**Paper 2:**

5 Forces

6 Waves

7 Magnetism and electromagnetism

8 Space physics (physics only)

**How it’s assessed**

Written exam: 1 hour 45 minutes

Foundation and Higher Tier

100 marks

50 % of GCSE

Questions: Multiple choice, structured, closed short answer and open response.

Questions in Paper 2 may draw on an understanding of energy changes and transfers due to heating, mechanical and electrical work and the concept of energy conservation from Energy and Electricity.

**5. FORCES**

1. Forces and their interactions
2. Work done and energy transfer
3. Forces and elasticity
4. *Practical activity: investigate the relationship between force and extension for a spring.*
5. Moments, levers and gears (physics only)
6. Pressure and pressure differences in fluids (physics only)
7. Forces and motion
8. *Practical activity: 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.*
9. Momentum (HT only)
10. *Practical activity: 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.*

**6. WAVES**

1. Waves in air, fluids and solids
2. *Practical activity (physics only): investigate the reflection of light by different types of surface and the refraction of light by different substances.*
3. Electromagnetic waves
4. *Practical activity: investigate how the amount of infrared radiation absorbed or radiated by a surface depends on the nature of that surface.*
5. Black body radiation (physics only)

**7. MAGNETISM and ELECTROMAGNETISM**

1. Permanent and induced magnetism, magnetic forces and fields
2. The motor effect
3. Induced potential, transformers and the National Grid (physics only) (HT only)

**8. SPACE PHYSICS (physics only)**

1. Solar system; stability of orbital motions; satellites (physics only)
2. Red-shift (physics only)

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| **4.5 Forces** |  |  |  |
| *4.5.1 Forces and their interactions* |  |  |  |
| **4.5.1.1 Scalar and vector quantities** |  |  |  |
| 1. Scalar quantities have magnitude (size) only.
2. Vector quantities have magnitude and an associated direction.
3. 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.
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| **4.5.1.2 Contact and non-contact forces** |  |  |  |
| 1. 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.
1. Examples of contact forces include
	* friction
	* air resistance
	* tension
	* normal contact force
2. Examples of non-contact forces are
	* gravitational force
	* electrostatic force
	* magnetic force
3. Force is a vector quantity.
4. 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.
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| **4.5.1.3 Gravity** |  |  |  |
| 1. Weight is the force acting on an object due to gravity.
2. The force of gravity close to the Earth is due to the gravitational field around the Earth.
3. The weight of an object depends on the gravitational field strength where the object is.
 |  |  |  |
| a) The weight of an object can be calculated using the equation:* $weight=mass x gravitational field strength$
* $W=m x g$

weight, *W*, in newtons, Nmass, *m*, in kilograms, kggravitational field strength, *g*, in newtons per kilogram, N/kg (In any calculation the value of the gravitational field strength (*g*) will be given.)b) The weight of an object may be considered to act at a single point referred to as the object’s ‘centre of mass’.c) The weight of an object and the mass of an object are directly proportional.d) Weight is measured using a calibrated newton meter (spring-balance). |  |  |  |
| **4.5.1.4 Resultant forces** |  |  |  |
| 1. 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.
2. This single force is called the resultant force.
3. Be able to calculate the resultant of two forces that act in a straight line.

(HT only, d to g)1. describe examples of the forces acting on an isolated object or system
2. 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.
3. know 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.
4. 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).
 |  |  |  |
| *4.5.2 Work done and energy transfer* |  |  |  |
| a) 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.b) The work done by a force on an object can be calculated using the equation:* $work done=force x distance moved along the line of action of the force$
* $W=F x s$

work done, *W*, in joules, Jforce, *F*, in newtons, Ndistance, *s*, in metres, me) One joule of work is done when a force of one newton causes a displacement of one metre.1 joule = 1 newton-metref) Students should be able to describe the energy transfer involved when work is done.g) Students should be able to convert between newton-metres and joules.h) Work done against the frictional forces acting on an object causes a rise in the temperature of the object. |  |  |  |
| *4.5.3 Forces and elasticity* |  |  |  |
| a) 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.

