

Edexcel AS

Physics Revision Note



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Edexcel AS Physics Revision Note

for,

Pearson Edexcel International Advanced Subsidiary in Physics
First examination 2014

Pearson Edexcel GCE Advanced Subsidiary in Physics
First examination 2009

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Unit 1: Physics on the Go

Chapter: Mechanics

1 use the equations for uniformly accelerated motion in one dimension, $v = u + at$, $s = ut + \frac{1}{2}at^2$, $v^2 = u^2 + 2as$

1. $v = u + at$
2. $s = ut + \frac{1}{2}at^2$
3. $v^2 = u^2 + 2as$

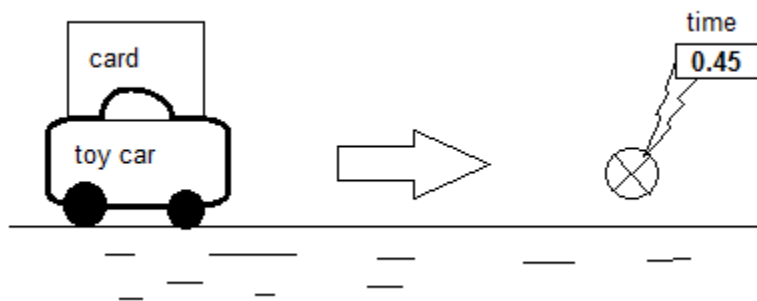
2 demonstrate an understanding of how ICT can be used to collect data for, and display, displacement/time and velocity/time graphs for uniformly accelerated motion and compare this with traditional methods in terms of reliability and validity of data

Motion can be represented using graphs. Traditionally, data might have been collected using rulers and stopwatches. ICT methods are now readily available, for example using a motion sensor.

This setup records displacement at regular intervals and can be used to create graphs of displacement against time or velocity against time. Light gates can also be used to measure motion. Both of these methods will eliminate human error, so time or displacement will be measured more accurately. They also allow greater precision than stopwatches. The data will have improved validity and reliability. With light gates, the length of the object interrupting the beam, or the distance between the gates, must still be measured manually.

Experiment: Determine speed and acceleration, for example use light gates

Measuring speed using light gate method

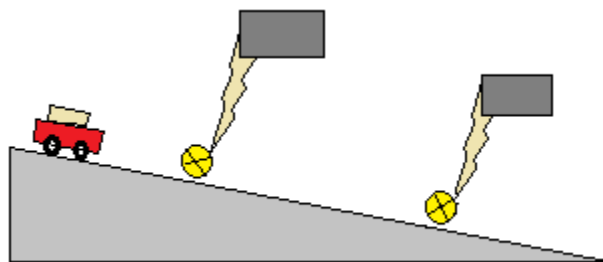


1. Attach a card of measured length centrally to the top of the toy car.

- Air track ensures a frictionless way for the toy car.
- A gentle push can move the toy car at a steady speed.
- Arrange for the card to block a light gates beam as it passes through it.
- Electronic timer measures how long the card takes to pass through the beam.
- Now calculate the toy car's average velocity as it passes the light gate by:

$$v = \frac{\text{length of the card}}{\text{interruption time}}$$

Measuring acceleration using light gate method



- A card is mounted on the top of a trolley. The length of the card is measured.
- One light is set at the top of the track and the second one is at the end of the track.
- The trolley is given a gentle push to move through the track.
- When the trolley passes through the first light gate the electronic timer measures the t_1 to cross the length of the card.
- So the velocity at the position of first light gate is measured by velocity.
 - $V_1 = \text{length of the first card} \div t_1$
- During passing the second light gate, if the time measured by electronic timer is t_2 then the velocity can be measured by:
 - $V_2 = \text{length of the second card} \div t_2$
- The time t_3 is measured for the trolley to travel from first light gate to the second light gate by using a stopwatch.
- Now acceleration is = velocity difference $\div t_3$

$$= \{(\text{length of the first card} \div t_1) - (\text{length of the second card} \div t_2)\} \div t_3$$

3 identify and use the physical quantities derived from the slopes and areas of displacement/time and velocity/time graphs, including cases of non-uniform acceleration

Displacement – time graphs

The line on a displacement – time graphs is straight if the object is moving with constant velocity. A curve shows that the object is accelerating.

The gradient of a displacement – time is change in displacement/change in time which is velocity.

$$v = \frac{\Delta s}{\Delta t}$$

This is also described as rate of change of displacement. Note that the units for the gradient are the units of the y-axis divided by the units of x-axis, i.e. m/s . If the object is accelerating, the velocity is found from the gradient of a tangent to the line.

Velocity – time graphs

The gradient of a velocity-time graph is the change in velocity/change in time, which is acceleration.

$$a = \frac{\Delta v}{\Delta t}$$

This is also described as rate of change of velocity. The area between the line and the time axis on a velocity-time graph is equal to the displacement.

4 investigate, using primary data, recognise and make use of the independence of vertical and horizontal motion of a projectile moving freely under gravity

Projectile

A projectile is an object which is projected. A force acts on it to start it moving and it is then subjected to a constant force while it means that the object is in free fall in the Earth's gravitational field.

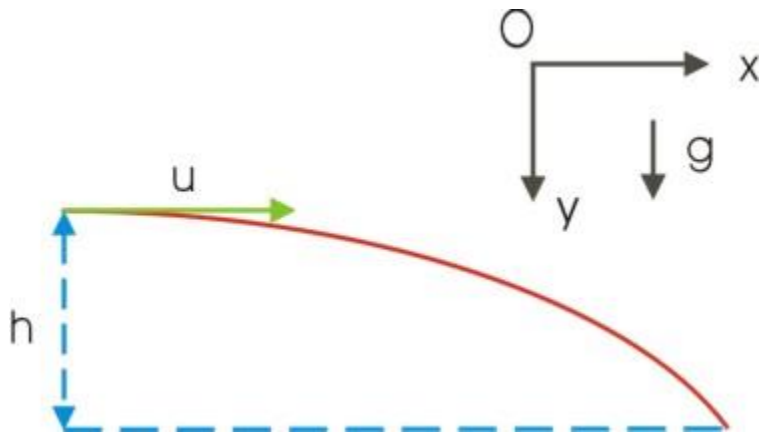
Characteristics

1. Only downwards force act on it.
2. It has acceleration in the downwards direction.
3. In the horizontal direction, it has no acceleration.
4. The path travelled by a projectile is parabolic.

Horizontal projection

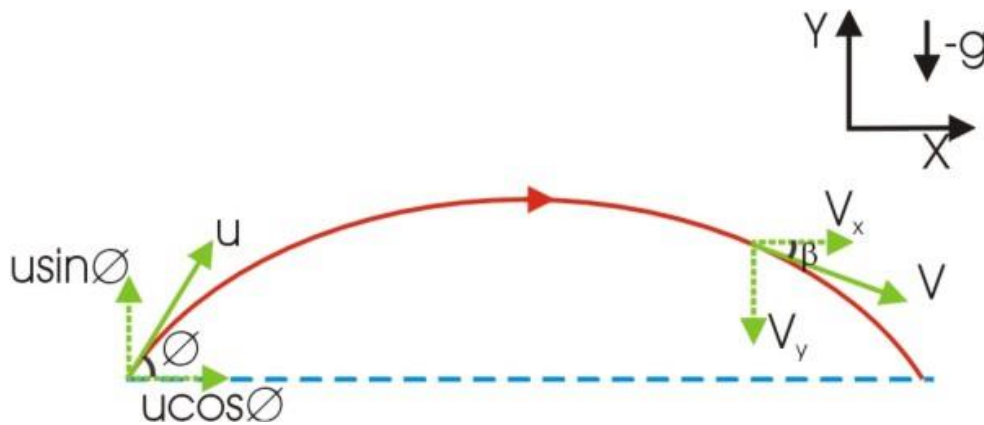
The diagram shows an object that has been projected horizontally and is now falling freely under gravity. The horizontal velocity is the same at each point, but the downward velocity is

increasing. The path followed is determined by the resultant velocity at each instant and is parabolic.



Projection at an angle

If an object is not launched horizontally or vertically, you start a problem by resolving the initial velocity into horizontal and vertical components. A problem will often involve calculating the time of flight by considering the vertical motion. Find the time to reach the maximum height (when the vertical component is zero) and double it. You then find the maximum horizontal distance travelled (known as the range) from the time of flight and the horizontal velocity.



Horizontal displacement

$$s = ut \cos \alpha$$

Vertical displacement

$$h = ut \sin \alpha - \frac{1}{2}gt^2$$

Range of a projectile

$$R = \frac{u^2 \sin \alpha}{g}$$

In absence of air resistance, the maximum range is achieved for a launch at angle of 45° .

Experiment: Strobe photography or video camera to analyse motion

5 distinguish between scalar and vector quantities and give examples of each

Physical quantities (i.e. things you can measure or calculate) can be classified as either **scalars** or **vectors**. A scalar quantity only has magnitude, not direction, but with a vector quantity you need to state the direction as well as the magnitude. For example, a bag of sugar has a mass of 1kg, but the force on it due to gravity is 9.8N downwards.

Common scalar quantities: distance, speed, mass, volume, energy, power.

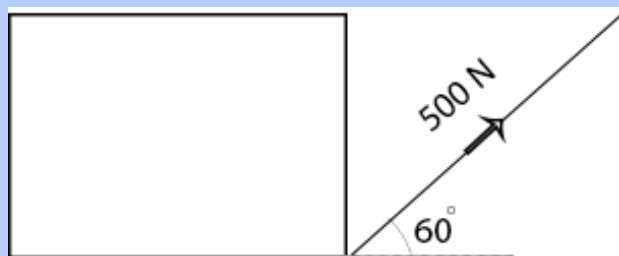
Common vector quantities: displacement, velocity, acceleration, force.

6 resolve a vector into two components at right angles to each other by drawing and by calculation

A single vector can be represented as the sum of two perpendicular vectors, known as its **components**. Vectors at right angles can then be treated independently, and can have third magnitude added to other parallel vectors if necessary.

The components of a vector are found by using that vector as the diagonal of a parallelogram of vectors or as the hypotenuse of a right-angled triangle of vectors.

Example



A boy is pulling a block with a force of 500N with the horizontal. What force is applied along the surface of the earth? What force is applied upward on the block?

A: Horizontal component = P

$$\cos 60 = \frac{P}{500}$$

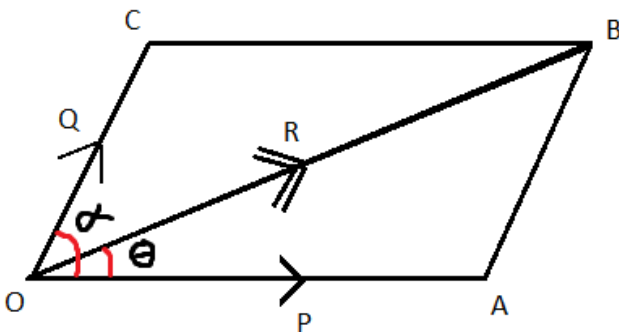
$$P = 250 \text{ N (Ans)}$$

Vertical component = Q

$$\sin 60 = \frac{Q}{500}$$

$$Q = 433 \text{ N (Ans)}$$

Parallelogram theorem

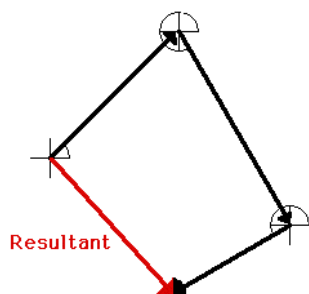


P and Q are represented by two arms: OA and OC. The resultant will be represented by the diagonal OB.

$$R = \sqrt{P^2 + Q^2 + 2PQ \cos \alpha}$$

$$\theta = \tan^{-1} \frac{\sin \alpha}{P + Q \cos \alpha}$$

Combining more than two vectors



If there are more than two vectors, they can be combined by continuing the tip-to-tail procedure. The resultant is found by drawing from the tail of the first vector to the tip of the last.

7 combine two coplanar vectors at any angle to each other by drawing, and at right angles to each other by calculation

Perpendicular vectors

When two vectors are at right angles to each other, it may be easier to find the resultant by calculation, using Pythagoras' theorem and trigonometry.

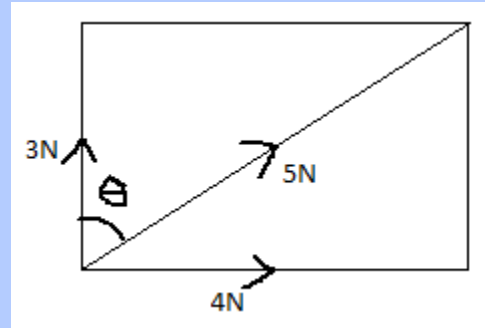
Example

A block is being pushed at north with force of 3N and at east with force of 4N. Calculate the resultant force and its direction.

$$\begin{aligned} \text{A: } R &= \sqrt{4^2 + 3^2} \\ &= 5 \text{ N} \end{aligned}$$

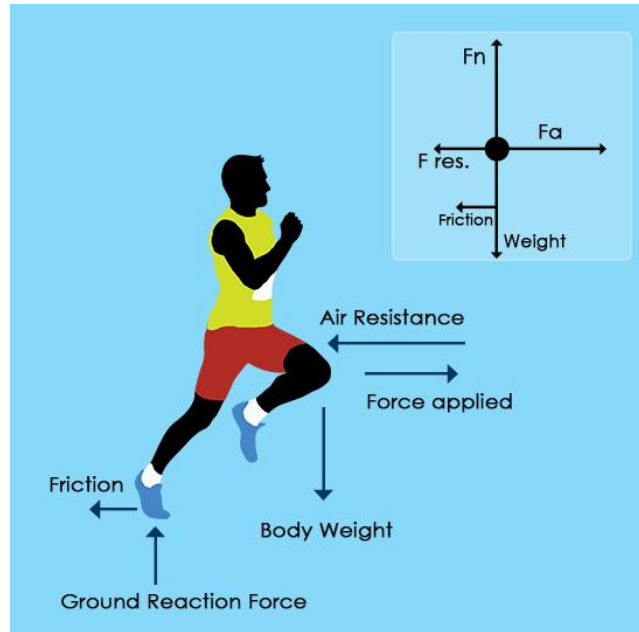
$$\begin{aligned} \cos \theta &= \frac{3}{5} \\ \theta &= 53.1^\circ \end{aligned}$$

So the resultant force is 5N at angle of 53.1° from the north.



8 draw and interpret free-body force diagrams to represent forces on a particle or on an extended but rigid body, using the concept of centre of gravity of an extended body

A diagram which shows all the forces acting on a body in a certain situation is called a free-body diagram. A free body diagram doesn't show forces acting on object other than the one we considered.



Experiment: Find the centre of gravity of an irregular rod

9 investigate, by collecting primary data, and use $\Sigma F = ma$ in situations where m is constant (Newton's first law of motion ($a = 0$) and second law of motion)

Newton's first law of motion

This states that, if the forces acting on a body are in **equilibrium**, its velocity will remain constant.

Newton's second law of motion

If there is a resultant force, then there will be a change in velocity, i.e. an acceleration.

Newton's second law states that the acceleration of an object is proportional to the resultant force and inversely proportional to its mass. Taking these together:

$$\text{resultant force} = \text{mass} \times \text{acceleration}$$

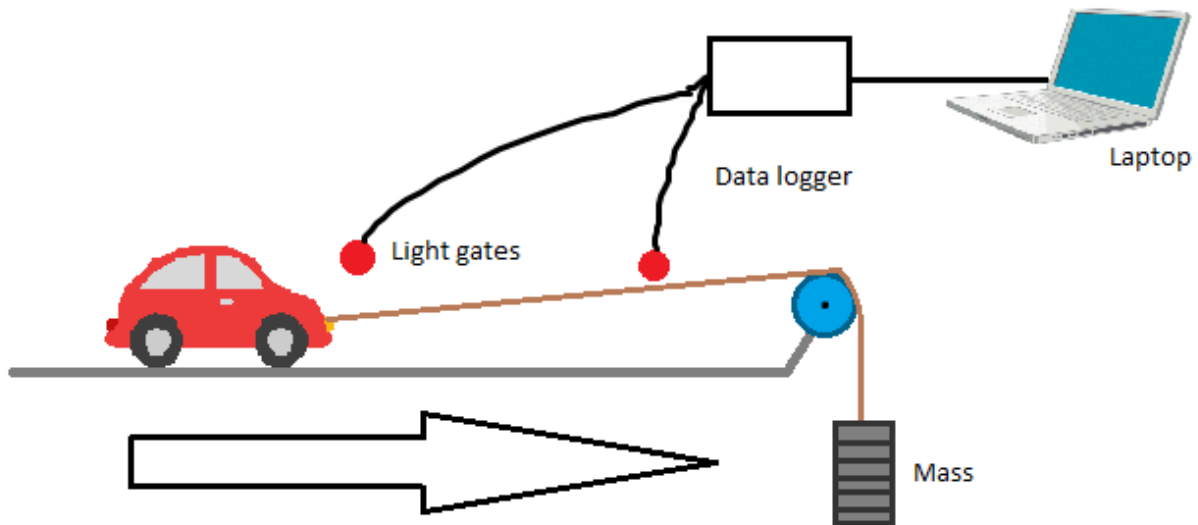
$$\Sigma F = ma$$

where, F is the force in N, m in mass in kg and a is acceleration in ms^{-2} (ΣF means the sum of all forces, i.e. the resultant force). Acceleration and force are both vectors and must act in the same direction.

