time graph. (HT only) The distance travelled by an object (or displacement of an object) can be calculated from the area under a velocity–time graph. Students should be able to:	MS 4a, b, c, d, f
• draw velocity–time graphs from measurements and interpret lines and slopes to determine acceleration • (HT only) interpret enclosed areas in velocity–time graphs to determine distance travelled (or displacement)	WS 3.3
• (HT only) measure, when appropriate, the area under a velocity–time graph by counting squares.	WS 3.3
The following equation applies to uniform acceleration: ($final\ velocity^2 - initial\ velocity^2 = 2 \times acceleration \times distance$) [$v^2 - u^2 = 2\,a\,s$] final velocity, v, in metres per second, m/s initial velocity, u, in metres per second, m/s acceleration, a, in metres per second squared, m/s^2 distance, s, in metres, m Near the Earth's surface any object falling freely under gravity has an acceleration of about 9.8 m/s^2.	MS 3b, 3c Students should be able to apply this equation which is given on the Physics equation sheet.
An object falling through a fluid initially accelerates due to the force of gravity. Eventually the resultant force will be zero and the object will move at its terminal velocity. (Physics only) Students should be able to:	

Content	Key opportunities for skills development
• draw and interpret velocity–time graphs for objects that reach terminal velocity • interpret the changing motion in terms of the forces acting.	WS 3.3, 3.5 AT1,2 Investigation to measure the effect of air resistance on a falling object eg a model parachute.

4.5.6.2 Forces, accelerations and Newton's Laws of motion

4.5.6.2.1 Newton's First Law

Content	Key opportunities for skills development
Newton's First Law: If the resultant force acting on an object is zero and: • the object is stationary, the object remains stationary • the object is moving, the object continues to move at the same speed and in the same direction. So the object continues to move at the same velocity. So, when a vehicle travels at a steady speed the resistive forces balance the driving force. So, the velocity (speed and/or direction) of an object will only change if a resultant force is acting on the object. Students should be able to apply Newton's First Law to explain the motion of objects moving with a uniform velocity and objects where the speed and/or direction changes. (HT only) The tendency of objects to continue in their state of rest or of uniform motion is called inertia.	

4.5.6.2.2 Newton's Second Law

Content	Key opportunities for skills development
Newton's Second Law:	
The acceleration of an object is proportional to the resultant force acting on the object, and inversely proportional to the mass of the object. As an equation:	MS 3a Students should recognise and be able to use the symbol for proportionality, $\propto$

Content	Key opportunities for skills development
$resultant\ force = mass \times acceleration$ $F = m\,a$ force, *F*, in newtons, N mass, *m*, in kilograms, kg acceleration, *a*, in metres per second squared, m/s^2	MS 3b, c WS 4.2 Students should be able to recall and apply this equation.
(HT only) Students should be able to explain that: • inertial mass is a measure of how difficult it is to change the velocity of an object • inertial mass is defined as the ratio of force over acceleration.	MS 3a
Students should be able to estimate the speed, accelerations and forces involved in large accelerations for everyday road transport. Students should recognise and be able to use the symbol that indicates an approximate value or approximate answer, ~	MS 1d

Required practical activity 7: investigate the effect of varying the force on the acceleration of an object of constant mass, and the effect of varying the mass of an object on the acceleration produced by a constant force.

4.5.6.2.3 Newton's Third Law

Content	Key opportunities for skills development
Newton’s Third Law:	
Whenever two objects interact, the forces they exert on each other are equal and opposite. Students should be able to apply Newton’s Third Law to examples of equilibrium situations.	WS 1.2

4.5.6.3 Forces and braking

4.5.6.3.1 Stopping distance

Content	Key opportunities for skills development
The stopping distance of a vehicle is the sum of the distance the vehicle travels during the driver's reaction time (thinking distance) and the distance it travels under the braking force (braking distance). For a given braking force the greater the speed of the vehicle, the greater the stopping distance. (Physics only) Students should be able to estimate how the distance for a vehicle to make an emergency stop varies over a range of speeds typical for that vehicle.	
(Physics only) Students will be required to interpret graphs relating speed to stopping distance for a range of vehicles.	WS 3.3

4.5.6.3.2 Reaction time

Content	Key opportunities for skills development
Reaction times vary from person to person. Typical values range from 0.2 s to 0.9 s. A driver's reaction time can be affected by tiredness, drugs and alcohol. Distractions may also affect a driver's ability to react. Students should be able to: • explain methods used to measure human reaction times and recall typical results	
• interpret and evaluate measurements from simple methods to measure the different reaction times of students	WS 3.5, 3.7
• evaluate the effect of various factors on thinking distance based on given data.	WS 1.5, 2.2 MS 1a, c AT 1 Measure the effect of distractions on reaction time.

