GCSE

WJEC GCSE in
PHYSICS

APPROVED BY QUALIFICATIONS WALES

GUIDANCE FOR TEACHING

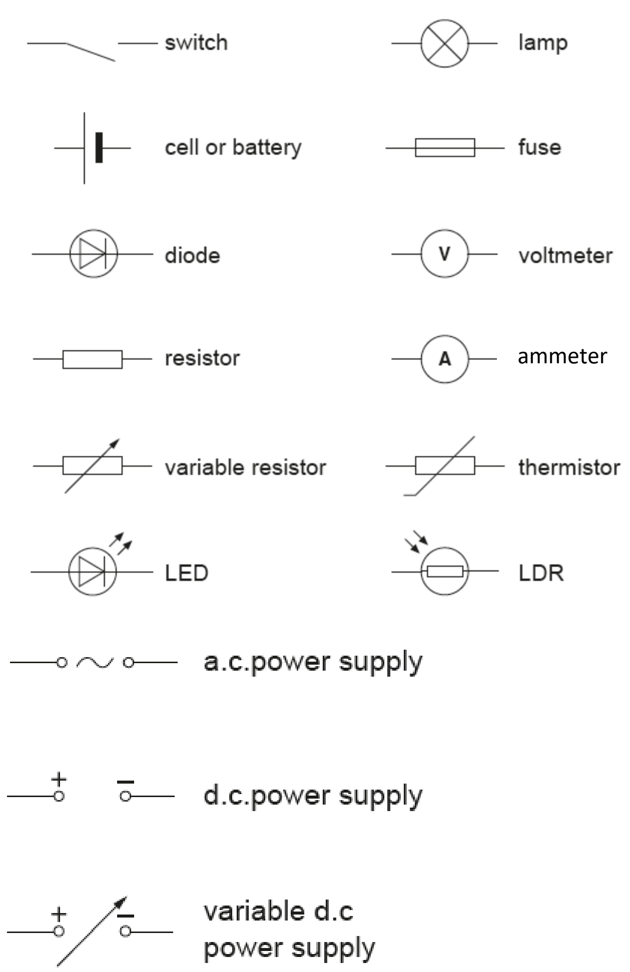
Teaching from 2016

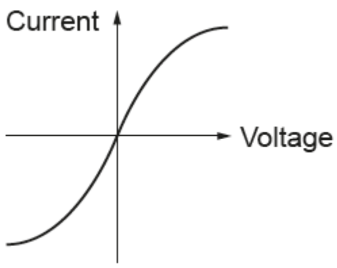
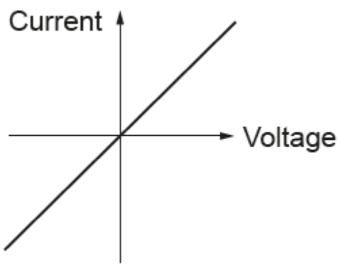
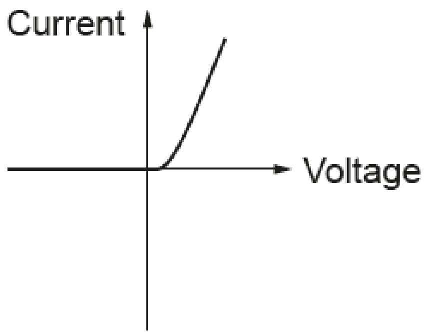
This Qualifications Wales regulated qualification is not available to centres in England.

Contents

UNIT 1 – ELECTRICTY, ENERGY AND WAVES

1.1 ELECTRIC CIRCUITS

Spec Statement		Comment
(a)	the symbols of components (cell, switch, lamp, voltmeter, ammeter, resistor, variable resistor, fuse, LED, thermistor, LDR, diode) used in electrical circuits	Be able to draw circuit diagrams. 
(b)	series circuits in which the current is the same throughout a circuit and voltages add up to the supply voltage; parallel circuits in which the voltage is the same across each branch and the sum of the currents in each branch is equal to the current in the supply	Including appreciation of types of household circuits e.g. ring main, household lighting circuits. Can be linked to topic 1.4 - domestic electricity.

(c)	voltmeters and ammeters to measure the voltage across and current in electrical components in electrical circuits	Know that an ammeter must be connected in **series** and a voltmeter must be connected in **parallel**.
(d)	circuits to investigate how current changes with voltage for a component e.g. for a resistor (or wire) at constant temperature, a filament lamp and a diode	The circuits could include a variable resistor or a variable power supply. Including knowledge of how: • R varies with V for a lamp because temperature is not constant • R varies with positive (forward bias) and negative voltages (reverse bias) for a diode and that normally a diode will not conduct until a particular voltage is reached. Current plotted on the y-axis and voltage on the x-axis.  
(e)	the significance of and the relationship between current, voltage and resistance, $I = \frac{V}{R}$	The qualitative and quantitative relationships should be known. If R is constant then $I \propto V$. If V is constant then $I \propto \frac{1}{R}$
(f)	how adding components in series increases total resistance in a circuit; adding components in parallel decreases total resistance in a circuit	

(g)	how to calculate total resistance and total current in a series circuit, **a parallel circuit and circuits consisting of combinations of series and parallel connections;** $R = R_1 + R_2$; $\frac{\mathbf{1}}{\boldsymbol{R}} = \frac{\mathbf{1}}{\boldsymbol{R_1}} + \frac{\mathbf{1}}{\boldsymbol{R_2}}$	**Includes calculating current in a branch of a parallel circuit.** **Includes calculating the p.d. across a resistor.** **No limit to the number of parallel branches.** **Learners should be encouraged to not express their final answer in terms of a fraction.**
(h)	power as energy transferred per unit time: $E = Pt$	Including the relationship between the units watts and joules i.e. 1 W = 1 J/s
(i)	the power transferred using: power = voltage × current $P = VI$ **power = current² × resistance** $= \boldsymbol{P = I^2 R}$	$P = \frac{V^2}{R}$ is not required
(j)	explain the design and use of circuits to explore the variation of resistance – including for lamps, diodes, ntc thermistors and LDRs	Including knowledge of how: • R varies with T for a ntc thermistor • R varies with light intensity for a LDR A multimeter could be used as an ohmmeter to explore the variation of resistance in a thermistor and LDR. Links with statement (d) in this section also.

SPECIFIED PRACTICAL WORK

- Investigation of the current-voltage (I-V) characteristics for a component

Investigation of the current-voltage (*I-V*) characteristics of a component

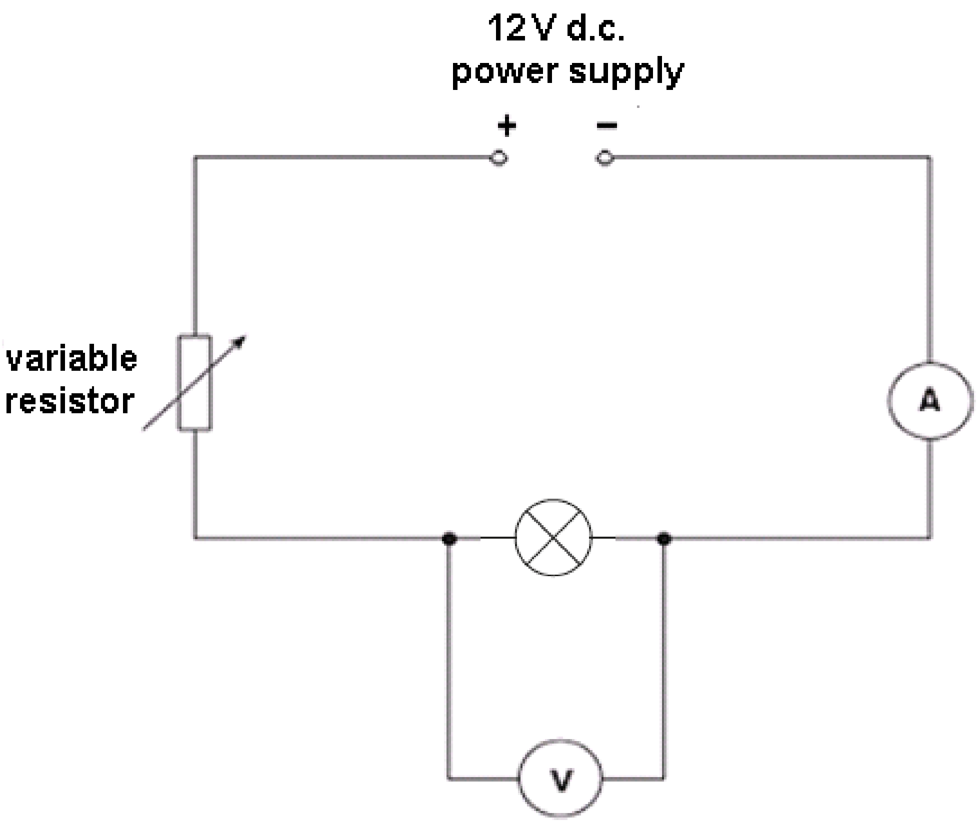
Introduction

The voltage across and the current through a component can be measured and the results plotted on a graph to show the *I-V* characteristic of the component.

Apparatus

12 V filament lamp
voltmeter ±0.01 V
ammeter ±0.01 A
connecting leads
12 V d.c. power supply
variable resistor

Diagram of Apparatus



Method

1. Connect the circuit as shown in the diagram.
2. Adjust the variable resistor until the voltmeter reads 1 V.
3. Record the readings of voltage and current.
4. Adjust the variable resistor to increase the voltmeter reading to 2 V.
5. Record the readings of voltage and current.
6. Repeat steps 4 to 5, increasing the voltage by 1 V each time, until the voltmeter reads 12 V.

Analysis

1. Plot a graph of current (y-axis) vs voltage (x-axis).

Technician / Teacher notes

Risk Assessment

Hazard	Risk	Control measure
Hot lamps can burn	Burning skin on hot lamps when moving/touching lamps	Allow lamp to cool before touching them.

Ray box lamps are suitable to use instead of 12 V lamps.

d.c. voltmeters and ammeters must be used.

If variable resistors are not available then a variable power supply could be used. Students should read the voltage directly from the voltmeter rather than using the settings on the power supply.

If students are constructing the circuits, it is advisable they should be checked for short circuits before use.

The graph should show a non-linear relationship.

More able students should be encouraged to discuss how the resistance of the filament changes due to the heating effect.

Working scientifically skills covered

2. Experimental skills and strategies
Apply knowledge of a range of techniques, instruments, apparatus and materials to select those appropriate to the experiment.

Make and record observations and measurements using a range of apparatus and methods.

3. Analysis and Evaluation
Present observations and other data using appropriate methods.

Translate data from one form to another.

Carry out and represent mathematical analysis.

Interpret observations and other data, including identifying patterns and trends, making inferences and drawing conclusions.

4. Scientific vocabulary, quantities, units, symbols and nomenclature
Use SI units and IUOAC chemical nomenclature unless inappropriate.

1.2 GENERATING ELECTRICITY

	Spec Statement	Comment
(a)	the advantages and disadvantages of renewable energy technologies (e.g. hydroelectric, wind power, wave power, tidal power, waste, crops, solar and wood) for generating electricity on a national scale using secondary information	Consider economic, environmental and sustainability issues as well as generating capacities and start-up time. Links with statement (h) in this section.
(b)	the advantages and disadvantages of non-renewable energy technologies (fossil fuels and nuclear) for generating electricity	As above.
(c)	the processes involved in generating electricity in a fuel based power station	Including energy changes and the roles of turbines and generators.
(d)	Sankey diagrams to show energy transfers; energy efficiency in terms of input energy and energy usefully transferred in a range of contexts including electrical power generation and transmission: $\% \text{ efficiency} = \frac{\text{energy [or power] usefully transferred}}{\text{total energy [or power] supplied}} \times 100$	Including drawing Sankey diagrams to scale. See section 2.3 – work and energy statement (h).
(e)	the need for the National Grid as an electricity distribution system including monitoring power use and responding to changing demand	Recognise the term base load. The role of different types of power stations in responding to changes in demand i.e. start-up times. Understand how the National Grid makes the electricity supply more reliable. Recognise power stations, step-up and step-down transformers, transmission lines and consumers on a diagram. Interpret graphs of demand through a time period. Importing and exporting of electricity to other European countries.
(f)	advantages and disadvantages of using different voltages of electricity at different points in the National Grid to include transmission of electricity and use in the home, selecting and using the equation: power = voltage × current; $P = VI$	Step-up transformers increase voltage and decrease current – reducing energy losses in transmission lines making distribution more efficient. Step-down transformers reduce voltage to safer levels for consumers. See section 1.4 – domestic electricity statement (d).
(g)	the use of step-up and step-down transformers used in the transmission of electricity from the power station to the user in qualitative terms (they should be treated as voltage changers without any reference to how they perform this function)	

(h)	efficiency, reliability, carbon footprint and output to compare different types of power stations in the UK including those fuelled by fossil fuels, nuclear fuel and renewable sources of energy	Involves the interpretation of given data. Links with statement (a) in this section.