If the resultant force is zero, then acceleration will be zero. So Newton's first law is just a special case of the second law: if $\Sigma f = 0$, then $\Delta v = 0$.

Experiment: Use an air track to investigate factors affecting acceleration

Investigating: $a \propto F$



1. Set up the apparatus as shown in the diagram.
2. After the car starts moving, the first light gate will measure the initial velocity and the next light gate, the final velocity. An electronic timer will be used to measure the time required to travel from first light gate to second. Using $a = \frac{v-u}{t}$, we can find the acceleration.
3. Now change the weight and repeat the experiment for more different values of acceleration and force.

Force F/N	Acceleration a/ms ⁻²
0.1	0.20
0.2	0.40
0.3	0.60
0.4	0.80
0.5	1.00
0.6	1.20

4. Plotting an acceleration-time graph, a straight line will show that acceleration is proportional to the resultant force.

Investigating: $a \propto 1/m$

1. Follow the same diagram as previous.
2. After the car starts moving, the first light gate will measure the initial velocity and the next light gate, the final velocity. An electronic timer will be used to measure the time required to travel from first light gate to second. Using $a = \frac{v-u}{t}$, we can find the acceleration.
3. Now change the mass of the car by keeping the weight(force) constant. Repeat the experiment, and determine the acceleration for each case.

Mass/kg	Acceleration/ ms^{-2}
0.5	1.00
0.6	0.83
0.7	0.71
0.8	0.63
0.9	0.55
1.0	0.50

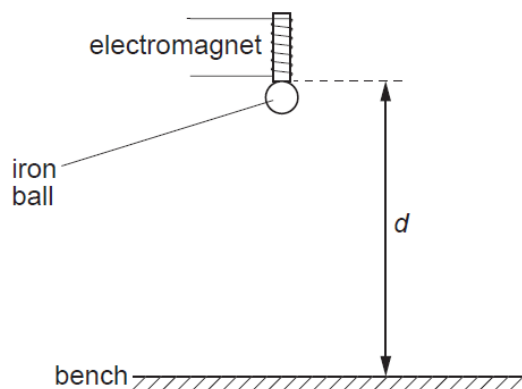
4. The results in table show that there is a different relationship between a and m . Here $a \propto 1/m$. We can say that a is inversely proportional to m .

10 use the expressions for gravitational field strength $g = F/m$ and weight $W = mg$

Gravitational field strength g is defined as the force per unit mass, in mathematical term: $g=F/m$. The SI unit is N kg^{-1} and it is a vector quantity.

The weight of an object is calculated from this relationship: $W=mg$.

Experiment: Measure g using, for example, light gates



1. The arrangement is done as shown in the diagram.
2. The iron ball is released by switching off the switch. As soon as it is done, the stopwatch will be started manually.
3. The time taken for the ball to reach the bench is measured. And the distance between the ball and bench is measured with a ruler

4. Calculation:

$$s = ut + \frac{1}{2} at^2$$

$$= 0 + \frac{1}{2} gt^2$$

$$g = 2s/t$$

5. The value of g can be measured by this equation.

Experiment: Estimate, and then measure, the weight of familiar objects

11 identify pairs of forces constituting an interaction between two bodies (Newton's third law of motion)

Newton's third law of motion

This states that, if body A exerts a force on body B, then body B exerts a force of the same type on body A that is equal in magnitude and opposite in direction.

To describe the Newton's third law pair force in a given situation, just keep the magnitude and type of force the same and swap the direction and body acted on. For example, the Earth exerts a downward gravitational force of 10N on a rock, so the rock exerts an upwards gravitational force of 10N on the Earth.

12 use the relationship $E_k = \frac{1}{2}mv^2$ for the kinetic energy of a body

Moving bodies have kinetic energy by virtue of their motion. The formula is:

$$\text{kinetic energy} = \frac{1}{2} \times \text{mass} \times (\text{speed})^2$$

$$E_k = \frac{1}{2}mv^2$$

A change in kinetic energy can also be found based on work done.

13 use the relationship $\Delta E_{\text{grav}} = mg\Delta h$ for the gravitational potential energy transferred near the Earth's surface

When an object is lifted, work is done against the downward gravitational force, i.e. the weight. The distance moved is the vertical height through which the object is raised. Therefore,

$$\text{change in gravitational potential energy} = \text{weight} \times \text{change in height}$$

$$\Delta E_{\text{grav}} = W \times \Delta h$$

and, as weight = mass \times g

$$\Delta E_{\text{grav}} = mg\Delta h$$

The change in gravitational potential energy is related to the change in height – you don't need the total height above the ground. Also note that, although this is related to a specific direction, it is still a scalar quantity.

14 investigate and apply the principle of conservation of energy including use of work done, gravitational potential energy and kinetic energy

Principle of conservation of energy: Energy can be neither created nor destroyed, but it can be transferred. This means that, in any process, total energy at the start = total energy at the end.

Energy transformation

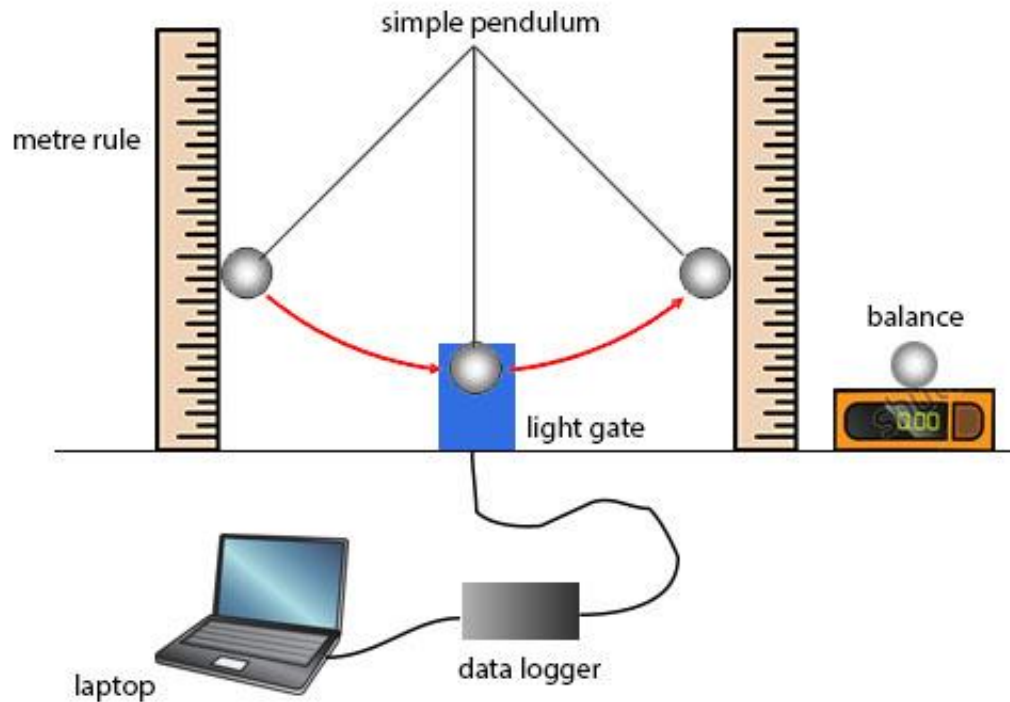
Energy can be transferred by two ways: (i) Heating and (ii) Working

Heating: If we heat an object, it transfers energy to it using a temperature difference - perhaps, by means of flame. It is by means of temperature gradient.

Working: If we wish to transfer energy without making use of a temperature difference we do it by doing a work. For example, by lifting an object of the floor onto a table. It is by means of moving a force.

Experiment: Energy exchange in pendulum

Galileo pendulum experiment in which he determined that the pendulum would always return to some height illustrates the conservation of gravitational and potential energy nicely.



By careful measurement of the height a pendulum rises and falls through its swing. We can determine the gravitational potential energy it loses and gain throughout one oscillation. This can be then compared with kinetic energy as it passes through the lowest point. The experiment will show that the energy is constantly being transferred from kinetic energy to gravitational potential energy and vice versa.

Experiment: Use, for example, light gates to investigate the speed of a falling object

15 use the expression for work $\Delta W = F\Delta s$ including calculations when the force is not along the line of motion

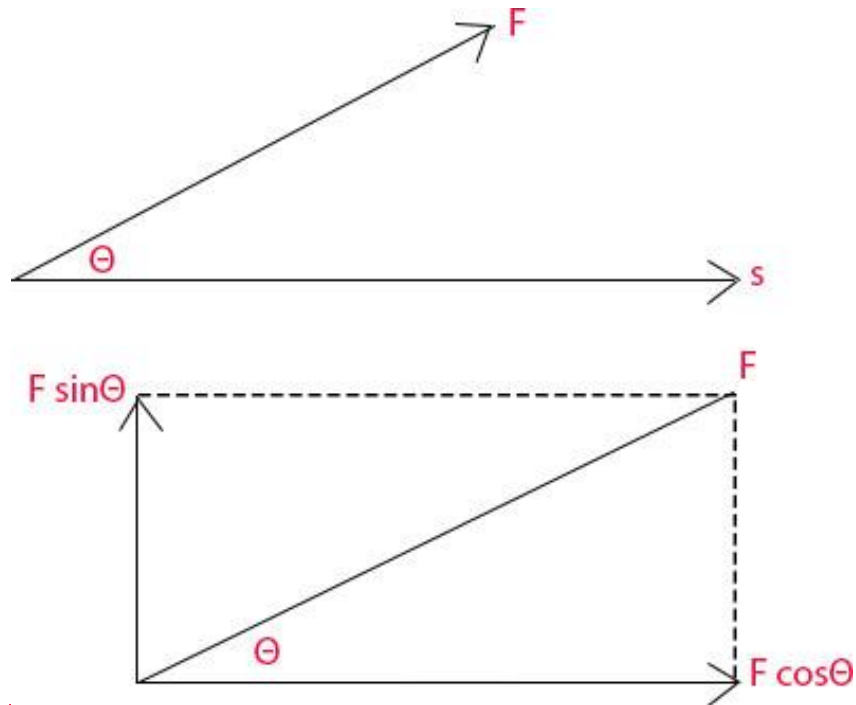
When a force acts on an object and transfers energy, work has been done. For example, someone pushes a car, which accelerates and gains kinetic energy. Energy is transferred from the person to the car as work is done by the person on the car.

work done = force x distance moved in direction of force

The SI unit of energy is joule (J).

Calculating force when displacement is different direction

Although work done is a scalar quantity, force and displacement are vectors, so their direction is important. If the force and the displacement are in different directions, the force must be resolved in order to calculate the work done. The figure below shows how this is done. In this figure, the force is resolved so that one component ($F \cos\theta$) lies in the same direction as the displacement. This is the component of the force that is involved in transferring energy. The component of the force perpendicular to the displacement does no work, as it does not move in the direction which is acting.



Resolving a force to calculate work done. In this case, work done = $F \cos\theta \times s$.

16 understand some applications of mechanics, for example, to safety or to sports

Pg – 46 of Student Book

17 investigate and calculate power from the rate at which work is done or energy transferred

Power is the energy transferred to the time taken.

$$\text{Power} = \frac{\text{energy transferred}}{\text{time taken}}$$

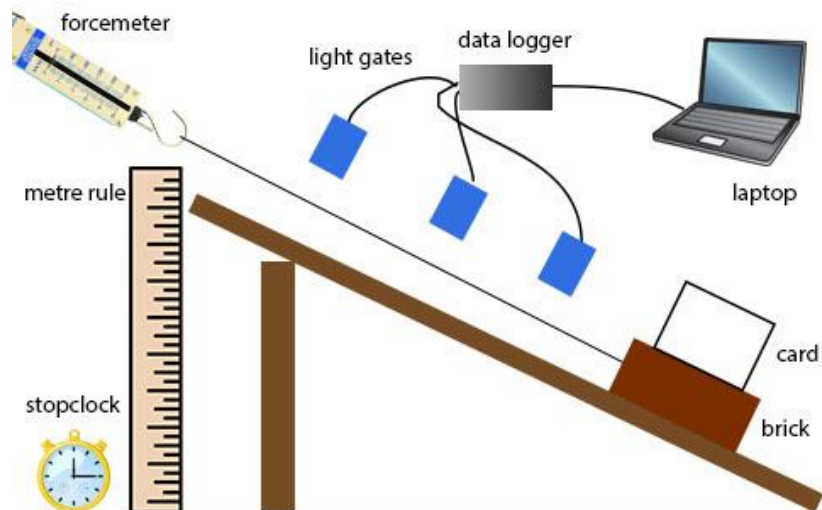
Relations of efficiency

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{energy input}} \times 100\%$$

$$\text{efficiency} = \frac{\text{useful power output}}{\text{power input}} \times 100\%$$

Experiment: Estimate power output of electric motor (see 53)

Investigating power and efficiency

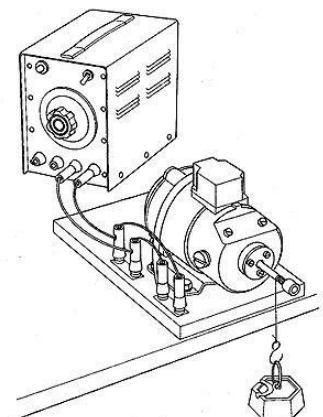


A brick is pulled up a ramp at a constant velocity and using a constant force. The forcemeter measures the force and the light gates are used to measure the velocity of the brick. Now we can calculate the power output by, $P = Fv$

Power input can be calculated by $P = \text{work done} / \text{time}$. Work done = gain in GPE = mgh . The mass can be measured by an electronic balance, the height is measured by the metre rule and the time taken is measured by stopclock. Now efficiency can be calculated by $\eta = \text{power output} / \text{power input} \times 100\%$

Measuring the output power of an electric motor

The motor in figure is switched on until the load is raised almost up to the pulley wheel and is then switched off. A stopclock is used to measure the time, Δt , when the motor is working, and a metre rule is used to find the distance, Δh , through which the load is lifted. The experiment is repeated for a range of masses to investigate the effect of the load on the power output of the motor using the equation:



$$\textit{Power output of motor} = \frac{\Delta GPE}{\Delta t} = \frac{mg\Delta h}{\Delta t}$$

Materials

18 understand and use the terms density, laminar flow, streamline flow, terminal velocity, turbulent flow, upthrust and viscous drag, for example, in transport design or in manufacturing

Density: Density is mass per unit volume:

$$\rho = \frac{m}{v}$$

where mass m is in kg, volume V is in m^3 and density ρ is in kg m^{-3} .

Pressure: It is the force per unit area:

$$P = \frac{F}{A}$$

Pressure in fluids is calculated by:

$$P = h\rho g$$

Pressure increases as you go deeper under a fluid due to the weight of the fluid above you.

Upthrust: When an object is submerged in a fluid, it feels an upward force caused by the fluid pressure. This upward force is called upthrust.

According to Archimedes principle, upthrust is equal to the weight of the fluid displaced by the object. Therefore,

$$\text{upthrust} = \text{weight of fluid} = mg = v\rho g$$

If the upthrust on a fully submerged object is less than its weight, the object will sink. An object will float if it can displace its own weight of fluid without becoming fully submerged.

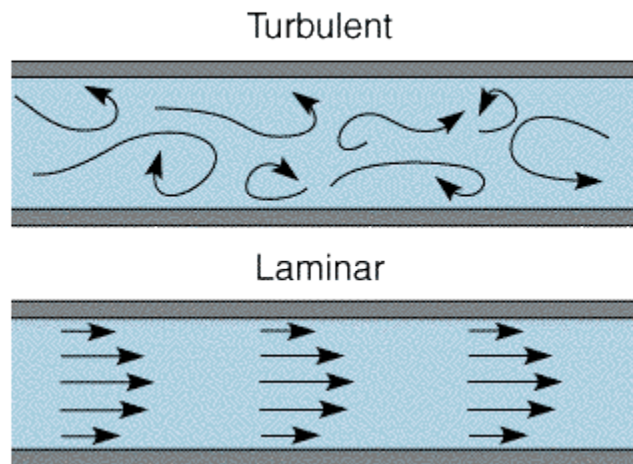
Moving fluids – laminar and turbulent flow

Streamlines represent the velocity of a fluid at each point within it. They can be drawn as arrowed lines that show the paths taken by small regions of the fluid.

Laminar flow (or **streamline flow**) occurs when adjacent layers of fluid do not cross into each other. They usually occurs at lower speeds and around more streamlined objects. The layers do not mix, so your drawings should not show streamlines crossing over. The layers are roughly parallel. The speed and direction at any point remain constant over time. There are no sudden

changes in speed or direction along the streamlines either, so do not draw sharply angled changes in direction when the lines flow around the objects.

Turbulent flow occurs when the streamlines are not continuous. The flow is chaotic and subject to sudden changes in speed and direction. There is a lot of large-scale mixing of layers, so eddies and vortices are frequently seen.



