PHYSICS
at a glance

Tim Mills

Full Physics content of the

New GCSE

GCSE Science and Additional Syllabus

- One topic per page
- Diagrams and mind maps
- Full colour throughout

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FROM THE AUTHOR

Physics at a Glance contains all the physics material you require for any of the major GCSE examination boards. It begins with the theory of two major ideas in physics, force and energy. We discover that for anything useful to happen there must be a transfer of energy; and then describe that transfer, by waves, electrically, thermally and by nuclear processes, in more depth. To conclude many applications of physics are explored. Not all the material covered may be relevant to your course and you should ask your teacher or use your examination specification to find out which parts you can leave out.

Many examinations only test a small range of topics encouraging you just to learn the bits you need for your examination and then move on. To be successful at physics it is important to try to make connections between important ideas and, therefore, you will find the same ideas appearing a number of times. This is to help you learn physics by reviewing earlier ideas as you examine a wide range of applications.

The book's visual presentation encourages you to use the mind mapping type approach in your revision, which many learners find helpful as this is often how the brain organizes information. It is intended that the book gives you the 'big picture' while a companion traditional textbook can fill in the detail.

Physics is a mathematical science so some of the questions require you to carry out a calculation. Many of these are of the 'show that' type where an approximate answer is given, so that you can check that you are able to reach the correct solution for yourself. It is vital to show how you got to the solution by showing all your calculations. There are always marks for this and is a good habit to develop. Many questions are quite straightforward, but there a couple designed to make you think, sometimes quite hard about the physics. Tackling these, and persisting until you are successful, will develop real understanding of physics.

The GCSE specifications also require you to understand 'How Science Works'. There is a page midway through the book devoted to these ideas together with examples and questions throughout designed to develop your ability to address these issues in context. I hope you enjoy using ***Physics at a Glance*** and your GCSE Physics course.

T. Mills

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PHYSICS
at a Glance

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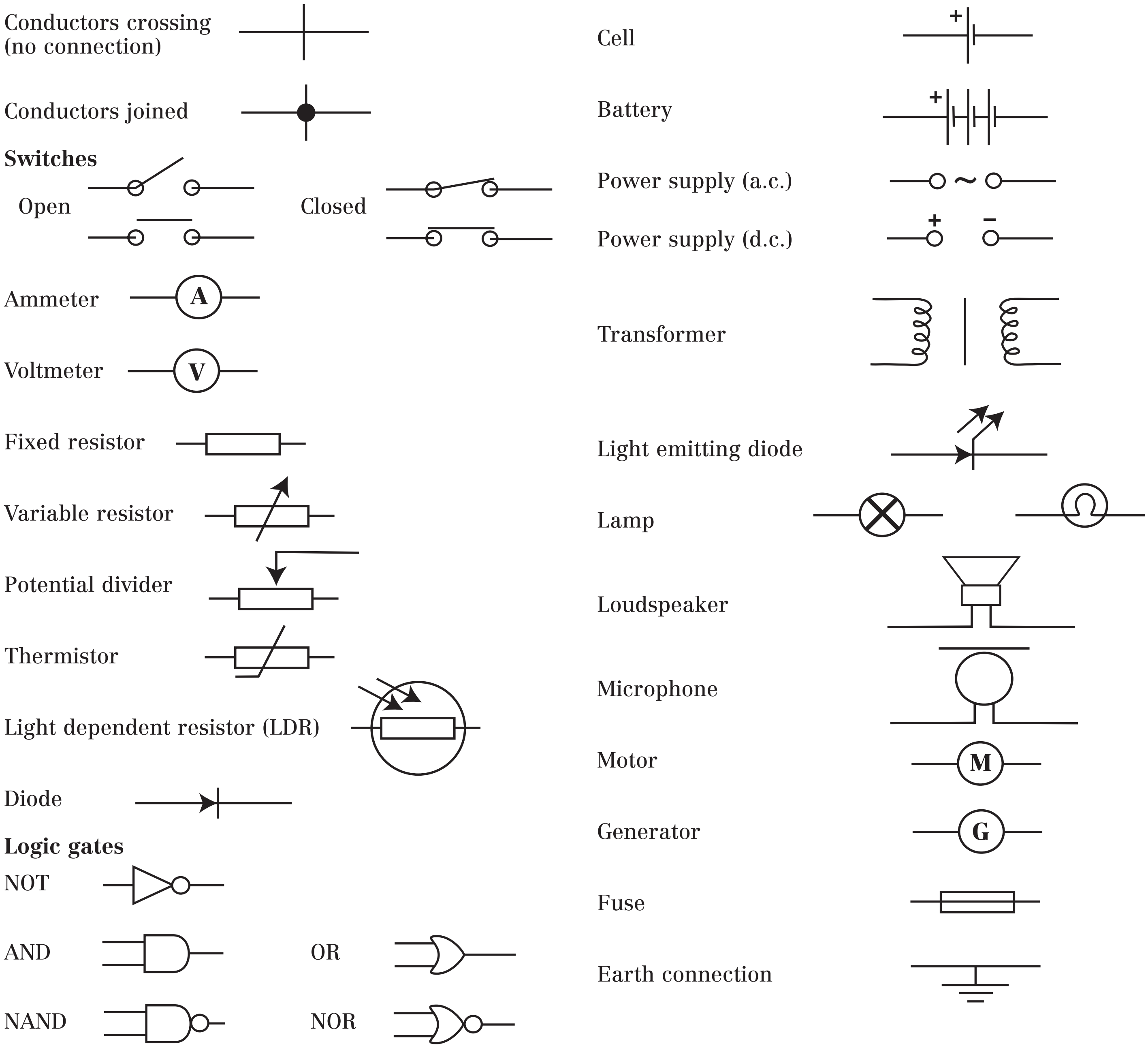
ELECTRICAL CIRCUIT SYMBOLS



FUNDAMENTAL CONCEPTS

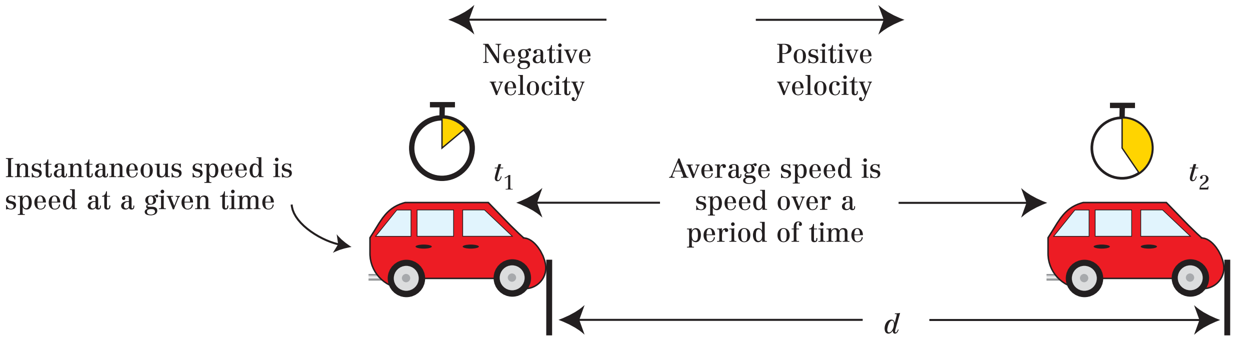
FORCES AND MOTION

Measuring and Describing Motion

$$\text{Speed (m/s)} = \frac{\text{distance (m)}}{\text{time (s)}}$$

Velocity is speed in a given direction (an example of a **vector** – it has size and direction)

$$\text{Average speed (m/s)} = \frac{\text{total distance (m)}}{\text{time taken (s)}}$$



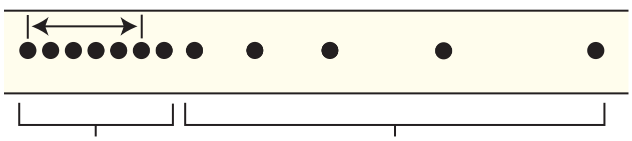
Time over a known distance

$$\text{Acceleration (m/s}^2\text{)} = \frac{\text{change in velocity (m/s)}}{\text{time taken (s)}}$$

Measuring speed

Ticker tape – 1 dot every 1/50$^{\text{th}}$ second

1/10 second

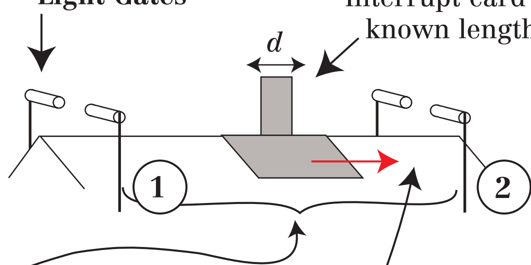


Constant speed – equally spaced dots. Measure distance for 5 dots, time taken was 1/10$^{\text{th}}$ second.

Acceleration – dots get further apart. Length of a 5-tick is proportional to the speed.

Light Gates

Interrupt card of known length



$$\text{Speed in gate} = \frac{\text{length of interrupt card}}{\text{time beam blocked}}$$

$$\text{Acceleration} = \frac{\text{change in speed between gates}}{\text{time between gates}}$$

$$\text{Average speed} = \frac{\text{distance between gates}}{\text{time between gates}}$$

SCALAR – size only

SPEED – rate of change of position.

VELOCITY – speed in a given direction.

ACCELERATION – rate of change of velocity (usually taken as increasing, but can be either).

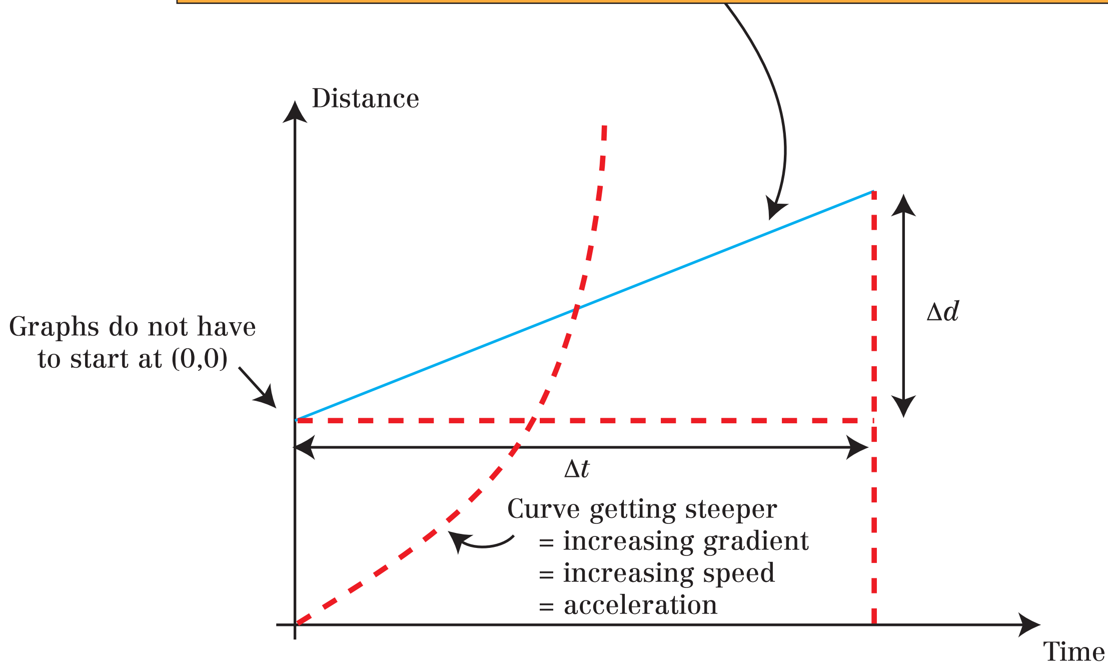
DECELERATION – rate of decrease of velocity.