1.3 MAKING USE OF ENERGY

	Spec Statement	Comment
(a)	how temperature differences lead to the transfer of energy thermally by conduction, convection and radiation	Conduction occurs well in metals and convection occurs in fluids.
(b)	the equation: $\text{density} = \frac{\text{mass}}{\text{volume}}$ and explain the differences in density between the three states of matter in terms of the arrangements of the atoms or molecules	Be able to work in both g/cm^3 and kg/m^3 but no conversions will be expected.
(c)	**conduction using a model of molecular motion and account for the better conduction in metals by the presence of mobile electrons**	Free electrons, de-localised electrons, mobile electrons are all suitable terms to use.
(d)	**convection in liquids and gases in terms of molecular behaviour and variations in volume and density**	For example: "when a section of liquid (gas) is heated the molecules gain energy and move more vigorously. As a result this section of the liquid increases in volume and its density decreases. This less dense liquid then rises and colder more dense liquid sinks to takes its place. This process continues until all of the liquid is heated." Learners need to be familiar with the term convection currents.
(e)	how energy loss from houses can be restricted e.g. loft insulation, double glazing, cavity wall insulation and draught excluders	Link method of heat transfer reduction to each method of insulation. Loft insulation and cavity wall insulation reduce heat loss by both conduction and convection. Be able to explain about the importance of "trapped air." An awareness of the environmental benefits of house insulation is required.
(f)	the cost effectiveness and efficiency of different methods of reducing energy loss from the home, to compare their effectiveness; use data to compare the economics of domestic insulation techniques, including calculating the payback time; the economic and environmental issues surrounding controlling energy loss	$\text{payback time} = \frac{\text{installation cost}}{\text{annual savings}}$

(g)	how data can be obtained and used to investigate the cost of using a variety of energy sources for heating and transport	Consideration of the different costs of energy sources of vehicles and the range they allow: e.g. the fuel efficiency of cars, the cost-efficiency of oil-fired heating etc.

SPECIFIED PRACTICAL WORK

- Investigation of the methods of heat transfer
- Determination of the density of solids and liquids (regular and irregular)

Investigation of the methods of heat transfer

Introduction

Heat can be transferred through materials (and indeed empty space) in different ways. This series of experiments explores the methods of heat transfer and aims to develop your understanding of the differences between conduction, convection and radiation.

Apparatus

Convection:
2 × 250 cm^3 beaker
1 crystal of potassium manganate(VII)
10 cm^3 glass tube
tripod and gauze
heat proof mat
Bunsen burner
forceps

Radiation:
filament lamp
2 × thermometers
1 small piece of black paper
1 small piece of silver foil
Sellotape
stopwatch
2 × clamp stand, clamp and boss

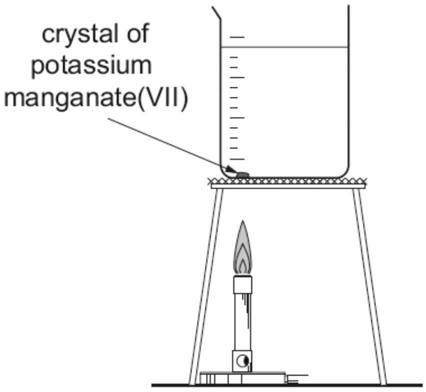
Conduction:

EITHER
4 × metal rods
(aluminium, brass, copper and iron)
4 × drawing pins
Vaseline
tripod
Bunsen burner
heat proof mat
stopwatch

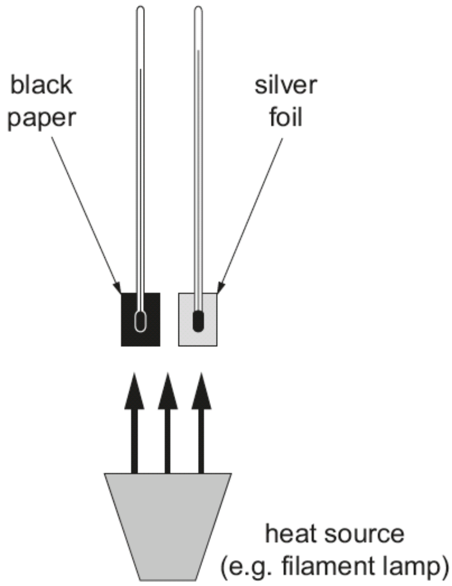
OR
conductive ring
(aluminium, brass, copper and steel)
4 × wooden matches
Vaseline
clamp stand, clamp and boss
Bunsen burner
heat proof mat
stopwatch

Diagram of Apparatus

Convection Experiment

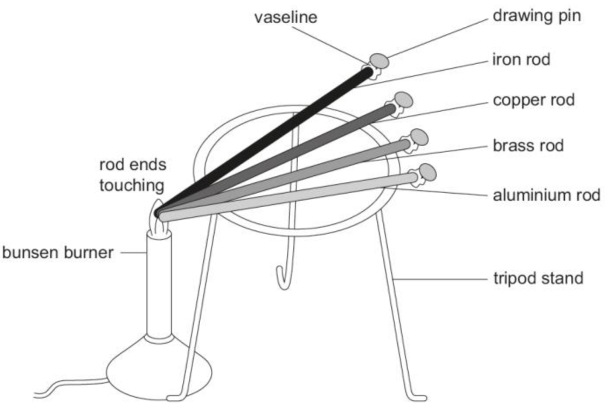


Radiation Experiment

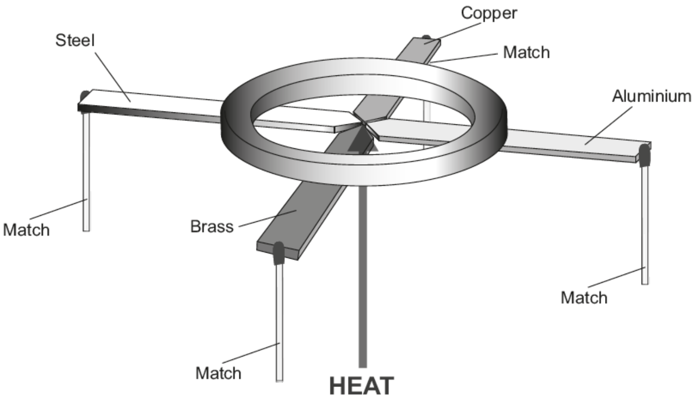


Conduction Experiment

EITHER
Metal Rods Experiment



OR
Conductive Ring Experiment



Method

Convection Experiment

1. Fill the beaker to ¾ full of water.
2. Use forceps to pick up a single crystal of potassium manganate(VII) and drop it carefully
   through the glass tube to one side of the bottom of the beaker.
3. Place your finger on the top of the tube and remove carefully.
4. Light the Bunsen burner well away from the apparatus. Use the gas tap to get the smallest
   blue flame that you can.
5. Put the small Bunsen flame directly underneath the crystal and record your observations.

Method

Radiation Experiment

1. Use Sellotape to attach a 2 cm strip of black paper to the bulb of one thermometer.
2. In the same way attach a 2 cm strip of silver foil to the bulb of another thermometer.
3. Clamp the 2 thermometers **the same distance away** (about 10 cm) from a filament lamp.
4. Record the temperatures shown by the two thermometers.
5. Switch on the lamp and record the temperatures again after 10 minutes.

Analysis

1. Determine which colour is the best absorber of heat.

Method

Conduction Experiment

<u>Metal Rods Experiment</u>

1. Set up the apparatus as shown in the diagram above.
2. Attach a drawing pin to the end of each rod with a small blob of Vaseline.
3. The ends of the rods (without the drawing pins) should be brought together so that they can be heated equally (see diagram).
4. Heat the ends of the rods equally with a blue Bunsen flame.
5. Record the time taken for each rod to lose its drawing pin.

Conductive Ring Experiment

1. Clamp the conductive ring taking care to keep the clamp away from the mid-point of the ring.
2. Attach a wooden match to the outer end of each metal using a small blob of Vaseline.
3. Heat the centre point of the ring with a blue Bunsen flame.
4. Record how long it takes for each metal to lose its wooden match.

Analysis

1. Determine the order of conductivity of the metals.

Teacher / Technician Notes

Risk Assessments

Convection Experiment

Hazard	Risk	Control measure
Potassium manganate(VII) is harmful/oxidising	Could harm skin if touched	Use tweezers to drop a single crystal through the glass tube to bottom of beaker. Do not handle
Hot apparatus can burn	Burning fingers when moving apparatus	Allow apparatus to cool before any attempt to move it. Hold tripod at bottom of a leg, Bunsen burner at base and gauze at the corner.

Radiation Experiment

Hazard	Risk	Control measure
Hot filament lamp can burn	Burning fingers when moving lamp	Allow lamp to cool before any attempt to move it.

Conduction Experiment

Hazard	Risk	Control measure
Hot metal rods can burn	Burning fingers when moving rods	Allow the rods to cool thoroughly before attempting to move them from the tripod
Hot tripod can burn	Burning fingers when moving tripod	Allow the tripod to cool. Do not touch the top. Move by holding bottom of a leg
Aluminium melting can burn	Molten aluminium falling on back of hand causing burning/injury	Do not overheat aluminium. Observe aluminium for signs of melting and remove heat. Do not hold the Bunsen when it is directly beneath end of aluminium rod

Convection experiment
A small supply of potassium manganate (VII) crystals may be supplied in an evaporating basin (with some forceps) for shared use. Students should take care not to handle the crystals or get them on their clothes as it does stain. Please see the CLEAPPS card 48 on potassium manganate(VII) for further safety advice.

Strong heating does result in all the water becoming coloured very quickly. A small flame allows the convection to be seen much more easily. Students should adjust the gas tap to achieve the smallest blue flame that they can. If the flame goes out they should turn off the gas at the gas tap and then re-light the Bunsen burner and try again.

Students should be encouraged to describe their observations fully. It is not that the water all becomes coloured that is important but rather how this happens. They should be able to observe the convection currents in the water (as the purple colour rises, spreads across and sinks down the other side). They can then be encouraged to discuss / explain their observations.

Radiation experiment

Infra-red lamps (perhaps used for microscope work) may be used as an alternative to filament lamps in the radiation experiment. The experiment works well if pieces of Sellotape are used to attach the foil/ paper. The temperature of the thermometer with the silver foil rises less despite the fact that the aluminium is a metal and a good conductor of heat. Alternatively, white paper could be used instead of the silver-coloured aluminium foil for a "fairer" experiment. Care should be taken to have the two thermometers (on the bench or clamped) at exactly the same distance from the heat source.

Students could be asked to predict what will happen. Some may suggest that the black paper will get hotter because it "attracts" more heat. This idea will need to be challenged in the discussion following the experiment.
Students should be encouraged to describe and explain their results. They should use relevant scientific terms such as heat waves, infra-red radiation, absorb and reflect.

Conduction experiment

The expected order is:	**copper**	**(best conductor),**
	aluminium,	
	brass,	
	iron/ steel	**(poorest conductor).**

Some groups may find aluminium to be the best conductor. It is often very close between copper and aluminium. Hopefully, a quick survey of each group's results will reveal more votes for copper than for aluminium as the best conductor.
The metal rods may roll off the tripod and onto the bench. Thick cloths should be available for the teacher to pick them up and place them onto the heat proof mat to avoid marking the benches.

The Vaseline makes this a potentially messy experiment. Students need access to soap and hot water to remove Vaseline from hands.   A plentiful supply of paper towels should be available to wipe Vaseline from benches. Wooden splints may be used to transfer Vaseline from a small pot onto the drawing pin / metal rod. Students should be encouraged to use the smallest amount of Vaseline that is needed to attach each drawing pin to the rod.