4.5.6.3.3 Factors affecting braking distance 1

Content	Key opportunities for skills development
The braking distance of a vehicle can be affected by adverse road and weather conditions and poor condition of the vehicle. Adverse road conditions include wet or icy conditions. Poor condition of the vehicle is limited to the vehicle's brakes or tyres. Students should be able to: • explain the factors which affect the distance required for road transport vehicles to come to rest in emergencies, and the implications for safety	
• estimate how the distance required for road vehicles to stop in an emergency varies over a range of typical speeds.	MS 1c, 1d, 2c, 2d, 2f, 2h, 3b, 3c

4.5.6.3.4 Factors affecting braking distance 2

Content	Key opportunities for skills development
When a force is applied to the brakes of a vehicle, work done by the friction force between the brakes and the wheel reduces the kinetic energy of the vehicle and the temperature of the brakes increases. The greater the speed of a vehicle the greater the braking force needed to stop the vehicle in a certain distance. The greater the braking force the greater the deceleration of the vehicle. Large decelerations may lead to brakes overheating and/or loss of control. Students should be able to:	
• explain the dangers caused by large decelerations	WS 1.5
• (HT only) estimate the forces involved in the deceleration of road vehicles in typical situations on a public road.	(HT only) MS 1d

4.5.7 Momentum (HT only)

4.5.7.1 Momentum is a property of moving objects

Content	Key opportunities for skills development
Momentum is defined by the equation: $momentum = mass \times velocity$ $p = m\,v$ momentum, p, in kilograms metre per second, kg m/s mass, m, in kilograms, kg velocity, v, in metres per second, m/s	WS 1.2 MS 3b, c Students should be able to recall and apply this equation.

4.5.7.2 Conservation of momentum

Content	Key opportunities for skills development
In a closed system, the total momentum before an event is equal to the total momentum after the event. This is called conservation of momentum. Students should be able to use the concept of momentum as a model to: • describe and explain examples of momentum in an event, such as a collision • (physics only) complete calculations involving an event, such as the collision of two objects.	AT1,2,3 Investigate collisions between laboratory trollies using light gates, data loggers or ticker timers to measure and record data.

4.5.7.3 Changes in momentum (physics only)

Content	Key opportunities for skills development
When a force acts on an object that is moving, or able to move, a change in momentum occurs.	
The equations $F = m \times a$ and $a = \frac{v - u}{t}$ combine to give the equation $F = \frac{\Delta [illegible]}{[illegible]}$ where $m\Delta v$ = change in momentum ie force equals the rate of change of momentum.	MS 3b, c Students should be able to apply this equation which is given on the Physics Equation sheet.

Content	Key opportunities for skills development
Students should be able to explain safety features such as: air bags, seat belts, gymnasium crash mats, cycle helmets and cushioned surfaces for playgrounds with reference to the concept of rate of change of momentum.	WS 1.2, 4
Students should be able to apply equations relating force, mass, velocity and acceleration to explain how the changes involved are inter-related.	MS 3b, 3c, 3d

4.6 Waves

Wave behaviour is common in both natural and man-made systems. Waves carry energy from one place to another and can also carry information. Designing comfortable and safe structures such as bridges, houses and music performance halls requires an understanding of mechanical waves. Modern technologies such as imaging and communication systems show how we can make the most of electromagnetic waves.

4.6.1 Waves in air, fluids and solids

4.6.1.1 Transverse and longitudinal waves

Content	Key opportunities for skills development
Waves may be either transverse or longitudinal. The ripples on a water surface are an example of a transverse wave. Longitudinal waves show areas of compression and rarefaction. Sound waves travelling through air are longitudinal.	
Students should be able to describe the difference between longitudinal and transverse waves.	WS 1.2
Students should be able to describe evidence that, for both ripples on a water surface and sound waves in air, it is the wave and not the water or air itself that travels.	WS 1.2, 2.2