VECTOR – size and direction

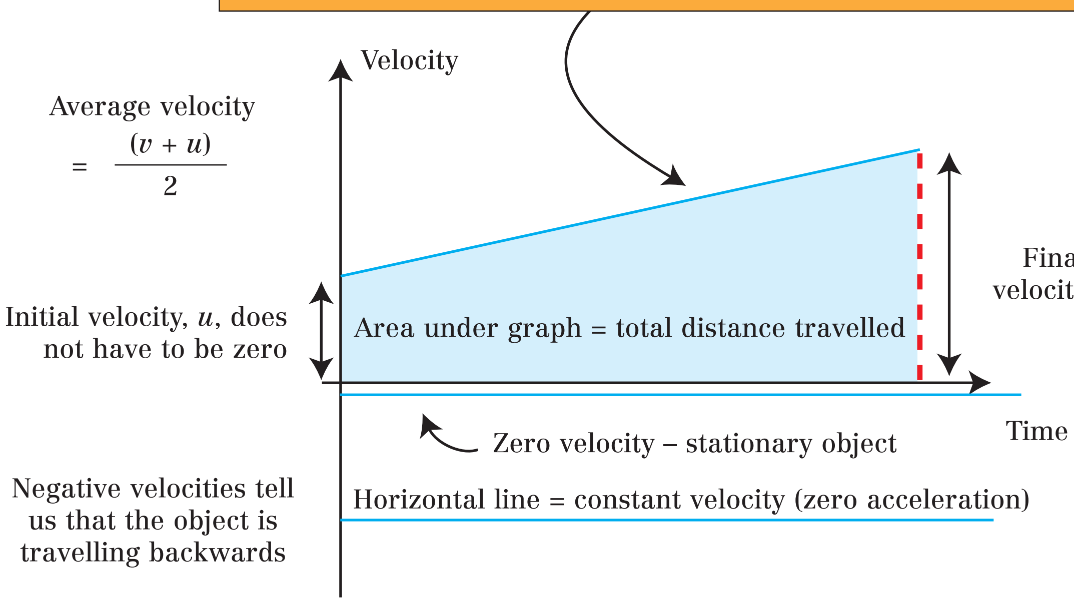
Questions

1. A toy train runs round a circular track of circumference 3 m. After 30 s, it has completed one lap.
   a. What was the train's average speed?
   b. Why is the train's average velocity zero?
   c. The train is placed on a straight track. The train accelerated uniformly from rest to a speed of 0.12 m/s after 10 s. What was its acceleration?
   d. Describe three different ways of measuring the train's average speed and two different ways of measuring the train's instantaneous speed.
   e. How could light gates be used to measure the train's acceleration along a 1 m length of track?
2. Explain the difference between a scalar and vector. Give an example of each.
3. A car leaks oil. One drip hits the road every second. Draw what you would see on the road as the car accelerates.

$$\text{Gradient} = \frac{\text{change in distance (m)}}{\text{change in time (s)}} = \frac{\Delta d}{\Delta t} = \text{speed (m/s)}$$

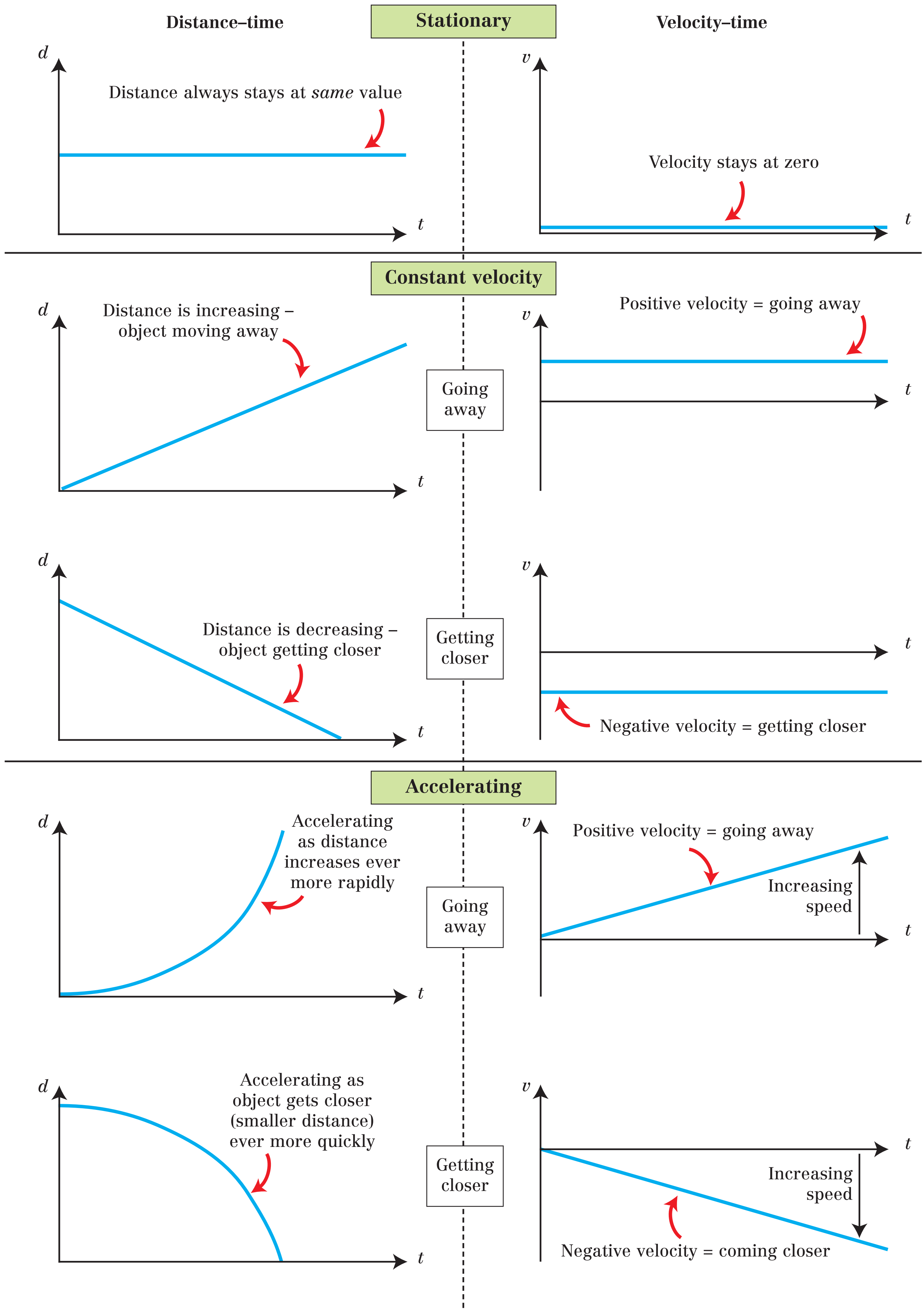


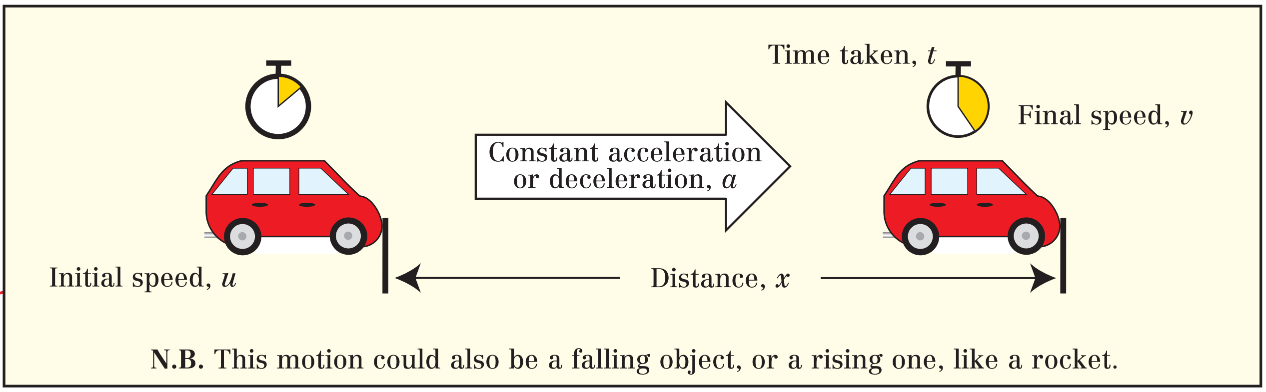
$$\text{Gradient} = \frac{\text{change in velocity (m/s)}}{\text{change in time (s)}} = \frac{\Delta v}{\Delta t} = \text{acceleration (m/s}^2\text{)}$$



Questions

1. Copy and complete the following sentences:
   a. The slope of a distance – time graph represents ____________________
   b. The slope of a velocity – time graph represents ____________________
   c. The area under a velocity – time graph represents ____________________
2. Redraw the last four graphs from p7 for an object that is decelerating (slowing down).
3. Sketch a distance–time graph for the motion of a tennis ball dropped from a second floor window.
4. Sketch a velocity–time graph for the motion of a tennis ball dropped from a second floor window. Take falling to be a negative velocity and bouncing up to be a positive velocity.

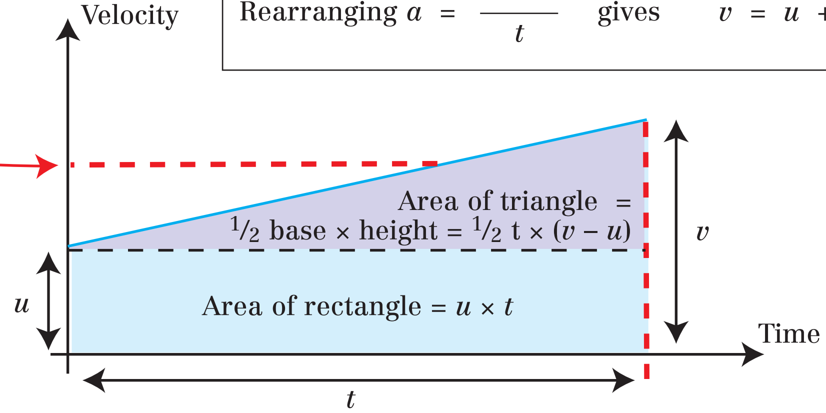

Distance–time
Stationary
Velocity–time
d
Distance always stays at *same* value
t
v
Velocity stays at zero
t
Constant velocity
d
Distance is increasing – object moving away
t
Going away
v
Positive velocity = going away
t
d
Distance is decreasing – object getting closer
t
Getting closer
v
t
Negative velocity = getting closer
Accelerating
d
Accelerating as distance increases ever more rapidly
t
Going away
v
Positive velocity = going away
Increasing speed
t
d
Accelerating as object gets closer (smaller distance) ever more quickly
t
Getting closer
v
t
Increasing speed
Negative velocity = coming closer



Gradient = acceleration = $\dfrac{\text{change in velocity}}{\text{time taken}} = \dfrac{(v-u)}{t}$

Rearranging $a = \dfrac{v-u}{t}$ gives $v = u + at$. **(1)**

Velocity–time graph for this motion



N.B.
average speed

$= \dfrac{(v+u)}{2}$

$= \dfrac{\text{total distance}}{\text{total time}}$

$= \dfrac{x}{t}$

So

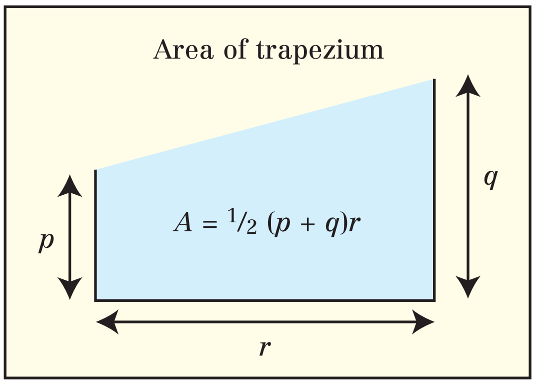
$\dfrac{(v+u)}{2} = \dfrac{x}{t}$ and therefore

$x = \tfrac{1}{2}(v+u)t$

Total distance travelled $= x =$ area under graph
$= u \times t + \tfrac{1}{2}\, t \times (v-u)$

From **(1)**: $(v-u) = at$ so $x = ut + \tfrac{1}{2}\, t\, (at)$

$x = ut + \tfrac{1}{2}\, at^2$ **(2)**



Alternatively, distance travelled $= x =$ area under graph
= area of trapezium
$= \tfrac{1}{2}(u+v)\, t$

same result

But from **(1)** $t = \dfrac{(v-u)}{a}$

so $x = \tfrac{1}{2}(u+v) \times \dfrac{(v-u)}{a}$

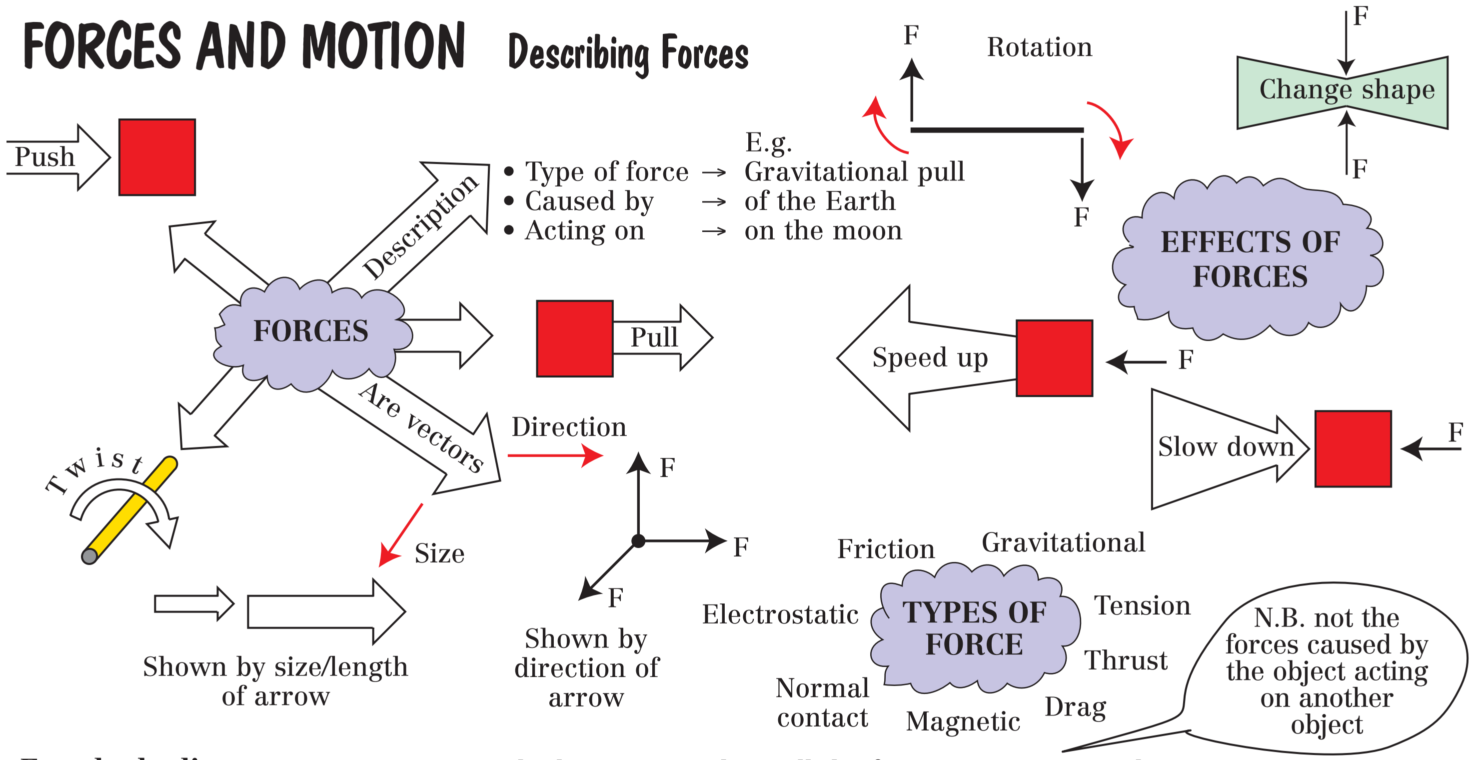
Rearranging $v^2 = u^2 + 2ax$ **(3)**

Questions

Show ALL your working.