Laminar flow is an important consideration in fluid motion. The uplift on an aeroplane's wings is dependent on laminar flow, and passengers experience a rocky ride when turbulent conditions are encountered. Similarly, the drag forces on a motor car are affected by turbulence, and wind tunnels are used to observe the nature of the airflow over prototype designs.

The efficiency of fluid transfer through tubes is greatly reduced if turbulence occurs, so the rate of flow of oil and gas must be controlled so that the critical speed is not exceeded.

In the food industry, the flow of sweet casings such as toffee and chocolate over nuts or other fillings should be laminar so that air bubbles are not trapped as a result of turbulence.

Viscous drag: When solids and fluids move relative to each other, the layer of fluid next to the solid exerts a frictional force on it. Successive layers of fluid experience frictional forces between each other as well. The frictional forces cause **viscous drag**, which is one of the causes of air resistance.

More will be covered in 20.

19 recall, and use primary or secondary data to show that the rate of flow of a fluid is related to its viscosity

Viscosity: The viscosity of a fluid relates to its stickiness and thus to its viscous drag. It can be described in terms of the resistance between adjacent layers in laminar flow.

The **coefficient of viscosity**, η , usually just called viscosity, is used to compare different fluids. Fluids with lower viscosity will have a greater rate of flow and cause less viscous drag.

The unit of viscosity is $\text{kg m}^{-1} \text{s}^{-1}$ or N s m^{-2} .

Experiment: To investigate how fluid rate depends on its viscosity.

Diagram from Hodder Pg – 54

Using the apparatus in the figure, fill the funnel with liquid to a level just above the upper mark. For example, water. Open the clip to allow the liquid to flow through the tube in the beaker. Start timing passes the upper mark and stop as it passes the lower one. Repeat for various samples, e.g.: chocolate and then note down the time taken.

Observation: Samples that took longer time is more viscous. And therefore, their (chocolate) fluid rate is lower comparing to other (water).

Precaution: For runny liquids like water or sugar solution of a low concentration, a capillary tube with a diameter of 1mm should be used so that very short times (and large percentage uncertainties) are avoided. For syrup, etc, tubes with bores of 5mm or wider can be used.

20 recognise and use the expression for Stokes' Law, $F = 6\pi\eta rv$ and upthrust = weight of fluid displaced

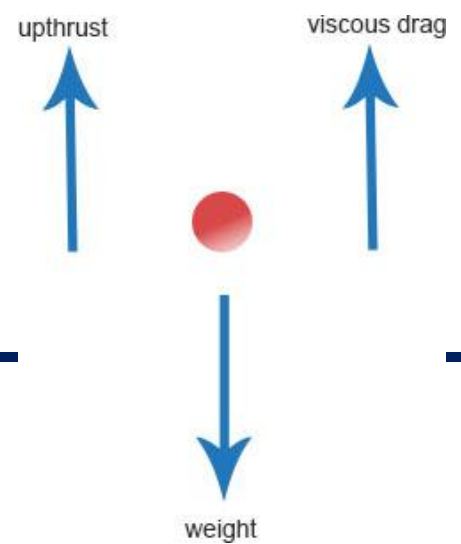
Stoke's law gives a formula for viscous drag for a small sphere at low speeds in laminar flow. The viscous drag force, F , is given by:

$$F = 6\pi\eta rv$$

where r is the radius of the sphere, in metres, η is the viscosity, in N s m^{-2} , and v is the velocity, in ms^{-1} .

Terminal velocity

In a falling object in liquid, three forces act on it – weight, upthrust and drag as in the figure. Drag force changes with speed. When upthrust and drag force balances the weight, the velocity becomes constant which we call **terminal velocity**. In equation:



$$\text{upthrust} + \text{viscous drag} = \text{weight}$$

Expressing in terms of Stoke's law gives:

$$\frac{4}{3}\pi r^3 \rho_{\text{fluid}} g + 6\pi\eta r v = \frac{4}{3}\pi r^3 \rho_{\text{steel}} g$$

Rearranging further gives:

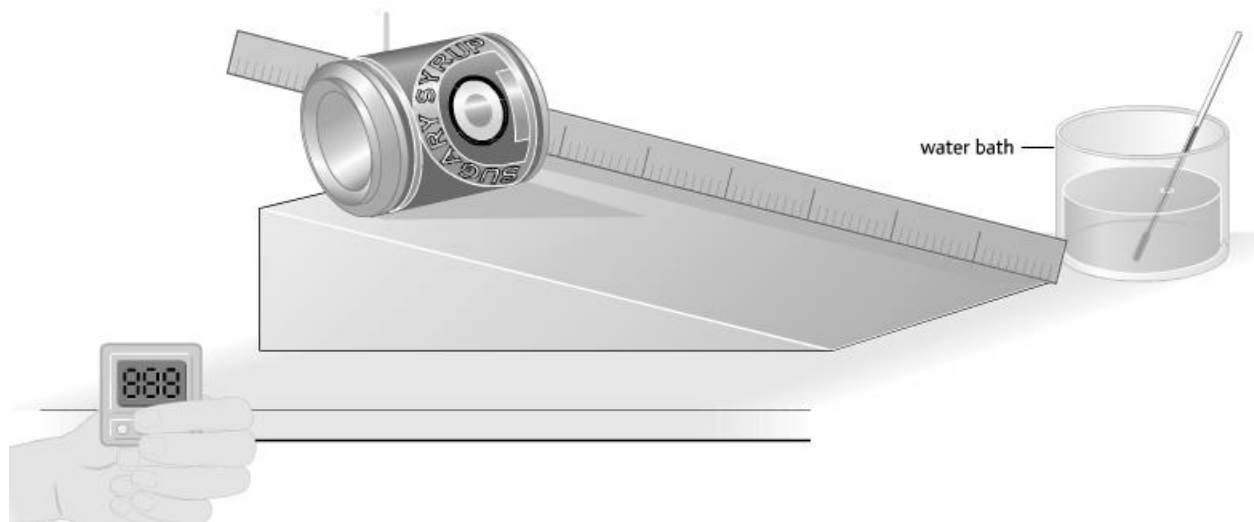
$$v = \frac{2r^2 g (\rho_{\text{steel}} - \rho_{\text{fluid}})}{9\eta}$$

21 investigate, using primary or secondary data, and recall that the viscosities of most fluids change with temperature. Explain the importance of this for industrial applications

An even greater variation in viscosity of liquid chocolate is caused by changes in its temperature. If a sweet manufacture wants to account for variations in a recipe (which might come from something as minor as change in supplier of cocoa beans), they can adjust the flow rate by altering the temperature. Viscosity is directly related to fluid temperature. In general, liquids have a lower coefficient of viscosity at higher temperature. For gases, viscosity increases with temperature.

Experiment: To investigate the change of viscosity with temperature

The change in viscosity of a liquid with temperature can be observed in a school laboratory using re-sealable tin or bottle half full of a test fluid.



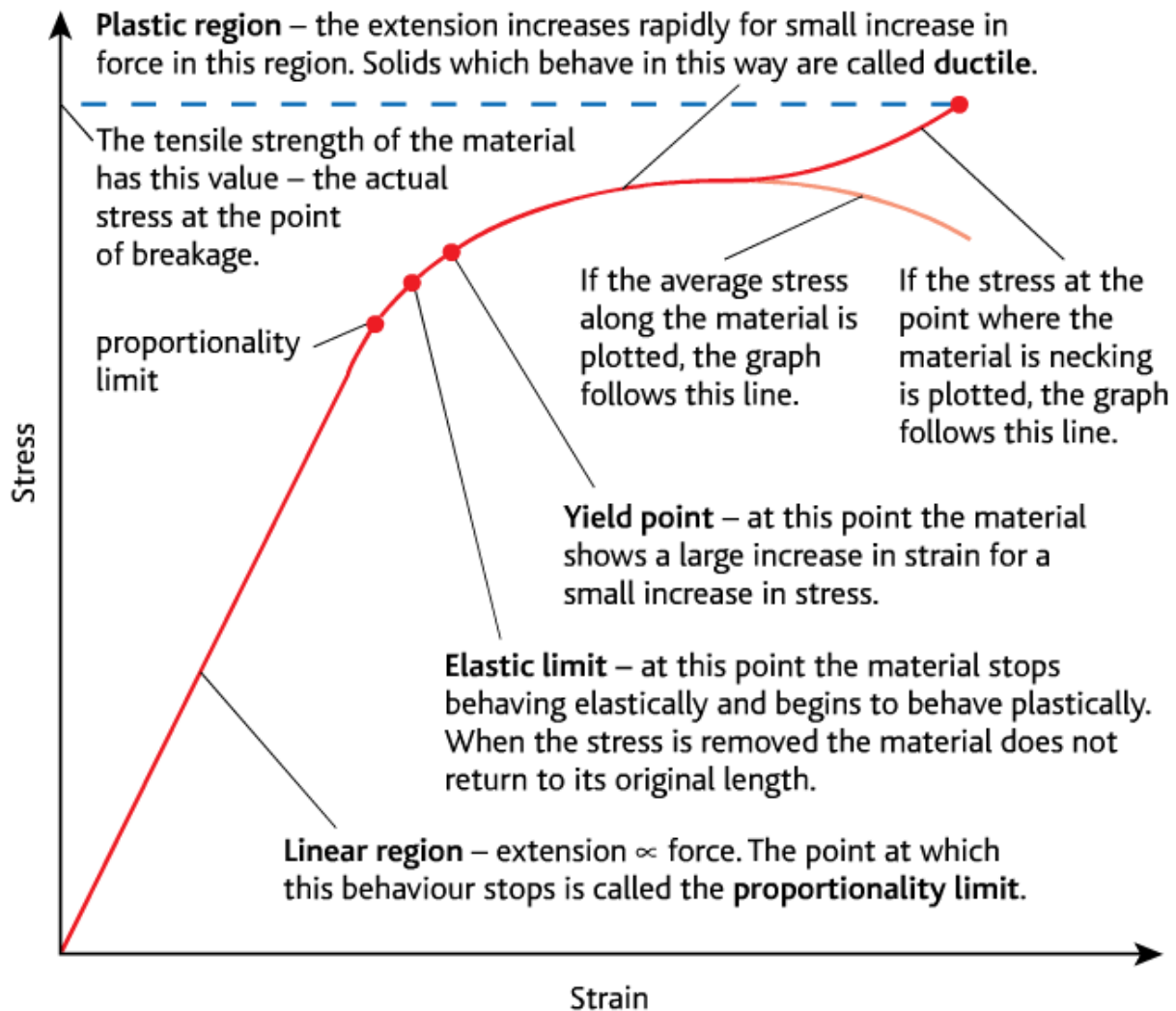
The temperature of the liquid is varied using a water bath. The viscosity of the liquid will affect the rate at which the tin or bottle rolls down a fixed ramp.

22 obtain and draw force-extension, force-compression, and tensile/compressive stress-strain graphs. Identify the limit of proportionality, elastic limit and yield point

Read 23, 24 first.

Stress-strain graphs

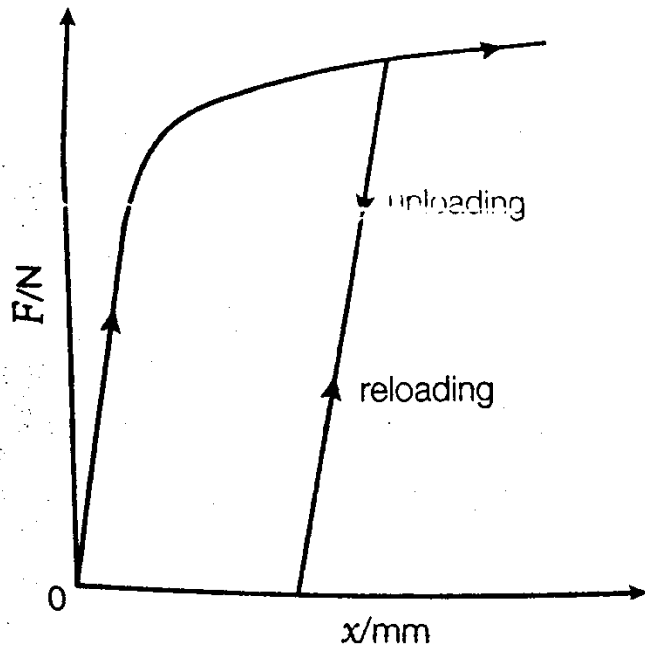
This figure shows a stress-strain graph a copper wire.



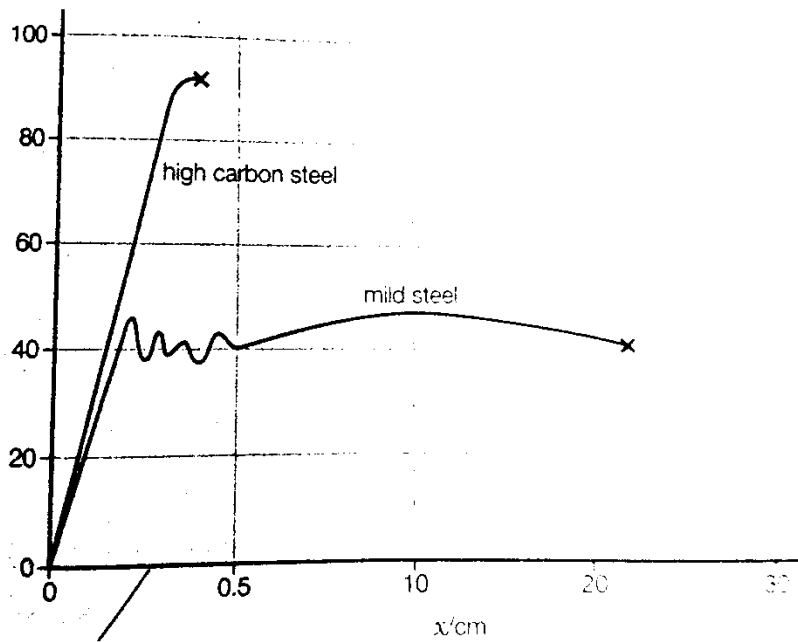
Obtain graphs for, for example, copper wire, nylon and rubber