This practical works well run as a circus of activities.

Working scientifically skills covered

2. Experimental skills and strategies
Carry out experiments appropriately having due regard to the correct manipulation of apparatus, the accuracy of measurements and health and safety considerations.

Make and record observations and measurements using a range of apparatus and methods.

3. Analysis and Evaluation

Interpret observations and other data including identifying patterns and trends, making inferences and drawing conclusions.

Evaluate data in terms of accuracy, precision, repeatability and reproducibility and identifying potential sources of random and systematic error.

4. Scientific vocabulary, quantities, units, symbols and nomenclature
Use scientific vocabulary, terminology and definitions.

Determination of the density of liquids and solids (regular and irregular)

Introduction

The density of a substance measures the mass it contains in a given volume. Density is calculated using the equation:

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Apparatus

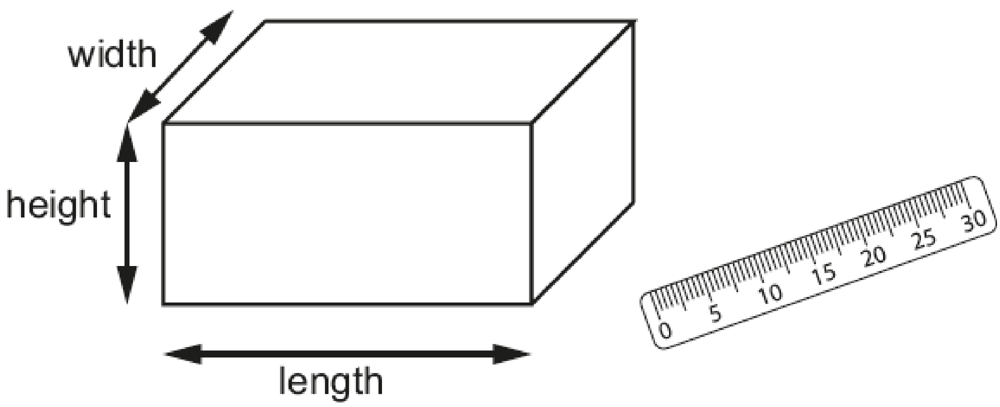
2 × regular shaped solids
2 × irregular shaped solids
30 cm ruler
50 cm^3 measuring cylinder
water

Access to:

electronic balance ± 0.1 g

Measuring the density of a regular shaped solid

Diagram of Apparatus



Method

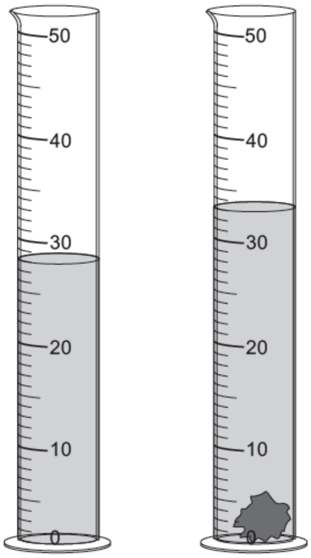
1. Record the mass of the solid.
2. Record the length, width and thickness of the solid using a ruler.
3. Repeat for cubes of different material.

Analysis

1. Calculate the volume of the cube from: volume = length x height x width.
2. Calculate the density in g/cm^3.

Measuring the density of an irregular shaped solid

Diagram of Apparatus



Method

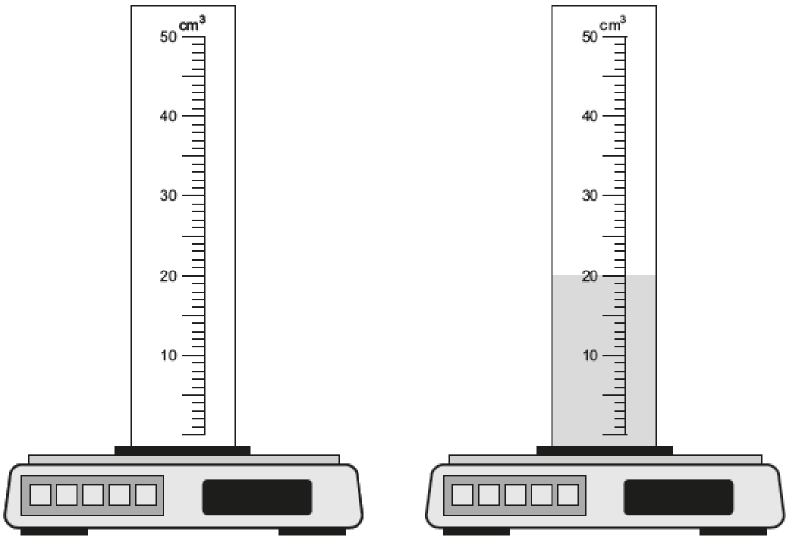
1. Record the mass of the solid.
2. Fill the measuring cylinder with water up to 20 cm^3 and record the volume.
3. Gently place the solid into the measuring cylinder and record the new volume.

Analysis

1. Calculate the volume of the solid by subtracting the original volume from the new volume.
2. Calculate the density in g/cm^3.

Measuring the density of a liquid

Diagram of Apparatus



Method

1. Record the mass of the empty measuring cylinder.
2. Add 20 cm^3 of water to the measuring cylinder.
3 Record the mass of the measuring cylinder with the water.

Analysis

1. Calculate the mass of the water by subtracting the mass of the measuring cylinder (without water) from the mass of the measuring cylinder with the water.
2. Calculate the density in g/cm^3.

Teacher / Technician notes

Small pieces of Blu-Tack or plasticine or small stones can be used as irregular shaped solids.

Students should be provided with a range of regular shaped common materials, e.g. cork, wood, steel, aluminium, polystyrene, rubber or plastic. However, care should be taken with the mass of the blocks to ensure balances are not damaged.

As an extension students could investigate how the addition of a salt such as sodium chloride to water changes its density.

This practical works well run as a circus of activities.

Working scientifically skills covered

2. **Experimental skills and strategies**
   Plan experiments or devise procedures to make observations, produce or characterise a substance, test hypotheses, check data or explore phenomena.

   Make and record observations and measurements using a range of apparatus and methods.

3. **Analysis and Evaluation**
   Carry out and representing mathematical analysis.

4. **Scientific vocabulary, quantities, units, symbols and nomenclature**

   Use SI units and IUPAC chemical nomenclature unless inappropriate.

   Use an appropriate number of significant figures in calculation.

1.4 DOMESTIC ELECTRICITY

	Spec Statement	Comment
(a)	the kilowatt (kW) as a convenient unit of power in the domestic context and the kilowatt hour (kWh) as a unit of energy	1 kWh is the electrical energy converted by a 1 kW appliance used for 1 hour. Be able to convert between kWh and joules.
(b)	the cost of electricity using the equations: units used (kWh) = power (kW) × time (h) cost = units used × cost per unit	Conversions between W and kW. Also between minutes/hours and hours/days and pence/£.
(c)	how data can be obtained either directly or using secondary sources (e.g. through the energy banding (A-G) and the power ratings of domestic electrical appliances) to investigate the cost of using them	Includes different types of lamps e.g. filament, halogen and LED. Includes payback time.
(d)	the difference between alternating current (a.c.) and direct current (d.c.)	An alternating current (a.c.) is one that continuously changes direction. Mains electricity is an a.c. supply. A direct current (d.c.) has a constant direction. Cells and batteries provide d.c. Graphical representation of a.c. and d.c. voltages on CRO screens. The UK mains supply is about 230 V and has a frequency of 50 cycles per second (50 Hz). See section 1.2 – generating electricity statement (g).
(e)	the functions of fuses, miniature circuit breakers (mcb) and residual current circuit breakers (rccb) including calculations of appropriate fuse ratings	A selection of fuse ratings will be given. Unlike fuses, mcb circuit breakers can be easily reset and use an electromagnet to open a switch if the current goes above a certain value. rccb circuit breakers switch off the circuit when there is a difference between the currents in the live and neutral wires of the appliance. They are more sensitive than mcb breakers. mcbs protect the circuit whilst rccbs protect the user.

(f)	the ring main, including the functions of the live, neutral and earth wires	The structure and wiring of a 3 pin plug is not needed. The function of the live wire is to carry current to the house/appliance at a high voltage. The neutral wire completes the circuit and carries current away at low/zero voltage. The earth wire is a safety wire that can carry current safely into the ground if a fault develops in a metal framed appliance. Appliances with metal cases are usually earthed. If the casing becomes live, a large current can flow along the low-resistance earth wire and this high current "will blow" a fuse or trip a mcb. Switches and fuses are placed into the live wire. The ring main is a looped parallel circuit. There are several advantages of using a ring main circuit: - the cables can be made thinner because there are two paths for the current; - each part of the cable carries less current because the current flows two ways; - a ring main circuit is more convenient since sockets can be placed anywhere on the ring; - each socket has 230 V applied and they can be operated separately.
(g)	the cost effectiveness of introducing domestic solar and wind energy equipment, including fuel cost savings and payback time by using data	Including output reliability and ability to meet domestic demand feed-in tariffs.
(h)	how to investigate energy transfers in a range of contexts including interpreting and analysing data; evaluation of validity of the data and methods, e.g. • the energy output from a renewable source (e.g. wind turbine: construction and location) • efficiency of energy transfer (e.g.using an electric kettle)	

1.5 FEATURES OF WAVES

	Spec Statement	Comment
(a)	the difference between transverse and longitudinal waves	Including definitions of both types of waves with comparison of the direction of vibrations and the direction of travel of the wave included. Be able to give examples of a transverse wave and a longitudinal wave.
(b)	the description of a wave in terms of amplitude, wavelength (λ), frequency (f) and wave speed (v)	Know that amplitude is the maximum displacement from rest. No knowledge of period is required. Be able to define only the term frequency i.e. the number of cycles of a wave that occur in one second.
(c)	the graphical representation of a transverse wave, including labelling the wavelength and amplitude	Including constructing a wave diagram from given data. Displacement – distance and displacement – time graphs are required.
(d)	diagrams showing plane wave fronts being reflected or refracted, e.g. as shown by water waves in a ripple tank	Only at plane boundaries required. Knowledge of the terms normal, angles of incidence / reflection / refraction required. Should know what happens to the speed / frequency / wavelength / direction of water waves as they move from deep to shallow water (and vice versa).
(e)	refraction in terms of the speed of waves on either side of a refracting boundary and the effect on the wavelength of the waves	Changes in wavelength are proportional to changes in wave speed.
(f)	the term "radiation" to both electromagnetic waves and to energy given out by radioactive materials	
(g)	the characteristics of radioactive emissions and short wavelength parts of the electromagnetic spectrum (ultraviolet, X-ray and gamma ray) as ionising radiation, able to interact with atoms and to damage cells by the energy they carry	No knowledge of alpha and beta is required here.
(h)	the difference between the different regions of the electromagnetic spectrum [radio waves, microwaves, infra-red, visible light, ultraviolet, X-rays and gamma rays] in terms of their wavelength and frequency and know that they all travel at the same speed in a vacuum	Be able to name the 7 regions of the em spectrum. Have knowledge of the order in which the regions are arranged in terms of wavelength, frequency or energy. In a question – speed of light, $c = 3 \times 10^8$ m s^{-1} will be given if needed.

(i)	the fact that all regions of the electromagnetic spectrum transfer energy and certain regions are commonly used to transmit information	Higher frequencies transmit higher energies. Awareness of the uses of the different regions of the em spectrum.
(j)	waves in terms of their wavelength, frequency, speed and amplitude	Including the relationship between wavelength and frequency i.e. inversely proportional and between amplitude and energy.
(k)	the equations: wave speed = wavelength × frequency; $v = \lambda f$ and $\text{speed} = \frac{\text{distance}}{\text{time}}$ applied to the motion of waves, including electromagnetic waves	Recognising expressions in standard form is expected on FT e.g. arranging values in a rank order. Calculations involving standard form will only be expected on HT. See section 1.6 – the total internal reflection of waves statement (c).
(l)	communication using satellites in geosynchronous/geostationary orbit	Signal travels double the orbit height. Requires the use of microwaves to pass through the atmosphere. The use of more than 1 satellite is required. A geosynchronous satellite has an orbit time of 24 h however the object in this orbit only returns to exactly the same position in the sky after a period of one day. A geostationary orbit is a particular type of geosynchronous orbit. The distinction being that while an object in geosynchronous orbit returns to the same point in the sky at the same time each day, an object in geostationary orbit never leaves that position. A base station can be in constant communication with a geostationary satellite but only once every 24 h with a geosynchronous satellite. See section 1.6 – the total internal reflection of waves statement (c).