4.6.1.2 Properties of waves

Content	**Key opportunities for skills development**
Students should be able to describe wave motion in terms of their amplitude, wavelength, frequency and period. The amplitude of a wave is the maximum displacement of a point on a wave away from its undisturbed position. The wavelength of a wave is the distance from a point on one wave to the equivalent point on the adjacent wave. The frequency of a wave is the number of waves passing a point each second.	MS 1c, 3b, c
$period = \frac{1}{frequency}$ [$T = \frac{1}{f}$] period, T, in seconds, s frequency, f, in hertz, Hz The wave speed is the speed at which the energy is transferred (or the wave moves) through the medium. All waves obey the wave equation:	MS 1c, 3b, c Students should be able to apply this equation which is given on the Physics equation sheet.
$wave\ speed = frequency \times wavelength$ [$v = f\lambda$] wave speed, v, in metres per second, m/s frequency, f, in hertz, Hz wavelength, λ, in metres, m Students should be able to: • identify amplitude and wavelength from given diagrams	MS 1c, 3b, 3c Students should be able to recall and apply this equation.
• describe a method to measure the speed of sound waves in air	AT1 WS 2.3, 2.4, 2.6, 2.7, 3.1, 3.5
• describe a method to measure the speed of ripples on a water surface.	AT1, AT4 WS 2.3, 2.4, 2.6, 2.7, 3.1, 3.5
(Physics only) Students should be able to show how changes in velocity, frequency and wavelength, in transmission of sound waves from one medium to another, are inter-related.	(Physics only) MS 1c, 3b, 3c

Required practical activity 8: make observations to identify the suitability of apparatus to measure the frequency, wavelength and speed of waves in a ripple tank and waves in a solid and take appropriate measurements.

4.6.1.3 Reflection of waves (physics only)

Content	Key opportunities for skills development
Waves can be reflected at the boundary between two different materials. Waves can be absorbed or transmitted at the boundary between two different materials.	
Students should be able to construct ray diagrams to illustrate the reflection of a wave at a surface. Students should be able to describe the effects of reflection, transmission and absorption of waves at material interfaces.	MS 5a, 5c WS 1.2

Required practical activity 9 (physics only): investigate the reflection of light by different types of surface and the refraction of light by different substances.

4.6.1.4 Sound waves (physics only) (HT only)

Content	Key opportunities for skills development
Sound waves can travel through solids causing vibrations in the solid. Within the ear, sound waves cause the ear drum and other parts to vibrate which causes the sensation of sound. The conversion of sound waves to vibrations of solids works over a limited frequency range. This restricts the limits of human hearing. Students should be able to: • describe, with examples, processes which convert wave disturbances between sound waves and vibrations in solids. Examples may include the effect of sound waves on the ear drum • explain why such processes only work over a limited frequency range and the relevance of this to human hearing. Students should know that the range of normal human hearing is from 20 Hz to 20 kHz.	

4.6.1.5 Waves for detection and exploration (physics only) (HT only)

Content	Key opportunities for skills development
Students should be able to explain in qualitative terms, how the differences in velocity, absorption and reflection between different types of wave in solids and liquids can be used both for detection and exploration of structures which are hidden from direct observation.	
Ultrasound waves have a frequency higher than the upper limit of hearing for humans. Ultrasound waves are partially reflected when they meet a boundary between two different media. The time taken for the reflections to reach a detector can be used to determine how far away such a boundary is. This allows ultrasound waves to be used for both medical and industrial imaging. Seismic waves are produced by earthquakes. P-waves are longitudinal, seismic waves. P-waves travel at different speeds through solids and liquids. S-waves are transverse, seismic waves. S-waves cannot travel through a liquid. P-waves and S-waves provide evidence for the structure and size of the Earth's core. Echo sounding, using high frequency sound waves is used to detect objects in deep water and measure water depth.	WS 1.4
Students should be aware that the study of seismic waves provided new evidence that led to discoveries about parts of the Earth which are not directly observable.	WS 1.1

4.6.2 Electromagnetic waves

4.6.2.1 Types of electromagnetic waves

Content	Key opportunities for skills development
Electromagnetic waves are transverse waves that transfer energy from the source of the waves to an absorber. Electromagnetic waves form a continuous spectrum and all types of electromagnetic wave travel at the same velocity through a vacuum (space) or air. The waves that form the electromagnetic spectrum are grouped in terms of their wavelength and their frequency. Going from long to short wavelength (or from low to high frequency) the groups are: radio, microwave, infrared, visible light (red to violet), ultraviolet, X-rays and gamma rays.	

