COMBINED SCIENCE GCSE
PHYSICS PAPER 2
HIGHER

MAJOR FOCUS
NOT MENTIONED
NOT ASSESSED

6.5 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.

6.5.1 Forces and their interactions

6.5.1.1 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.	

6.5.1.2 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.	

6.5.1.3 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, $\propto$

6.5.1.4 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

6.5.2 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

6.5.3 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 122).
Students should be able to calculate relevant values of stored energy and energy transfers.	MS 3c

Required practical activity 18: investigate the relationship between force and extension for a spring.

6.5.4 Forces and motion

6.5.4.1 Describing motion along a line

6.5.4.1.1 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.

6.5.4.1.2 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

Content	Key opportunities for skills development
distance travelled = *speed* × *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

6.5.4.1.3 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.	

6.5.4.1.4 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

6.5.4.1.5 Acceleration

Content	Key opportunities for skills development
The average acceleration of an object can be calculated using the equation:	
$acceleration = \frac{change\ in\ velocity}{time\ taken}$ [$a = \frac{\Delta v}{t}$] 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*.

Content	Key opportunities for skills development
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.	

6.5.4.2 Forces, accelerations and Newton's Laws of motion

6.5.4.2.1 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.	

6.5.4.2.2 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 × 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 19: investigate the effect of varying the force on the acceleration of anobject of constant mass, and the effect of varying the mass of an object on the acceleration produced by a constant force.

6.5.4.2.3 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

6.5.4.3 Forces and braking

6.5.4.3.1 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.	

6.5.4.3.2 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.

6.5.4.3.3 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	

Content	Key opportunities for skills development
• 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

6.5.4.3.4 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

6.5.5 Momentum (HT only)

6.5.5.1 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.

6.5.5.2 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.	AT 1, 2, 3 Investigate collisions between laboratory trollies using light gates, data loggers or ticker timers to measure and record data.

6.6 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.

6.6.1 Waves in air, fluids and solids

6.6.1.1 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

6.6.1.2 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	AT 1 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.	AT 1, AT 4 WS 2.3, 2.4, 2.6, 2.7, 3.1, 3.5

Required practical activity 20: 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 andtake appropriate measurements.

6.6.2 Electromagnetic waves

6.6.2.1 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

Content	Key opportunities for skills development
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.	

6.6.2.2 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

<u>Required practical activity 21</u>: investigate how the amount of infrared radiation absorbed orradiated by a surface depends on the nature of that surface.

6.6.2.3 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

6.6.2.4 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

6.7 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.

6.7.1 Permanent and induced magnetism, magnetic forces and fields

6.7.1.1 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.	

6.7.1.2 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

6.7.2 The motor effect

6.7.2.1 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

6.7.2.2 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*.

6.7.2.3 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.	