SPECIFIED PRACTICAL WORK

- Investigation of the speed of water waves

Investigation of the speed of water waves

Introduction

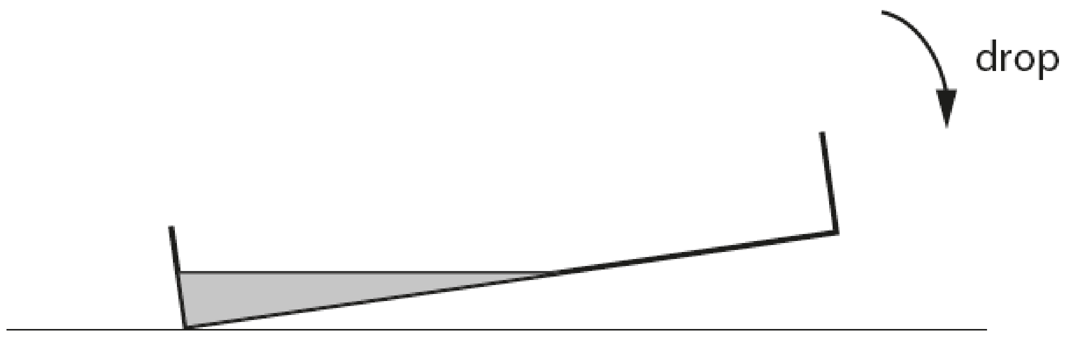
The speed of waves on the surface of water, created when the water is moved out of position, depends only on the depth of the water and the gravitational field strength. To measure the speed of the waves the time they take to travel a certain distance is measured and the following equation is applied.

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

Apparatus

rectangular apparatus tray with straight sides
stopwatch
large beaker
large measuring cylinder

Diagram of Apparatus



Method

1. Measure the length of the tray and record the result.
2. Add water to the tray to give a depth of 0.5 cm and record the volume used.
3. Lift the end of the tray up a few cm and gently replace on the desk.
4. Start the stopwatch when the wave produced hits the end of the tray.
5. Record how long it takes the waves to travel 3 lengths of the tray.
6. Repeat steps 3-5 four more times.
7. Repeat steps 2-6 increasing the depth each time by 0.5 cm up to 3.0 cm.

Analysis

1. Calculate the mean speed of the waves using:

$$\text{mean speed} = \frac{\text{distance}}{\text{mean time}}$$

2. Plot a graph of depth against speed.

Teacher / Technician notes

Risk Assessment

Hazard	Risk	Control measure
Wet floors are slippery	If water splashes on the floor during the experiment people may slip and be injured	Do not overfill the trays. Place tray down gently when producing waves. Mop up any spillages

Although straight sided trays are preferable, Gratnell trays work quite well in this experiment.

Pupils will need to be given the value for the volume of water required to fill the tray to a depth of 0.5 cm – in cm^3 this is numerically equal to half the surface area.

The data should give a smooth curve as the speed is proportional to $\sqrt{\text{depth}}$.

Students should plot a graph of depth against mean speed and be encouraged to plot a smooth curve of best fit (if they have measured carefully!) and to examine the quantitative relationship between the variables.

Students should be told that they need to use the length of tray $\times$ 3 in calculating the mean speed for each depth.

It is interesting to investigate the factor by which the depth must change to double the speed of the waves this could provide good extension opportunities for the more able.

Students should design their own table, but a suggested table format is shown below.

		Time taken for waves to travel three lengths of the tray (s)						
Depth of water (cm)	Length of tray (cm)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean	Mean speed (cm/s)

Working scientifically skills covered

2. Experimental skills and strategies

Carry out experiments appropriately having due regard to the correct manipulation of apparatus, the accuracy of measurements and health and safety considerations.

Make and record observations and measurements using a range of apparatus and methods.

Evaluate methods and suggest possible improvements and further investigations.

3. Analysis and Evaluation

Present observations and other data using appropriate methods.

Translate data from one form to another.

Carry out and representing mathematical analysis.

1.6 THE TOTAL INTERNAL REFLECTION OF WAVES

Spec Statement		Comment
(a)	the conditions for total internal reflection of light	The use of Snell's Law is not required. Definition of the critical angle is not required, however knowledge of what it is, is required. Know the conditions required for TIR to occur: i.e. angle of incidence is greater than the critical angle, movement from a more dense to a less dense material. Typical values for critical angle will be given e.g. glass/air boundary is 42°.
(b)	how optical fibres rely on total internal reflection for their operation	Be able to interact with simple TIR ray diagrams. Knowledge of monomode optical fibres is not required.
(c)	comparison of the advantages and disadvantages of optical fibres and geosynchronous / geostationary satellites for long distance communication	Including interpretation of data contained within a question. The use of more than 1 satellite is required. Know which types of em waves are used in optical fibres and by satellites. See section 1.5 – the features of waves statements (k) and (l).
(d)	the use of optical fibres for remote imaging, including endoscopic medical examinations and a comparison of endoscopy with CT scans for obtaining medical information	Endoscopy uses optical fibres and CT scans use X-rays. Endoscopy is used to investigate specific areas of the body and it is less harmful than CT scans. CT scans are used to generate more overall images of the body and are a higher risk than endoscopes. CT scans are 3D.

1.7 SEISMIC WAVES

Spec Statement		Comment
(a)	the properties of seismic P waves, S waves and surface waves, in terms of their nature, speed and ability to penetrate different materials	The different materials refer to solid rock and liquid /molten rock. Surface waves are the slowest, longitudinal, travel along the surface and cause the most damage. Detailed knowledge of surface waves e.g. Love and Rayleigh waves is not required. Note that the mantle can be assumed to be solid in the context of S waves travelling through it.
(b)	the fact that P waves are longitudinal and S waves are transverse	
(c)	simplified seismic records, to allow for the identification of the lag time between the arrival of the P and S waves to occur and to use the seismic records from several stations to locate the epicentre of an earthquake.	Including interacting with data contained within a question. This could include a seismogram. Knowledge about the focus of an earthquake is not required. See section 1.5 – features of waves statement (a).
(d)	the path of P and S waves through the Earth (the dependence of the speed of seismic waves on the density and stiffness of the material will not be examined)	Terms such as crust, mantle, inner core and outer core will be referred to. Assumption that the outer core is liquid. Appreciate that curved paths occur due to refraction.
(e)	how existence of the S wave shadow zone as shown on seismic records has led geologists to a model of the Earth with a solid mantle and a liquid core	

1.8 KINETIC THEORY

	Spec Statement	Comment
(a)	the concept of pressure qualitatively and select and use the relationship: $\text{pressure} = \frac{\text{force}}{\text{area}}$; $p = \frac{F}{A}$	1 Pascal (Pa) is equivalent to 1 N/m^2.
(b)	the behaviour of a fixed quantity of gas under conditions of varying pressure, volume and temperature	Links with statement (e) in this section.
(c)	how the behaviour of gases leads to the concepts of absolute zero and an absolute scale of temperature	Including analysis of data or information displayed graphically.
(d)	temperatures in kelvin and **use the relationship:** $\frac{pV}{T}$ **= constant** **for gases including circumstances in which one of the three variables remains constant**	Temperature (K) = Temperature (°C) + 273 **Universal gas constant (*R*) knowledge is not required.** $\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$ **may be helpful for learners.**
(e)	the variation of the pressure of gases with volume and temperature qualitatively by applying a model of molecular motion and collisions	Explanations using molecular model theory are expected. No knowledge of the assumptions of kinetic theory is required.
(f)	the equations: $Q = mc\Delta\theta$ and $Q = mL$ relating the heat transfer to changes of temperature and state respectively	Values for specific heat capacities or specific latent heat will be given. Interpretation of a cooling / heating curve. Appreciation that latent heat does not increase the temperature of matter – the energy supplied is used for the change of state to take place. Define specific heat capacity as the amount of heat energy required to increase the temperature of 1 kg of a substance by 1 °C. Define specific latent heat of fusion as the amount of heat energy needed to change a mass of 1 kg of the substance from a solid at its melting point into a liquid at the same temperature. The specific latent heat of vaporisation is the amount of heat energy required to change 1 kg of a liquid at its boiling point into a vapour without a change in temperature. Be able to relate the standard definitions to specific examples e.g. water has a specific heat capacity of 4 200 J / kg °C this means that 4 200 J of energy is required to increase the temperature of 1 kg of water by 1 °C.

(g)	**the explanation of changes in temperature and state of a substance, resulting from heat transfer, in terms of the behaviour of molecules**	**In terms of bond breaking or bond formation during changes of state.** **A smaller number of bonds are broken during fusion than vaporisation so this means more energy is required for vaporisation to occur.**

SPECIFIED PRACTICAL WORK

- Determination of the specific heat capacity of a material

Determination of the specific heat capacity of a material

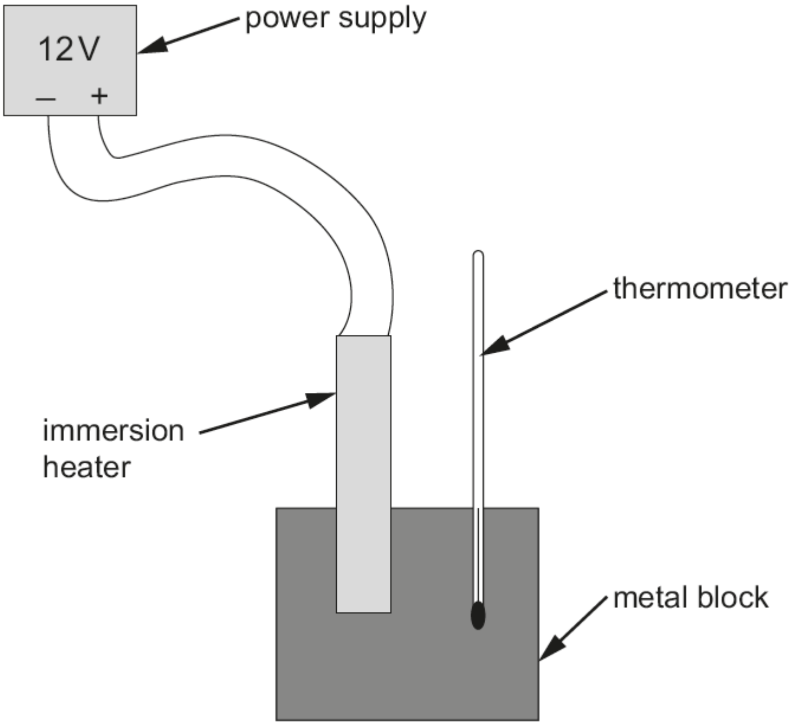
Introduction

You will determine the specific heat capacity of metals by measuring the heat energy transferred to the metal by an immersion heater and the temperature rise of the metal.

Apparatus

1 kg metal block
stopwatch
12 V d.c. power supply
connecting leads
50 W 12 V immersion heater
thermometer

Diagram of Apparatus



Method

1. Ensure the power supply is switched off.
2. Place the immersion heater and thermometer in the holes provided in the metal block.
3. Record the initial temperature of the metal block.
4. Switch on the 12 V power supply.
5. Record the temperature of the metal block every minute for 10 minutes.

Analysis

1. The heat energy transferred to the metal can be calculated from the equation:

   Energy = Power × Time (seconds)

2. The specific heat capacity (c) of the metal can be calculated from:

   $Q = mc\Delta\theta$

   Where:

   Q = Heat energy supplied

   m = Mass of block

   $\Delta\theta$ = Temperature rise of block

   Calculate the specific heat capacity of the metal.

Technician / Teacher notes

Risk Assessment

Hazard	Risk	Control measure
Hot immersion heater can burn	Burning skin when moving hot immersion heater	Allow to cool before touching

Do not switch on the immersion heater outside the metal block.

Power supplies should be set at 12 V.