Force-extension graphs

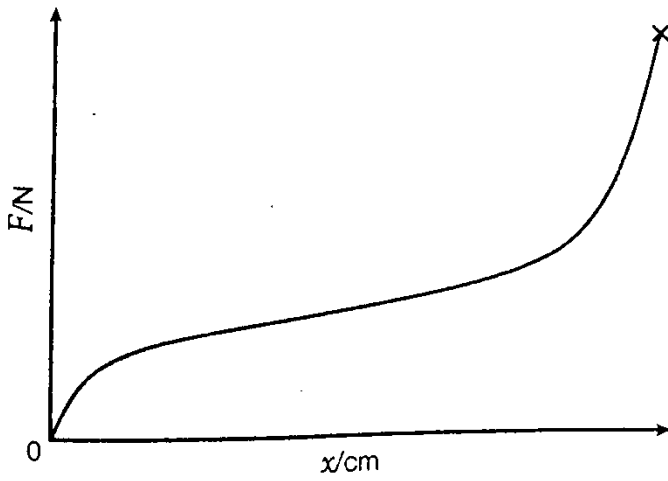
Copper wire



Steel wires

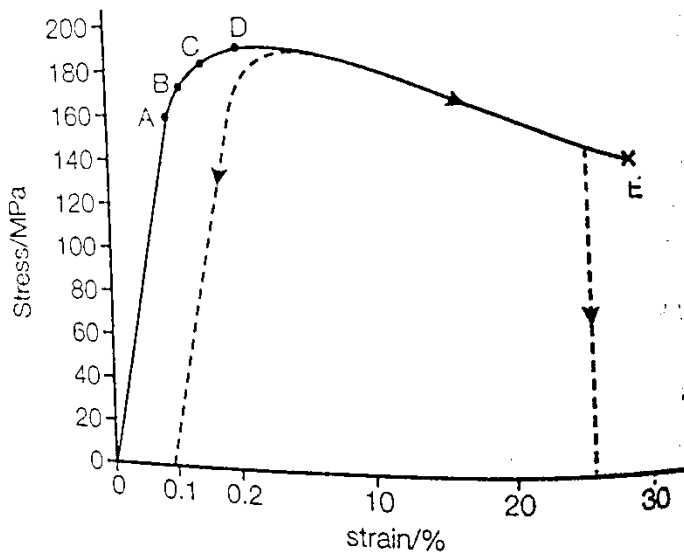


Natural rubber

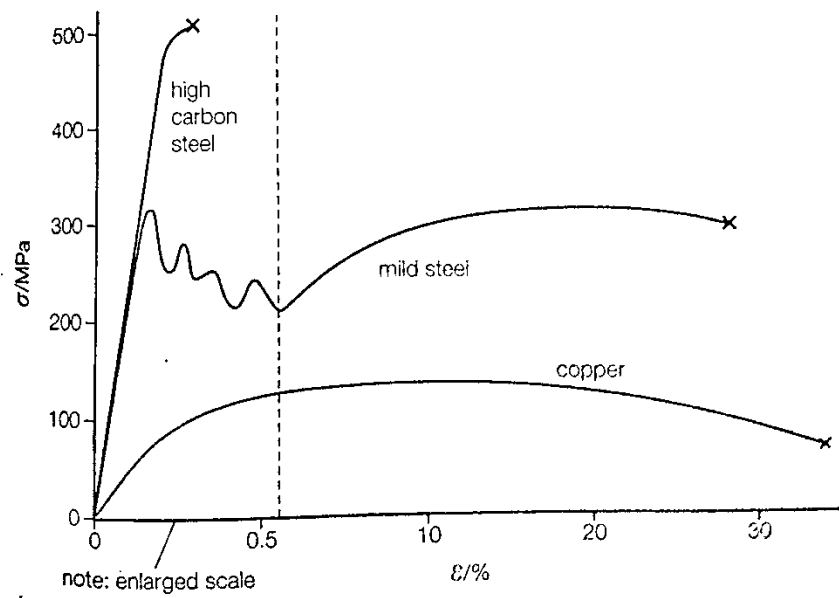


Stress-strain graphs

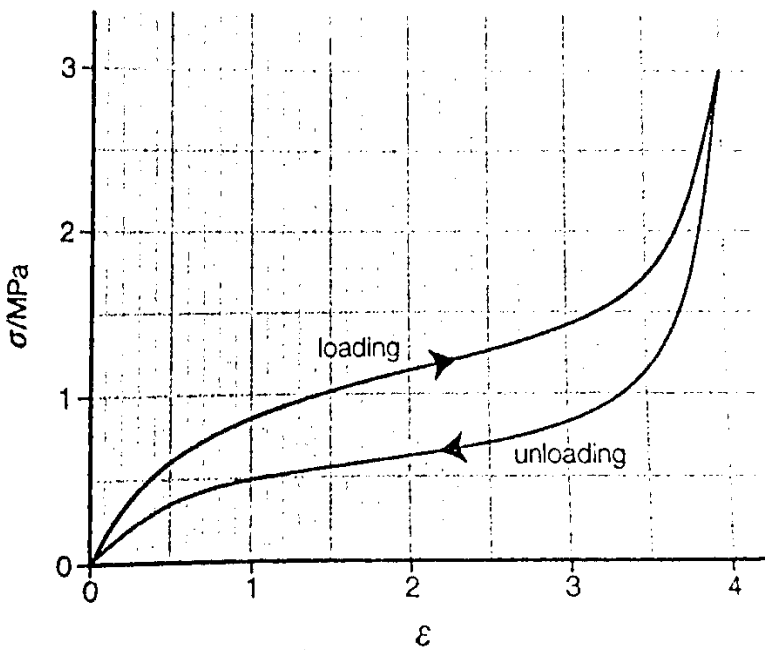
Copper wire



Steel wires



Rubber



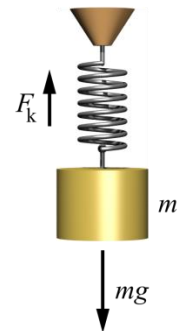
23 investigate and use Hooke's law, $F = k\Delta x$, and know that it applies only to some materials

Hooke's law states that, up to given load, the extension of a spring is directly proportional to the force applied to the spring.

$F = -k\Delta x$; where k is the constant for a particular spring called constant of proportionality or spring constant. It represents the stiffness of the spring.

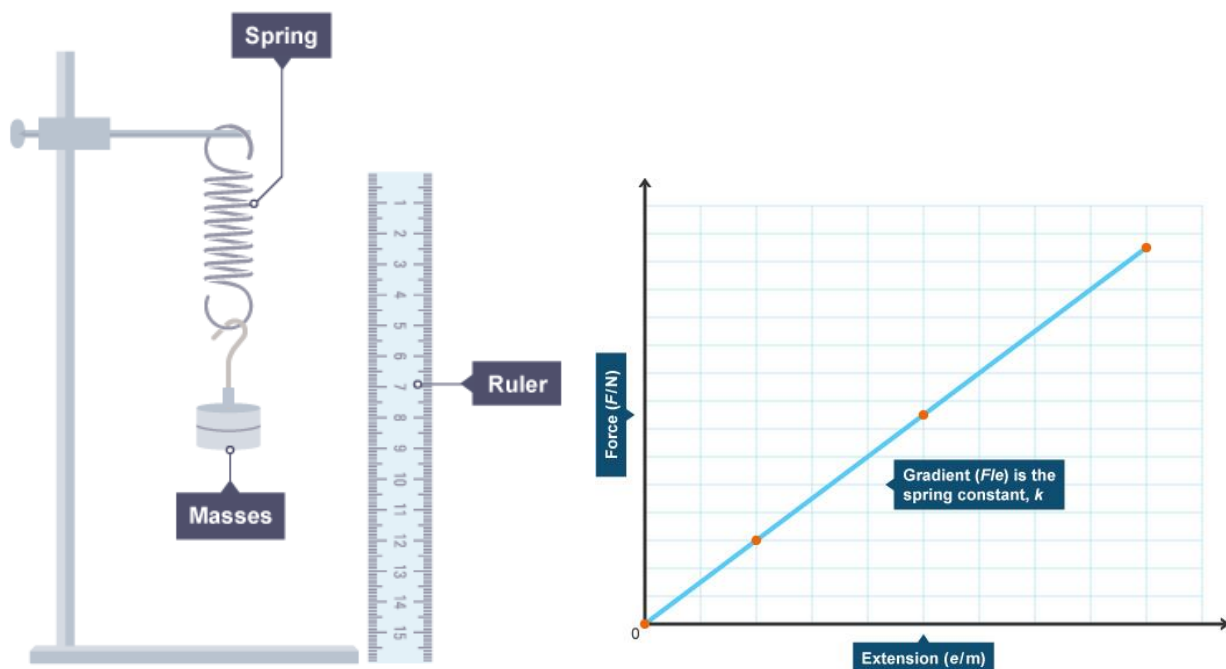
The negative sign shows that the force exerted by the spring in the opposite direction to the extension.

The spring constant k is different for different materials – the larger the k the stiffer the spring.



Experiment: To investigate Hooke's law

The apparatus for the experiment and a sketch of the resulting load-extension graph are shown below.



The straight line formed confirms that the Hooke's law is obeyed.

Elastic limit: The limit beyond which the extension increases rapidly than expected and the spring remains permanently deformed when the load is removed is called the elastic limit. Upto the limit, the spring regain its original shape whenever the load is removed.

24 explain the meaning and use of, and calculate, tensile/compressive stress, tensile/compressive strain, strength, breaking stress, stiffness and Young Modulus. Obtain the Young modulus for a material

The extension of a material depends on the stiffness, k , and the applied force. But it is also the case that for a given force a longer sample will experience a greater extension, and a thicker sample will extend less. If different materials are to be compared fairly, the effect of the sample's thickness and length must be taken into account. In order to do this, graphs of force against extension are replaced with graphs of **stress** against **strain**.

A **tensile force** is the force used in a material to stretch it apart. A **compressive force** is when the material is being compressed.

Stress: The applied force per unit area is called stress, σ .

$$\text{tensile/compressive stress} = \frac{\text{tensile/compressive force}}{\text{cross-sectional area}}$$

$$\sigma = \frac{F}{A}$$

Stress has units N m^{-2} or Pa

Strain: The extension per unit length is called strain.

$$\text{tensile/compressive strain} = \frac{\text{extension}}{\text{original length}}$$

$$\varepsilon = \frac{\Delta x}{x}$$

Strain has no unit.

Strength: The strength of a materials is the stress at which the material breaks.

Breaking stress: The maximum stress a material can stand before it breaks is called the breaking stress or ultimate tensile stress.

Young modulus: The ratio of stress to strain is a constant. This constant is called Young modulus, E .

$$\text{Young modulus} = \frac{\text{stress}}{\text{strain}} = \frac{\text{applied force/cross-sectional area}}{\text{extension/original length}}$$

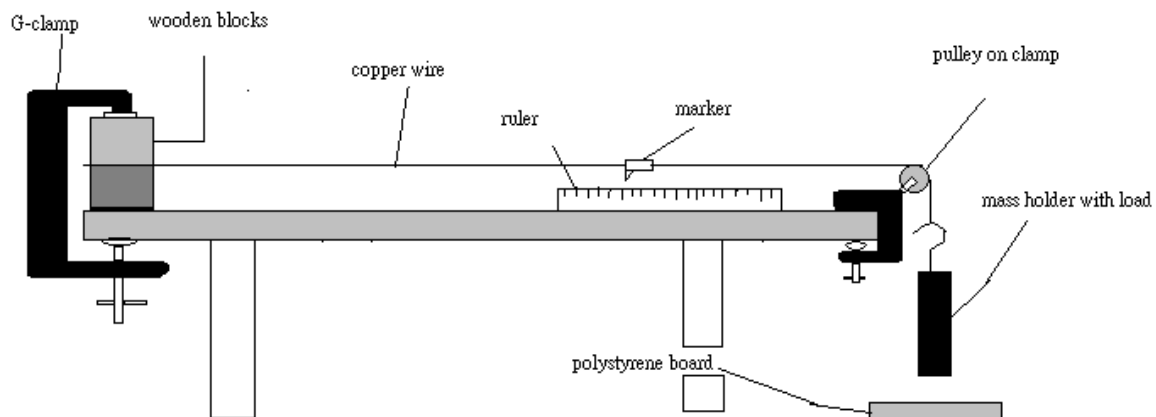
$$E = \frac{\sigma}{\epsilon} = \frac{Fx}{A\Delta x}$$

The units of the Young modulus are N m^{-2} , or Pa. For many materials, MPa (10^6 Pa) is a more convenient unit as the Pa is very small.

Experiment: To measure the Young modulus

The apparatus used to measure the Young modulus is shown in the diagram below. Increase the force applied to a long, thin wire by adding masses of known weight. Measure the diameter of the wire with a micrometer screw gauge, remembering to measure at different positions and in different planes, and find a mean value. Measure the original length, from the clamp to the marker, with a metre rule, and then measure the increase in length (the extension) using a fixed scale as the force is changed.

Plot a graph of force against extension, and find the gradient, $F/\Delta x$. This is multiplied by the original length/cross-sectional area to find the Young modulus.



Uncertainties in measurements

To measure the Young modulus all that is necessary in principle is to measure the extension of a sample for a given force and then to calculate the

To find E , a graphical method is usually used. Since:

$$E = \text{tensile strain} = \frac{\sigma}{\epsilon}$$

then,

$$\sigma = E\epsilon$$

tensile stress and tensile strain, from E can be calculated. In practice such a method is unlikely to lead to very reliable results.

It follows that a graph of tensile stress plotted against tensile strain will have slope E (compare $\sigma = E\varepsilon$ with $y = mx + c$).

To plot the graph you will need to make a number of measurements. The table below suggests possible uncertainties in these measurements when using simple equipment.

Measurement	Possible uncertainty in measurement	Note
Force/N	$\pm 2\%$ (if using slotted masses)	Slotted masses may have very variable uncertainties in their mass. If carefully selected, they are unlikely to have an uncertainty of more than $\pm 2g$. The mass used will need to be converted to weight using an appropriate value of g – the approximation of g to 10 N kg^{-1} would lead to an uncertainty of more than $+1\%$.
Diameter of wire/m	$\pm 2\%$ (using micrometer)	A micrometer should be capable of measuring a wire 1mm in diameter to within $\pm 0.02\text{mm}$ if used carefully. This is an uncertainty of $\pm 2\%$, which will also be the uncertainty of the radius ($d/2$).
Cross-sectional area/ m^2	$\pm 4\%$ (depends on radius ²)	Since the cross-sectional area of the wire depends on its radius ² , the uncertainty of the cross-sectional area will be twice the uncertainty of the radius. (Where two quantities are multiplied together or one is divided by the other their uncertainties are added to find the uncertainty of the result. Where two quantities are added or subtracted their uncertainties are averaged to find the uncertainty of the result.)
Original length of wire/m	$\pm 1.5\%$ (using metre rule)	If a piece of wire 2m long is used, its length can be measured to within around 3mm using a metre rule – an uncertainty of 1.5%.
Extension of wire/m	10%	The extension of the wire depends on many factors like its length, cross-sectional area and the material it is made of. If extensions of the order of 5mm are measured to within 0.5mm, the uncertainty is $\pm 10\%$.
Tensile stress = F/A	$\pm 6\%$	This is the sum of the uncertainties of F and A .
Tensile stress = $\Delta x/x$	$\pm 11.5\%$	This is the sum of uncertainties for Δx and x .

The largest uncertainty in any measurement of E comes in the measurement of extension. Accurate methods for measuring E thus concentrate on measuring Δx with a precision as great as possible. The percentage errors are calculated by finding what fraction of the value the error represents. For example, for the error in the extension of the wire.

error in measurement = ± 0.5 mm

value of measurement = 5 mm

$$\% \text{ error} = \frac{0.5}{5} \times 100\% = 10\%$$

The overall uncertainty in E is likely to be $\pm 6\% + \pm 11.5\%$ i.e. $\pm 17.5\%$.

Investigations could include, for example, copper and rubber

25 investigate elastic and plastic deformation of a material and distinguish between them

A material undergoing **elastic** deformation will return to its original dimensions when the deforming force is removed. A **plastic** material will remain deformed.

26 explore and explain what is meant by the terms brittle, ductile, hard, malleable, stiff and tough. Use these terms, give examples of materials exhibiting such properties and explain how these properties are used in a variety of applications, for example, safety clothing, foodstuffs

Brittle: Brittle materials break with little or no plastic deformation. e.g: glass, ceramics

Ductile: Ductile materials show large plastic deformation before failure under tension. These materials can be pulled into wires or threads. e.g.: copper

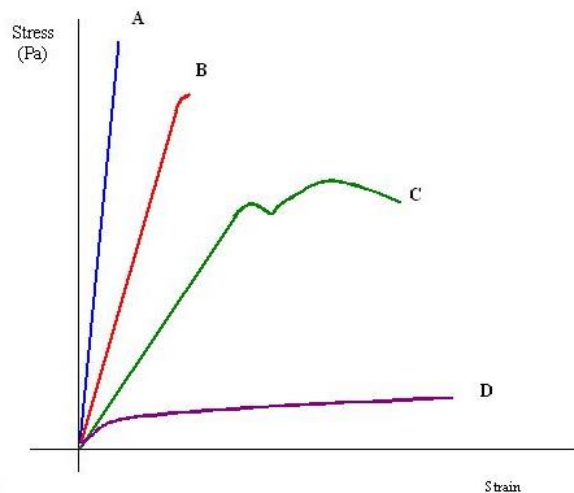
Hard: Hard materials resist plastic deformation by surface indentation or scratching. e.g.: diamond

Malleable: Malleable materials show a large plastic deformation under compression. These materials can be beaten into sheets. e.g.: gold

Stiff: A stiff material exhibits very small deformation even subjected to large forces. e.g.: steel

Tough: Tough materials can withstand impact forces and absorb a lot of energy before breaking. Large forces produce a moderate deformation. e.g.: mild steel, copper, rubber tyres.

- A is a brittle material which is also strong e.g glass
- B is a strong material which is not ductile e.g steel
- C is a ductile material e.g copper
- D is plastic material



27 calculate that the elastic strain energy E_{el} is a deformed material sample, using the expression $E_{el} = \frac{1}{2}F\Delta x$, and from the area under its force/extension graph

Elastic strain energy

The energy stored in a stretched spring is equal to work done on it as it is stretched. Since the force increases linearly from zero to F as the spring is stretched, the average force used to stretch it is given by.

$$\frac{0 + F}{2} = \frac{F}{2}$$

So the work done on the spring = $\frac{1}{2} F \Delta x$

Since, $F = -k\Delta x$

$$\text{Work done} = \frac{1}{2} k \Delta x^2$$

This is the work done by the spring. The spring gains energy which is called its potential energy or elastic strain energy.

The area under the force-extension graph gives work done or energy strain.

Unit 2: Physics on the Work

Chapter: Waves

28 understand and use the terms amplitude, frequency, period, speed and wavelength

Amplitude: The amplitude of a wave is the maximum displacement from its equilibrium position.

Frequency: The frequency is the number of oscillations per second.

Period: The period is the time taken from one complete oscillation to take place.

Wavelength: The wavelength is the length between two points in consecutive cycle that are in phase.

29 identify the different regions of the electromagnetic spectrum and describe some of their applications

Light is a small part of the electromagnetic spectrum, consisting only of the part to which our eyes are sensitive. All electromagnetic spectrum share some common properties:

- they are all transverse waves
- they all consist of an oscillating electric field and magnetic field

Applications of electromagnetic waves

These are just some of the applications of different parts of the electromagnetic spectrum.

Radio waves: Broadcast communications for TV and radio are the most obvious use for radio waves. These are particularly easy to generate as any alternating current can produce them. Since these will not interfere with those of another frequency, many radio stations can broadcast in the same area.

An upper layer in atmosphere, the ionosphere is electrically charged and will reflect and refract radio waves. This is useful for long-distance broadcasting as the waves won't get lost out of Earth. However, radio communication with satellites is not possible.

Microwaves: Microwaves has higher frequency and thus is not reflected by the ionosphere. Thus they are used for communications with satellites. They are used for handheld communication devices such as mobile phones.

Infrared: Infrared waves can travel through glass in a very similar way to visible light can use total internal reflection to be carried along optical fibres. They are used for wired communication along with visible light, to increase the number of available frequencies, simultaneously, maximizes the amount of data that can be transmitted.

They are used by some alarm system, toasters/grills to cook food taking advantage of heat radiation by radio waves.