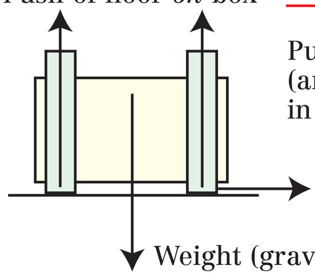
1. What quantities do the variables x, u, v, a, and t each represent?
2. Write a list of three equations which connect the variables x, u, v, a, and t.
3. A car accelerates from 10 m/s to 22 m/s in 5 s. Show that the acceleration is about 2.5 m/s^2.
4. Now show the car in (3) travelled 80 m during this acceleration:
   a. Using the formula $v^2 = u^2 + 2ax$.
   b. Using the formula $x = ut + \tfrac{1}{2}at^2$.
5. A ball falls from rest. After 4 s, it has fallen 78.4 m. Show that the acceleration due to gravity is 9.8 m/s^2.
6. Show that $x = \tfrac{1}{2}(u+v)(v-u)/a$ rearranges to $v^2 = u^2 + 2ax$.
7. A ball thrown straight up at 15 m/s, feels a downward acceleration of 9.8 m/s^2 due to the pull of the Earth on it. How high does the ball go before it starts to fall back?

FORCES AND MOTION Describing Forces



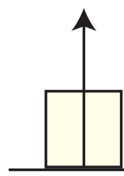
Free body diagrams Simple diagrams to show all the forces acting *on* an object.

E.g. Sliding box



Push of floor *on* box — properly called → Normal contact force

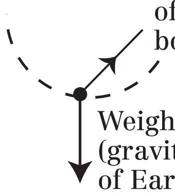
Push of floor = weight (arrows same length but act in opposite directions)



Normal contact force: Push of one surface on another at right angles to the surface. Due to atoms in each surface being slightly squashed together and pushing back

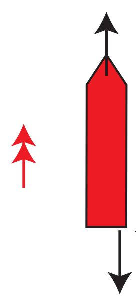
Weight (gravitational pull of Earth *on* box) → **Weight** – shorthand for 'the gravitational pull of a planet or moon (usually the Earth) on an object'

E.g. pendulum

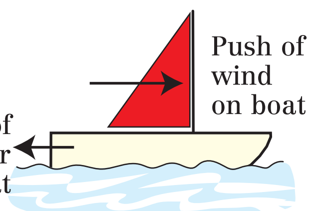


Resultant force – a single force that can replace all the forces acting on a body and have the same overall effect as all the individual forces acting together.
It is the sum of all the individual forces taking their directions into account.

E.g. rocket



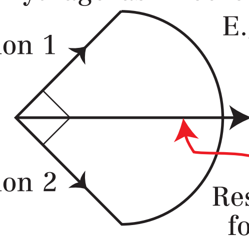
Parallel forces – add



Resultant = push of wind on boat – drag of water on boat

Shows opposite direction

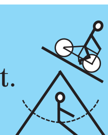
Perpendicular forces – Pythagoras Theorem



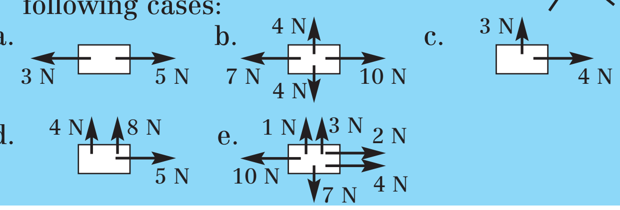
R^2 = (tension 1)^2 + (tension 2)^2

Questions

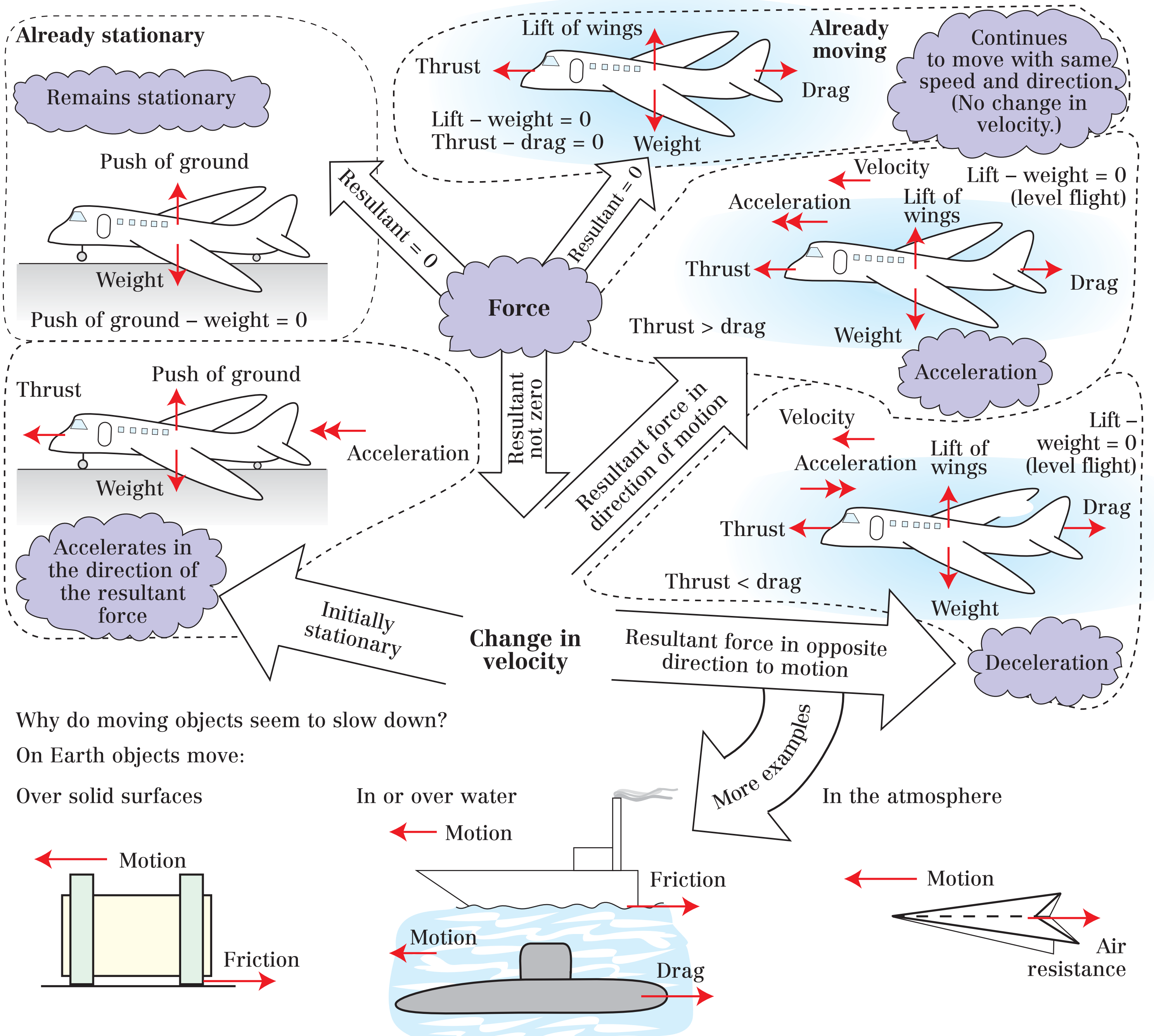
1. List three effects forces can have.
2. Explain what the term 'resultant force' means.
3. To describe a force fully, what three pieces of information should be recorded?
4. Copy and add arrows to these diagrams to show all the forces (and their directions) acting on:
   a. A netball flying through the air.
   b. A jet ski.
   c. A cyclist freewheeling down a hill.
   d. A child on a swing pushed by an adult.



5. Calculate the resultant force in the following cases:



FORCES AND MOTION Balanced Forces – Newton's First Law



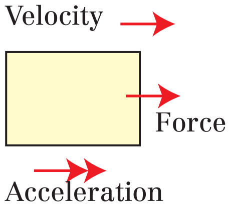
In all cases, resistive forces act to oppose motion. Therefore, unless a force is applied to balance the resistive force the object will slow down. In space, there are no resistive forces and objects will move at constant speed in a straight line unless another force acts.

Newton's First Law of Motion:
- If the resultant force acting on a body is zero, it will remain at rest or continue to move at the same speed in the same direction.
- If the resultant force acting on a body is not zero, it will accelerate in the direction of the resultant force.

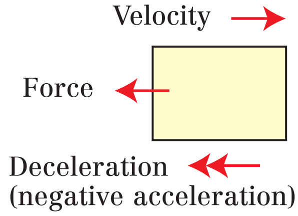
Questions

1. In which of the following situations is the resultant force zero? Explain how you decided.
   a. A snooker ball resting on a snooker table.
   b. A car accelerating away from traffic lights.
   c. A ball rolling along level ground and slowing down.
   d. A skier travelling down a piste at constant speed.
   e. A toy train travelling round a circular track at constant speed.
2. A lift and its passengers have a weight of 5000 N. Is the tension in the cable supporting the lift:
   i. Greater than 5000 N, ii. Less than 5000 N, iii. Exactly 5000 N when:
   a. The lift is stationary?
   b. Accelerating upwards?
   c. Travelling upwards at a constant speed?
   d. Decelerating whilst still travelling upwards?
   e. Accelerating downwards?
   f. Travelling downwards at constant velocity?
   g. Decelerating while still travelling downward?
3. Explain why all objects moving on Earth will eventually come to rest unless another force is applied?

FORCES AND MOTION Unbalanced Forces – Newton's Second Law



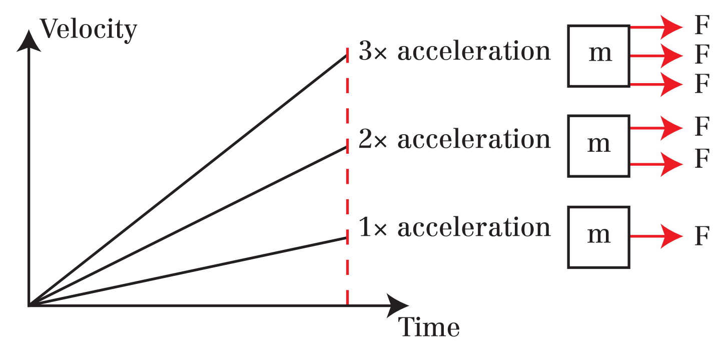
Speed up ⟸ **Non-zero resultant force** ⟹ Slow down

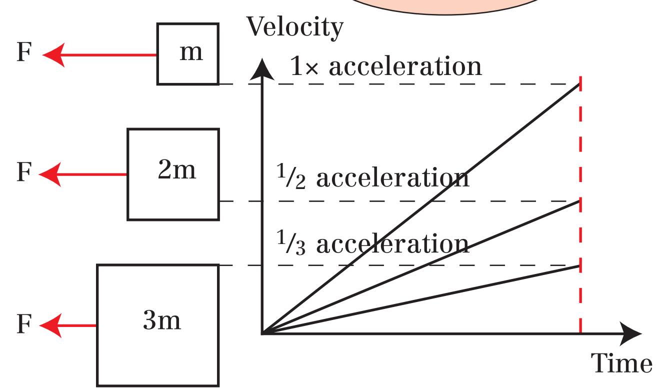


Experiments show acceleration is

Directly proportional to → **Force**

Inversely proportional to → **Mass**

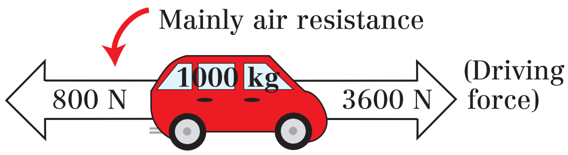




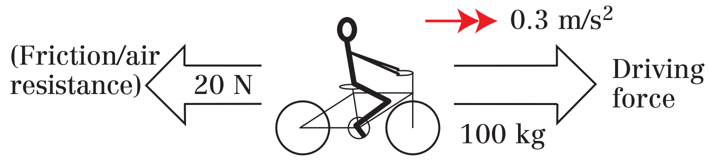
We *define* the Newton as the force needed to accelerate a 1 kg mass at 1 m/s^2. Therefore, we can write:

Force (N) = mass (kg) × acceleration (m/s^2). **Newton's Second Law**

E.g.