A variety of materials could be used by different groups, e.g. aluminium, copper or iron and the results compared. In addition, students could be given the published value for the specific heat capacity for each metal and then compare it with the value they have calculated.

Working scientifically skills covered

2. **Experimental skills and strategies**
Make and record observations and measurements using a range of apparatus and methods.

3. **Analysis and Evaluation**
Carry out and representing mathematical analysis.

Represent distributions of results and make estimations of uncertainty.

Evaluate data in terms of accuracy, precision, repeatability and reproducibility and identifying potential sources of random and systematic error.

4. **Scientific vocabulary, quantities, units, symbols and nomenclature**
Use SI units and IUPAC chemical nomenclature unless inappropriate.

Use prefixes and powers of ten for orders of magnitude.

1.9 ELECTROMAGNETISM

	Spec Statement	Comment
(a)	the magnetic field patterns of bar magnets, straight wires and solenoids	To include magnetic field directions (N $\rightarrow$ S) and their spacing to indicate magnetic field strength.
(b)	how a magnet and a current carrying conductor exert a force on one another (the motor effect) and use Fleming's left hand rule to predict the direction of one of the following: force on the conductor, the current and the magnetic field when two are provided	Application of Flemings Left Hand Rule is required.
(c)	**the equation that links the force (F) on a conductor to the strength of the field (B), the current (I) and the length of conductor (l), when the field and current are at right angles:** $F = BIl$	**SI units only to be examined.** **Know that B-field is measured in Tesla (T).**
(d)	a simple d.c. motor, by predicting its direction of rotation and understand qualitatively the effect on increasing the current, magnetic field strength and number of turns	Knowledge of turning force, torque or moments is not required. FT will not be expected to have an understanding of quantitative relationships between the stated variables. Appreciate the purpose of split rings and carbon brushes. Links with statement (c) in this section.
(e)	the conditions in which a current is induced in circuits by changes in magnetic fields and the movement of wires	Basic electromagnetic induction knowledge is expected. Links with statement (f) in this section.
(f)	electromagnetic induction to explain the operation of a simple a.c. electric generator including the factors upon which its output depends	Number of coils, rate of coil rotation, strength of magnetic field, area of coil or iron core are factors that may be included. However, only qualitatively. Appreciate the purpose of slip rings and carbon brushes.
(g)	the direction of the induced current in a generator to the direction of the magnetic field and the direction of rotation of the coil	Use of Flemings Right Hand rule. No quantitative knowledge required.

(h)	the operation of a transformer qualitatively by reference to electromagnetic induction	Explanation to include alternating voltages and alternating magnetic fields. Awareness of the lamination of the soft iron core is required. Knowledge of magnetic leakage, hysteresis and eddy currents is not required. See section 1.4 – domestic electricity statement (d).
(i)	how the output of a 100% efficient transformer depends upon the number of turns on the coils: $\frac{V_1}{V_2} = \frac{N_1}{N_2}$	Can be examined in both theoretical and practical contexts. The terms primary and secondary will be used to identify voltages and coils within the context of the transformer. Note that 1s and 2s are used as subscripts in the equation to denote primary and secondary respectively.

SPECIFIED PRACTICAL WORK

- Investigation of the output of an iron-cored transformer

Investigation of the output of an iron-cored transformer

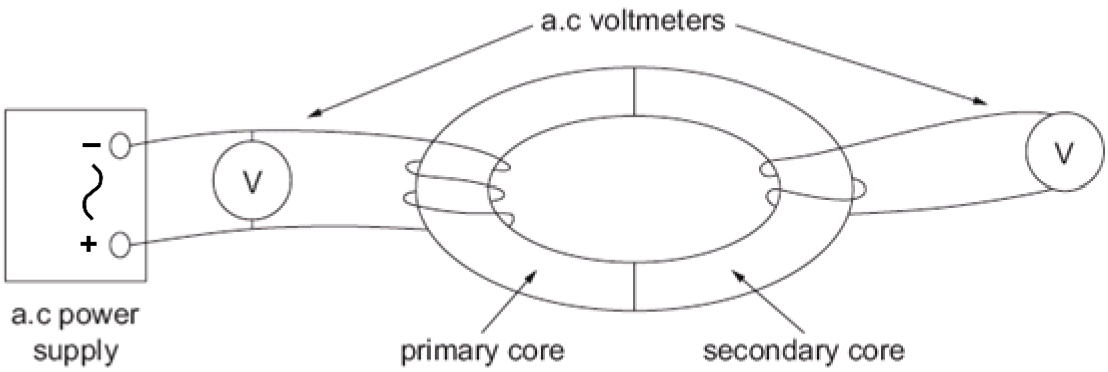
Introduction

A transformer can be constructed from iron 'C' cores and flexible insulated wire. You will investigate the relationship between the number of turns on the secondary coil and secondary voltage.

Apparatus

C-cores (20/40/60/80/100 turns)
a.c. power supply
2 × a.c. voltmeters ±0.01V
connecting wires
crocodile clips

Diagram of Apparatus



Method

1. Ensure the power supply is switched off.
2. Set up the circuit as shown with 100 turns on the primary core and 20 turns on the secondary core.
3. Switch on the power supply.
4. Record the voltages.
5. Turn off the power supply.
6. Add 20 further turns to the secondary core.
7. Repeat steps 3 to 6 to until there are 100 turns on the secondary core.

Analysis

1. Draw a graph of the number of turns on the secondary core (N_2) against the secondary voltage (V_2).

Teacher / Technician notes

Risk Assessment

Hazard	Risk	Control measure
Hot wires can burn	Burning skin on hot wire whilst taking readings	Do not exceed 4 V Switch off the power supply after taking readings Allow wire to cool before handling

Ensure power supplies are set to a maximum of 4 V a.c. (Note a.c. must be used).

Wire used should be thin flexible insulated wire and should be cut in lengths that easily allow 100 turns to be wound around the iron core

Approximately 2 cm of the insulation should be removed from the end of each wire to allow students to connect crocodile clips to the wire.

To prevent the wires overheating the power supply should be switched off immediately after taking readings.

Please note, a.c. voltmeters should be used, or, alternatively, a multimeter set on a suitable a.c. scale.

The primary core (100 turns) should be made up in advance. Sellotape / elastic bands can be wrapped around the finished core to prevent the wire coming loose. The core should be clearly labelled (100 turns).

Students should tabulate:

Number of turns on secondary core (N_2) and the secondary voltage (V_2).

Students should design their own table, but a suggested table format is shown below.

Number of turns on primary (N_1)	Number of turns on secondary (N_2)	Primary Voltage (V_1)/ V	Secondary Voltage (V_2)/ V
100	20		
100	40		
100	60		
100	80		
100	100		

A graph of the number of turns on the secondary core (N_2) against the secondary voltage (V_2) should be plotted. Students should explain the relationship between the two variables. A linear relationship would be expected, with a straight line through the origin.

Students who discover a non-linear relationship should be encouraged to explain why e.g. incorrect number of turns wound on secondary coil, heat loss in wires, resistance of contact (crocodile clips).

More able students should be able to explain whether or not the variables are directly proportional to each other using data from their graphs.

More able students could use the transformer equation and their value of the primary voltage (V_1) to calculate a value for the expected secondary voltage (V_2). They could then discuss the efficiency of the transformer.

Working scientifically skills covered

1. **Development of scientific thinking**
   Explain every day and technological applications of science; evaluate associated personal, social, economic and environmental implications and make decisions based on the evaluation of evidence and arguments.

3. **Analysis and Evaluation**
   Present observations and other data using appropriate methods.

   Carry out and representing mathematical analysis.

   Interpret observations and other data including identifying patterns and trends, making inferences and drawing conclusions.

   Evaluate data in terms of accuracy, precision, repeatability and reproducibility and identifying potential sources of random and systematic error.

4. **Scientific vocabulary, quantities, units, symbols and nomenclature**
   Use scientific vocabulary, terminology and definitions.

   Use an appropriate number of significant figures in calculations.

UNIT 2 – FORCES, SPACE AND RADIOACTIVITY

2.1 DISTANCE, SPEED AND ACCELERATION

Spec Statement		Comment
(a)	motion using speed, velocity and acceleration	An understanding of the distinction between scalar (speed) and vector (velocity) quantities is needed.
(b)	speed-time and distance-time graphs	Be able to describe the motion represented by a motion graph including calculations where appropriate such as speed or mean speed for a distance-time graph and acceleration or **distance travelled (higher tier only) for a velocity-time graph.** Calculations will be required for curved sections of graphs as estimations and an understanding of the motion of the object will be expected. See section 2.2 – Newton's laws statement (d). Links with statements (c) & (d) in this section.
(c)	the equations: $\text{speed} = \frac{\text{distance}}{\text{time}}$ and $\text{acceleration (or deceleration)} = \frac{\text{change in velocity}}{\text{time}}$	
(d)	velocity-time graphs to determine acceleration **and distance travelled**	Links with statements (b) &(c) in this section.
(e)	the principles of forces and motion to the safe stopping of vehicles, including knowledge of the terms reaction time, thinking distance, braking distance and overall stopping distance and discuss the factors which affect these distances	Be able to state how different factors affect thinking or braking distance.
(f)	the physics of motion together with presented data and opinions to discuss traffic control arising from the above, e.g. the need for speed limits and seat belts	Need to appreciate that the greater the speed of a vehicle the greater the stopping distance and so in urban areas speed limits are important.

2.2 NEWTON'S LAWS

	Spec Statement	Comment
(a)	the concept of inertia, that mass is an expression of the inertia of a body	Understand that inertia is a resistance to a change in motion and that objects with greater mass have greater inertia and so a greater resultant force will be required to change its motion.
(b)	Newton's first law of motion **and be able to state it**	For FT need to understand that balanced forces do not change the motion of an object. **For HT should also state Newton's first law: that an object will remain at rest or in uniform motion in a straight line unless acted upon by an external resultant force.**
(c)	how unbalanced forces produce a change in a body's motion and that the acceleration of a body is directly proportional to the resultant force and inversely proportional to the body's mass	Be able to calculate the resultant force by considering the forces acting on an object. Be able to recognise direct or inverse proportion from tabulated or graphical data. Apply understanding to situations where mass is not constant e.g. a rocket on take-off.
(d)	Newton's second law of motion, **and be able to state it**, in the form: resultant force = mass × acceleration; $F = ma$	Need to be able to recognise it is Newton's second law. **Can be stated in words or as an equation.**
(e)	the distinction between the weight and mass of an object, the approximation that the weight of an object of mass 1 kg is 10 N on the surface of the Earth and use data on gravitational field strength in calculations involving weight ($W = mg$) and gravitational potential energy: weight (N) = mass (kg) × gravitational field strength (N/kg)	That weight is the force of gravity acting on an object whereas mass is the amount of matter in an object. Candidates should know that mass is measured in kg and weight is measured in N. See section 2.3 – work and energy.
(f)	forces and their effects to explain the behaviour of objects moving through the air, including the concept of terminal speed	This could apply to either vertical or horizontal motion. Good examples are the explanation of a skydiver's motion and a vehicle reaching maximum speed. Need to be able to explain how terminal speed is attained. The term terminal speed will be used rather than terminal velocity.

(g)	Newton's third law of motion **and be able to state it**	**State Newton's third law: if a body A exerts a force on body B then body B exerts an equal and opposite force on body A.** Be able to apply their knowledge of Newton's third law in different situations e.g. rocket propulsion, gravitational force of the Earth on a body and of the body on the Earth.

SPECIFIED PRACTICAL WORK

- Investigation of the terminal speed of a falling object

Investigation of the terminal speed of a falling object

Introduction

When objects fall through the air, they accelerate until they reach a maximum speed - known as the terminal speed. You are going to investigate how the terminal speed of a falling object depends upon its mass. You are going to use paper cake cases. These are quite light and have a relatively large area. They reach their terminal speed after falling a very short distance.