Long wavelength → Short wavelength

Radio waves	Microwaves	Infrared	Visible light	Ultraviolet	X-rays	Gamma rays

Low frequency → High frequency

Our eyes only detect visible light and so detect a limited range of electromagnetic waves.

Students should be able to give examples that illustrate the transfer of energy by electromagnetic waves.

4.6.2.2 Properties of electromagnetic waves 1

Content	Key opportunities for skills development
(HT only) Different substances may absorb, transmit, refract or reflect electromagnetic waves in ways that vary with wavelength. (HT only) Some effects, for example refraction, are due to the difference in velocity of the waves in different substances. Students should be able to construct ray diagrams to illustrate the refraction of a wave at the boundary between two different media.	
(HT only) Students should be able to use wave front diagrams to explain refraction in terms of the change of speed that happens when a wave travels from one medium to a different medium.	WS 1.2

Required practical activity 10: investigate how the amount of infrared radiation absorbed or radiated by a surface depends on the nature of that surface.

4.6.2.3 Properties of electromagnetic waves 2

Content	Key opportunities for skills development
(HT only) Radio waves can be produced by oscillations in electrical circuits. (HT only) When radio waves are absorbed they may create an alternating current with the same frequency as the radio wave itself, so radio waves can themselves induce oscillations in an electrical circuit. Changes in atoms and the nuclei of atoms can result in electromagnetic waves being generated or absorbed over a wide frequency range. Gamma rays originate from changes in the nucleus of an atom.	
Ultraviolet waves, X-rays and gamma rays can have hazardous effects on human body tissue. The effects depend on the type of radiation and the size of the dose. Radiation dose (in sieverts) is a measure of the risk of harm resulting from an exposure of the body to the radiation.	WS 1.5
1000 millisieverts (mSv) = 1 sievert (Sv) Students will not be required to recall the unit of radiation dose. Students should be able to draw conclusions from given data about the risks and consequences of exposure to radiation. Ultraviolet waves can cause skin to age prematurely and increase the risk of skin cancer. X-rays and gamma rays are ionising radiation that can cause the mutation of genes and cancer.	WS 1.5

4.6.2.4 Uses and applications of electromagnetic waves

Content	Key opportunities for skills development
Electromagnetic waves have many practical applications. For example: • radio waves – television and radio • microwaves – satellite communications, cooking food • infrared – electrical heaters, cooking food, infrared cameras • visible light – fibre optic communications • ultraviolet – energy efficient lamps, sun tanning • X-rays and gamma rays – medical imaging and treatments.	

Content	Key opportunities for skills development
(HT only) Students should be able to give brief explanations why each type of electromagnetic wave is suitable for the practical application.	(HT only) WS 1.4

4.6.2.5 Lenses (physics only)

Content	Key opportunities for skills development
A lens forms an image by refracting light. In a convex lens, parallel rays of light are brought to a focus at the principal focus. The distance from the lens to the principal focus is called the focal length. Ray diagrams are used to show the formation of images by convex and concave lenses. The image produced by a convex lens can be either real or virtual. The image produced by a concave lens is always virtual.	
Students should be able to construct ray diagrams to illustrate the similarities and differences between convex and concave lenses. The magnification produced by a lens can be calculated using the equation:	MS 5a, 5c WS 1.2
$magnification = \frac{image\ height}{object\ height}$ Magnification is a ratio and so has no units. Image height and object height should both be measured in either mm or cm. In ray diagrams a convex lens will be represented by:  A concave lens will be represented by: 	MS 3b, c Students should be able to apply this equation which is given on the Physics equation sheet. AT4,8 Investigate the magnification produced by a range of convex lenses.

4.6.2.6 Visible light (physics only)

Content	Key opportunities for skills development
Each colour within the visible light spectrum has its own narrow band of wavelength and frequency. Reflection from a smooth surface in a single direction is called specular reflection. Reflection from a rough surface causes scattering: this is called diffuse reflection. Colour filters work by absorbing certain wavelengths (and colour) and transmitting other wavelengths (and colour). The colour of an opaque object is determined by which wavelengths of light are more strongly reflected. Wavelengths that are not reflected are absorbed. If all wavelengths are reflected equally the object appears white. If all wavelengths are absorbed the objects appears black. Objects that transmit light are either transparent or translucent. Students should be able to explain: • how the colour of an object is related to the differential absorption, transmission and reflection of different wavelengths of light by the object • the effect of viewing objects through filters or the effect on light of passing through filters • why an opaque object has a particular colour.	