Resultant force = 2800 N
Acceleration = force/mass = 2800 N/1000 kg = 2.8 m/s^2.



Resultant force = mass × acceleration
= 100 kg × 0.3 m/s^2
= 30 N
Resultant force = driving force – 20 N
Driving force = 50 N

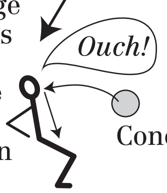
What is mass?

The reluctance of the object to accelerate when a force is applied (its inertia). ← Means 'resistance to change' (in this case its velocity).

A measure of the amount of material in an object.

Never varies from place to place.

Large mass

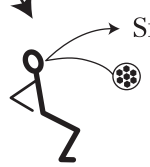


Large force for small acceleration

Concrete ball

Small mass

Small force gives large acceleration.



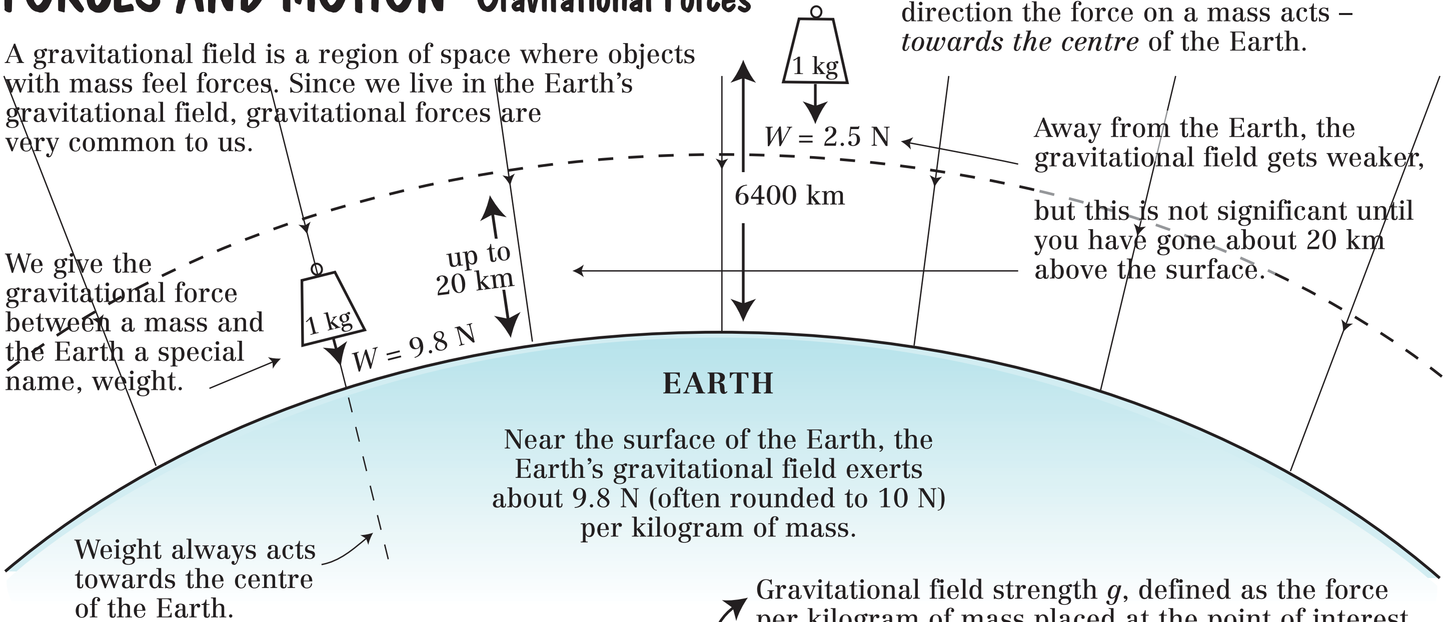
Football

Questions

1. Calculate:
   a. The force needed to accelerate a 70 kg sprinter at 6 m/s^2.
   b. The acceleration of a 10 g bullet with 2060 N explosive force in a gun barrel.
   c. The mass of a ship accelerating at 0.09 m/s^2 with a resultant thrust of 6 400 000 N from the propellers.
2. An underground tube train has mass of 160 000 kg and can produce a maximum driving force of 912 000 N.
   a. When accelerating in the tunnel using the maximum driving force show the acceleration should be 5.7 m/s^2.
   b. In reality, the acceleration is only 4.2 m/s^2. Hence show the resistive forces on the train are 240 000 N.
3. Explain why towing a caravan reduces the maximum acceleration of a car (two reasons).
4. A football made of concrete would be weightless in deep space. However, it would not be a good idea for an astronaut to head it. Why not?

FORCES AND MOTION Gravitational Forces

A gravitational field is a region of space where objects with mass feel forces. Since we live in the Earth's gravitational field, gravitational forces are very common to us.

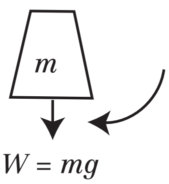


Gravitational field strength g, defined as the force per kilogram of mass placed at the point of interest.

The force per kilogram of mass is a good way of measuring the strength of the Earth's gravitational field.

Weight (N) = mass (kg) × gravitational field strength (N/kg).

If an object is in free fall, the only force on it is weight (difficult in practice because of air resistance).



Applying Newton's second law → Resultant force = mass × acceleration

Then acceleration (m/s^2) = weight (N) / mass (kg).

10 m/s^2 Hence, acceleration due to free fall is equivalent to gravitational field strength.

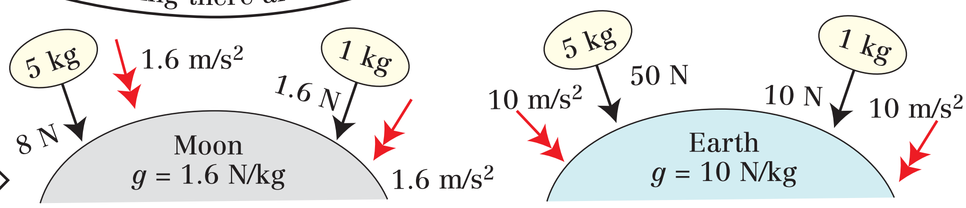
However, this is also the definition of gravitational field strength.

g = 10 N/kg

All masses fall with an acceleration of about 10 m/s^2 (providing there are no resistive forces).

You can think of this as the weight increasing to compensate for the increased mass so all objects fall at the same rate, independent of their mass.

The mass of an object is the same everywhere. The weight depends on the gravitational field strength.



Questions

1. Near the surface of the Earth, what are the values of:
   a. The acceleration due to free fall?
   b. The gravitational field strength?
2. What are the weights on the Earth of:
   a. A book of mass 2 kg?
   b. An apple of mass 100 g?
   c. A girl of mass 60 kg?
   d. A blade of grass of mass 0.1 g?
3. What would the masses and weights of the above objects be on the moon? (Gravitational field strength on the moon = 1.6 N/kg).
4. 6400 km above the surface of the Earth a 1 kg mass has a weight of 2.5 N. What is the gravitational field strength here? If the mass was dropped, and started falling towards the centre of the Earth, what would its initial acceleration be?
5. Write a few sentences to explain the difference between mass and weight.

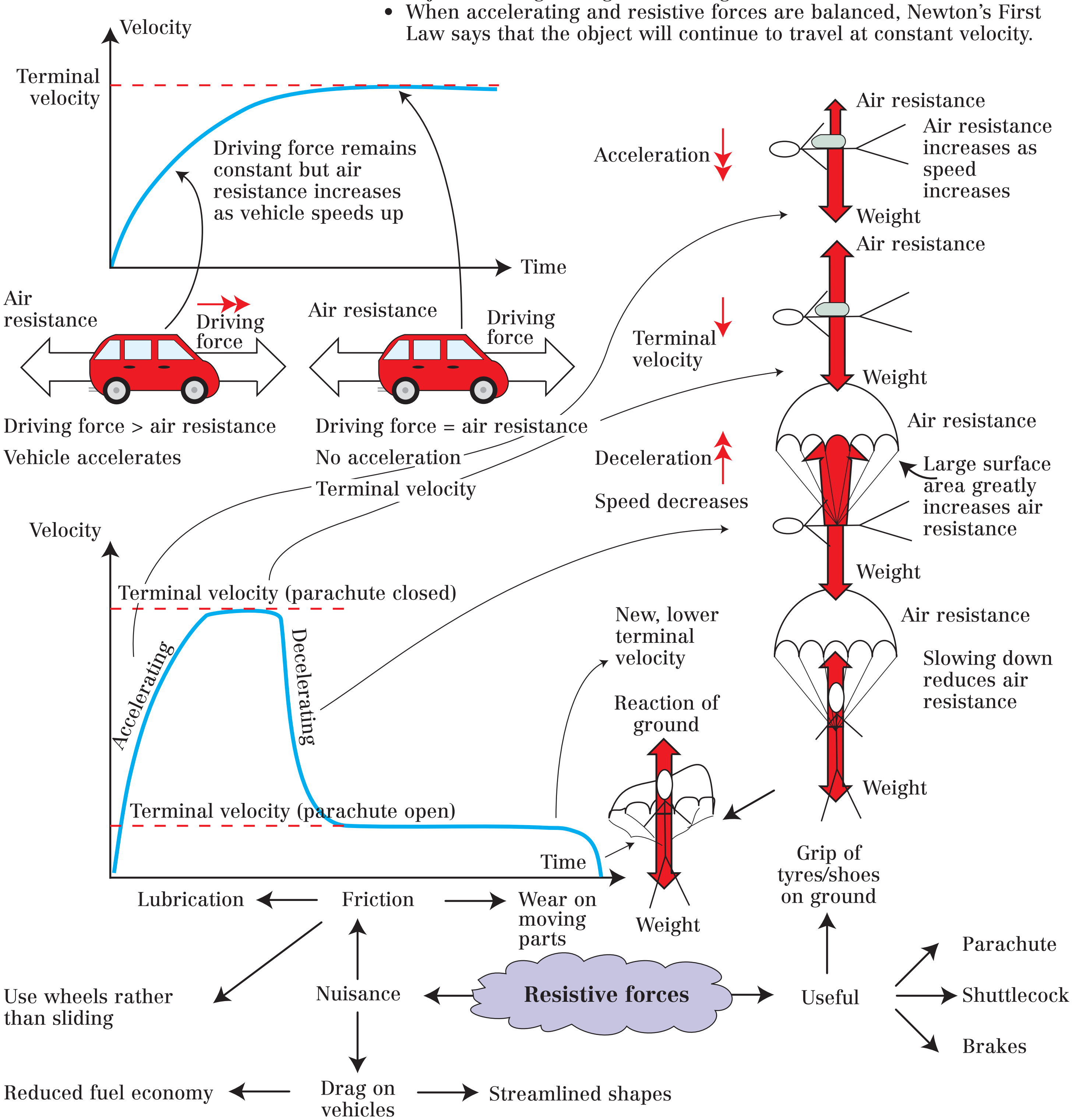
FORCES AND MOTION

Terminal Velocity

Terminal velocity occurs when the accelerating and resistive force on an object are balanced.

Key ideas:

- Drag/resistive forces on objects increase with increasing speed for objects moving through a fluid, e.g. air or water.
- When accelerating and resistive forces are balanced, Newton's First Law says that the object will continue to travel at constant velocity.



Questions

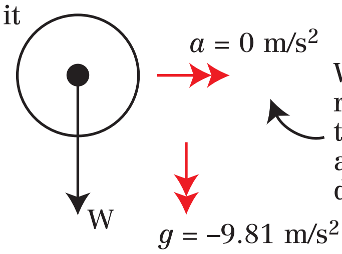
1. What happens to the size of the drag force experienced by an object moving through a fluid (e.g. air or water) as it speeds up?
2. What force attracts all objects towards the centre of the Earth?
3. Why does a car need to keep its engine running to travel at constant velocity?
4. A hot air balloon of weight 6000 N is released from its mooring ropes.
   a. The upward force from the hot air rising is 6330 N. Show the initial acceleration is about 0.5 m/s^2.
   b. This acceleration gradually decreases as the balloon rises until it is travelling at a constant velocity. Explain why.
   c. A mass of 100 kg is thrown overboard. What will happen to the balloon now?
   d. Sketch a velocity–time graph for the whole journey of the balloon as described in parts a–c.
5. Explain why the following are likely to increase the petrol consumption of a car:
   a. Towing a caravan.
   b. Adding a roof rack
   c. Driving very fast.

FORCES AND MOTION

Projectiles

The secret is to consider the velocity of the projectile to be made up of horizontal and vertical velocities, which can be considered separately.

A true projectile only has one force, weight, acting on it when it is in flight.