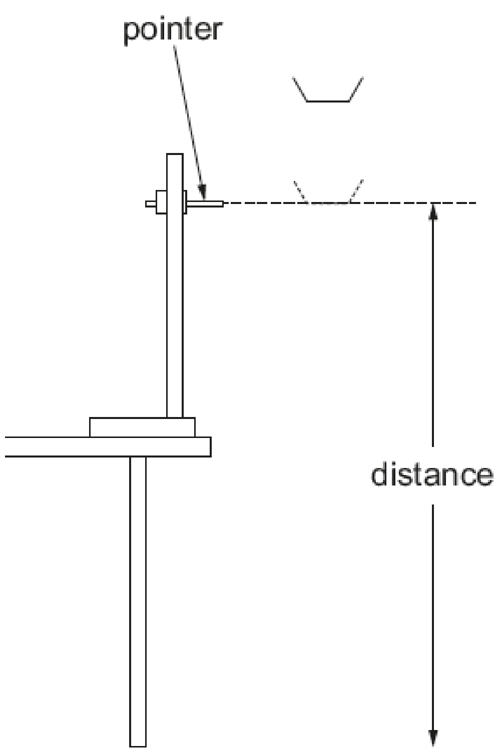
Apparatus

6 × paper cake cases
stopwatch
2 × metre rulers ± 1 mm
clamp stand, boss and clamp
pointer (e.g. pencil)

Access to:

electronic balance ± 0.1 g

Diagram of Apparatus



Method

1. Set up a pointer in the clamp stand and adjust its height to a convenient level above the floor, e.g. 150 cm. Record this height accurately.
2. Take a single cake case and record its mass.
3. Drop the cake case from a height well above (e.g. about 20 cm) the pointer and record the time it takes to fall from the level of the pointer to the floor.
4. Repeat step 3 another four times.
5. Repeat steps 2 to 4 with 2, 3, 4, 5 and 6 cake cases in a stack.

Analysis

1. Calculate the terminal speed of each stack of cake cases using:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

2. Plot the number of cake cases against the terminal speed.

Teacher / Technician notes

Cake cases are readily available from local shops / supermarkets.

Students will need to use the equation:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

to calculate the terminal speed of each stack of cake cases. We assume that the cakes cases have reached their terminal speed by the time they pass the pointer.

Students should design their own table, but a suggested table format is shown below.

Number of cake cases	Mass of cake cases (g)	Time taken for paper cake case to fall (s)						Terminal speed (m/s)
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean	
1								
2								
3								
4								
5								
6								

Students could discuss the repeatability and reproducibility of the results obtained, evaluate the method used and suggest improvements. They could also discuss whether the cakes cases have actually reached their terminal speed as they pass the pointer and how this may be investigated.

Working scientifically skills covered

2. Experimental skills and strategies
Carry out experiments appropriately having due regard to the correct manipulation of apparatus, the accuracy of measurements and health and safety considerations.

Make and record observations and measurements using a range of apparatus and methods.

3. Analysis and Evaluation
Carry out and representing mathematical analysis.

Represent distributions of results and make estimations of uncertainty.

Evaluate data in terms of accuracy, precision, repeatability and reproducibility and identifying potential sources of random and systematic error.

2.3 WORK AND ENERGY

	Spec Statement	Comment
(a)	the fact that, when a force acts on a moving body, energy is transferred although the total amount of energy remains constant	Links with statement (c) in this section.
(b)	the equation: work = force × distance moved in the direction of the force ; $W = Fd$	Calculations will not be required where the force is at an angle to the direction of motion. Need to be able to recognise situations where no work is done as there is no motion in the direction of the force. Need to be able to link $W = Fd$ with changes in kinetic or gravitational potential energy to calculate the mean resistive force acting. See statement (e) in this section.
(c)	the fact that work is a measure of the energy transfer, i.e. that work = energy transfer (in the absence of thermal transfer)	In situations where thermal transfer does occur calculations may be required. See statement (e) in this section.
(d)	the fact that an object can possess energy because of its motion (kinetic energy) and position (gravitational potential energy) and deformation (elastic energy)	Various contexts could be discussed, e.g. an aeroplane, a falling object, a stretched rubber band, a catapult etc.
(e)	**the equations for kinetic energy and changes in gravitational potential energy:** **kinetic energy** $= \dfrac{\textbf{mass} \times \textbf{velocity}^2}{\textbf{2}}$ **;** $\mathbf{KE} = \tfrac{1}{2}\boldsymbol{mv}^2$ **change in potential energy = mass × gravitational field strength × change in height ;** $\mathbf{PE} = \boldsymbol{mgh}$ **PE =** ***mgh***	See statements (a), (b) and (c) in this section.

(f)	the relationship between force and extension for a spring and other simple systems; force = spring constant × extension; $F = kx$	Simple systems could include springs connected together (series or parallel) but not a combination. Be able to predict the effect on the extension and energy stored in a spring of different spring constant in a given situation. No explanation of the term spring constant is required.
(g)	**the work done in stretching by finding the area under the force-extension (F-x) graph**; $W = \frac{1}{2}Fx$ **for a linear relationship**	Force plotted on the y-axis and extension on the x-axis.
(h)	how energy efficiency of vehicles can be improved (e.g. by reducing aerodynamic losses/air resistance and rolling resistance, idling losses and inertial losses)	Be able to give examples of how to reduce losses e.g. aerodynamic losses reduced by more streamlined designs. Rolling resistance is reduced by having correctly inflated tyres and using materials which don't heat up as much as they are squashed. Stop – start systems reduce idling losses. Inertial losses are reduced by having lighter cars. Link to the design of the vehicle and not driving style. See section 1.2 – generating electricity statement (d).
(i)	the principles of forces and motion to an analysis of safety features of cars e.g. air bags and crumple zones	Answer can be expressed in terms of **work done:** i.e. an air bag and a crumple zone increase the distance over which the energy is transferred, so reducing the force. Or in terms of **momentum**: i.e. the same change in momentum happens over a longer time so there is decreased deceleration so the force decreases.

SPECIFIED PRACTICAL WORK

- Investigation of the force-extension graph for a spring

Investigation of the force-extension graph for a spring

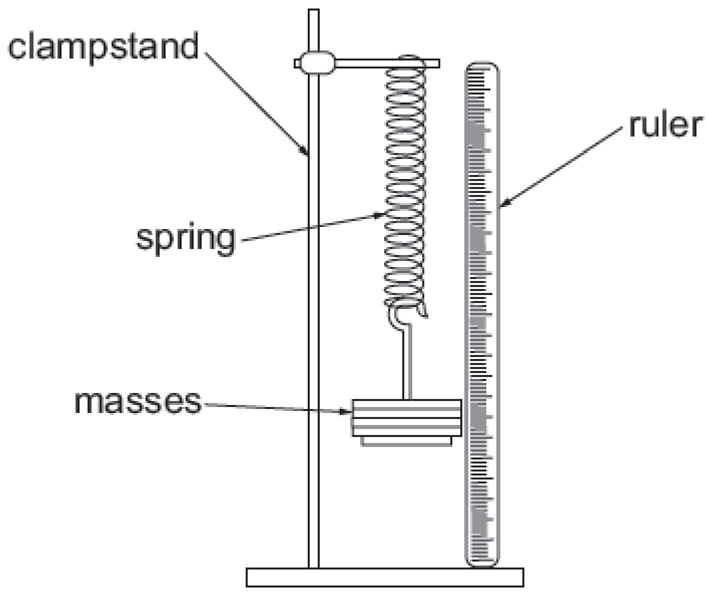
Introduction

When a force is applied to a spring its length increases. The extension of the spring is found by subtracting the original length of the spring from its length with the force applied. Hooke's Law states that the extension is directly proportional to the force applied provided that the elastic limit is not exceeded. You will investigate if the spring obeys Hooke's law.

Apparatus

spring
100 g mass hanger
6 × 100 g masses
clamp stand, boss and clamp
metre ruler ± 1 mm

Diagram of Apparatus



Method

1. Record the original length of the spring.
2. Suspend the spring from the clamp and attach the 100 g mass hanger.
3. Record the new length of the spring.
4. Add a further 100 g to the spring and record the new length.
5. Repeat steps 2-3 until a total mass of 700 g has been added.
6. Repeat steps 1-5 once more.

Analysis

1. Calculate the mean length for each mass added.
2. Calculate the extension for each mass added.
3. Plot a graph of force (y-axis) against extension (x-axis). (100 g = 1 N)
4. Determine whether the spring obeys Hooke's law or not.

Teacher / Technician Notes

Students may be asked to measure the length of the spring itself and not the loops at each end. Including one, or indeed, both loops, will make no difference to their final values for extension. However, students must be consistent in making the same measurement throughout the investigation.

Students should be encouraged to measure and record each result to the nearest 0.1 cm (1 mm). If the result is 9 cm they should write 9.0 in their table.

Students should be asked to *gently* place the masses onto the spring and to ensure that the spring is stationary each time when measuring its new length.

Students should load the spring up to a limit of 700 g. This will ensure that the elastic limit is not exceeded and the springs are not over-stretched. The teacher could demonstrate the effect of further increasing the force applied.

A graph should then be plotted of force (y-axis) against extension (x-axis). The line of best fit expected is a straight line through the origin. This proves that the spring obeys Hooke's Law.

Students should design their own table, but a suggested table format is shown below.

Mass (g)	Force (N)	Length (cm)		Mean length (cm)	Extension (cm)
		1	2		

Working scientifically skills covered

2. Experimental skills and strategies
Plan experiments or devise procedures to make observations, produce or characterise a substance, test hypotheses, check data or explore phenomena.

3. Analysis and evaluation
Translate data from one form to another.

Carry out and representing mathematical analysis.

Present reasoned explanations including relating data to hypotheses.

4. **Scientific vocabulary, quantities, units, symbols and nomenclature**
Interconvert units

Use an appropriate number of significant figures in calculation.

2.4 FURTHER MOTION CONCEPTS

	Spec Statement	Comment
(a)	qualitatively how the momentum of a body depends upon its mass and its velocity, and select and use the equation: momentum = mass × velocity ; $p = mv$	The vector property of momentum (and velocity) should be applied to give positive and negative momentum values from a given positive vector direction (usually to the right in diagrams). See section 2.1 – distance, speed and acceleration statement (a).
(b)	Newton's second law of motion in the form: $\text{force} = \dfrac{\text{change in momentum}}{\text{time}}$	See section 2.2 – Newton's laws statement (d). See section 2.3 – Work and energy statement (i).
(c)	the law of conservation of momentum and relate it to Newton's third law of motion and to use it quantitatively to perform calculations involving collisions **or explosions**, including selecting **and using the kinetic energy equation: to compare the kinetic energy before and after an interaction**	Need to recognise the directional property of momentum. **Consider conservation of energy in collisions**.
(d)	how the motion of objects can be modelled using the equations: $v = u + at$ $x = \dfrac{u+v}{2}t$ $x = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2ax$	These equations to be applied to constant acceleration only.
(e)	the Principle of Moments, limited to situations involving a pivot and parallel forces, e.g. a balanced metre rule	A statement of the principle is required. i.e. the sum of clockwise moments about a point is equal to the sum of anticlockwise moments about the same point. Single support problems only need to be studied. Clockwise and anticlockwise nature of moments should be applied to problems rather than positive and negative moments.
(f)	describe examples in which forces cause rotation; define and calculate the moment of the force in such examples (moment = force × distance (normal to the direction of the force) [$M = Fd$])	Dealing with components of non-normal forces is not required.

SPECIFIED PRACTICAL WORK

- Investigation of the Principle of Moments

Investigation of the Principle of Moments

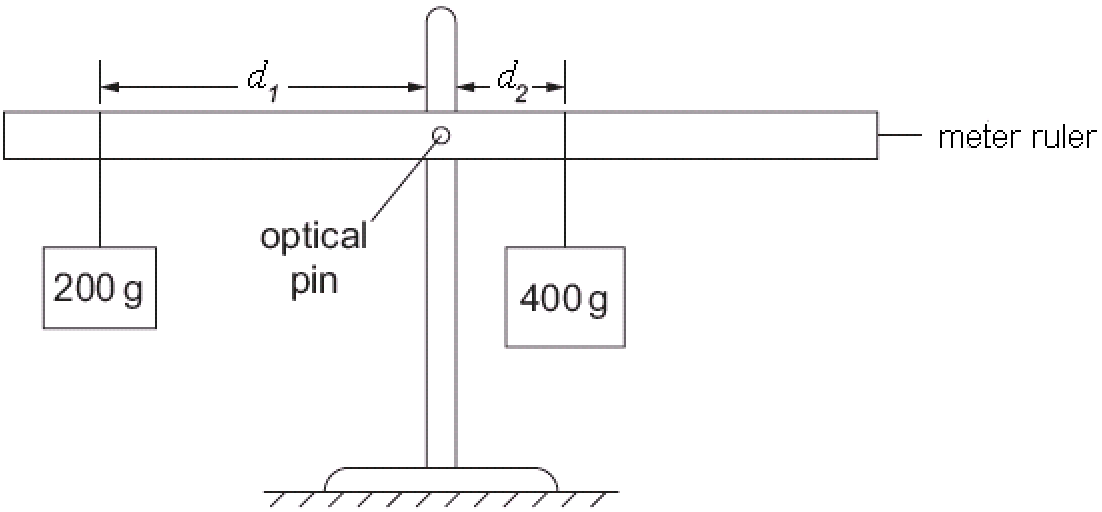
Introduction

A force can have a moment (turning effect) about a hinge or a pivot which may be clockwise or anticlockwise. For any object in equilibrium the total clockwise moment must be equal to the total anticlockwise moment. In this investigation a metre ruler and 100 g masses are used to verify the Principle of Moments.