4.6.3 Black body radiation (physics only)

4.6.3.1 Emission and absorption of infrared radiation

Content	Key opportunities for skills development
All bodies (objects), no matter what temperature, emit and absorb infrared radiation. The hotter the body, the more infrared radiation it radiates in a given time. A perfect black body is an object that absorbs all of the radiation incident on it. A black body does not reflect or transmit any radiation. Since a good absorber is also a good emitter, a perfect black body would be the best possible emitter.	

4.6.3.2 Perfect black bodies and radiation

Content	Key opportunities for skills development
Students should be able to explain: • that all bodies (objects) emit radiation • that the intensity and wavelength distribution of any emission depends on the temperature of the body. (HT only) A body at constant temperature is absorbing radiation at the same rate as it is emitting radiation. The temperature of a body increases when the body absorbs radiation faster than it emits radiation. (HT only) The temperature of the Earth depends on many factors including: the rates of absorption and emission of radiation, reflection of radiation into space. (HT only) Students should be able to explain how the temperature of a body is related to the balance between incoming radiation absorbed and radiation emitted, using everyday examples to illustrate this balance, and the example of the factors which determine the temperature of the Earth.	
(HT only) Students should be able to use information, or draw/ interpret diagrams to show how radiation affects the temperature of the Earth's surface and atmosphere.	WS 1.2

4.7 Magnetism and electromagnetism

Electromagnetic effects are used in a wide variety of devices. Engineers make use of the fact that a magnet moving in a coil can produce electric current and also that when current flows around a magnet it can produce movement. It means that systems that involve control or communications can take full advantage of this.

4.7.1 Permanent and induced magnetism, magnetic forces and fields

4.7.1.1 Poles of a magnet

Content	Key opportunities for skills development
The poles of a magnet are the places where the magnetic forces are strongest. When two magnets are brought close together they exert a force on each other. Two like poles repel each other. Two unlike poles attract each other. Attraction and repulsion between two magnetic poles are examples of non-contact force. A permanent magnet produces its own magnetic field. An induced magnet is a material that becomes a magnet when it is placed in a magnetic field. Induced magnetism always causes a force of attraction. When removed from the magnetic field an induced magnet loses most/all of its magnetism quickly. Students should be able to describe: • the attraction and repulsion between unlike and like poles for permanent magnets • the difference between permanent and induced magnets.	

4.7.1.2 Magnetic fields

Content	Key opportunities for skills development
The region around a magnet where a force acts on another magnet or on a magnetic material (iron, steel, cobalt and nickel) is called the magnetic field. The force between a magnet and a magnetic material is always one of attraction. The strength of the magnetic field depends on the distance from the magnet. The field is strongest at the poles of the magnet. The direction of the magnetic field at any point is given by the direction of the force that would act on another north pole placed at that point. The direction of a magnetic field line is from the north (seeking) pole of a magnet to the south(seeking) pole of the magnet. A magnetic compass contains a small bar magnet. The Earth has a magnetic field. The compass needle points in the direction of the Earth's magnetic field. Students should be able to: • describe how to plot the magnetic field pattern of a magnet using a compass • draw the magnetic field pattern of a bar magnet showing how strength and direction change from one point to another • explain how the behaviour of a magnetic compass is related to evidence that the core of the Earth must be magnetic.	WS 2.2

4.7.2 The motor effect

4.7.2.1 Electromagnetism

Content	Key opportunities for skills development
When a current flows through a conducting wire a magnetic field is produced around the wire. The strength of the magnetic field depends on the current through the wire and the distance from the wire. Shaping a wire to form a solenoid increases the strength of the magnetic field created by a current through the wire. The magnetic field inside a solenoid is strong and uniform. The magnetic field around a solenoid has a similar shape to that of a bar magnet. Adding an iron core increases the strength of the magnetic field of a solenoid. An electromagnet is a solenoid with an iron core. Students should be able to:	
• describe how the magnetic effect of a current can be demonstrated • draw the magnetic field pattern for a straight wire carrying a current and for a solenoid (showing the direction of the field) • explain how a solenoid arrangement can increase the magnetic effect of the current.	WS 2.2
(Physics only) Students should be able to interpret diagrams of electromagnetic devices in order to explain how they work.	(Physics only) WS 1.4

4.7.2.2 Fleming's left-hand rule (HT only)

Content	Key opportunities for skills development
When a conductor carrying a current is placed in a magnetic field the magnet producing the field and the conductor exert a force on each other. This is called the motor effect. Students should be able to show that Fleming's left-hand rule represents the relative orientation of the force, the current in the conductor and the magnetic field. Students should be able to recall the factors that affect the size of the force on the conductor.	