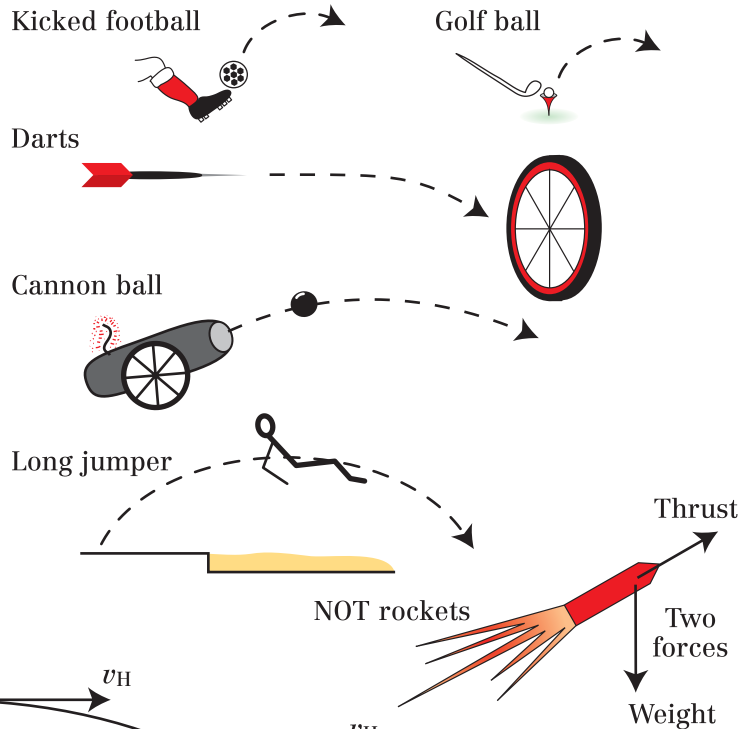
At any time motion is made up of

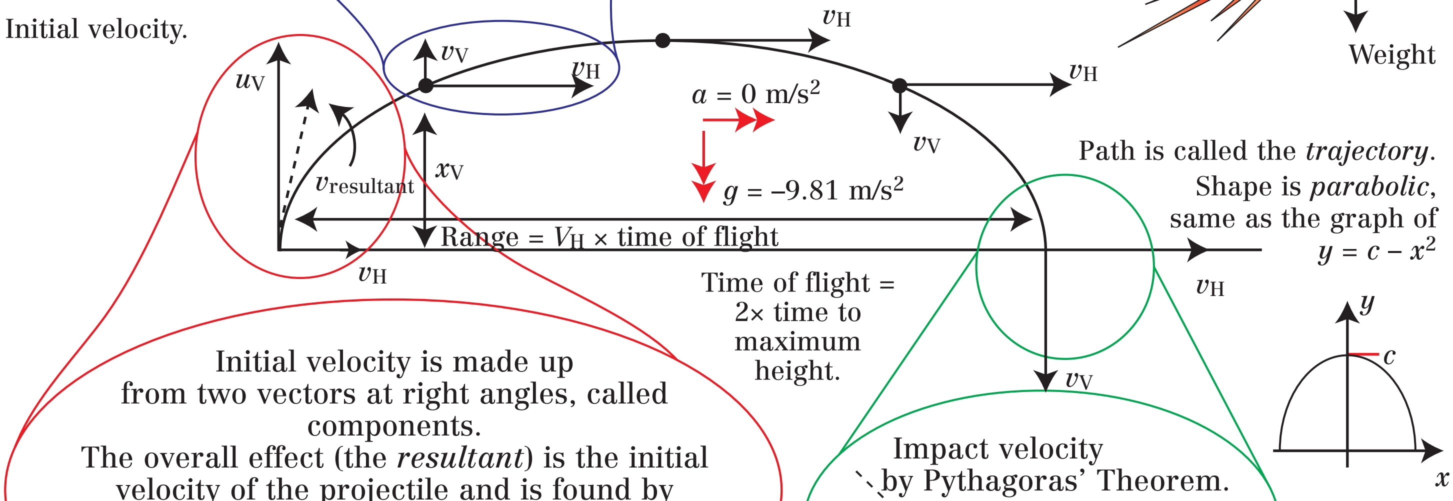
1. Horizontal velocity:
No horizontal forces (ignoring air resistance). Therefore by Newton's First Law, no change in velocity horizontally.

2. Vertical velocity:
Projectile accelerates downwards under gravity, slowing as it rises, stopping at the top and falling back.

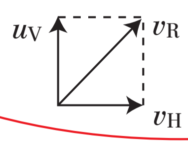
Use $v_V = u_V + gt$ and $x_V = u_Vt + {}^1/_2\ gt^2$
where $g = -9.81$ m/s^2

Examples:



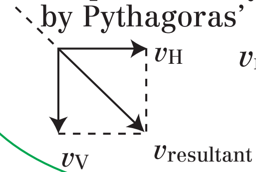


Initial velocity is made up from two vectors at right angles, called components.
The overall effect (the *resultant*) is the initial velocity of the projectile and is found by Pythagoras' Theorem.



$v_R = \sqrt{u_V + v_H}$

Impact velocity by Pythagoras' Theorem.



$v_{resultant} = \sqrt{v_V{}^2 + v_H{}^2}$

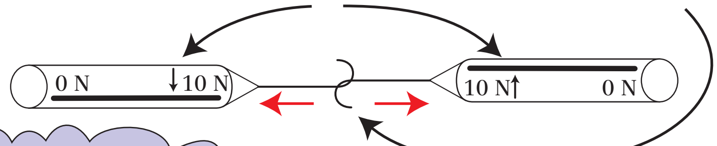
Questions

1. In an ideal world how many forces act on a projectile, and what are they?
2. State the value of the vertical acceleration of a projectile.
3. Explain why the horizontal acceleration of a projectile is zero. What assumption has to be made?
4. Explain why a firework rocket cannot be analysed as a projectile with the methods shown here.
5. A ball is kicked so it has a velocity of 15.59 m/s horizontally and 9.0 m/s vertically.

a. Show that the resultant velocity of the ball has a magnitude of 18.0 m/s.
b. Show that the ball takes 0.92 s to reach its maximum height above the ground.
c. For how long in total is the ball in the air and how far along the ground will it travel?
d. Show the maximum height the ball reaches is 4.1 m.
e. What will the magnitude of its resultant velocity be when it hits the ground? Hint: no calculation needed.

FORCES AND MOTION Newton's Third Law

Whenever an object experiences a force it always exerts an equal . . . . . and . . . . . opposite force on the object causing the force.



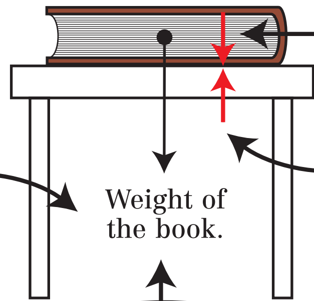
These pairs of forces are called Third Law pairs.

Always have the same *size*.

Always the same *type* of force.

Always act on different bodies (compare with Newton's First Law where we are only interested in the force acting on the body in question).

Always act in *opposite directions*.



Push of the book downwards on the table.

Equal

Push upward of the table on the book.

The reaction of the table on the book.

Normal contact forces.

Gravitational pull downwards of Earth on the book.

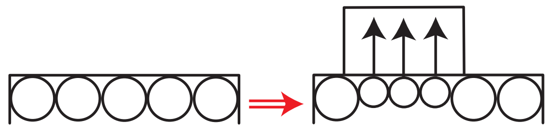
Weight of the book.

Equal

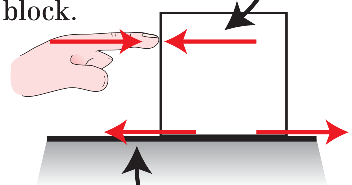
Gravitational pull upwards of book on Earth.

Third law pairs follow this format:

Force F of A on B in one direction =
Force F of B on A in the other direction



Molecules in the surface are pushed slightly closer together and push back. This is often called the *reaction* of a surface.



Push of the hand on the block.

Push of the block on the hand.

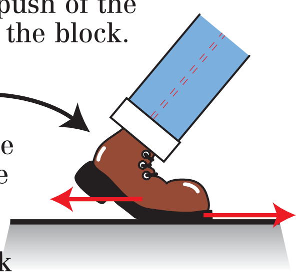
Frictional push of the block on the surface.

Frictional push of the surface on the block.

Examples

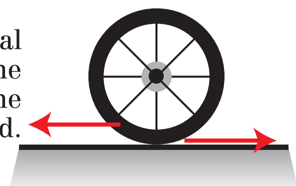
Push of the rocket on gas downwards (out of the rocket).

Push of gas on the rocket upwards (propelling the rocket upwards).



Frictional push of the foot on the ground (pushes Earth back slightly).

Frictional push of the ground on the foot (pushes foot forward – this is the force that propels us forward).



Frictional push of the tyre on the ground.

Frictional push of the ground on the tyre (pushes car forwards).

If the ground is icy, both these forces are very small and we cannot walk or drive forwards.

Questions

1. Explain what is meant by the term 'normal contact force'.
2. A jet engine in an aircraft exerts 200 000 N on the exhaust gases. What force do the gases exert on the aircraft?
3. Describe the force that forms a Third Law pair with the following. In each case, draw a diagram to illustrate the two forces:
   a. The push east of the wind on a sail.
   b. The push left of a bowstring on an arrow.
   c. The frictional push south of a train wheel on a rail.
   d. The normal contact force downwards of a plate on a table.
   e. The attraction right of the north magnetic pole of a bar magnet on a south magnetic pole of a different magnet.
4. Why are the following not Third Law pairs? (There may be more than one reason for each.)
   a. The weight of a mug sitting on a table; the normal contact force of the tabletop on the mug.
   b. The weight of the passengers in a lift car; the upward tension in the lift cable.
   c. The weight of a pool ball on a table; the horizontal push of the cue on the ball.
   d. The attraction between the north and south magnetic poles of the same bar magnet.
5. Explain why it is very difficult (and dangerous) to ride a bicycle across a sheet of ice.

Momentum and Force (Newton's Laws revisited)

Momentum helps to describe how moving objects will behave.

Momentum (kgm/s) = mass (kg) × velocity (m/s)

Momentum is a vector. It has size and direction (the direction of the velocity).

Newton's Second Law

Resultant force = mass × acceleration

$F = m \times a$

acceleration = change in velocity/time taken

$a = (v - u)/t$

Resultant force = mass × change in velocity / time taken

$F = m\,(v - u)\,/\,t$

Rearranging

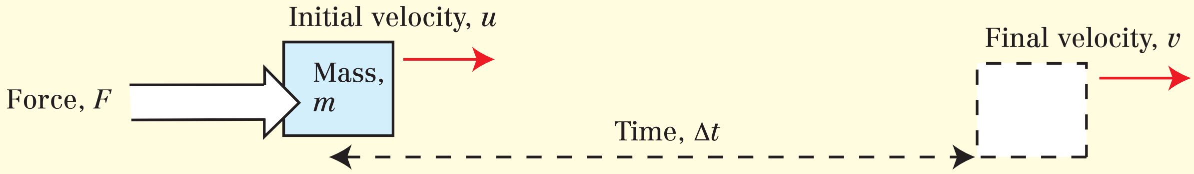
$F\Delta t = mv - mu$

$F\Delta t$: Impulse (Ns)

$mv - mu$: Change in momentum (kgm/s)

Hence, an alternative version of Newton's Second Law

If a resultant force acts on a body free to move a change in momentum occurs equal to the product of the force and the time for which it acts.



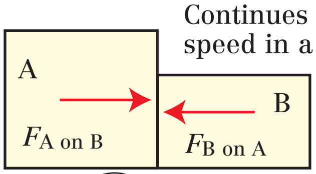
$F\Delta t = mv - mu$

Also consider

Zero resultant force → No change in momentum → No change in velocity → Stationary? → Stays stationary

Newton's First Law

No change in velocity → Already moving? → Continues to move at a steady speed in a straight line.



Newton's Third Law

As $F_{A\ on\ B} = -F_{B\ on\ A}$ and objects must be in contact for the same time, Δt,

$F\Delta t = mv - mu$

$F\Delta t$ = change in momentum.

then $(F_{A\ on\ B})\,\Delta t = -\,(F_{B\ on\ A})\,\Delta t$

Gain of momentum by B — Loss of momentum by A → Equal

Momentum transferred from A to B → Momentum is conserved

Consistent with the idea that when two objects collide they exert equal and opposite forces on each other.

Questions

1. What units do we use to measure momentum and impulse (2 answers)?
2. Calculate the momentum of:
   a. A 55 kg girl running at 7 m/s north.
   b. A 20 000 kg aircraft flying at 150 m/s south.
   c. A 20 g snail moving at 0.01 m/s east.
3. What is the connection between force and change in momentum?
4. What is the change in momentum in the following cases:
   a. A 5 N force acting for 10 s?
   b. A 500 N force acting for 0.01 s?
5. What force is required to:
   a. Accelerate a 70 kg athlete from 0 to 9 m/s in 2 s?
   b. Accelerate a 1000 kg car from rest to 26.7 m/s in 5 s?
   c. Stop a 10 g bullet travelling at 400 m/s in 0.001 s?
6. What would be the effect on the force needed to change momentum if the time the force acts for is increased?
7. A 2564 kg space probe is to be accelerated from 7.7 km/s to 11.0 km/s. If it has a rocket motor that can produce 400 N of thrust, for how long would it need to burn assuming that no resistive forces act? Why might this not be practical? How else might the space probe gain sufficient momentum (see p113 for ideas)?