Apparatus

metre ruler with small hole at centre
2 × 100g mass hangers
8 × 100g masses
2 × loops of cotton
clamp stand, boss and clamp
optical pin and cork
small piece of plasticine

Diagram of Apparatus



Method

1. Add plasticine to one end of the metre ruler so that it is balanced.
2. Use a cotton loop to hang a mass of 200 g at the 10 cm mark on the metre rule (d_1 = 40 cm).
3. Use a cotton loop to hang a mass of 400 g on the other side of the pivot so that the metre rule is balanced once again. Record the distance d_2.
4. Repeat steps 2 and 3 for d_1 = 30 cm and then d_1 = 20 cm.
5. Use a cotton loop to hang a mass of 200 g at the 5 cm mark on the metre rule (d_1 = 45 cm).
6. Use a cotton loop to hang a mass of 600 g on the other side of the pivot so that the metre rule is balanced once again. Record the distance d_2.
7. Repeat steps 5 and 6 for d_1 = 30 cm and then d_1 = 15 cm.
8. Use a cotton loop to hang a mass of 200 g at the 10 cm mark on the metre rule (d_1 = 40 cm).
9. Use a cotton loop to hang a mass of 800 g on the other side of the pivot so that the metre rule is balanced once again. Record the distance d_2.
10. Repeat steps 8 and 9 for d_1 = 20 cm.

Analysis

1. Calculate the clockwise and anticlockwise moment for each mass using the following formula (100 g = 1 N):

$$\text{Moment} = F\,d$$

2. Determine if the Principle of Moments is satisfied for each pair of values.

Teacher / Technician Notes

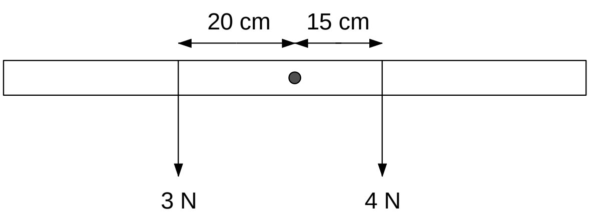
The apparatus should be set up for the students. The use of a little plasticine and the meaning of a “balanced” metre ruler should be demonstrated. Students should understand the terms clockwise and anticlockwise moment

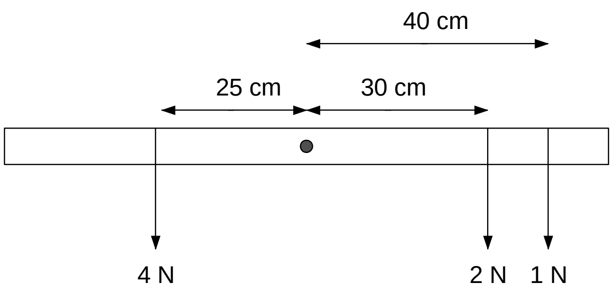
Students should design their own table, but a suggested table format is shown below.

Mass (g)	Weight, W_1 (N)	Distance, d_1 (cm)	Mass (g)	Weight, W_2 (N)	Distance, d_2 (cm)	Anticlockwise moment $W_1 \times d_1$ (N cm)	Clockwise moment $W_2 \times d_2$ (N cm)
200	2	40	400	4			
200	2	30	400	4			
200	2	20	400	4			
200	2	45	600	6			
200	2	30	600	6			
200	2	15	600	6			
200	2	40	800	8			
200	2	20	800	8			

Alternative apparatus that could be used to verify the principle of moments: flat wooden rods, square brass masses, pivots and pins.

Students could be challenged to test their understanding by predicting and testing other combinations of masses that would produce a balanced metre ruler. This could be extended from 2 to 3 sets of masses. They could be asked to produce simple diagrams of their successful experiments, e.g.





Working scientifically skills covered

2. Experimental skills and strategies
Plan experiments or devise procedures to make observations, produce or characterise a substance, test hypotheses, check data or explore phenomena.

3. Analysis and Evaluation
Carry out and representing mathematical analysis.

Evaluate data in terms of accuracy, precision, repeatability and reproducibility and identifying potential sources of random and systematic error.

4. Scientific vocabulary, quantities, units, symbols and nomenclature
Use SI units and IUPAC chemical nomenclature unless inappropriate.

Interconvert units

2.5 STARS AND PLANETS

	Spec Statement	Comment
(a)	the main features of our solar system: their order, size, orbits and composition to include the Sun, terrestrial planets and gaseous giant planets, dwarf planets, comets, moons and asteroids	Need to be able to recall the order of the planets including the position of the asteroid belt. Know which planets are rocky and which are gaseous and know that the asteroid belt comprises many rocky asteroids and dwarf planets. Appreciate that comets have highly elliptical orbits, passing far out of our solar system. Also appreciate that most of the planets, including some dwarf planets, have moons which orbit them.
(b)	the features of the observable universe (planets, planetary systems, stars and galaxies) and the use of appropriate units of distance: kilometres, astronomical units (AU) and light years (l-y)	Understand the difference in size of the objects listed. Recall that a planetary system (solar system) comprises a star and all the objects which orbit it and that a galaxy is a large collection of stars. Recall that 1 A.U. is the mean distance from the Sun to the Earth and that 1 light year is the distance that light will travel in 1 year. Be able to convert distances in light years into metres and be able to infer what a light minute or light second is.
(c)	the main observable stages in the life cycle of stars of different masses, using the terms: protostar, main sequence star, red giant, supergiant, white dwarf, supernova, neutron star and black hole	Describe the life cycle of stars from protostars to low mass main sequence stars like our Sun (to red giant and white dwarf) and high mass stars (to supergiant, supernova and neutron star or black hole).
(d)	the fact that the stability of stars depends upon a balance between gravitational force and a combination of gas and radiation pressure and that stars generate their energy by the fusion of increasingly heavier elements	In main sequence the forces acting on a star are balanced. Gravitational inward forces match outwards gas and radiation pressure forces. When the hydrogen reduces the star will begin to fuse helium and then other increasingly heavier elements to maintain fusion. The star will begin to swell as the combination of gas and radiation pressure exceeds the gravitational force and the forces become unbalanced. Eventually the gravitational force exceeds the combination of gas and radiation pressure and the star shrinks.
(e)	the return of material, including heavy elements, into space during the final stages in the life cycle of giant stars	Appreciate that heavy elements which are created in fusion in large stars are ejected during supernovae.

(f)	the origin of the solar system from the collapse of a cloud of gas and dust, including elements ejected in supernovae	Recall that gravitational forces cause the matter to get closer together creating the Sun and the planets. Use of the term nebula is not required. During formation rocks tended to gather close to the Sun and formed the rocky planets whilst gaseous substances gathered together at distances further away and formed the gas planets.
(g)	**the Hertzsprung-Russell (H-R) diagram as a means of displaying the properties of stars, depicting the evolutionary path of a star**	**Be able to interpret the H-R diagram to predict the path in the life cycle of a star.**

2.6 THE UNIVERSE

	Spec Statement	Comment
(a)	how atomic absorption spectra can be used to identify gases from a given absorption spectrum and additional data and explain how scientists in the nineteenth century were able to reveal the chemical composition of stars	Candidates should compare absorption line spectra to identify gases present. Appreciate that the absorption lines arise from gas atoms in a star's atmosphere absorbing specific wavelengths of visible light, and that the wavelengths absorbed are specific to the elements present in the star.
(b)	how the "cosmological red shift", revealed initially by Edwin Hubble's measurements on the spectra of distant galaxies, revealed that the wavelengths of the absorption lines are increased and that this effect increases with distance	To attribute cosmological red shift to the increasing space between the distant source and observers on Earth (as opposed to Doppler red shift). The increase in wavelength increases with distance of the source from us. Be aware that the recession velocity increases with the distance of the galaxy and it is this which implies that all galaxies originated from a single point.
(c)	cosmological red shift in terms of the expansion of the Universe since the radiation was emitted	Appreciation that light from further galaxies shows the most red shift due to it having travelled for a greater amount of time through an expanding universe. Therefore increasing the wavelength.
(d)	the role played by the cosmological red shift in supporting the Big Bang model of the origin of the Universe	If expansion of the universe was reversed, then everything would revert back to one single point.
(e)	how the existence of the Cosmic Microwave Background Radiation supports the hot Big Bang model of the origin of the Universe	The wavelength of the early radiation in the form of short wavelength radiation (gamma rays) has become longer wavelength (microwave) radiation that presently pervades the Universe. This change (increase) in wavelength is believed to be due to the expansion of space.

2.7 TYPES OF RADIATION

Spec Statement		Comment
(a)	the terms nucleon number (A), proton number (Z) and isotope, and relate them to the number of protons and neutrons in an atomic nucleus	Be able to explain what is meant by the term isotope. Define isotopes of the same element has having equal numbers of protons but differing numbers of neutrons in their nuclei.
(b)	radioactive emissions as arising from unstable atomic nuclei because of an imbalance between the numbers of protons and neutrons	Candidates will not be given credit for stating that an atom is radioactive because “it has too many neutrons.”
(c)	the fact that waste materials from nuclear power stations and nuclear medicine are radioactive and some of them will remain radioactive for thousands of years	The implications of this for the safe disposal of nuclear waste should be understood. Appreciation that this is due to the long half-lives of some radioactive substances.
(d)	background radiation and be able to make an allowance for it in measurements of radiation	See statement (i) in the section below.
(e)	the random nature of radioactive decay and that it has consequences when undertaking experimental work, requiring repeat readings to be made or measurements over a lengthy period as appropriate	Understand that small variations in count rate are to be expected as radioactive decay is a random process.
(f)	the differences between alpha, beta and gamma radiation in terms of their penetrating power, relating their penetrating powers to their potential for harm and discussing the consequences for the long term storage of nuclear waste	Understand the difference in risk for alpha, beta or gamma sources outside or inside the body. Different methods of disposal of nuclear waste should be considered along with their advantages and disadvantages. Links with statement (c) in this section.
(g)	alpha radiation as a helium nucleus, beta radiation as a high energy electron and gamma radiation as electromagnetic	No credit will be given for stating that an alpha particle is “helium” or a “helium atom” or a ”helium ion”. Recognise an alpha particle as being a group of two neutrons and two protons.

(h)	**producing** and balancing nuclear equations for radioactive decay using the symbols ${}^{4}_{2}\mathrm{He}^{2+}$ or ${}^{4}_{2}\alpha$ for the alpha particle and ${}^{0}_{-1}\mathrm{e}$ and ${}^{0}_{-1}\beta$ for the beta particle	Recall of the symbols is required.
(i)	natural and artificial sources of background radiation, respond to information about received dose from different sources (including medical X-rays) and discuss the reasons for the variation in radon levels	Be able to identify if sources are natural or man-made. Understand that background radiation varies with altitude as at higher altitudes there will be more cosmic radiation. Know that radon originates from rocks especially granite so the type of rock in an area determines the amount of radon. Know how householders can be protected from radon.