Content	Key opportunities for skills development
For a conductor at right angles to a magnetic field and carrying a current: $force = magnetic\ flux\ density \times current \times length$ [$F = B I l$] force, *F*, in newtons, N magnetic flux density, *B*, in tesla, T current, *I*, in amperes, A (amp is acceptable for ampere) length, *l*, in metres, m	MS 3b, c Students should be able to apply this equation which is given on the *physics equation sheet*.

4.7.2.3 Electric motors (HT only)

Content	Key opportunities for skills development
A coil of wire carrying a current in a magnetic field tends to rotate. This is the basis of an electric motor. Students should be able to explain how the force on a conductor in a magnetic field causes the rotation of the coil in an electric motor.	

4.7.2.4 Loudspeakers (physics only) (HT only)

Content	Key opportunities for skills development
Loudspeakers and headphones use the motor effect to convert variations in current in electrical circuits to the pressure variations in sound waves. Students should be able to explain how a moving-coil loudspeaker and headphones work.	

4.7.3 Induced potential, transformers and the National Grid (physics only) (HT only)

4.7.3.1 Induced potential (HT only)

Content	Key opportunities for skills development
If an electrical conductor moves relative to a magnetic field or if there is a change in the magnetic field around a conductor, a potential difference is induced across the ends of the conductor. If the conductor is part of a complete circuit, a current is induced in the conductor. This is called the generator effect. An induced current generates a magnetic field that opposes the original change, either the movement of the conductor or the change in magnetic field. Students should be able to recall the factors that affect the size of the induced potential difference/induced current. Students should be able to recall the factors that affect the direction of the induced potential difference/induced current. Students should be able to apply the principles of the generator effect in a given context.	

4.7.3.2 Uses of the generator effect (HT only)

Content	Key opportunities for skills development
The generator effect is used in an alternator to generate ac and in a dynamo to generate dc. Students should be able to:	
• explain how the generator effect is used in an alternator to generate ac and in a dynamo to generate dc • draw/interpret graphs of potential difference generated in the coil against time.	WS 1.4

4.7.3.3 Microphones (HT only)

Content	Key opportunities for skills development
Microphones use the generator effect to convert the pressure variations in sound waves into variations in current in electrical circuits. Students should be able to explain how a moving-coil microphone works.	

4.7.3.4 Transformers (HT only)

Content	Key opportunities for skills development
A basic transformer consists of a primary coil and a secondary coil wound on an iron core. Iron is used as it is easily magnetised. Knowledge of laminations and eddy currents in the core is not required. The ratio of the potential differences across the primary and secondary coils of a transformer V_p and V_s depends on the ratio of the number of turns on each coil, n_p and n_s.	
$\left[\frac{V_p}{V_s} = \frac{n_p}{n_s} \right]$ potential difference, V_p and V_s in volts, V In a step-up transformer $V_s > V_p$ In a step-down transformer $V_s < V_p$ If transformers were 100% efficient, the electrical power output would equal the electrical power input.	MS 3b, c Students should be able to apply this equation which is given on the Physics equation sheet.
$V_s \times I_s = V_p \times I_p$ Where $V_s \times I_s$ is the power output (secondary coil) and $V_p \times I_p$ is the power input (primary coil). power input and output, in watts, W Students should be able to: • explain how the effect of an alternating current in one coil in inducing a current in another is used in transformers • explain how the ratio of the potential differences across the two coils depends on the ratio of the number of turns on each • calculate the current drawn from the input supply to provide a particular power output	MS 3b, c Students should be able to apply this equation which is given on the Physics equation sheet.
• apply the equation linking the p.d.s and number of turns in the two coils of a transformer to the currents and the power transfer involved, and relate these to the advantages of power transmission at high potential differences.	MS 1c, 3b, c