b) 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.* $force=spring constant x extension$
* $F=k x e$

force, *F*, in newtons, Nspring constant, *k*, in newton per metre, N/mextension, *e*, in metres, mc) This relationship also applies to the compression of an elastic object, where ‘*e*’ would be the compression of the object.d) A force that stretches (or compresses) a spring does work and elastic potential energy is stored in the spring. Provided the spring is not permanently deformed, the work done on the spring and the elastic potential energy stored are equal.Students should be able to:1. describe the difference between a linear and non-linear relationship between force and extension
2. calculate a spring constant in linear cases
3. interpret data from an investigation of the relationship between force and extension
4. calculate work done in stretching (or compressing) a spring (up to the limit of proportionality) using the equation:
* $elastic potential energy=\frac{1}{2} x spring constant x extension^{2}$
* $E\_{e}= \frac{1}{2} x k x e^{2}$

This equation is also given in Changes in energy.i) Students should be able to calculate relevant values of stored energy and energy transfers. |  |  |  |
| **Required practical activity 6**: investigate the relationship between force and extension for a spring. |  |  |  |
| *4.5.4 Moments, levers and gears (physics only)* |  |  |  |
| a) A force or a system of forces may cause an object to rotate.b) Students should be able to describe examples in which forces cause rotation.c) The turning effect of a force is called the moment of the force. The size of the moment is defined by the equation:* $moment=force x distance$
* $M=F x d$

moment of a force, *M*, in newton-metres, Nmforce, *F*, in newtons, Ndistance, *d*, is the perpendicular distance from the pivot to the line of action of the force, in metres, m.d) If an object is balanced, the total clockwise moment about a pivot equals the total anticlockwise moment about that pivot.e) Students should be able to calculate the size of a force, or its distance from a pivot, acting on an object that is balanced.f) A simple lever and a simple gear system can both be used to transmit the rotational effects of forces.g) Students should be able to explain how levers and gears transmit the rotational effects of forces. |  |  |  |
| *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*** |  |  |  |
| a) A fluid can be either a liquid or a gas.b) The pressure in fluids causes a force normal (at right angles) to any surface.c) The pressure at the surface of a fluid can be calculated using the equation:* $pressure= \frac{force (normal to the surface)}{area}$
* $P= \frac{F}{A}$

pressure, *p*, in pascals, Pa (or N/m**2**)force, *F*, in newtons, Narea, *A*, in metres squared, m**2** |  |  |  |
| ***4.5.5.1.2 Pressure in a fluid 2 (HT only)*** |  |  |  |
| a) The pressure due to a column of liquid can be calculated using the equation:* $pressure=height of the column x density of the liquid$
* $p=h x ρ x g$

pressure, *p*, in pascals, Paheight of the column, *h*, in metres, mdensity, *ρ*, in kilograms per metre cubed, kg/m3gravitational field strength, g, in newtons per kilogram, N/kg (In any calculation the value of the gravitational field strength (*g*) will be given.)b) 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.c) Students should be able to calculate the differences in pressure at different depths in a liquid.d) 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.e) Students should be able to describe the factors which influence floating and sinking. |  |  |  |
| **4.5.5.2 Atmospheric pressure** |  |  |  |
| 1. 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.
2. Air molecules colliding with a surface create atmospheric pressure.
3. 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:1. describe a simple model of the Earth’s atmosphere and of atmospheric pressure
2. explain why atmospheric pressure varies with height above a surface.
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| *4.5.6 Forces and motion* |  |  |  |
| **4.5.6.1 Describing motion along a line** |  |  |  |
| ***4.5.6.1.1 Distance and displacement*** |  |  |  |
| 1. Distance is how far an object moves. Distance does not involve direction. Distance is a scalar quantity.
2. 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.
3. Students should be able to express a displacement in terms of both the magnitude and direction.
 |  |  |  |
| ***4.5.6.1.2 Speed*** |  |  |  |
| 1. Speed does not involve direction. Speed is a scalar quantity.
2. The speed of a moving object is rarely constant. When people walk, run or travel in a car their speed is constantly changing.
3. The speed at which a person can walk, run or cycle depends on many factors including: age, terrain, fitness and distance travelled.
4. 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. Typical values may be taken as:
	* + - walking ≈ 1.5 m/s
			- running ≈ 3 m/s
			- cycling ≈ 6 m/s
5. It is not only moving objects that have varying speed. The speed of sound and the speed of the wind also vary.
6. A typical value for the speed of sound in air is 330 m/s.
7. Students should be able to make measurements of distance and time and then calculate speeds of objects.