Experiment: Wave machine or computer simulation of wave properties

30 use the wave equation $v = f\lambda$

The speed of the wave is given by the equation $v = f\lambda$, (f = frequency, λ =wavelength)

31 recall that a sound wave is a longitudinal wave which can be described in terms of the displacement of molecules

Sound waves are longitudinal waves. They travel as the particles of air displaces from their equilibrium position and produce compression and rarefaction.

Experiment: Demonstration using a loudspeaker

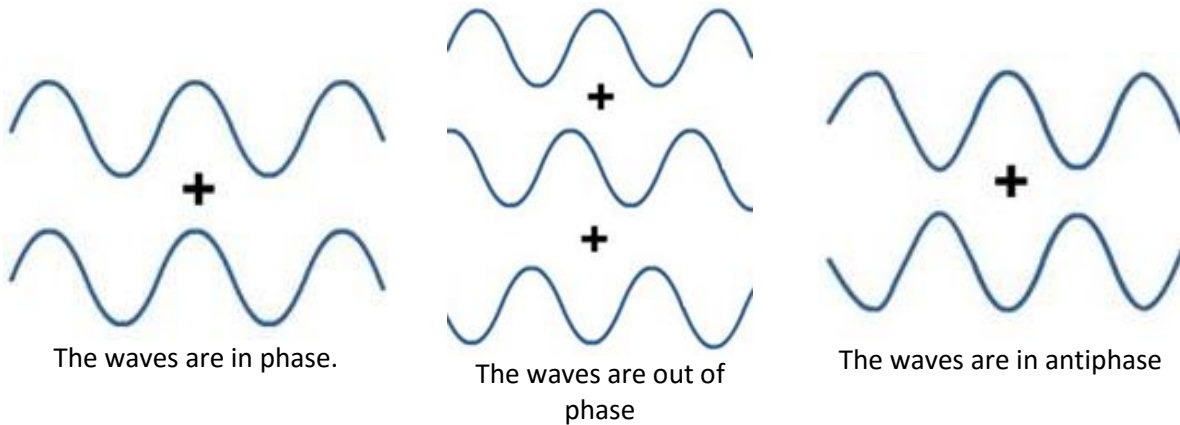
Experiment: Demonstration using waves on a long spring

32 use graphs to represent transverse and longitudinal waves, including standing (stationary) waves

33 explain and use the concepts of wavefront, coherence, path difference, superposition and phase

Wavefront: The line that joins the particles of the same phase (all the crests or all the troughs) is called wave fronts.

Phase:



If one wave appears with crest and trough in the same position as other, they are said to be **in phase**. There is no phase difference in these waves.

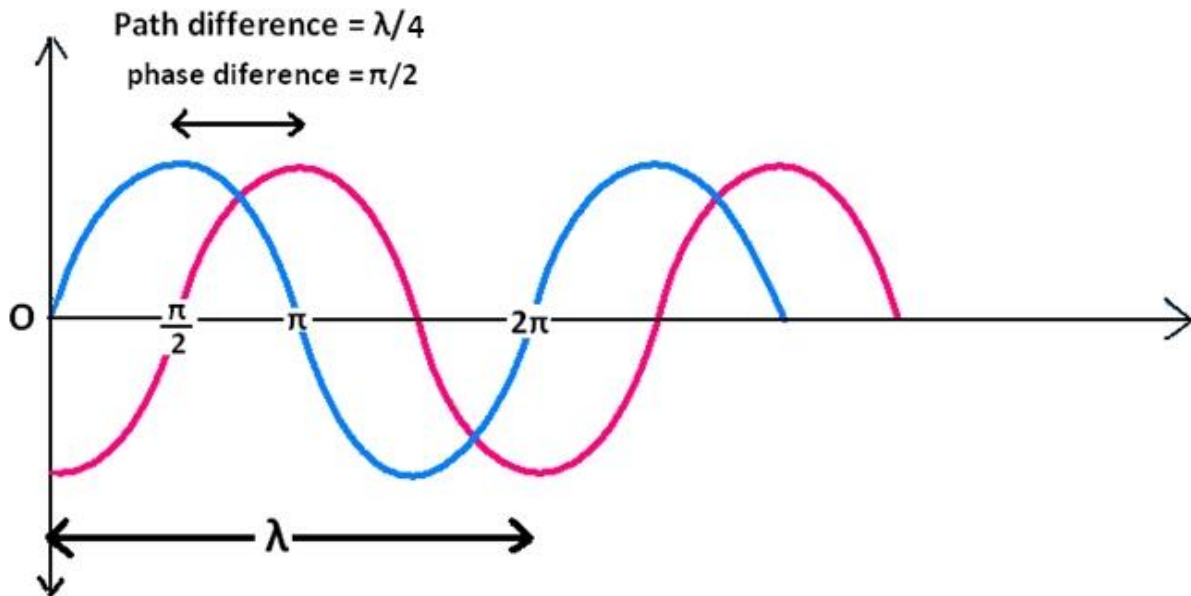
If the crests and troughs of the waves do not coincide with each other, they are said to be **out of phase**.

If the crest of one wave is in the same degree as the other's trough, then they are completely out of phase. They are said to be **in antiphase**. Their path difference is $\lambda/2$.

Coherence: The sources of waves are called coherent if they have the same wavelength, frequency and the two waves are exactly in phase or keep exactly the same phase difference all the time.

Path difference: The difference in distance of waves from each source to a particular point is called the path difference. It is measured as fractions of wavelength.

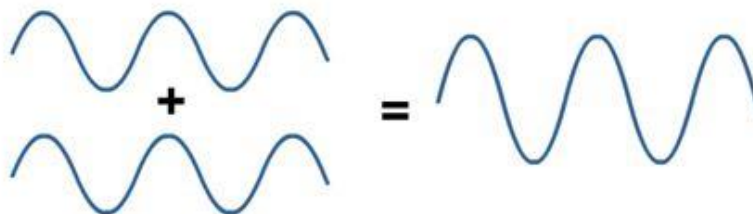
Phase difference: Phase difference is the same as path difference i.e. the difference in distance of two waves. But it is measured as degrees or radians.



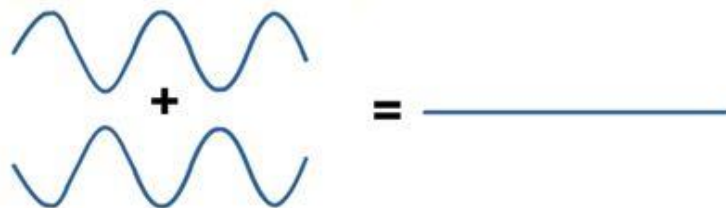
Superposition: The principle of the superposition states that: Where two or more waves meet, the total displacement at any point is the sum of the displacements that each individual wave would cause at that point.

If the two waves meet in phase, the superposition is constructive. Meaning that the amplitude will double the original wave. If two waves meet in antiphase, then the superposition is destructive. Meaning that the amplitude will be zero.

Constructive Interference



Destructive Interference



Experiment: Demonstration with ripple tank

34 recognise and use the relationship between phase difference and path difference

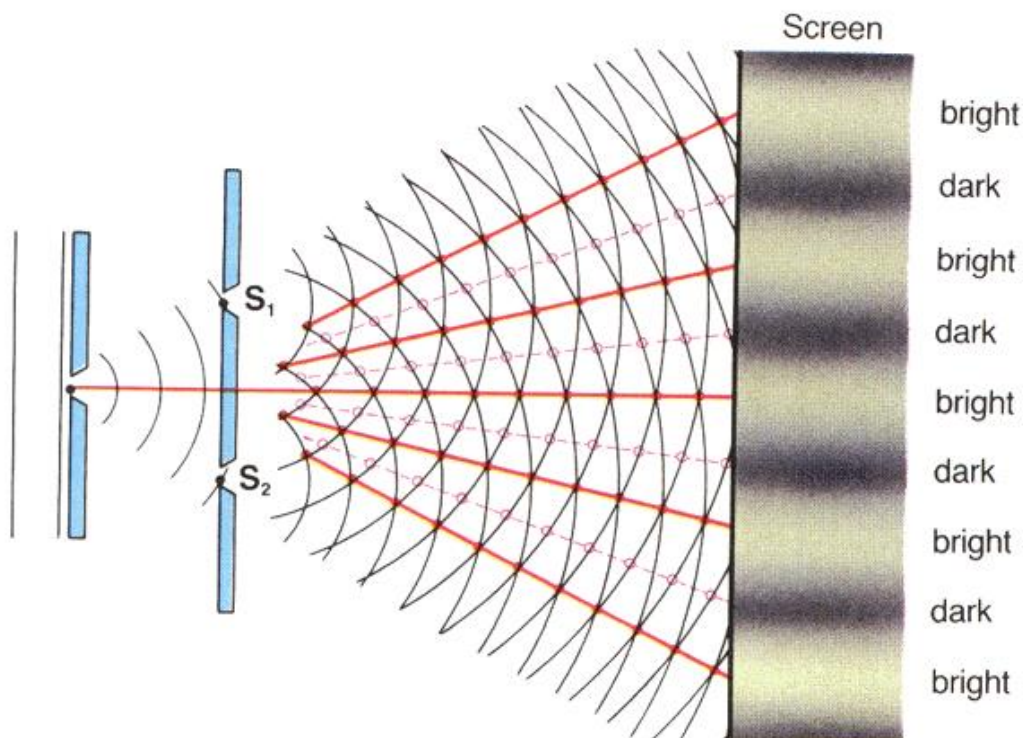
Interference

Interference is the effect of the superposition of waves.

When two coherent waves interact with each other, the point in space where two crests or two troughs meet will be constructive interference. The point in space where a crest meets a trough will result in cancellation of each other called destructive interference.

In Young's slits experiment, light first passes through a single slit and diffracts. The light then passes through two slits. These slits act as a source of light waves.

The two wave diffract and overlap. When they overlap, there can be constructive or destructive interference. In the diagram below, all the constructive interference wavefronts are in red and all the destructive interference are in light pink. These form antinodal and nodal lines.



For constructive interference the path difference between the two waves must be a whole number of wavelengths or an even number of half wavelengths $\frac{2\lambda}{2}, \frac{4\lambda}{2}, \frac{6\lambda}{2}$ etc.

For destructive interference to occur the path difference between the two waves must be an odd half a wavelength $\frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}$ etc.

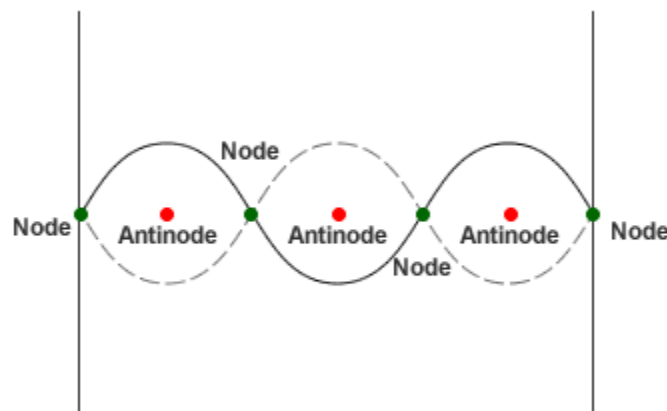
35 explain what is meant by a standing (stationary) wave, investigate how such a wave is formed, and identify nodes and antinodes

Waves can be classified into two types: progressive and stationary.

Progressive waves are waves in which the positions of its peaks and troughs are moving. These waves are important because of their properties as energy carriers.

A standing wave remains in a constant position i.e. the peaks and troughs are not moving. Their importance lies in oscillation that occur in many systems, including stretched strings and in column of air and in structures such as bridges and vehicle components.

In these waves the point with maximum displacement (maxima) is known as antinodes and the point with no or minimum displacement (minima) is known as nodes.



Standing waves can occur when the medium is moving in the opposite direction to the wave or it can arise in a stationary medium as a result of interference between two waves travelling in opposite directions (the most obvious source – guitars etc.).

Examples of a stationary wave: Guitar string

An example of a stationary wave is the wave set up when the string of a guitar is plucked. When the string is plucked, it vibrates. Parts of the string vibrate to and fro, while other parts do not move. At its simplest, the string vibrates in a single loop, with a stationary point at either end and a point of maximum oscillation in the middle.

The shape of the vibrating guitar is due to the formation of a stationary wave on it. At the instant the string is plucked a progressive transverse wave travels along it from left to right. This wave is reflected

back from the end of the string, and the result is a stationary wave. The principle of superposition can be used to explain how two progressive waves travelling in opposite direction can produce stationary wave.

Harmonics

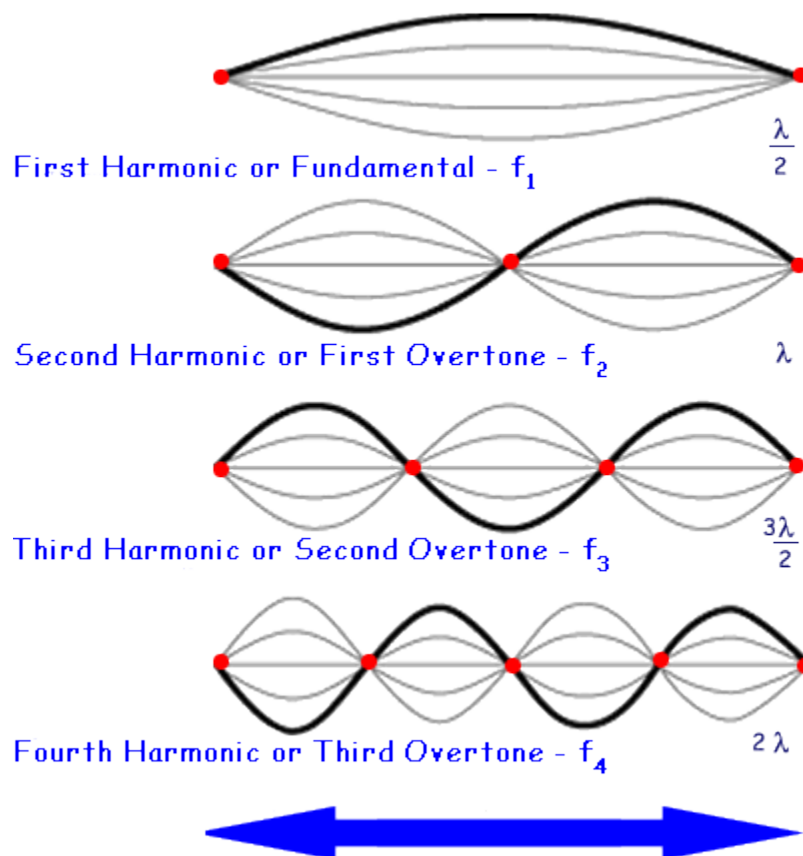
The standing wave pattern is only created within the medium at specific frequencies of vibration. These frequencies are known as harmonic frequencies, or merely harmonics. At any frequency other than a harmonic frequency, the interference of reflected and incident waves leads to a resulting disturbance of the medium that is irregular and non-repeating.

For a string stretched between two rigid boundaries, it has a node on both the end. Given this restriction, it can be shown that the only waves that are possible on the string are those where:

$$\lambda = \frac{2l}{n}$$

where l = the length of the string and n is any whole number like 1, 2, 3 etc.

This means that the node will occur on the string at a distance of $0, \lambda/2, \lambda, 3\lambda/2$ from the end of it, and that neighbouring nodes are separated by a distance of $\lambda/2$.

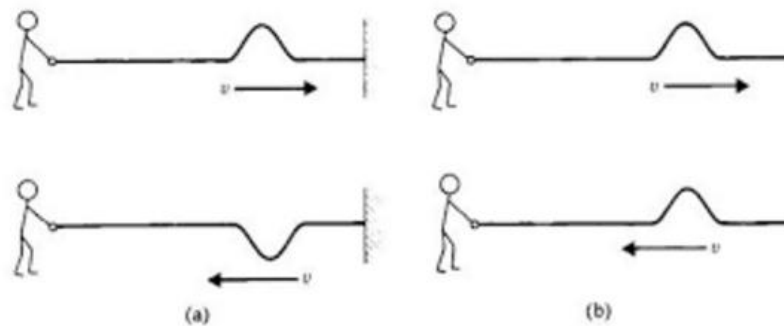


The fundamental frequency or first harmonic happens when the string vibrates with a wavelength twice the length of the string. The second and the rest can be found out by the equation discussed above.

Reflection at the end of the string

The formation of a stationary wave on a string relies on the reflection of a progressive wave at the ends of the string.

What happens to a wave moving through a medium at the end of that medium? It depends on whether the end is fixed or free. If the end is fixed, a hard reflection occurs and the wave change phase of 180° . If the end is free, reflection also occurs but there will be no phase change.



(a) Fixed boundary (b) Free boundary

Finding the frequency for harmonics

Equations:

1. $v = \sqrt{\frac{T}{\mu}}$, where T is the tension in the string and μ is the mass per unit length of the string.
2. $v = f\lambda$
3. $\lambda = \frac{2l}{n}$

Substituting all these equation, we get,

$$f = \frac{n}{2l} \times \sqrt{\frac{T}{\mu}}$$

Worked example

A piece of copper wire is fixed firmly at one end, and the other end is passed over a pulley and attached to a mass of 2 kg. The length of the wire between the fixed support and the pulley is 1.5m. Separate measurements show that the mass per unit length of the wire is 20 g m^{-1} . What is the fundamental frequency of the wire if it is set in free oscillation?