Law of Conservation of Momentum:

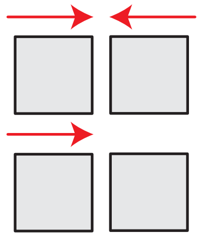
> Momentum cannot be created or destroyed but can be transferred from one object to another when they interact.

There are no exceptions to this. It is applied to analyse interactions between objects, which can be classified as:

Velocities

Up and **right** are taken as **positive.**

Down and **left** are taken as **negative.**

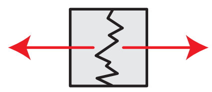


Or

Objects initially moving towards each other → **Collisions**

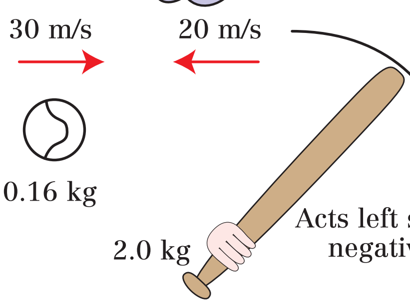
or

Objects originally stationary and move apart → **Explosions**



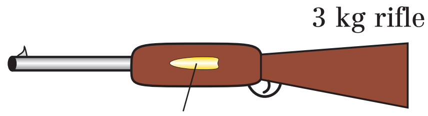
1. Momentum before collision

Add up all the individual momenta taking care over their directions.



$m_1u_1 + m_2u_2 =$
0.16 kg × 30 m/s + 2 kg × (–20 m/s)
= –35.2 kgm/s

Overall momentum acts to the left.

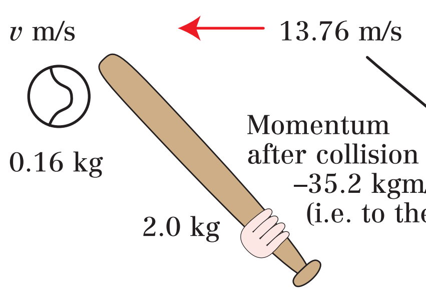


Momentum = 0 kgm/s

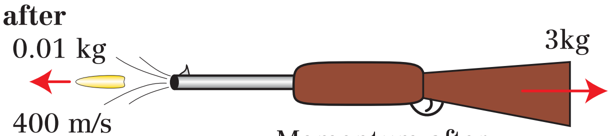
Initial momentum is always *zero* for an explosion.

2. By momentum conservation: momentum before = momentum after

Again take care over the direction of the velocities, are they positive or negative?



Momentum after collision = –35.2 kgm/s (i.e. to the left)



Momentum after explosion = 0 kgm/s (rifle and bullet move off in opposite directions)

Acts left so negative

3. Equate momentum before and after to find unknown masses or velocities.

Do not worry about the direction of an unknown velocity. The maths will tell you whether it is positive or negative, and therefore its direction.

Momentum after = $m_1v_1+m_2v_2$

35.2 gm/s = 0.16 kg × v + 2 kg × (–13.76 m/s)

v = –48 m/s

Negative sign tells us the ball travels to the left (as expected).

Momentum after = $m_1v_1 + m_2v_2$

0 kgm/s = 0.01 kg × (–400 m/s) + 3 kg × v

v = +1.33 m/s

Positive tells us the rifle recoils to the right (as expected).

4. The force involved depends on the size of the change of momentum and the time it is exerted for.

Use $F\Delta t = mv - mu$

If time of collision = 0.02 s the force on the ball

F × 0.02 s = 0.16 kg × (–48 m/s) – (0.16 kg × 30 m/s)

F = –624 N (i.e. to the left)

If time of explosion = 0.002 s then the force on the bullet

F × 0.002 s = 0.01 kg × –400 m/s – (0.01 kg × 0)

F = –2000 N (i.e. to the left)

The calculation of the force exerted on the bullet and the ball would work equally well if the force on the bat or the rifle were calculated. The size of the force would be the same, but in the opposite direction according to Newton's Third Law. Again using $F\Delta t = mv - mu$.

Force of ball on bat

$F \times 0.02$ s = 2 kg × (–13.76 m/s) – 2 kg (–20m/s)

F = 624 N (positive, to the right).

Force of bullet on gun

$F \times 0.002$ s = (3 kg × 1.33 m/s) – (3 kg × 0 m/s)

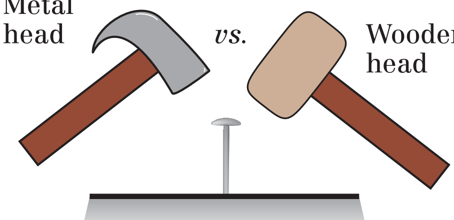
F = 2000 N (positive, to the right).

These calculations show that the force involved depends on.

Time of impact

Both 1 kg

Metal head *vs.* Wooden head



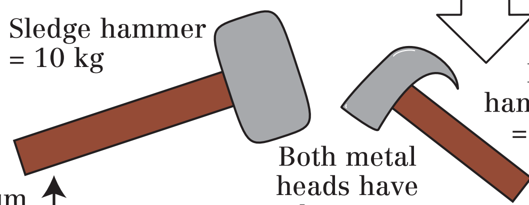
Short impact time – larger force.

Long impact time – less force.

Change of momentum

Sledge hammer = 10 kg

Light hammer = 1 kg



Both metal heads have the same contact time.

Larger change of momentum exerts a larger force.

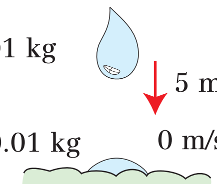
This is where the incorrect idea of a force being needed to keep something moving comes from.

Sometimes it appears that momentum is not conserved.

Raindrop

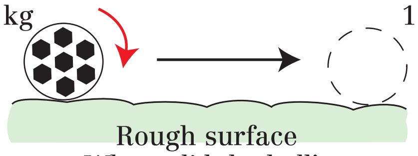
0.01 kg, 5 m/s

0.01 kg, 0 m/s



Where did the drop's momentum go?

2 m/s, 1.0 kg → 0 m/s, 1.0 kg



Rough surface

Where did the ball's momentum go?

Both drop and ball have an external force applied (contact force of the ground on the drop and friction with the ground on the ball).

External force applied by Earth means

Their momentum was transferred to the Earth.

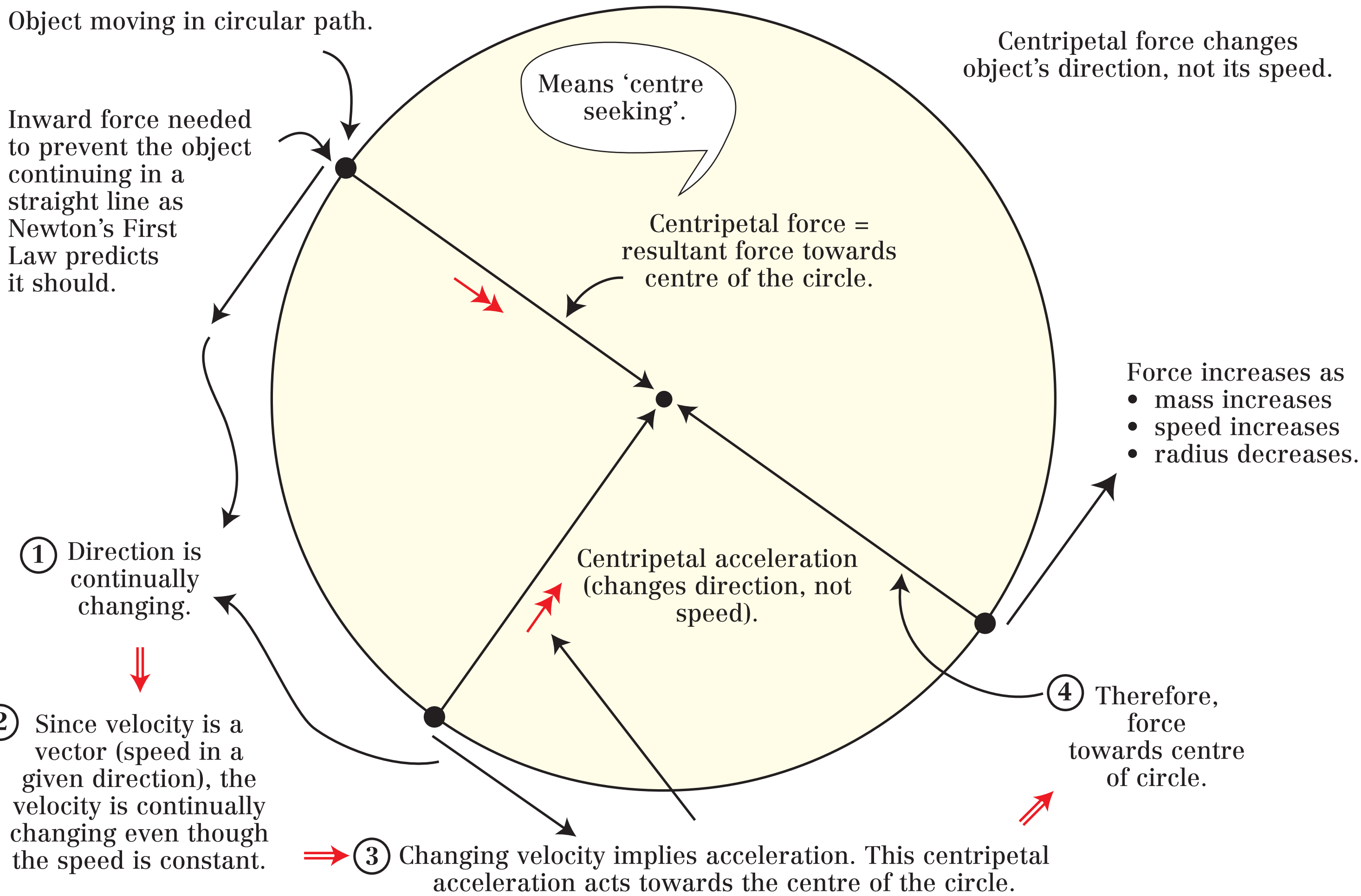
Therefore, a better form of the Principle of Conservation of Momentum is . . .

Momentum is conserved provided no external forces act.

If external forces act, momentum is transferred to or from the body exerting the force.

Questions

1. When a raindrop hits the ground where does its momentum go?
2. Why do boxers wear padded gloves?
3. A squash ball is hit against a wall and bounces off. An equal mass of plasticine is thrown at the same wall with the same speed as the ball, but it sticks on impact. Which exerts the larger force on the wall and why?
4. A golfer swings a 0.2 kg club at 45 m/s. It hits a stationary golf ball of mass 45 g, which leaves the tee at 65 m/s.
   a. What was the momentum of the club before the collision?
   b. What was the momentum of the ball after the collision?
   c. Hence, show that the club's velocity is about 30 m/s after the collision.
   d. If the club is in contact with the ball for 0.001 s, what is the average force the club exerts on the ball?
5. A 1.5 kg air rifle fires a 1 g pellet at 150 m/s. What is the recoil velocity of the rifle? Show that the force exerted by the rifle on the pellet is about 70 N if the time for the pellet to be fired is 0.0021 s.
6. Assume that the average mass of a human being is 50 kg. If all 5.5×10^9 humans on Earth stood shoulder to shoulder in one place, and jumped upward at 1 m/s with what velocity would the Earth, mass 6×10^{24} kg recoil?
7. Two friends are ice-skating. One friend with mass 70 kg is travelling at 4 m/s. The other of mass 60 kg travelling at 6 m/s skates up behind the first and grabs hold of them. With what speed will the two friends continue to move while holding onto each other?



Centripetal acceleration (m/s²) = $\frac{[\text{velocity (m/s)}]^2}{\text{radius (m)}}$

$a = v^2/r$

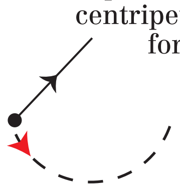
Centripetal force = mass (kg) × acceleration (m/s²)

= $\frac{\text{mass (kg)} \times [\text{velocity (m/s)}]^2}{\text{radius (m)}}$

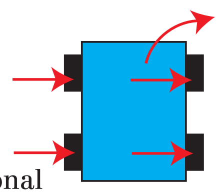
$F = mv^2/r$

Centripetal force is not a force in its own right – it must be *provided* by another type of force.

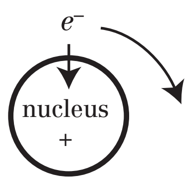
Tension provides centripetal force



Pendulum

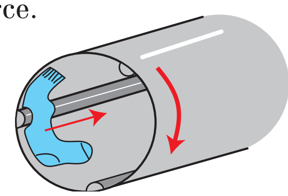


Frictional push sideways of road on tyres.

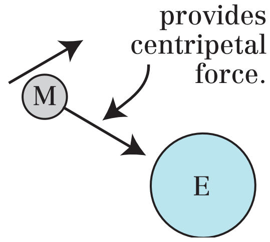


Electrostatic attraction of electron in atoms to the nucleus provides centripetal force.

Normal contact force on clothes in washing machine drum provides centripetal force.



Gravitational attraction of Moon to Earth provides centripetal force.