2.8 HALF-LIFE

Spec Statement		Comment
(a)	the random nature of radioactive decay and to model the decay of a collection of atoms using a constant probability of decay, e.g. using a large collection of dice, coins or a suitably programmed spreadsheet	Links with statement (b) in this section.
(b)	how to plot or sketch decay curves for radioactive materials, understand that a given radioactive material has a characteristic half-life and determine the half-life of a material from the decay curve	Plot smooth curves of best fit when producing decay curves. Be able to draw suitable horizontal and vertical construction lines onto the decay curve in order to show a clear determination of the half-life.
(c)	how to perform simple calculations involving the activity and half-life of radioactive materials in a variety of contexts, e.g. carbon dating	Be able to calculate the activity after a certain number of half-lives, or calculate half-life from given data on changes to activity. Define half-life as the time taken for the number of radioactive nuclei / mass / activity to reduce to one half of its initial value.
(d)	the different uses of radioactive materials, relating to the half-life, penetrating power and biological effects of the radiation e.g. radioactive tracers and cancer treatment	Be able to select a suitable isotope for a given application and explain their choice.

SPECIFIED PRACTICAL WORK

- Determination of the half-life of a model radioactive source, e.g. using dice

Determination of the half-life of a model radioactive source [e.g. using cubes or dice]

Introduction

Radioactive decay is a random process. The number of radioactive atoms present in a given sample will halve in a fixed time period depending on the probability of decay for that particular radioisotope. This is known as the half-life of the substance. This is a simulation in which radioactive atoms are represented by cubes. The cubes are considered to be decayed when they land with a particular face upwards.

Apparatus

50 × cubes with one face shaded
margarine tub
tray

Diagram of Apparatus

Method

1. Count the cubes to ensure that you have 50 and put them into the margarine tub.
2. Shake the tub and gently throw the cubes into the plastic tray.
3. Record the number of cubes that have landed with the shaded face upwards and remove from the tray
   [These represent the radioactive atoms that have decayed.]
4. Put the cubes remaining in the tray back into the margarine tub.
   [These represent the radioactive atoms that have NOT yet decayed.]
5 Repeat steps 2 and 3 another 9 times.

Analysis

1. Use the results from the whole class to plot a graph of the number of radioactive atoms remaining (y-axis) against the number of throws (x-axis).
2. Use the graph to determine the half-life of the cubes.

Teacher / Technician Notes

Students should design their own table, but a suggested table format is shown below.

Throw	Number decayed	Number remaining
0	0	50
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

The third column may be calculated by subtracting the number decayed from the total number of cubes.

Note that rather than calculate the mean results, students should simply calculate the total class results. This effectively increases the sample size from 50 to 500. The results may be collated by providing the following grid for students, e.g. on a white board/ excel spreadsheet:

Throw	Number remaining										
	Gp 1	Gp 2	Gp 3	Gp 4	Gp 5	Gp 6	Gp 7	Gp 8	Gp 9	Gp10	TOTAL
0	50	50	50	50	50	50	50	50	50	50	**500**
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											

The graph should be a good approximation to an exponential decay curve. Students are asked in the analysis section to find how many throws were required to reduce the number of cubes to half the original number and then half again etc. (fractions of a throw are allowed) and the concept of half-life introduced.

The half-life should be determined from the graph. The graph will start at 500 (at 0 throws). A horizontal line should be drawn from 250 to the curve and then a vertical line drawn downwards from this point on the curve. The half-life is the intercept on the number of throws axis. A second value should be obtained, e.g. by drawing a horizontal line from 125 to the curve and then a vertical line downwards. The second value of half-life is then determined by subtracting the "250 intercept" from the "125 intercept". A mean value for the half-life can then be determined by adding the 2 values and dividing by 2.

Note that lines could be drawn onto the graph to determine the half-life using other pairs of numbers, e.g. 400 to 200 and 200 to 100.

Working scientifically skills covered

1. **Development of scientific thinking**
   Use a variety of models such as representational, spatial, descriptive, computational and mathematical to solve problems, make predictions and to develop scientific explanations and understanding of familiar and unfamiliar facts.

2. **Experimental skills and strategies**
   Recognise when to apply a knowledge of sampling techniques to ensure that any samples collected are representative

   Make and record observations and measurements using a range of apparatus and methods.

3. **Analysis and Evaluation**
   Translate data from one form to another.

   Carry out and representing mathematical analysis.

   Represent distributions of results and make estimations of uncertainty.

2.9 NUCLEAR DECAY AND NUCLEAR ENERGY

Spec Statement		Comment
(a)	the fact that the absorption of slow neutrons can induce fission in certain nuclei, referred to as fissile nuclei, such as uranium -235 ($^{235}_{92}\mathrm{U}$), and that the emission of neutrons from such fission reactions can lead to a sustainable chain reaction	Know that slow neutrons are captured by heavy U-235 nuclei during collisions releasing further fast moving neutrons. Links with statement (b) in this section.
(b)	the roles of the moderator and control rods in a nuclear fission reactor	Control rods are arranged to absorb neutrons so that for every two or three neutrons that are released from a fission reaction, only one (on average) goes on to produce further fission. The effect of raising and lowering control rods should be understood along with the way in which a reactor is completely shut down. The moderator slows down fast moving neutrons to enable absorption by U-235 nuclei to occur.
(c)	the radioactive nature of fission products with a large range of half-lives	This presents a problem for long term storage of nuclear waste. See section 2.7 – types of radiation statement (c).
(d)	the fact that high energy collisions between light nuclei, especially the isotopes of hydrogen $^{2}_{1}\mathrm{H}$ (deuterium) and $^{3}_{1}\mathrm{H}$ (tritium) can result in fusion which releases energy	Mutual repulsion of nuclei should be understood as the reason for the need for high energy nuclei. Requires very high temperatures and pressures. Occurs naturally in stars. Use of the equation $E = mc^2$ is not required. Links with statement (f) in this section.
(e)	the nuclear symbol, $^{1}_{0}\mathrm{n}$, for a neutron and use data to **produce and** balance nuclear equations for nuclear fission and fusion	Conservation of proton number and nucleon number during nuclear reactions.
(f)	the problems of containment in fission and fusion reactors including neutron and gamma shielding and pressure containment in fission reactors and maintaining a high temperature in fusion reactors	Knowledge of specific materials used for containment will not be expected. Links with statement (d) in this section.

EQUATIONS

A list of equations will be included at the start of each examination paper. FT learners will not be expected to change the subject of an equation. However, they may be expected to recognise and use them in other formats i.e. a version of the equation may be given to them in a question which is different to the version that appears on the list of equations at the start of the paper. For example, on page 2 the power equation appears in the form: power = voltage × current. So if the question asked the learner to calculate the voltage then the equation would be given to them in the question as: $\text{voltage} = \frac{\text{power}}{\text{current}}$ because it is in a different form to that on page 2.
HT learners will be expected to rearrange equations.

FOUNDATION TIER – EQUATION LIST

UNIT 1 – Electricity, Energy and Waves

$\text{current} = \frac{\text{voltage}}{\text{resistance}}$	$I = \frac{V}{R}$
total resistance in a series circuit	$R = R_1 + R_2$
energy transferred = power × time	$E = Pt$
power = voltage × current	$P = VI$
$\text{\% efficiency} = \frac{\text{energy [or power] usefully transferred}}{\text{total energy [or power] supplied}} \times 100$	
$\text{density} = \frac{\text{mass}}{\text{volume}}$	$\rho = \frac{m}{V}$
units used (kWh) = power (kW) × time (h) cost = units used × cost per unit	
wave speed = wavelength × frequency	$v = \lambda f$
$\text{speed} = \frac{\text{distance}}{\text{time}}$	
$\text{pressure} = \frac{\text{force}}{\text{area}}$	$p = \frac{F}{A}$
change in thermal energy = mass × specific heat capacity × change in temperature	$\Delta Q = mc\Delta\theta$
thermal energy for a change of state = mass × specific latent heat	$Q = mL$

V_1 = voltage across the primary coil V_2 = voltage across the secondary coil N_1 = number of turns on the primary coil N_2 = number of turns on the secondary coil	$\frac{V_1}{V_2} = \frac{N_1}{N_2}$

SI multipliers

Prefix	Multiplier
m	1×10^{-3}
k	1×10^{3}
M	1×10^{6}

HIGHER TIER – EQUATION LIST

UNIT 1 – Electricity, Energy and Waves

$\text{current} = \frac{\text{voltage}}{\text{resistance}}$	$I = \frac{V}{R}$
total resistance in a series circuit	$R = R_1 + R_2$
total resistance in a parallel circuit	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$
energy transferred = power × time	$E = Pt$
power = voltage × current	$P = VI$
power = current^2 × resistance	$P = I^2R$
$\%\ \text{efficiency} = \frac{\text{energy [or power] usefully transferred}}{\text{total energy [or power] supplied}} \times 100$	
$\text{density} = \frac{\text{mass}}{\text{volume}}$	$\rho = \frac{m}{V}$
units used (kWh) = power (kW) × time (h) cost = units used × cost per unit	
wave speed = wavelength × frequency	$v = \lambda f$
$\text{speed} = \frac{\text{distance}}{\text{time}}$	
$\text{pressure} = \frac{\text{force}}{\text{area}}$	$p = \frac{F}{A}$
p = pressure V = volume T = kelvin temperature	$\frac{pV}{T} = constant$
	T / K = θ / °C + 273
change in thermal energy = mass × specific heat capacity × change in temperature	$\Delta Q = mc\Delta\theta$
thermal energy for a change of state = mass × specific latent heat	$Q = mL$

force on a conductor (at right angles to a magnetic field) carrying a current = magnetic field strength × current × length		$F = BIl$
V_1 = voltage across the primary coil V_2 = voltage across the secondary coil N_1 = number of turns on the primary coil N_2 = number of turns on the secondary coil		$\frac{V_1}{V_2} = \frac{N_1}{N_2}$

SI multipliers

Prefix	Multiplier
p	1×10^{-12}
n	1×10^{-9}
μ	1×10^{-6}
m	1×10^{-3}

Prefix	Multiplier
k	1×10^{3}
M	1×10^{6}
G	1×10^{9}
T	1×10^{12}

FOUNDATION TIER – EQUATION LIST

UNIT 2 – Forces, Space and Radioactivity

$\text{speed} = \frac{\text{distance}}{\text{time}}$	
$\text{acceleration [or deceleration]} = \frac{\text{change in velocity}}{\text{time}}$	$a = \frac{\Delta v}{t}$
acceleration = gradient of a velocity-time graph	
resultant force = mass × acceleration	$F = ma$
weight = mass × gravitational field strength	$W = mg$
work = force × distance	$W = Fd$
force = spring constant × extension	$F = kx$
momentum = mass × velocity	$p = mv$
$\text{force} = \frac{\text{change in momentum}}{\text{time}}$	$F = \frac{\Delta p}{t}$
u = initital velocity v = final velocity t = time a = acceleration x = displacement	$v = u + at$ $x = \frac{u + v}{t} t$
moment = force × distance	$M = Fd$

SI multipliers

Prefix	Multiplier
m	1×10^{-3}
k	1×10^{3}
M	1×10^{6}

HIGHER TIER – EQUATION LIST

UNIT 2 – Forces, Space and Radioactivity

speed = $\frac{\text{distance}}{\text{time}}$	
acceleration [or deceleration] = $\frac{\text{change in velocity}}{\text{time}}$	$a = \frac{\Delta v}{t}$
acceleration = gradient of a velocity-time graph	
distance travelled = area under a velocity-time graph	
resultant force = mass × acceleration	$F = ma$
weight = mass × gravitational field strength	$W = mg$
work = force × distance	$W = Fd$
kinetic energy= $\frac{\text{mass} \times \text{velocity}^2}{2}$	$KE = \frac{1}{2}mv$
change in potential energy = mass × gravitational field strength × change in height	$PE = mgh$
force = spring constant × extension	$F = kx$
work done in stretching = area under a force-extension graph	$W = \frac{1}{2}Fx$
momentum = mass × velocity	$p = mv$
force = $\frac{\text{change in momentum}}{\text{time}}$	$F = \frac{\Delta p}{t}$
u = initital velocity v = final velocity t = time a = acceleration x = displacement	$v = u + at$ $x = \frac{u \pm v}{2}t$ $x = ut + \frac{1}{2}at^2$ $v^2 + u^2 = 2ax$
moment = force × distance	$M = Fd$

SI Mulitpliers

Prefix	Multiplier
p	1×10^{-12}
n	1×10^{-9}
μ	1×10^{-6}
m	1×10^{-3}

Prefix	Multiplier
k	1×10^{3}
M	1×10^{6}
G	1×10^{9}
T	1×10^{12}