h) For an object moving at constant speed the distance travelled in a specific time can be calculated using the equation:* $distance travelled=speed x time$
* $s=v x t$

distance, *s*, in metres, mspeed, *v*, in metres per second, m/stime, *t*, in seconds, si) Students should be able to calculate average speed for non-uniform motion. |  |  |  |
| ***4.5.6.1.3 Velocity*** |  |  |  |
| 1. The velocity of an object is its speed in a given direction. Velocity is a vector quantity.
2. Students should be able to explain the vector–scalar distinction as it applies to displacement, distance, velocity and speed.
3. (HT only) Students should be able to explain qualitatively, with examples, that motion in a circle involves constant speed but changing velocity.
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| ***4.5.6.1.4 The distance–time relationship*** |  |  |  |
| 1. If an object moves along a straight line, the distance travelled can be represented by a distance–time graph.
2. The speed of an object can be calculated from the gradient of its distance–time graph.
3. (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:1. draw distance–time graphs from measurements
2. extract and interpret lines and slopes of distance–time graphs, translating information between graphical and numerical form
3. determine speed from a distance–time graph
 |  |  |  |
| ***4.5.6.1.5 Acceleration*** |  |  |  |
| a) The average acceleration of an object can be calculated using the equation:* $acceleration= \frac{change in velocity}{time taken}$
* $a= \frac{Δv}{t}$

acceleration, *a*, in metres per second squared, m/s**2**change in velocity, Δ*v*, in metres per second, m/stime, *t*, in seconds, s1. An object that slows down is decelerating.
2. Students should be able to estimate the magnitude of everyday accelerations.
3. The acceleration of an object can be calculated from the gradient of a velocity–time graph.
4. (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:1. draw velocity–time graphs from measurements and interpret lines and slopes to determine acceleration
2. (HT only) interpret enclosed areas in velocity–time graphs to determine distance travelled (or displacement)
3. (HT only) measure, when appropriate, the area under a velocity–time graph by counting squares.
 |  |  |  |
| a) The following equation applies to uniform acceleration (e.g. acceleration due to gravity):* $final velocity^{2}- initial velocity^{2}=2 x acceleration x distance$
* $v^{2}- u^{2}=2 x a x s$

final velocity, *v*, in metres per second, m/sinitial velocity, *u*, in metres per second, m/sacceleration, *a*, in metres per second squared, m/s**2**distance, *s*, in metres, mb) Near the Earth’s surface any object falling freely under gravity has an acceleration of about 9.8 m/s**2**.c) 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:d) draw and interpret velocity–time graphs for objects that reach terminal velocitye) interpret the changing motion in terms of the forces acting. |  |  |  |
| **4.5.6.2 Forces, accelerations and Newton’s Laws of motion** |  |  |  |
| ***4.5.6.2.1 Newton’s First Law*** |  |  |  |
| 1. Newton’s First Law:

If the resultant force acting on an object is zero:* and the object is stationary, the object remains stationary
* and the object is moving, the object continues to move at the same speed and in the same direction and at the same velocity.
1. When a vehicle travels at a steady speed the resistive forces balance the driving force.
2. 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:1. the motion of objects moving with a uniform velocity
2. the motion of objects where the speed and/or direction changes.
3. (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*** |  |  |  |
| 1. 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.1. As an equation:

$$resultant force=mass x acceleration$$$$F=m x a$$force, *F*, in newtons, Nmass, *m*, in kilograms, kgacceleration, *a*, in metres per second squared, m/s**2**1. Students should recognise and be able to use the symbol for proportionality, ∝
2. (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.
1. Students should be able to estimate the speed, accelerations and forces involved in large accelerations for everyday road transport.
2. Students should recognise and be able to use the symbol that indicates an approximate value or approximate answer, ≈, ~.
 |  |  |  |
| **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*** |  |  |  |
| 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.
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| **4.5.6.3 Forces and braking** |  |  |  |
| ***4.5.6.3.1 Stopping distance*** |  |  |  |
| 1. 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).
2. For a given braking force the greater the speed of the vehicle, the greater the stopping distance.
3. (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.
4. (Physics only) Students will be required to interpret graphs relating speed to stopping distance for a range of vehicles.
 |  |  |  |
| ***4.5.6.3.2 Reaction time*** |  |  |  |
| 1. Reaction times vary from person to person. Typical values range from 0.2 s to 0.9 s.
2. 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:1. explain methods used to measure human reaction times and recall typical results
2. interpret and evaluate measurements from simple methods to measure the different reaction times of students
3. evaluate the effect of various factors on thinking distance based on given data.
 |  |  |  |
| ***4.5.6.3.3 Factors affecting braking distance 1*** |  |  |  |
| 1. The braking distance of a vehicle can be affected by adverse road and weather conditions and poor condition of the vehicle.
2. 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:1. explain the factors which affect the distance required for road transport vehicles to come to rest in emergencies, and the implications for safety
2. estimate how the distance required for road vehicles to stop in an emergency varies over a range of typical speeds.
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| ***4.5.6.3.4 Factors affecting braking distance 2*** |  |  |  |
| 1. 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.
2. The greater the speed of a vehicle the greater the braking force needed to stop the vehicle in a certain distance.
3. 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:1. explain the dangers caused by large decelerations
2. (HT only) estimate the forces involved in the deceleration of road vehicles in typical situations on a public road.
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| *4.5.7 Momentum (HT only)* |  |  |  |
| **4.5.7.1 Momentum is a property of moving objects** |  |  |  |
| Momentum is defined by the equation:* $momentum=mass x velocity$
* $p=m x v$

momentum, *p*, in kilograms metre per second, kg m/smass, *m*, in kilograms, kgvelocity, *v*, in metres per second, m/s |  |  |  |
| **4.5.7.2 Conservation of momentum** |  |  |  |
| 1. In a closed system, the total momentum before an event is equal to the total momentum after the event.
2. This is called conservation of momentum.

Students should be able to use the concept of momentum as a model to:1. describe and explain examples of momentum in an event, such as a collision
2. (physics only) complete calculations involving an event, such as the collision of two objects.
 |  |  |  |
| **4.5.7.3 Changes in momentum (physics only)** |  |  |  |
| 1. When a force acts on an object that is moving, or able to move, a change in momentum occurs.
2. The equations $F=m x a and a= \frac{v-u}{t}$ combine to give the equation $F=m x \frac{Δv}{Δt}$

where *m* Δ*v* = change in momentumie force equals the rate of change of momentum.1. Students should be able to explain safety features such as:
* air bags
* seat belts
* gymnasium crash mats
* cycle helmets
* cushioned surfaces for playgrounds

with reference to the concept of rate of change of momentum.1. Students should be able to apply equations relating force, mass, velocity and acceleration to explain how the changes involved are inter-related.
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| **4.6 Waves** |  |  |  |
| *4.6.1 Waves in air, fluids and solids* |  |  |  |
| **4.6.1.1 Transverse and longitudinal waves** |  |  |  |
| 1. Waves may be either transverse or longitudinal.
2. The ripples on a water surface are an example of a transverse wave.
3. Longitudinal waves show areas of compression and rarefaction.
4. Sound waves travelling through air are longitudinal.
5. Students should be able to describe the difference between longitudinal and transverse waves.
6. 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.
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| **4.6.1.2 Properties of waves** |  |  |  |
| 1. Students should be able to describe wave motion in terms of their amplitude, wavelength, frequency and period.
2. The amplitude of a wave is the maximum displacement of a point on a wave away from its undisturbed position.
3. The wavelength of a wave is the distance from a point on one wave to the equivalent point on the adjacent wave.
4. The frequency of a wave is the number of waves passing a point each second.
* $period= \frac{1}{frequency}$
* $T= \frac{1}{f}$

period, *T*, in seconds, sfrequency, *f*, in hertz, Hze) The wave speed is the speed at which the energy is transferred (or the wave moves) through the medium. |  |  |  |
| a) All waves obey the wave equation:* $wave speed=frequency x wavelength$
* $v=f x λ$