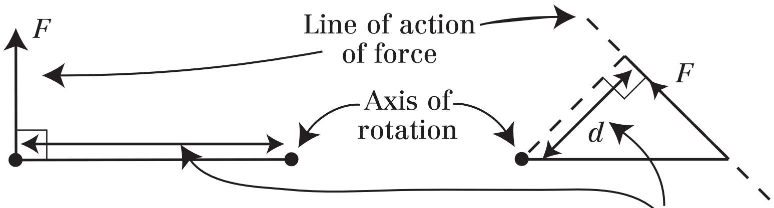
Questions

1. What force provides the centripetal force in each of these cases?
   a. The Earth moving in orbit around the Sun.
   b. Running around a sharp bend.
   c. A child on a swing.
2. Explain how a passenger on a roundabout at a funfair can be moving at constant speed around the circle and yet accelerating. In what direction is the acceleration?
3. What is the centripetal acceleration of, and force on, the following:
   a. A wet sweater of mass 1 kg, spinning in a washing machine drum of radius 35 cm, moving at 30 m/s.
   b. A snowboarder of mass 70 kg travelling round a half pipe of radius 6 m at 5 m/s.
4. The Earth has a mass of 6×10^{24} kg. Its orbit radius is 1.5×10^{11} m and the gravitational attraction to the Sun is 3.6×10^{22} N.
   a. Show that the circumference of the Earth's orbit is about 9.5×10^{11} m.
   b. Show that the Earth's speed around the Sun is about 30 000 m/s.
   c. Therefore, show that the time to orbit the Sun is about 3×10^7 s.
   d. Show that this is about 365 days.
5. On a very fast rotating ride at a funfair, your friend says that they feel a force trying to throw them sideways out of the ride. How would you convince your friend that actually they are experiencing a force pushing *inwards*? You should refer to Newton's First and Third Laws in your explanation.

FORCES AND MOTION

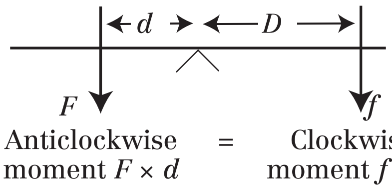
Moments and Stability

A moment (or torque) is the turning effect of a force.

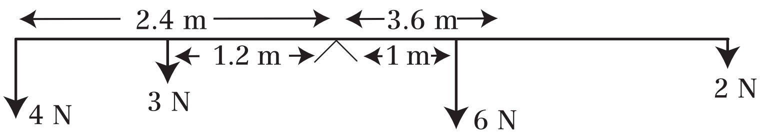


Moment (*Nm*) = Force (*N*) × perpendicular distance from line of action of the force to the axis of rotation (*m*).

A body will not rotate if there is no resultant moment.



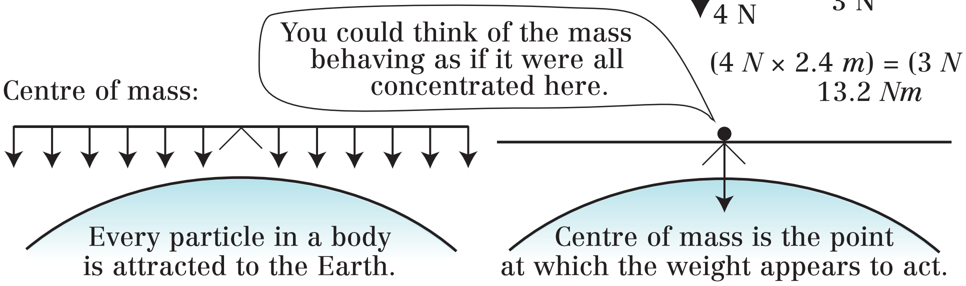
Sum of anticlockwise moments = sum of clockwise moments when in equilibrium.



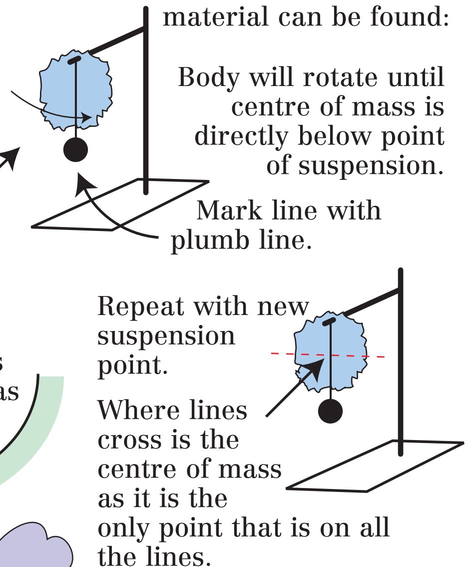
(4 *N* × 2.4 *m*) = (3 *N* × 1.2 *m*) = (6 *N* × 1 *m*) + (2 *N* × 3.6 *m*)

13.2 *Nm* = 13.2 *Nm*

Centre of mass:

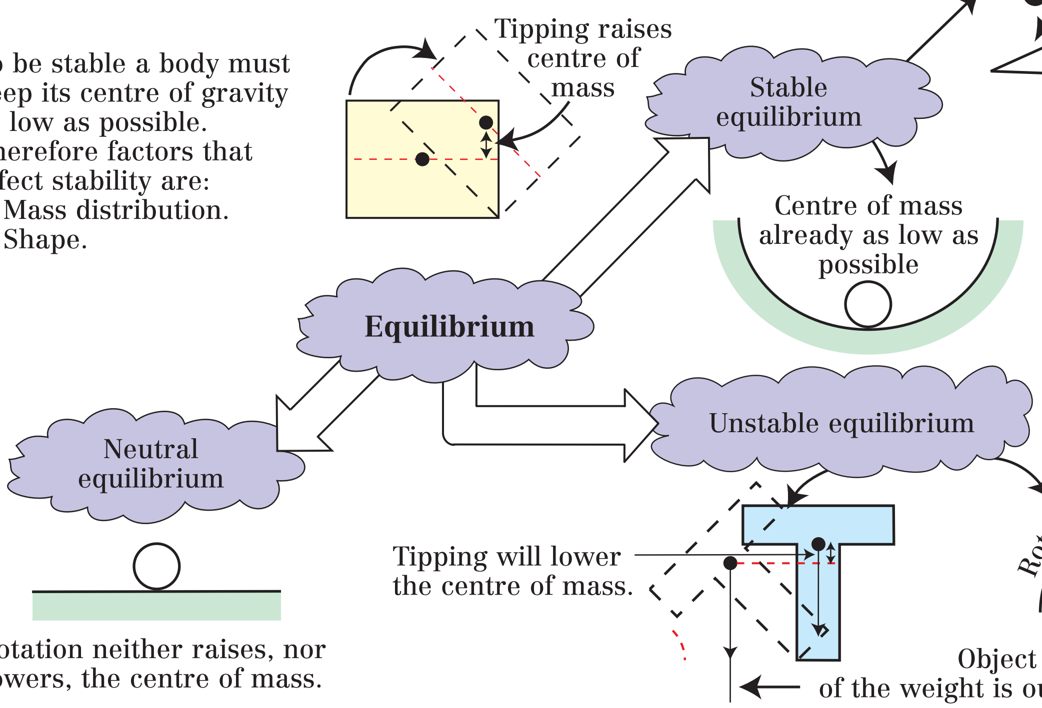


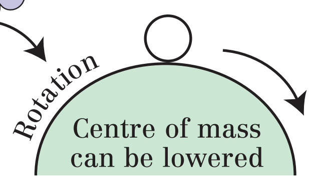
The centre of mass of a thin sheet of material can be found:



To be stable a body must keep its centre of gravity as low as possible. Therefore factors that affect stability are:

- Mass distribution.
- Shape.

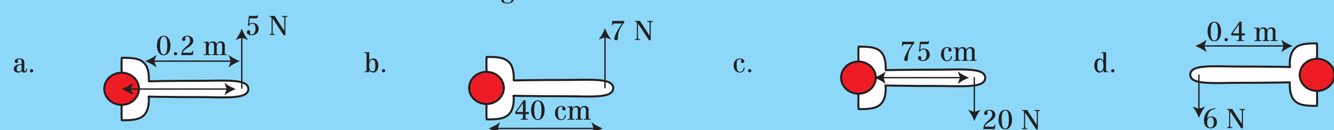




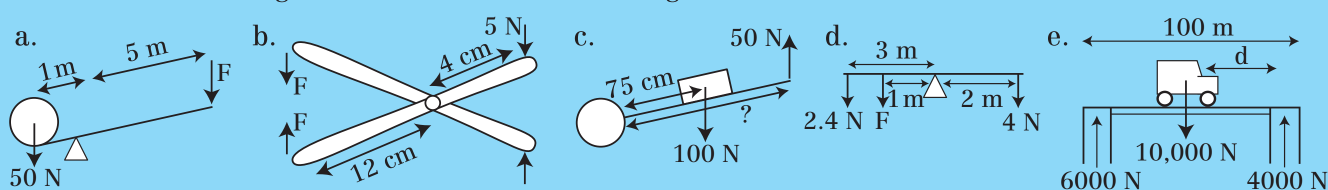
Object topples if the line of action of the weight is outside the base of the body.

Questions

1. What is the moment in each of the diagrams below?



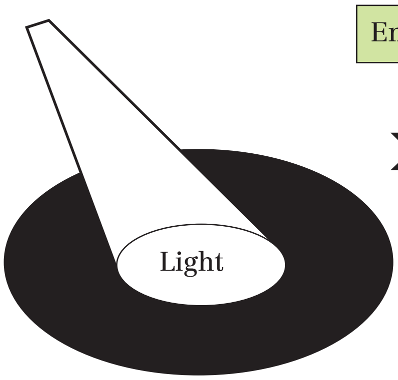
2. If the forces in question 1 acted at 60° to the spanner rather than 90° would the moment be greater, the same as, or less than that calculated in question 1? Explain.
3. What are the missing forces or distances in the diagrams below?



4. A letter P is cut from thin cardboard. Explain how to locate its centre of mass.
5. The following letters are cut from a thick plank of wood. W, P, O, I, H, L, U. If stood upright in their normal positions, which are in stable equilibrium, which unstable, and which neutral? Which letter would you expect to be easiest to topple and why?

ENERGY Types of Energy and Energy Transfers

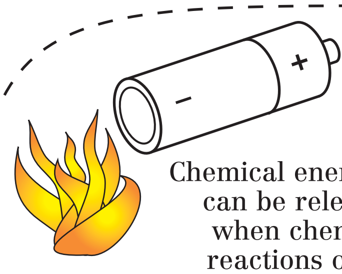
Energy is the ability to make something useful happen.



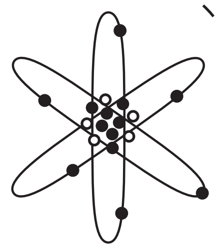
Kinetic – energy an object has due to its motion.

Energy comes in a number of different types:

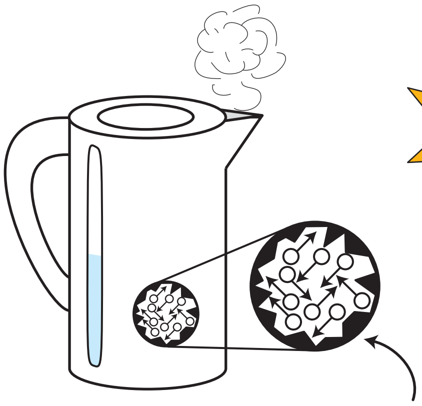
These types are easily stored.



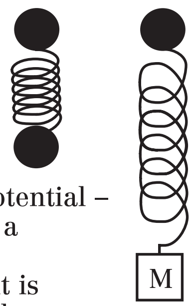
Chemical energy – can be released when chemical reactions occur (including burning of fuels and the reactions of chemicals in batteries).



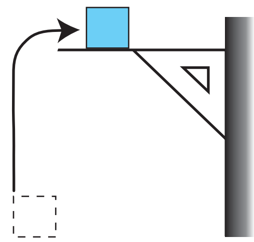
Nuclear energy – stored in the nucleus of atoms and can be released in nuclear reactions.



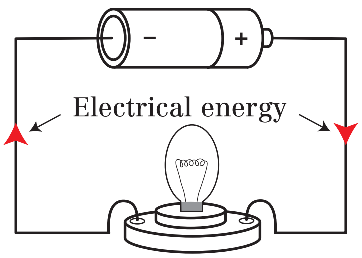
Heat (or thermal) – a measure of the total kinetic energy of the particles making up a material.

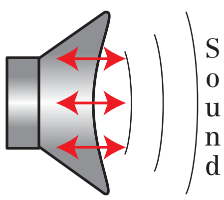


Elastic potential – stored in a material because it is stretched or compressed. It is released when the object returns to its natural shape and size.



Gravitational potential energy – stored by objects raised up above the Earth's surface. It is released if the object falls towards the Earth.





Whenever something useful happens, energy is transferred.

Energy transfers can be shown on simple diagrams.

Transducer: A device that converts one form of energy into another.

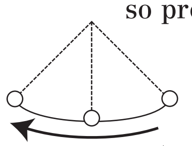
Input energy → Output energy 1, Output energy 2

Many transducers have a number of output energies. Sometimes we ignore some of these if they are insignificant.