Ans: Since, they wanted fundamental frequency, $n = 1$
 $T = \text{Weight of mass} = 2 \times 9.81 = 19.6$
 $\mu = 20/1000 = 0.02$
 $l = 1.5$

$$f = \frac{1}{2 \times 1.5} \times \sqrt{\frac{19.6}{0.02}} = 10.4 \text{ Hz}$$

Experiment: Melde's experiment, sonometer

36 recognise and use the expression for refractive index ${}^1\mu_2 = \sin i / \sin r = v_1/v_2$, determine refractive index for a material in the laboratory, and predict whether total internal reflection will occur at an interface using critical angle

Relation of refractive index, sine angle of incidence and sine of angle of refraction. This relationship is known as Snell's law.

$${}^1\mu_2 = \frac{\sin i}{\sin r}$$

${}^1\mu_2$ indicates the refractive index of wave moving from medium 1 to medium 2.

Relation of refractive index and speed

$${}^1\mu_2 = \frac{\text{speed in medium 1}}{\text{speed in medium 2}} = \frac{v_1}{v_2}$$

$${}^1\mu_2 = \frac{v_2}{v_1} = \frac{1}{{}^1\mu_2}$$

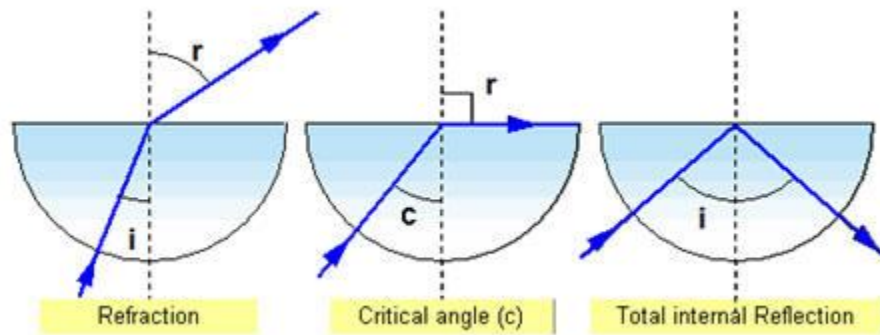
Worked Example

A ray of light enters a diamond. If it travels at $c = 3 \times 10^8$ m/s in air, how fast does the light travel in diamond. (RI of diamond = 2.42)

- ${}^1\mu_2 = \frac{3 \times 10^8}{v_2}$
- $v_2 = 1.24 \times 10^8$ m/s

Total internal reflection and critical angle

When light falls on the surface of a lighter medium from denser medium at an angle of incidence greater than critical angle, then the light does not refract. It rather reflects in the self-medium. This type of reflection is called total internal reflection.

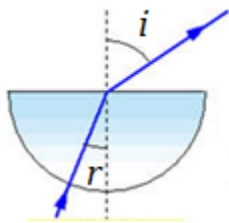


Condition of total internal reflection:

1. Light should fall in the surface of lighter medium from denser medium.
2. Angle of incidence must be greater than the critical angle.

37 investigate and explain how to measure refractive index

Experiment: Measure the refractive index of solids and liquids



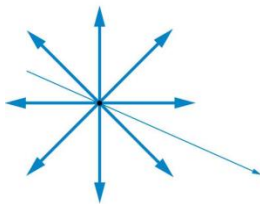
- Find i and corresponding r
- Plot $\sin r$ and $\sin i$
- Gradient = $\frac{1}{\mu_2}$

38 discuss situations that require the accurate determination of refractive index

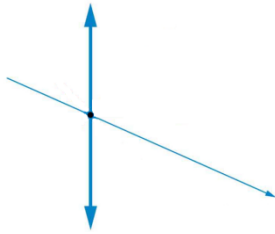
Sometimes the refractive index of a material needs to be known very accurately. For example, the glass used to make spectacle lenses must have a precisely known refractive index if the lens grinder is to match the lens shape to the exact power needed for a person's eye prescription.

39 investigate and explain what is meant by plane polarised light

- When the oscillations in a light take place in all planes at right angles to the direction of travel, it is said to be unpolarised light.



- When the oscillations in a light take place in one plane at right angles to the direction of travel, it is said to be polarised light.

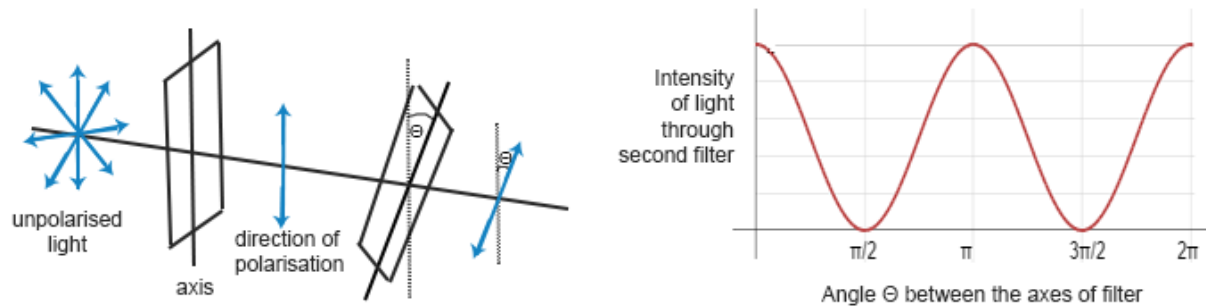


The phenomenon of polarization is only showed by transverse waves.

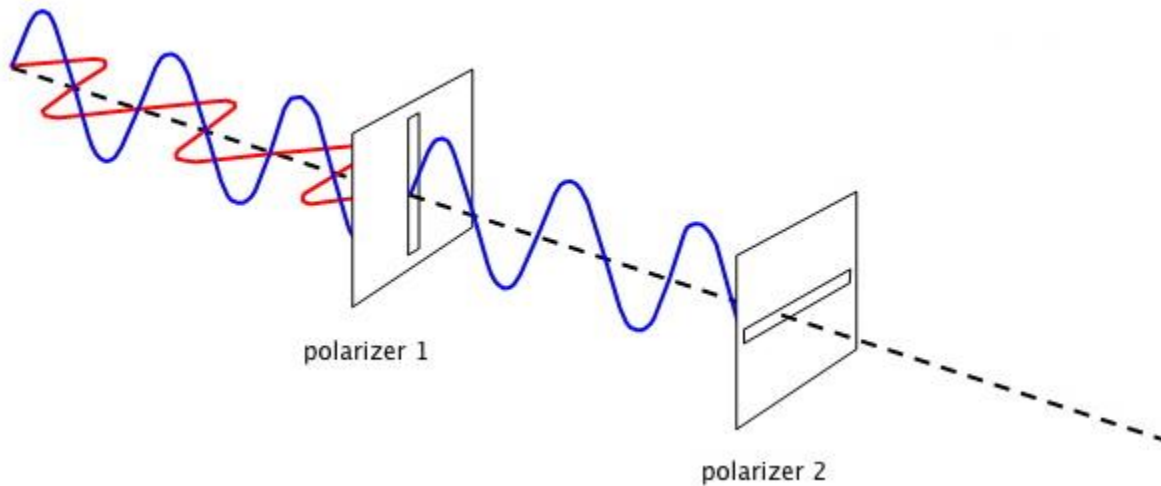
Polarising filter

If unpolarised light encounters a polarizing filter, some of it is absorbed and the emerging light is polarized.

If polarized light encounters a polarizing filter, polarized light emerges, and its brightness and plane of polarization depend on the orientation of the filter.



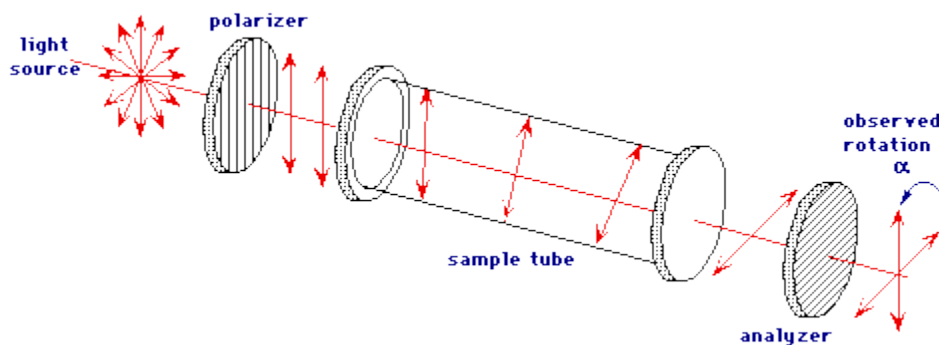
If two polarizing filters are arranged so that they are orientated at right angles to each other, then they will completely absorb unpolarised light. The filters are said to be crossed.



Optical activity

Optically active substances such as sugar solutions rotate the plane of polarization by an amount of proportion to their concentration and the depth of liquid through which the light travels. This can be used to measure the concentration of sugar solutions. The process is called polarimetry and is used in confectionery industry to manufacture sweets.

Experiment: Models of structures to investigate stress concentrations



Two polarizing filters and a 360° protractor can be used to measure the effect of the concentration of a sugar solution on the plane polarization of light, but simple polarimeters are widely available.

Distilled water is put into the cell to check that the scale reading is zero when the filters are crossed and the light-emitting diode (LED) blocked out. A number of sugar solutions of different concentration (20 – 100g in 100 ml of distilled water) are prepared. The cell is filled to a fixed level with the solution. The upper filter is rotated until the light source disappears. The angle of

rotation is measured. The angle is found for all known concentrations and some unknown solutions, including those containing clear honey and syrup.

A graph of the angle of rotation against the concentration is plotted and used to find the values for the unknown concentrations.

40 investigate and explain how to measure the rotation of the plane of polarization

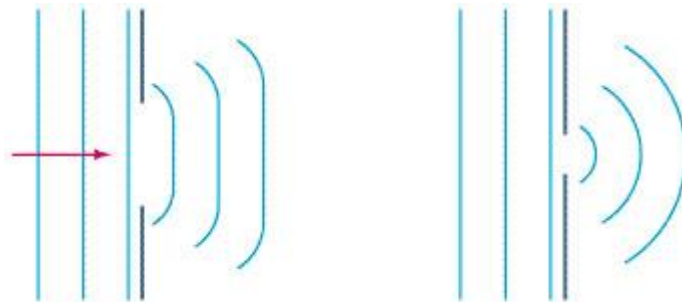
You need a polarising filter with a known plane of polarisation (usually marked on the filter). It should be mounted in a holder with an angle scale.

To measure the plane of polarisation (of a beam of light say) you place the filter in the beam and rotate the filter; when the amount of light transmitted is a maximum (e.g. measured with a light meter) the plane of polarisation of the filter is the same as the plane of polarisation of the light. You just read-off the angle.

41 investigate and recall that waves can be diffracted and that substantial diffraction occurs when the size of the gap or obstacle is similar to the wavelength of the wave

When a wave passes through a gap or around a barrier it may be deviated from its path. This deviation is called diffraction.

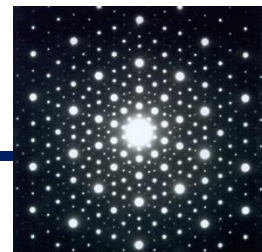
The amount of diffraction that occurs depends on the relationship between the size of the gap or the object and the wavelength of the wave. When the two are similar in size, diffraction occurs.



Experiment: Demonstration using a ripple tank

42 explain how diffraction experiments provide evidence for the wave nature of electrons

A beam of electrons were directed at a crystal in an experiment. This produced a pattern like this:



The electron beam must have diffracted through the layers of atoms in the crystal. This proves that electrons can behave like waves. The wavelength of the electron must be similar to the length of the gap in layers of atoms.

43 discuss how scientific ideas may change over time, for example, our ideas on the particle/wave nature of electrons

Just like most theories, electrons were initially thought to be particles. However, in 1924 de Broglie suggested it might have wave properties which was later confirmed by Clinton Davisson and George Thomson by the electron diffraction experiment.

44 recall that, in general, waves are transmitted and reflected at an interface between media

Partial reflection

In most cases of reflection, not all the incident light is reflected. In general, at any boundary between media, some wave energy passes across the boundary – it is **transmitted** – whilst some of the energy is reflected. You may have noticed this when trying to look under a water surface which is reflecting a lot of light.

Experiment: Demonstration using a laser

45 explain how different media affect the transmission/ reflection of waves travelling from one medium to another

Density of materials affects the transmission and reflection of waves travelling from one medium to another. The greater the difference in density between the two materials, the stronger the reflection occurs.

Some other boundary behavior are below:

- the wavelength is always greatest in the least dense medium,
- the frequency of a wave is not altered by crossing a boundary,
- the reflected pulse becomes inverted when a wave in a less dense medium is heading towards a boundary with a more dense medium,
- the amplitude of the incident pulse is always greater than the amplitude of the reflected pulse.

46 explore and explain how a pulse-echo technique can provide details of the position and/or speed of an object and describe applications that use this technique

Finding position

Radar sends a pulse of radio waves which hits nearby object and reflects back to the detector. The time taken is measured, and we know the speed of radio waves i.e. 3×10^8 m/s. Using the equation $distance = speed \times time$, we find the position of an object.

Worked Example

A radar sends a pulse of radio waves, which returns 0.20 ms later. Calculate the distance to the reflecting object. The speed of radio waves is 3×10^8 m/s.

$$distance = speed \times time = 3 \times 10^8 \times 0.20 \text{ ms} = 60\,000 \text{ m}$$

So the distance to the reflecting object is 30 km. (Distance should be halved as the waves have travelled there and back)

Finding speed

To work out the speed of a moving vehicle a radar gun will send out an initial pulse and measure the distance of the vehicle. It will send out a second pulse several seconds later and measure the distance again. Then calculate the distance difference and divide it by total time. You will get the speed of the object.

Worked example

A radar gun sends out an impulse and finds that a car is 50m away. A second impulse is sent out 2s later and the car is now 100m away. Find the speed in which the car is moving.

In 2s, the car has travelled = $100 - 50 = 50\text{m}$

$$\text{So, } speed = \frac{distance}{time} = \frac{50}{2} = 25 \text{ m/s}$$

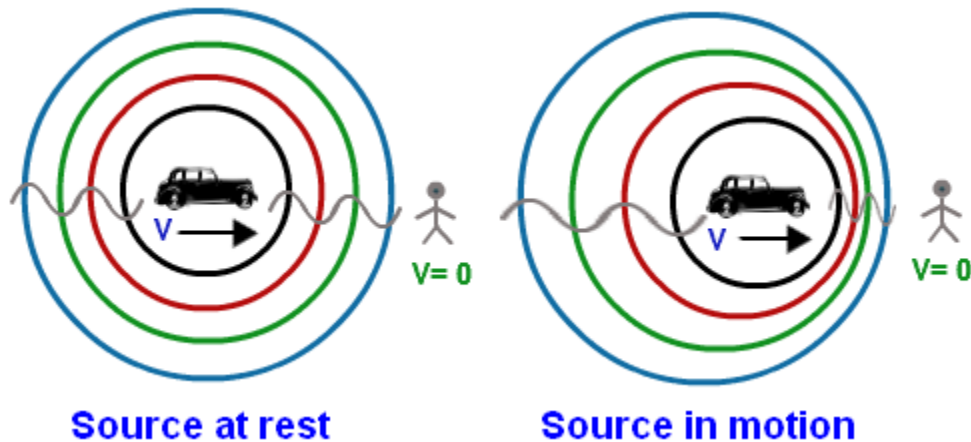
Application

This technique is used by bats, dolphins to move. Engineers have developed similar pulse-echo ranging and imaging systems in a very wide range of technological applications, from sonar on ships and submarines to air traffic control radar, medical imaging and the measurement of distance to asteroids and to the Moon.

47 explain qualitatively how the movement of a source of sound or light relative to an observer/detector gives rise to a shift in frequency (Doppler effect) and explore applications that use this effect

Doppler effect

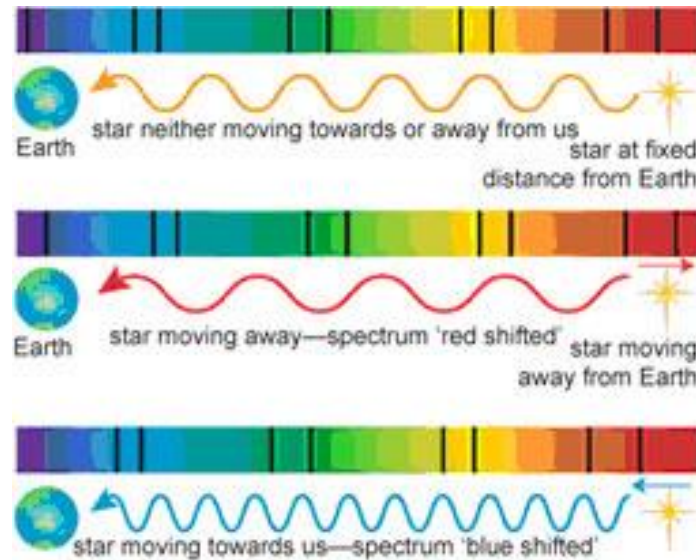
Imagine that you are standing on a pavement and a police car is approaching you. As the police car gets closer the pitch of its siren gets higher. As it moves away the pitch gets lower.