wave speed, *v*, in metres per second, m/sfrequency, *f*, in hertz, Hzwavelength, *λ*, in metres, mStudents should be able to:1. identify amplitude and wavelength from given diagrams
2. describe a method to measure the speed of sound waves in air
3. describe a method to measure the speed of ripples on a water surface.
4. (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.
 |  |  |  |
| **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)** |  |  |  |
| 1. Waves can be reflected at the boundary between two different materials.
2. Waves can be absorbed or transmitted at the boundary between two different materials.
3. Students should be able to construct ray diagrams to illustrate the reflection of a wave at a surface.
4. Students should be able to describe the effects of reflection, transmission and absorption of waves at material interfaces.
 |  |  |  |
| **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)** |  |  |  |
| 1. Sound waves can travel through solids causing vibrations in the solid.
2. 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.
3. 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
4. explain why such processes only work over a limited frequency range and the relevance of this to human hearing.
5. 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)** |  |  |  |
| 1. 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.
2. Ultrasound waves
* have a frequency higher than the upper limit of hearing for humans.
* 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.
1. 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.
1. S-waves cannot travel through a liquid. P-waves and S-waves provide evidence for the structure and size of the Earth’s core.
2. Echo sounding, using high frequency sound waves is used to detect objects in deep water and measure water depth.
3. 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.
 |  |  |  |
| *4.6.2 Electromagnetic waves* |  |  |  |
| **4.6.2.1 Types of electromagnetic waves** |  |  |  |
| 1. Electromagnetic waves are transverse waves that transfer energy from the source of the waves to an absorber.
2. Electromagnetic waves form a continuous spectrum and all types of electromagnetic wave travel at the same velocity through a vacuum (space) or air.
3. 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 |

d) Our eyes only detect visible light and so detect a limited range of electromagnetic waves.e) Our skin can detect temperature so we can detect infra-red waves.f) 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** |  |  |  |
| 1. (HT only) Different substances may absorb, transmit, refract or reflect electromagnetic waves in ways that vary with wavelength.
2. (HT only) Some effects, for example refraction, are due to the difference in velocity of the waves in different substances.
3. Students should be able to construct ray diagrams to illustrate the refraction of a wave at the boundary between two different media.
4. (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.
 |  |  |  |
| **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** |  |  |  |
| 1. (HT only) Radio waves can be produced by oscillations in electrical circuits.
2. (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.
3. 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.
4. 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.
5. Radiation dose (in sieverts) is a measure of the risk of harm resulting from an exposure of the body to the radiation.
6. 1000 millisieverts (mSv) = 1 sievert (Sv)

Students will not be required to recall the unit of radiation dose.1. Students should be able to draw conclusions from given data about the risks and consequences of exposure to radiation.
2. Ultraviolet waves can cause skin to age prematurely and increase the risk of skin cancer.
3. X-rays and gamma rays are ionising radiation that can cause the mutation of genes and cancer.
 |  |  |  |
| **4.6.2.4 Uses and applications of electromagnetic waves** |  |  |  |
| 1. 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.
1. (HT only) Students should be able to give brief explanations why each type of electromagnetic wave is suitable for the practical application.
 |  |  |  |
| **4.6.2.5 Lenses (physics only)** |  |  |  |
| 1. A lens forms an image by refracting light.
2. 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.
3. Ray diagrams are used to show the formation of images by convex and concave lenses.
4. The image produced by a convex lens can be either real or virtual.
5. The image produced by a concave lens is always virtual.
6. Students should be able to construct ray diagrams to illustrate the similarities and differences between convex and concave lenses.
7. The magnification produced by a lens can be calculated using the equation:
* $magnification= \frac{image height}{object height}$
* Magnification is a ratio and so has no units.
* Image height and object height should both be measured in the same unit e.g. cm.

h) In ray diagrams a convex lens will be represented by: i) A concave lens will be represented by: |  |  |  |
| **4.6.2.6 Visible light (physics only)** |  |  |  |
| 1. Each colour within the visible light spectrum has its own narrow band of wavelength and frequency.
2. Reflection from a smooth surface in a single direction is called specular reflection.
3. Reflection from a rough surface causes scattering: this is called diffuse reflection.
4. Colour filters work by absorbing certain wavelengths (and colour) and transmitting other wavelengths (and colour).
5. The colour of an opaque object is determined by which wavelengths of light are more strongly reflected.
6. Wavelengths that are not reflected are absorbed.
7. If all wavelengths are reflected equally the object appears white.
8. If all wavelengths are absorbed the objects appears black.
9. Objects that transmit light are either transparent or translucent.