4.8 Space physics (physics only)

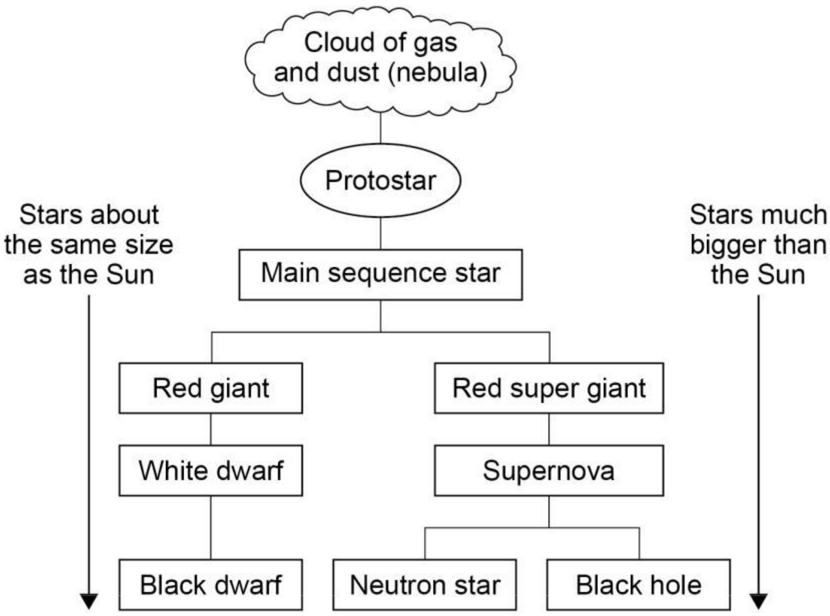
Questions about where we are, and where we came from, have been asked for thousands of years. In the past century, astronomers and astrophysicists have made remarkable progress in understanding the scale and structure of the universe, its evolution and ours. New questions have emerged recently. ‘Dark matter’, which bends light and holds galaxies together but does not emit electromagnetic radiation, is everywhere – what is it? And what is causing the universe to expand ever faster?

4.8.1 Solar system; stability of orbital motions; satellites (physics only)

4.8.1.1 Our solar system

Content	Key opportunities for skills development
Within our solar system there is one star, the Sun, plus the eight planets and the dwarf planets that orbit around the Sun. Natural satellites, the moons that orbit planets, are also part of the solar system. Our solar system is a small part of the Milky Way galaxy. The Sun was formed from a cloud of dust and gas (nebula) pulled together by gravitational attraction. Students should be able to explain: • how, at the start of a star's life cycle, the dust and gas drawn together by gravity causes fusion reactions • that fusion reactions lead to an equilibrium between the gravitational collapse of a star and the expansion of a star due to fusion energy.	

4.8.1.2 The life cycle of a star

Content	Key opportunities for skills development
A star goes through a life cycle. The life cycle is determined by the size of the star. Students should be able to describe the life cycle of a star: • the size of the Sun • much more massive than the Sun.  Fusion processes in stars produce all of the naturally occurring elements. Elements heavier than iron are produced in a supernova. The explosion of a massive star (supernova) distributes the elements throughout the universe. Students should be able to explain how fusion processes lead to the formation of new elements.	

4.8.1.3 Orbital motion, natural and artificial satellites

Content	Key opportunities for skills development
Gravity provides the force that allows planets and satellites (both natural and artificial) to maintain their circular orbits. Students should be able to describe the similarities and distinctions between the planets, their moons, and artificial satellites. (HT only) Students should be able to explain qualitatively how: • (HT only) for circular orbits, the force of gravity can lead to changing velocity but unchanged speed • (HT only) for a stable orbit, the radius must change if the speed changes.	

4.8.2 Red-shift (physics only)

Content	Key opportunities for skills development
There is an observed increase in the wavelength of light from most distant galaxies. The further away the galaxies, the faster they are moving and the bigger the observed increase in wavelength. This effect is called red-shift. The observed red-shift provides evidence that space itself (the universe) is expanding and supports the Big Bang theory.	
The Big Bang theory suggests that the universe began from a very small region that was extremely hot and dense. Since 1998 onwards, observations of supernovae suggest that distant galaxies are receding ever faster. Students should be able to explain: • qualitatively the red-shift of light from galaxies that are receding • that the change of each galaxy's speed with distance is evidence of an expanding universe • how red-shift provides evidence for the Big Bang model • how scientists are able to use observations to arrive at theories such as the Big Bang theory	WS 1.2
• that there is still much about the universe that is not understood, for example dark mass and dark energy.	WS 1.1, 1.3