As the siren approaches you the sound waves get bunched up and get closer together. In other words they are of higher frequency. As the siren moves away from you the sound waves spread further apart and are of lower frequency. This effect is called **Doppler effect**. It is defined as the change in frequency of a wave for an observer moving relative to its source. The shift in frequency is proportional to the relative speed of the motion.

Red shift

Another example of this effect can be seen we observe the distant galaxies. If a light emitting object is moving towards a stationary observer, the light waves will bunch up and have a shorter wavelength. In other words it will be shifted to the blue end of the spectrum (**blue-shift**). If a light emitting object is moving away from a stationary observer, the light waves will spread out and have a longer wavelength. In other words it will be shifted to the red end of the spectrum (**red-shift**). So what we observe that the spectra of the distant galaxies are shifted to the red end of the spectrum. This gives the evidence that the universe is expanding.



Doppler radar

Weather monitoring and air traffic control both use radar to find the position and movement of storms and planes, respectively. In both cases, the system uses the basic pulse-echo idea. However, by also measuring any change in the wavelength – the Doppler shift – of the echo compared with the original pulse, the system can calculate the speed of the object reflecting the waves.

Worked example

A radar trap emits a pulse of radio waves of frequency 24 GHz. A car moving at 30 mph causes a change of frequency of 1070 Hz. The reflected pulse from a car in a 30 mph zone has a wavelength of $1.249\,999 \times 10^{-2} \text{ m}$. Was the car moving towards or away from the radar trap, and was it speeding?

Calculate the received frequency using

$$f = \frac{v}{\lambda} = \frac{3 \times 10^8 \text{ m s}^{-1}}{1.249\,999 \times 10^{-2} \text{ m}} = 2.400\,0002 \times 10^{10} \text{ Hz} = 24.000\,0002 \text{ GHz}$$

As the frequency has increased from 24 GHz, the car was moving towards the source.

The change in frequency is 2000 Hz. This is larger than the change at 30 mph, so this car was speeding at approximately double the speed limit as the change in frequency is proportional to the relative speed of the motion.

Experiment: Demonstration using a ripple tank or computer simulation

48 explain how the amount of detail in a scan may be limited by the wavelength of the radiation or by the duration of pulses**Ultrasound**

Sounds waves with frequencies from 20 – 20 000 Hz can be heard by human beings. This is our audible frequency range. Sounds with a frequency above 20 kHz are known as ultrasound. These waves are used in variety of applications, in particular medical scans. This is most familiar to people as scans on unborn babies as it is less harmful than x-rays.

How ultrasound image is created?

Ultrasound imaging relies on the fact that at any boundary between media, there will be a partial reflection of sound waves. The difference in density at any boundary where a reflection occurs dictates how strong the reflection is. This type of tissue boundary involved in any reflection can be determined as this affects the proportion of energy reflected. The ultrasound transmitting device also acts as the detector for reflections, so it can accurately time how long the echo has taken to return, along with how much energy was reflected. With knowledge of the wave speed, a computer can calculate the depth within the body that each reflection occurs and build up an image showing features in different depths.

How wavelength affects detail?

The shorter the wavelength of the wave, the less diffraction they undergo. Therefore the shorter the wavelength of sound, the less the waves spread out when they travel. This means that shorter wavelengths can map tissues of different interfaces more precisely producing a clearer image.

Ultrasound also uses short pulses (usually lasting a few microseconds). This prevents reflections from nearby interfaces from reaching the transducer before the pulse has finished.

The gap between each pulse must be quite long (usually at least 1 millisecond). This is to make sure that all the reflected waves from one pulse return back to the transducer before the next pulse is emitted.

49 discuss the social and ethical issues that need to be considered, e.g. when developing and trialing new medical techniques on patients or when funding a space mission

Remember the acronym **SEES**.

Safety

Will it cause more harm than good? e.g. an X-ray could solve a medical problem, but are known to damage cells. Long exposures can cause cancer.

Ethical

Is it morally right? e.g. ultrasound scans can reveal the gender of a foetus. However this may lead to unnecessary termination.

Expense

Do benefits outweigh the cost? e.g. MRI scanner can produce a much clearer image than ultrasound and are safer than X-rays but are more expensive.

Social

Will it benefit society or adversely affect people? e.g. Doctors can scan foetuses for birth problems such as abnormal growth which they could put right. Alternatively this could lead to termination.

Chapter: DC Electricity

50 describe electric current as the rate of flow of charged particles and use the expression $I = \Delta Q / \Delta t$

An electric current is the rate of flow of charged particles:

$$I = \frac{\Delta Q}{\Delta t}$$

where I is the current and ΔQ is the charge that flows past a point in a time interval Δt .

The SI unit of electric charge is the coulomb, C, and the SI unit of current is the ampere, A:

$$1\text{A} = 1\text{C s}^{-1}$$

51 use the expression $V = W/Q$

Potential difference, p.d. (or voltage, V), is a measure of energy transfer between two points in electric circuit. When a charge of 1C moves through a p.d. of 1V then the energy transferred is 1J:

$$V = \frac{W}{Q}$$

where W is the work done (i.e. the energy transferred).

The SI unit of potential difference is the volt, V:

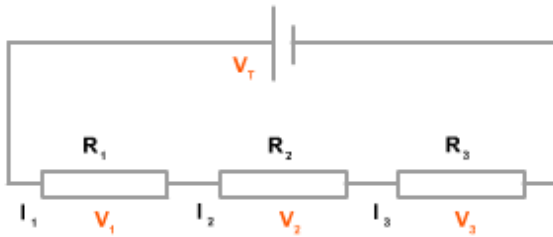
$$1\text{V} = 1\text{J C}^{-1}$$

52 recognise, investigate and use the relationships between current, voltage and resistance for series and parallel circuits, and know that these relationships are a consequence of the conservation of charge and energy

Resistors in series

At any point in a circuit, the charge flowing in must be the same as the charge flowing out. When resistors are joined in series, the current is the same through all of them.

The total energy supplied per coulomb of charge is converted by the resistors. Therefore, the sum of the individual p.d.s across each resistor is equal to the total p.d. applied.

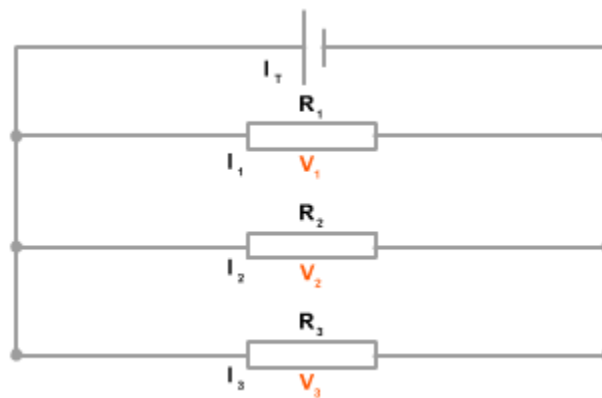


$$V_{total} = V_1 + V_2 + V_3 = IR_1 + IR_2 + IR_3$$

$$R_{total} = \frac{V}{I} = R_1 + R_2 + R_3$$

Resistors in parallel

When resistors are joined in parallel, the total current into any junction is equal to the sum of the currents coming out. The p.d. across each resistor is equal to the p.d. applied.



$$I_{total} = I_1 + I_2 + I_3 = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_2}$$

53 investigate and use the expressions $P = VI$, $W = VIt$. Recognise and use related expressions, e.g. $P = I^2R$ and $P = V^2/R$

The rate at which energy is transferred to an element in a circuit is called the power dissipation. It is measured in watts. The equations of power are:

1. $P = VI$
2. $W = Pt$
3. $P = I^2R$
4. $P = \frac{V^2}{R}$

54 use the fact that resistance is defined by $R = V/I$ and that Ohm's law is a special case when $I \propto V$

Ohm's law states that:

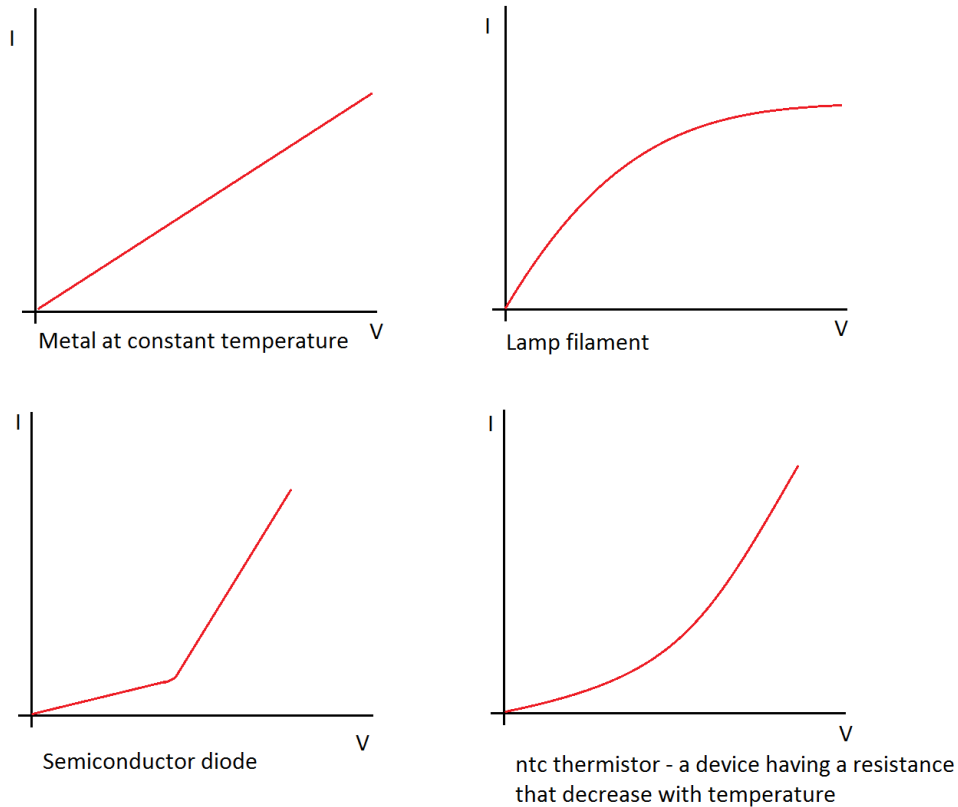
"Provided the temperature and other physical factors remain constant, the current through a wire is proportional to the potential difference across its ends."

This leads to a very simple mathematical relationship:

$$I = \frac{V}{R}$$

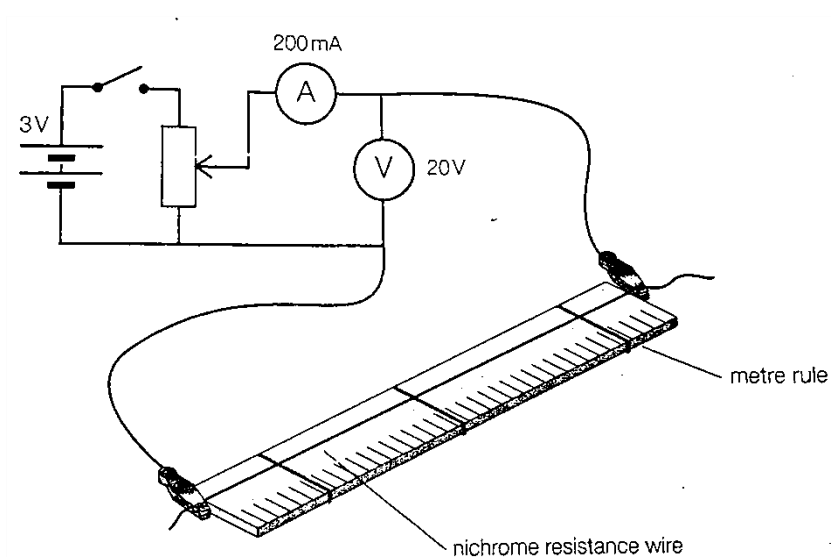
55 demonstrate an understanding of how ICT may be used to obtain current-potential difference graphs, including non-ohmic materials and compare this with traditional techniques in terms of reliability and validity of data**56 interpret current-potential difference graphs, including non-ohmic materials**

If the relationship between the current through a conductor and the pd across its ends is explored, the relationship is found to vary according to the circuit element. Conductors for which I-V graphs are straight lines are said to be **ohmic conductors** – a metal at a constant temperature is an example of such a conductor. Where I-V graph is non-linear, the conductor is said to be **non-ohmic** – a lamp filament and a semiconductor diode are two examples of non-ohmic conductors.



Investigate I–V graphs for filament lamp, diode and thermistor

Experiment: To investigate I-V characteristics of a metallic conductor



Cut just over a metre length of 0.25 mm nichrome wire and tape it to a metre rule as shown in Figure 13.2. Set up a potential divider circuit to provide a variable p.d. and connect a 1.000 m

length of wire to the circuit by clips. Ensure that the clips make a good connection. Set the p.d. to its minimum value and switch on. Gradually increase the p.d. and record the values of p.d., V and current, I , up to the maximum p.d. possible. Tabulate your values of V and I . Plot your data on a graph will give a straight line passing through origin as in graph we saw previously.

57 investigate and use the relationship $R = \rho l/A$

Resistance of a uniform conductor depends on:

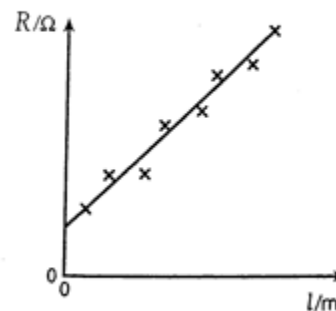
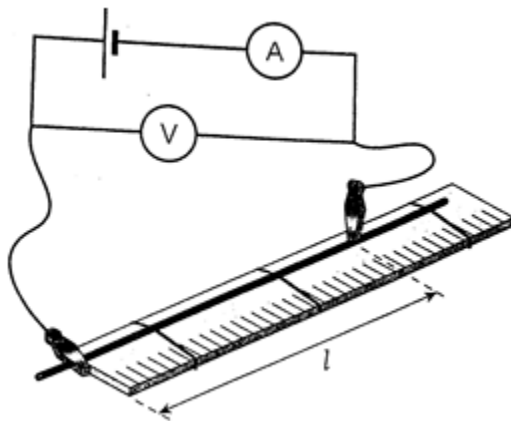
- its length (l)
- its cross-sectional area (A)
- the material of which it is made.

i.e. $R = \frac{\rho l}{A}$;

where ρ is the resistivity of the material from which the conductor is made. The SI unit of resistivity is Ωm .

Measure resistivity of a metal and polythene

Experiment: To measure the resistivity of graphite



A standard technique for determining the resistivity of material in the form of a wire is to calculate the cross-sectional area from measurements of the diameter and then get a value for $\frac{R}{l}$ by a graphical method.

An interesting experiment is to do this for graphite in the form of pencil 'lead'. The diameter, d , of the lead is measured with a micrometer at four places along its length, at different

orientations, to give a good average. The lead is taped to a half-metre rule, with about 1 cm protruding beyond the zero end of the rule, and the circuit in the figure is set up.

Firm contact is made at different lengths, l , along the lead. The current, I , and potential difference, V , are recorded, and the corresponding resistance, R , is calculated for each value of l . A graph of R against l is then plotted – it would be sensible to plot l in metres at this stage.

$$R = \frac{\rho l}{A}$$

where $A = \frac{\pi d^2}{4}$ and $\frac{R}{l}$ is the gradient of the graph.

58 investigate and explain how the potential along a uniform current-carrying wire varies with the distance along it and how this variation can be made use of in a potential divider

The potential divider

A potential divider consists of two resistors connected in series with a supply. Because they are in series, the same current flows through both resistors, and the potential difference of the supply is divided between them.

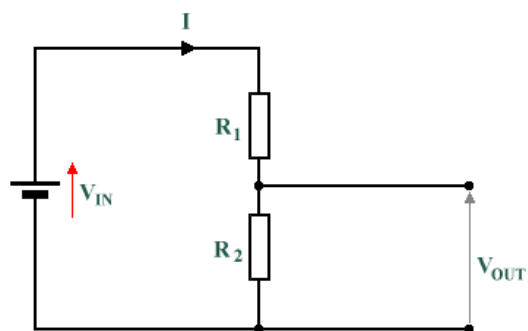
Using Ohm's law:

$$V_1 = IR_1 \text{ and } V_2 = IR_2$$

Dividing the first of these equations by the second gives:

$$\frac{V_1}{V_2} = \frac{R_1}{R_2}$$

The circuit can be used as a potential divider to provide a p.d. to another device or another circuit that is less than the p.d. of the power supply. If one of the resistors is variable, the p.d. from the potential divider can be easily adjusted.



Potential divider using resistance wire

A potential divider circuit can be used using a single piece of resistance wire in place of two resistors. This provides a continuously variable p.d. from zero up to the p.d. of the supply.