Students should be able to explain:1. how the colour of an object is related to the differential absorption, transmission and reflection of different wavelengths of light by the object
2. the effect of viewing objects through filters or the effect on light of passing through filters
3. 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** |  |  |  |
| 1. All bodies (objects), no matter what temperature, emit and absorb infrared radiation.
2. The hotter the body, the more infrared radiation it radiates in a given time.
3. 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.
4. 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** |  |  |  |
| 1. 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.
1. (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.
2. (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.
3. (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.
4. (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.
 |  |  |  |
| **4.7 Magnetism and electromagnetism** |  |  |  |
| *4.7.1 Permanent and induced magnetism, magnetic forces and fields* |  |  |  |
| **4.7.1.1 Poles of a magnet** |  |  |  |
| 1. The poles of a magnet are the places where the magnetic forces are strongest.
2. When two magnets are brought close together they exert a force on each other.
3. 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.
4. A permanent magnet produces its own magnetic field.
5. 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.
6. 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** |  |  |  |
| 1. 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.
2. The force between a magnet and a magnetic material is always one of attraction.
3. The strength of the magnetic field depends on the distance from the magnet. The field is strongest at the poles of the magnet.
4. 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.
5. The direction of a magnetic field *line* is from the north (seeking) pole of a magnet to the south (seeking) pole of the magnet.
6. 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.
7. 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.
 |  |  |  |
| *4.7.2 The motor effect* |  |  |  |
| **4.7.2.1 Electromagnetism** |  |  |  |
| 1. When a current flows through a conducting wire a magnetic field is produced around the wire.
2. The strength of the magnetic field depends on the current through the wire and the distance from the wire.
3. 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.
4. 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:1. describe how the magnetic effect of a current can be demonstrated
2. draw the magnetic field pattern for a straight wire carrying a current and for a solenoid (showing the direction of the field)
3. explain how a solenoid arrangement can increase the magnetic effect of the current.

(Physics only) Students should be able to interpret diagrams of electromagnetic devices in order to explain how they work. |  |  |  |
| **4.7.2.2 Fleming’s left-hand rule (HT only)** |  |  |  |
| 1. 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.
2. 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.
3. Students should be able to recall the factors that affect the size of the force on the conductor.
4. For a conductor at right angles to a magnetic field and carrying a current:
* $force=magnetic flux density x current x length$
* $F=B x I x l$

force, *F*, in newtons, Nmagnetic flux density, *B*, in tesla, Tcurrent, *I*, in amperes, A (amp is acceptable for ampere)length,$ l$, in metres, m |  |  |  |
| **4.7.2.3 Electric motors (HT only)** |  |  |  |
| 1. A coil of wire carrying a current in a magnetic field tends to rotate.
2. This is the basis of an electric motor.
3. 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)** |  |  |  |
| 1. Loudspeakers and headphones use the motor effect to convert variations in current in electrical circuits to the pressure variations in sound waves.
2. 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)** |  |  |  |
| 1. 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.
2. An induced current generates a magnetic field that opposes the original change, either the movement of the conductor or the change in magnetic field.
3. Students should be able to recall the factors that affect the size of the induced potential difference/induced current.
4. Students should be able to recall the factors that affect the direction of the induced potential difference/induced current.
5. 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)** |  |  |  |
| 1. The generator effect is used in an alternator to generate AC and in a dynamo to generate DC.

Students should be able to:1. explain how the generator effect is used in an alternator to generate A.C. and in a dynamo to generate D.C.
2. draw/interpret graphs of potential difference generated in the coil against time.
 |  |  |  |
| **4.7.3.3 Microphones (HT only)** |  |  |  |
| 1. Microphones use the generator effect to convert the pressure variations in sound waves into variations in current in electrical circuits.
2. Students should be able to explain how a moving-coil microphone works.
 |  |  |  |
| **4.7.3.4 Transformers (HT only)** |  |  |  |
| 1. A basic transformer consists of a primary coil and a secondary coil wound on an iron core.
2. Iron is used as it is easily magnetised.
3. The ratio of the potential differences across the **p**rimary and **s**econdary 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**.
* $\frac{V\_{p}}{V\_{s}}= \frac{n\_{p}}{n\_{s}}$

potential difference, *V***p** and *V***s** in volts, VIn a step-up transformer *V***s** > *V***p**In a step-down transformer *V***s** < *V***p**d) If transformers were 100 % efficient, the electrical power output would equal the electrical power input and so *V*s × *I*s = *V*p × *I*pWhere *V*s × *I*s is the power output (secondary coil) and *V*p × *I*p is the power input (primary coil).(power input and output, in watts, W)Students should be able to:e) explain how the effect of an alternating current in one coil in inducing a current in another is used in transformersf) explain how the ratio of the potential differences across the two coils depends on the ratio of the number of turns on eachg) calculate the current drawn from the input supply to provide a particular power outputh) apply the equation linking the potential difference 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. |  |  |  |
| **4.8 Space physics (physics only)** |  |  |  |
| *4.8.1 Solar system; stability of orbital motions; satellites (physics only)* |  |  |  |
| **4.8.1.1 Our solar system** |  |  |  |
| 1. Within our solar system there is one star, the Sun, plus the eight planets and the dwarf planets that orbit around the Sun.
2. Natural satellites, the moons that orbit planets, are also part of the solar system.
3. Our solar system is a small part of the Milky Way galaxy.
4. The Sun was formed from a cloud of dust and gas (nebula) pulled together by gravitational attraction.

Students should be able to explain:1. how, at the start of a star’s life cycle, the dust and gas drawn together by gravity causes fusion reactions
2. 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** |  |  |  |
| a) A star goes through a life cycle. The life cycle is determined by the size of the star.b) Students should be able to describe the life cycle of a star if it is i) the size of the Sunii) much more massive than the Sunc) Fusion processes in stars produce all of the naturally occurring elements. d) Elements heavier than iron are produced in a supernova.e) The explosion of a massive star (supernova) distributes the elements throughout the universe.f) 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** |  |  |  |
| 1. Gravity provides the force that allows planets and satellites (both natural and artificial) to maintain their circular orbits.
2. 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:1. (HT only) for circular orbits, the force of gravity can lead to changing velocity but unchanged speed
2. (HT only) for a stable orbit, the radius must change if the speed changes.
 |  |  |  |
| *4.8.2 Red-shift (physics only)* |  |  |  |
| 1. 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.
2. The observed red-shift provides evidence that space itself (the universe) is expanding and supports the Big Bang theory.
3. The Big Bang theory suggests that the universe began from a very small region that was extremely hot and dense.
4. Since 1998 onwards, observations of supernovae suggest that distant galaxies are receding ever faster.

Students should be able to explain:1. qualitatively the red-shift of light from galaxies that are receding
2. that the change of each galaxy’s speed with distance is evidence of an expanding universe
3. how red-shift provides evidence for the Big Bang model
4. how scientists are able to use observations to arrive at theories such as the Big Bang theory
5. that there is still much about the universe that is not understood, for example dark mass and dark energy.
 |  |  |  |