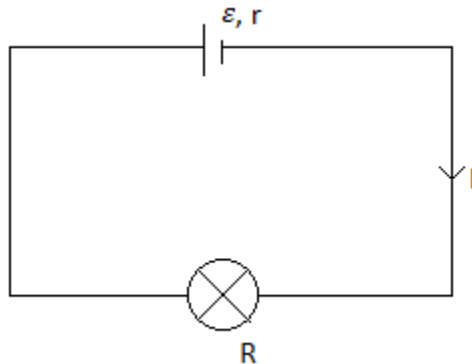
If a uniform wire is used, the resistance between any two points is proportional to the distance between them. When the wire carries a circuit, the graph of p.d. between one end and any other point is a straight line.

Use a digital voltmeter to investigate 'output' of a potential divider

59 define and use the concepts of emf and internal resistance and distinguish between emf and terminal potential difference

Electromotive force (usually written emf) is a measure applied to a source of electrical power such as battery. It is the energy available per coulomb of charge.

Not all of the chemical energy converted to electrical energy inside a cell emerges at the terminals of the cell. When a charge flows and produces in the cell, some of the energy is used up 'pushing' the internal resistance, r of the cell.



rate of energy lamp converted in cell = rate of work done against internal resistance + rate of work done in light

$$\epsilon I = I^2 r + IR$$

$$\epsilon = Ir + IR$$

$$\epsilon = V + Ir$$

where V is terminal potential difference.

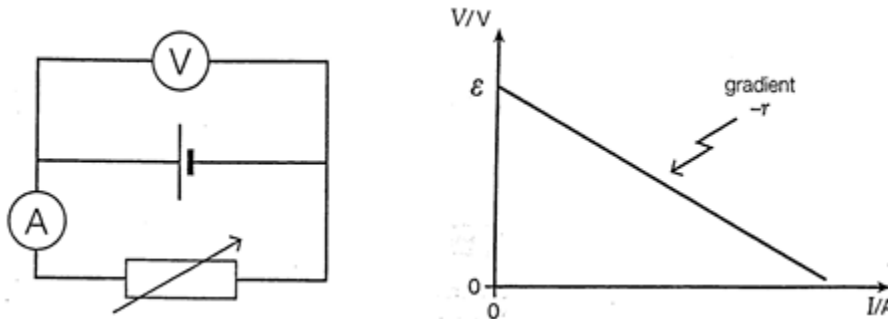
Measure the emf and internal resistance of a cell, e.g. a solar cell

Experiment: To find the e.m.f and internal resistance of a cell.

The figure shows a standard circuit to find the e.m.f and internal resistance for a zinc-carbon cell.

Starting with the variable resistor at the highest voltage (to minimize any heating effects), record the current in the cell and the potential difference across its terminals for different values of the resistor.

If a graph of V against I is plotted, we would expect to get a straight line of gradient $-r$ and the intercept on the y axis. In practice, the line may not be straight because the internal resistance may not be constant – particularly for larger currents.



A typical set of observations is recorded in a table. Plot a graph of this data and hence determine values of e.m.f and internal resistance of the cell.

60 investigate and recall that the resistance of metallic conductors increases with increasing temperature and that the resistance of negative temperature coefficient thermistors decreases with increasing temperature

The resistance of many electrical components changes with temperature. A current flowing through a component can raise its temperature and so change its resistance.

Metals

The resistance of most metals increases with temperature.

- There are free electrons in metals.
- As electrons move through the metal, they collide with vibrations of the lattice and are scattered.
- If the metal gets hotter, the atoms vibrate more vigorously.
- There are then more collisions between the atoms and the electrons.
- If the current decreases, the resistance has increased.

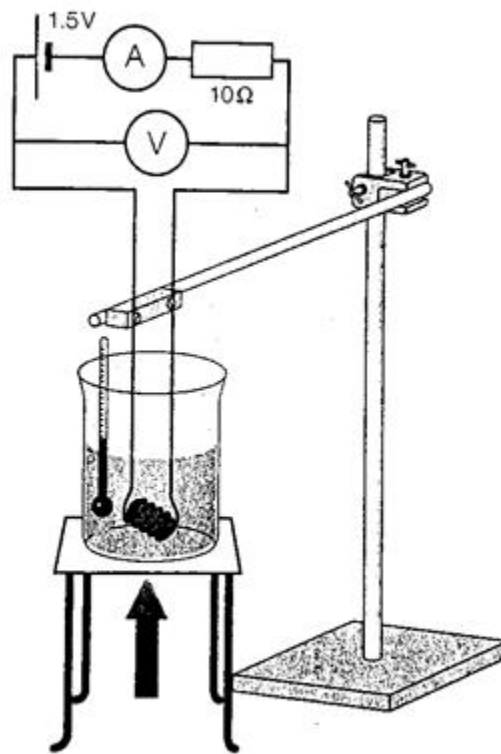
Semiconductors

Semiconductor materials contain far fewer free electrons than metals.

- Semiconductors with a negative temperature coefficient (NTC) have resistance that decreases with temperature. As the material gets hotter, increased vibration of the atoms releases more electrons. This increases the current (as $I = nqvA$, n increases, so I also increases): resistance has decreased.
- In semiconductors with positive temperature coefficient (PTC), the resistance increases with increasing temperature.

Use of ohmmeter and temperature sensor

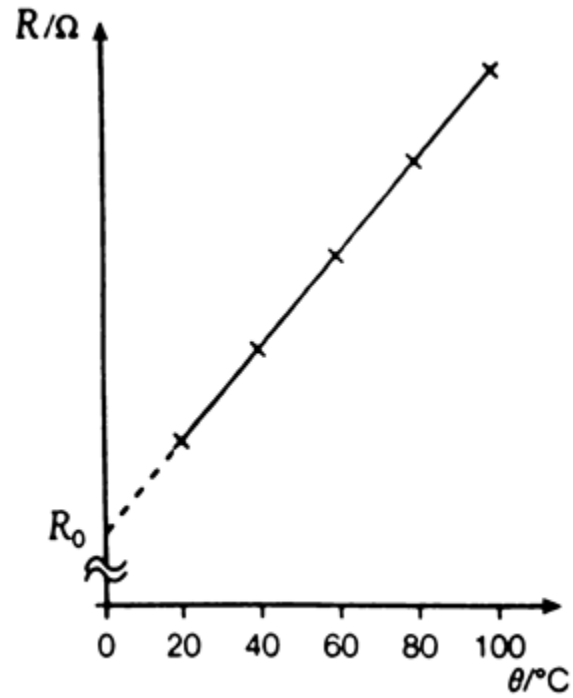
Experiment: To investigate the effect of temperature on the resistance of a copper wire



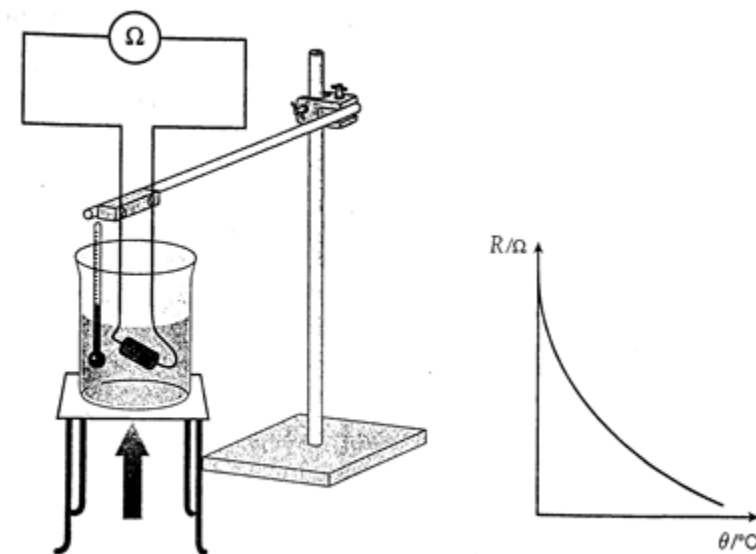
A coil of copper should be formed by winding about 2 metres of enameled 0.234 mm diameter copper wire around a short length of plastic tube. About 2 cm of each end of the wire should be scraped clean to form a good electrical contact in the connector block.

As the resistance of the coil is less than $1\ \Omega$, a voltmeter/ammeter method is needed to measure the resistance. Record the p.d. and current for a range of temperature from room temperature up to the boiling point of the water. Put your results in a table.

Plot a graph of resistance against temperature. Start at 0°C on the x-axis and choose a scale of y-axis such that a value for the resistance at 0°C can be read off. Your graph should look like this.



Experiment: To investigate the effect of temperature on the resistance of a thermistor can be investigated using the apparatus.



Start with the thermistor immersed in crushed ice. Record the lowest steady temperature and the corresponding resistance of the thermistor.

Now heat up the beaker of ice, being careful to keep the leads away from the flame and hot gauze. At intervals of about 10°C , take away the Bunsen burner, stir thoroughly and record the temperature and corresponding resistance. Continue every 10°C until the water boils. Put your results in a table.

Plot a graph of resistance against temperature. You should get a curve like that in the figure. This graph shows that the rate at which the resistance decreases is initially very rapid and then gradually become less.

61 use $I = nqvA$ to explain the large range of resistivities of different materials

A material with a small value of resistivity will be a good conductor. A good conductor will have large number of free electrons. The number density n is the number of conduction (free) electrons per unit volume of a material:

$$n = \frac{I}{QvA}$$

where I is the current in a sample, q is the charge on an electron ($1.6 \times 10^{-19} \text{ C}$), v is the drift velocity of the free electrons, and A is the cross-sectional area of the sample.

62 explain, qualitatively, how changes of resistance with temperature may be modelled in terms of lattice vibrations and the number of conduction electrons

Follow 60

Chapter: Nature of Lights

63 explain how the behaviour of light can be described in terms of waves and photons

Light behaves like a wave under some circumstances and like a particle under others. This means that neither the wave model nor the particle model of classical physics is adequate for understanding the behavior of light. For a full understanding of light we have to regard it as a **wavicle**, a wave-particle object that behaves sometimes like a classical wave and at other times like a classical particle – and at other times like a mixture of two. This is clear if we examine the **photoelectric effect**. And this says light is **quantized**, consisting of particle-like packets of energy. Each packet is called photon.

64 recall that the absorption of a photon can result in the emission of a photoelectron

When a single photon is absorbed by a metal surface, its energy is transferred to a single electron, which may then be released from the metal. This process is called **photoelectric emission** and the released electron is known as **photoelectron**.

65 understand and use the terms threshold frequency and work function and recognise and use the expression $hf = \phi + \frac{1}{2}mv_{\max}^2$

The minimum energy required to release the photoelectron from the metal surface is called **work function**, ϕ , of the metal. For photoelectric emission to occur, the energy of the photon must be equal to or greater than the work function.

Threshold frequency, f_0 , is the minimum frequency to allow photoelectric emission to occur.

$$E = hf_0 = \phi$$

where h is the Planck constant (6.63×10^{-34} Js).

If the energy of the photon is greater than the work function, then the photoelectron can acquire some kinetic energy. The kinetic energy of the photoelectron is completely independent on the intensity of the light but it only depends on the frequency of the incident light. By energy conservation:

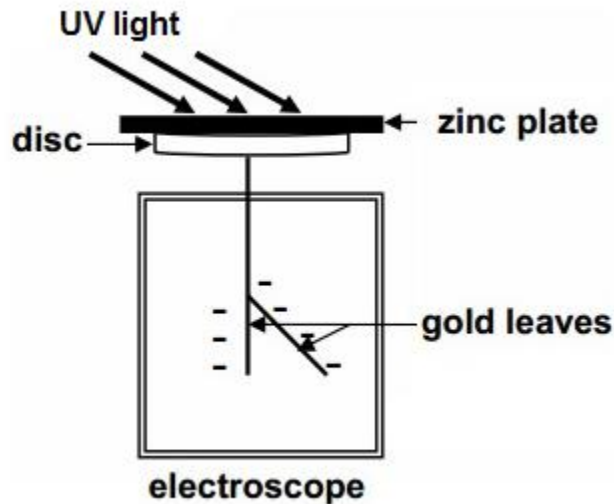
$$hf = \phi + \frac{1}{2}mv_{\max}^2$$

photon energy = work function + maximum kinetic energy of electron

Photoelectrons may have less than the maximum kinetic energy if they transfer energy to the metal on their way to the surface.

If the photon energy is less than the work function, then the electron won't release. However, the energy can cause a slight amount of heating on the metal.

Demonstration of discharge of a zinc plate by ultra violet light



The leaf on a negatively charged gold leaf electroscope slowly falls if a zinc plate resting on the cap of electroscope is irradiated with ultraviolet light. An investigation like this shows a number of interesting features:

- i. With no light falling on the zinc plate, the leaf falls only very slowly if at all.
- ii. Ultraviolet light shone onto the plate causes the leaf to fall rapidly. This fall is stopped if a shade of glass is placed between the zinc plate and the ultraviolet lamp.
- iii. The rate of fall of the leaf depends on the distance of the lamp from the plate. The closer the lamp, the more rapid the fall.
- iv. Visible light has no effect on the behavior of the leaf.
- v. A positively charged electroscope is unaffected by a ultraviolet light.

Regarding photoelectric effect, ultraviolet light was capable of transferring energy to electrons to a metal, giving them a sufficient energy to escape from the metal surface. The leaf of negatively charged electroscope falls as electrons are ejected from the zinc plate decreasing the overall negative charge on the plate. The leaf doesn't fall if the electroscope is positively charged as the ultraviolet light cannot transfer electrons to the plate – only energy.

66 use the non-SI unit, the electronvolt (eV) to express small energies

When dealing with small energies, such as in the photoelectric effect, it is convenient to use a smaller unit than the joule. We use the electronvolt (eV), which is the energy gained when an

electron moves through a potential difference of 1 V. The charge on an electron is $e = 1.6 \times 10^{-19}$ C. So

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

67 recognise and use the expression $E = hf$ to calculate the highest frequency of radiation that could be emitted in a transition across a known energy band gap or between known energy levels

The behavior of light can be modeled as a wave or as a photon (particle). The two models are linked by the relationship:

$$E = hf$$

where E is the energy of the photon (J), h is the Planck constant (6.63×10^{-34}) and f is the wave frequency (Hz).

68 explain atomic line spectra in terms of transitions between discrete energy levels

Spectrum is the result of diffraction of light by prism or any other methods. In a visible spectrum, there are range of colours starting from violet (highest frequency) to indigo, blue, green, yellow, orange and red (lowest frequency). Other electromagnetic radiation can also be spread into spectrum.

The light from a tungsten filament produces a **continuous spectrum**. However, if the light is from low pressured gas such as in gas discharge tube, it produces a line spectrum when the light is diffracted, i.e. only certain lines of distinct colour are present, separated by gaps. These spectra are due to the emission of energy, and so are called **emission spectra**. If light from a tungsten filament lamp is passed through gas which is not hot enough to be incandescent, it produces **absorption spectrum**, i.e. it is the opposite of emission spectra, black lines are coloured, coloured lines are darkened.

When photons from light hits the electrons within an atom, the energy transfers and it causes a transition from high energy state to low energy state. The energy of the emitted photon is equal to the energy difference between the two states. And when the electron returns to its original energy level, a photon is emitted. This photon causes coloured line in an emission spectrum. The darks lines in absorption spectrum are caused because electrons absorbed those photons' energy in order to move to a higher energy level.

Ground state is the energy level with most energy as it in $n = 1$.

69 define and use radiation flux as power per unit area

Solar cells transform light energy into electrical energy. The rate at which a beam of light supplies energy to a particular area is called the radiation flux (or intensity) of the beam. It is shown by the following relationship:

$$F = \frac{P}{A}$$

where F is the radiation flux (Wm^{-2}), P is the power (W) and A is the area perpendicular to the beam (m^2).

Power is the rate of supply of energy, so

$$P = \frac{E}{t}$$

where E is the energy (J) and t is the time (s).

70 recognise and use the expression efficiency = [useful energy (or power) output]/[total energy (or power) input]

A solar cell will not transform all the light energy to electrical energy because it is not perfectly efficient.

For any process or device:

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}}$$

or,

$$\text{efficiency} = \frac{\text{useful power output}}{\text{total power input}}$$

71 explain how wave and photon models have contributed to the understanding of the nature of light

Under certain conditions, light diffracts. Diffraction can only be explained using a wave model.

In the photoelectric effect, a wave model of light predicts that weak radiation would eventually release large numbers of electrons with low energy, but this is not what happens.

The photoelectric effect can only be explained using a photon model. Weak radiation causes instantaneous release of some electrons if the frequency is greater than the threshold frequency. The kinetic energy of individual photoelectrons depends only on the frequency of the radiation, not its intensity.

72 explore how science is used by society to make decisions, for example, the viability of solar cells as a replacement for other energy sources, the uses of remote sensing

Governments across the world are looking for viable ways of providing energy, without the use of fossil fuels. Solar cells provide electricity from a free, renewable source. Scientific knowledge may be used by society to make decisions about the viability of solar cells as a replacement for other energy sources.

Considerations include:

- efficiency of the cells
- cost
- availability of materials
- global energy prices
- impact of continuing use of fossil fuels.

At present, solar cells are of limited use as an energy source. They are often used for small, portable devices such as watches and calculators. Solar cells may be useful in countries that have guaranteed sunshine for most of the year. But until more efficient cells are developed, they are not suitable for places with little sunshine in the winter. The development of more efficient cells is expensive, and industry is not likely to make this investment unless governments also invest in the technology.