**PHYSICS EQUATIONS TO LEARN BY HEART (SEPARATE PHYSICS)**

| **FORCES** |
| --- |
|  | **Quantity** | **Unit** | **Equation** |
| *FORCES* | *14* | **W****m****g** | weightmassgravitational field strength | newtonkilogramnewton per kilogram | NkgN/kg | $$W=m x g$$ |
| *15* | **W****F****s** | work doneforce distance travelled | joulenewtonmetre | JNm | $$W=F x s$$ |
| *16* | **F****k****e** | forcespring constantextension | newtonnewton per metremetres | NN/mm | $$F=k x e$$ |
| *17\** | **M****F****d** | momentforcedistance (perpendicular to pivot) | newton metrenewtonkilogram | NmNkg | $$M=F x d$$ |
| *18\** | **p****F****A** | pressureforcearea | pascalnewtonmetre**2** | PaNm**2** | $$p=\frac{F}{A}$$ |
| *19* | **s****v****t** | distancevelocitytime | metremetre per secondsecond | mm/ss | $$s=v x t$$ |
| *20* | **a****v****u****t** | accelerationfinal velocityinitial velocitytime | metre per second**2**metre per secondmetre per secondsecond | m/s**2**m/sm/ss | $a=\frac{Δv}{t}$OR$$a=\frac{(v-u)}{t}$$ |
| *21* | **F****m****a** | forcemassacceleration | newtonkilogrammetre per second**2** | Nkgm/s**2** | $$F=m x a$$ |
| *22HT* | **p****m****v** | momentummassvelocity | kilogram metre per secondkilogrammetre per second | kg m/skgm/s | $$p=m x v$$ |
| **WAVES** |
|  | **Quantity** | **Unit** | **Equation** |
| *WAVES* | *23* | **v****f****λ** | velocityfrequencywavelength | metre per secondhertzmetre | m/sHzm | $$v=f x λ$$ |

 \* For separate sciences only.

 HT Higher tier only.

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| **Key ideas** |  |  |  |
| The complex and diverse phenomena of the natural and man-made world can be described in terms of a small number of key ideas in physics.These key ideas are of universal application, and are embedded throughout.Key ideas in physics include:1. the use of models, as in the particle model of matter or the wave models of light and of sound
2. the concept of cause and effect in explaining such links as those between force and acceleration, or between changes in atomic nuclei and radioactive emissions
3. the phenomena of ‘action at a distance’ and the related concept of the field as the key to analysing electrical, magnetic and gravitational effects
4. that differences, for example between pressures or temperatures or electrical potentials, are the drivers of change
5. that proportionality, for example between weight and mass of an object or between force and extension in a spring, is an important aspect of many models in science
6. that physical laws and models are expressed in mathematical form.
 |  |  |  |
| **Mathematical requirements** |  |  |  |
| **1 Arithmetic and numerical computation**a Recognise and use expressions in decimal formb Recognise and use expressions in standard formc Use ratios, fractions and percentagesd Make estimates of the results of simple calculations**2 Handling data**a Use an appropriate number of significant figuresb Find arithmetic meansc Construct and interpret frequency tables and diagrams, bar charts and histogramsd Understand the terms mean, mode and mediane Use a scatter diagram to identify a correlation between two variablesf Make order of magnitude calculations**3 Algebra**a Understand and use the symbols: =, <, <<, >>, >, ∝ , ~b Change the subject of an equationc Substitute numerical values into algebraic equations using appropriate units for physical quantitiesd Solve simple algebraic equations**4 Graphs**a Translate information between graphical and numeric formb Understand that *y = mx + c* represents a linear relationshipc Plot two variables from experimental or other datad Determine the slope and intercept of a linear graphe Draw and use the slope of a tangent to a curve as a measure of rate of changef Understand the physical significance of area between a curve and the x-axis and measure it by counting squares as appropriate**5 Geometry and trigonometry**a Use angular measures in degreesb Visualise and represent 2D and 3D forms including two dimensional representations of 3D objectsc Calculate areas of triangles and rectangles, surface areas and volumes of cubes |  |  |  |
| **Practical assessment** |  |  |  |
| Practical work is at the heart of physics.There are three main reasons for doing practical work in schools.1. To support and consolidate scientific concepts (knowledge and understanding).
2. applying and developing what is known and understood of abstract ideas and models.
3. making sense of new information and observations
4. provide insights into the development of scientific thinking.
5. To develop investigative skills. These transferable skills include:
	1. devising and investigating testable questions
	2. identifying and controlling variables
	3. analysing, interpreting and evaluating data.
6. To build and master practical skills such as:
	1. using specialist equipment to take measurements
	2. handling and manipulating equipment with confidence and fluency
	3. recognising hazards and planning how to minimise risk.
 |  |  |  |