E.g. Candle
Chemical energy (in wax) → Heat, Light (In flame)

E.g. Electric motor
Electrical energy (in wires) → Kinetic energy, Heat energy, Sound energy (very small so probably ignored)

Some transfers are cyclical
E.g. pendulum



Gravitational potential ⇄ Kinetic ⇄ Gravitational potential

Questions

1. Nuclear energy is stored in the nucleus of atoms. Make a list of the other types of energy that can be stored giving an example of each.
2. What is a transducer? Make a list of five transducers that might be found in a home and the main energy change in each case.
3. Draw an energy transfer diagrams for the following showing the main energy transfers in each case:
   a. Electric filament light bulb.
   b. Solar cell.
   c. Electric kettle.
   d. Loudspeaker.
   e. Mobile 'phone 'charger'.
   f. Clockwork alarm clock.
   g. Playground swing.
   h. Bungee jumper.
   i. Petrol engine.
   j. Microphone.
4. What provides the energy input for the human body? List all types of energy that the body can transfer the energy input into.

ENERGY Energy Conservation

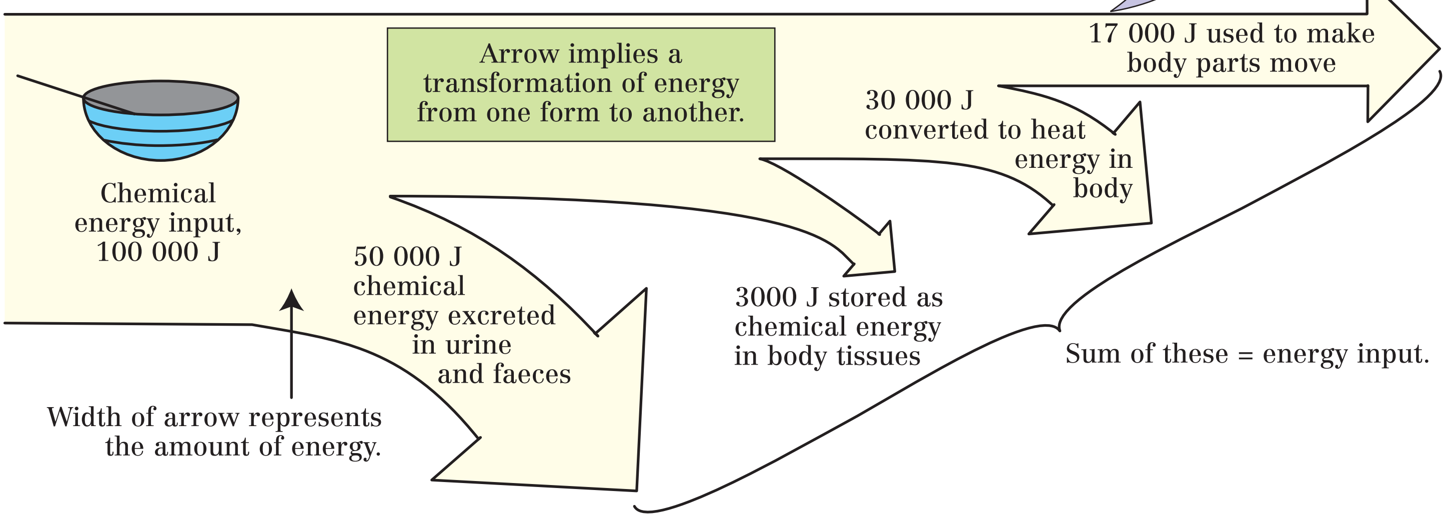
Probably the most important idea in Physics is the Principle of Conservation of Energy, which states:

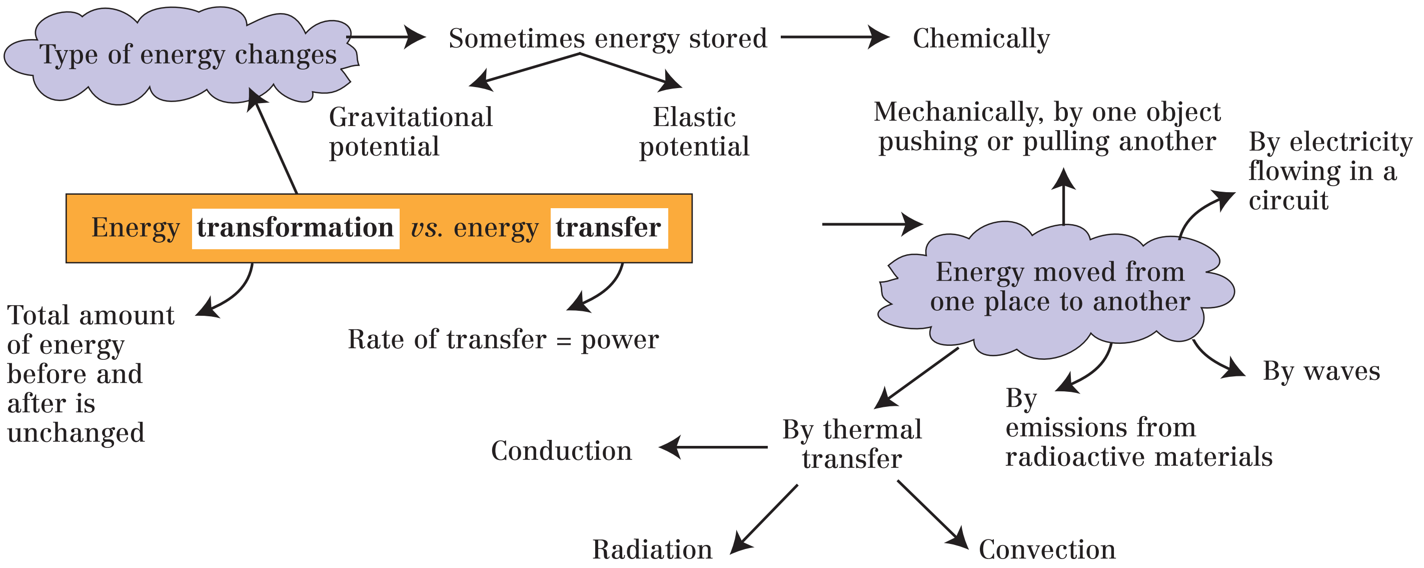
> Energy cannot be created or destroyed. It can only be transformed from one form to another form.

This means that the total energy input into a process is the same as the total energy output.

We can use a more sophisticated energy transfer diagram, called a *Sankey diagram*, to show this.

Energy is measured in Joules





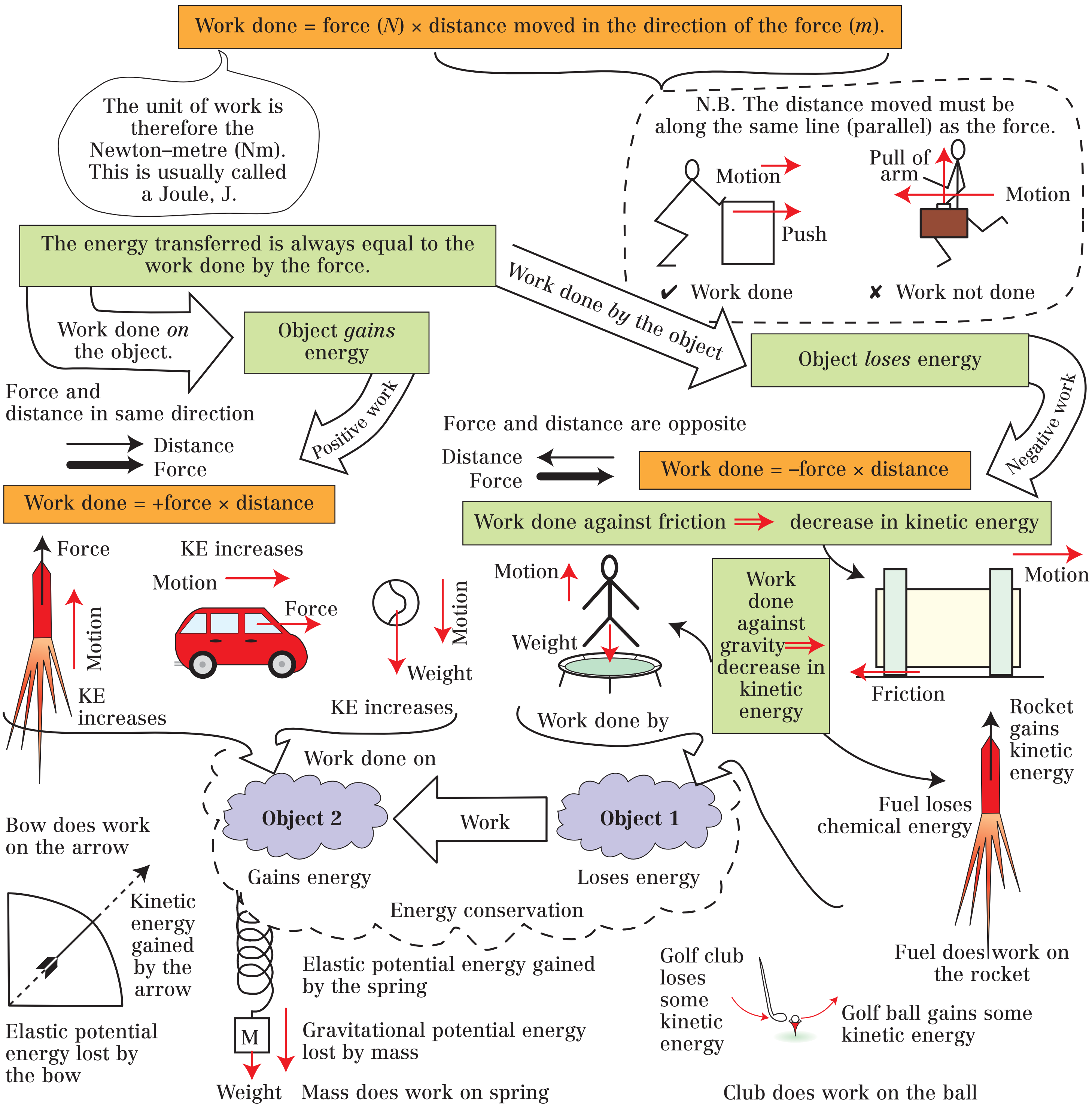
> The majority of the rest of this book explores this in more detail.

Questions

1. State the Principle of Conservation of Energy.
2. What units is energy measured in?
3. Explain the difference between energy transformations and energy transfers. Suggest four ways energy can be transferred.
4. A TV set uses 25 J of energy each second. If 15 J of energy is converted to light and 2 J is converted to sound, how much energy is converted to heat, assuming this is the only other form of energy produced?
5. The motor in a toy train produces 1 J of heat energy and 2 J of kinetic energy every second. What must have been the minimum electrical energy input per second? If the train runs uphill and the electrical energy input stays the same, what would happen to its speed?
6. Use the following data to draw a Sankey diagram for each device:
   a. Candle (chemical energy in wax becomes heat energy 80% and light 20%).
   b. Food mixer (electrical energy supplied becomes 50% heat energy in the motor, 40% kinetic energy of the blades, and 10% sound energy).
   c. Jet aircraft (chemical energy in fuel becomes 10% kinetic energy, 20% gravitational potential energy, and 70% heat).

ENERGY Work Done and Energy Transfer

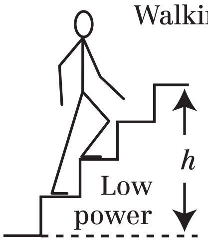
Whenever something useful happens, energy must be transferred but how can we measure energy? The only way to measure energy directly is by considering the idea of *work done*.



Questions

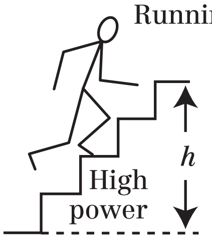
1. Copy and complete:
   'Work is done when a ? moves an object. It depends on the size of the ? measured in ? and the ? the object moves measured in ?. Whenever work is done, an equal amount of ? is transferred. The unit of energy is the ?. Work is calculated by the formula: work = ? × distance moved in the ? of the ?.'
2. I push a heavy box 2 m along a rough floor against a frictional force of 20 N. How much work do I do? Where has the energy come from for me to do this work?
3. A parachute exerts a resistive force of 700 N. If I fall 500 m, how much work does the parachute do?
4. A firework rocket produces a constant thrust of 10 N.
   a. The rocket climbs to 150 m high before the fuel is used up. How much work did the chemical energy in the fuel do?
   b. Explain why the chemical energy stored in the fuel would need to be much greater than the work calculated in (a).
   c. The weight of the empty rocket and stick is 2.5 N. How much work has been done against gravity to reach this height?
   d. The answers to parts (a) and (c) are not the same, explain why.

ENERGY Power



Slow gain in gravitational potential energy.

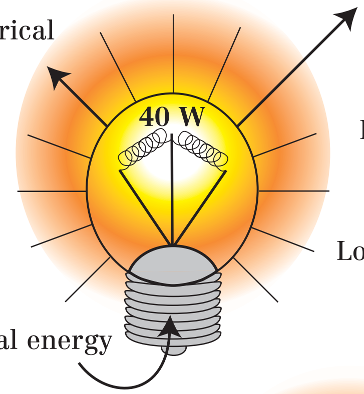
Low rate of doing work.



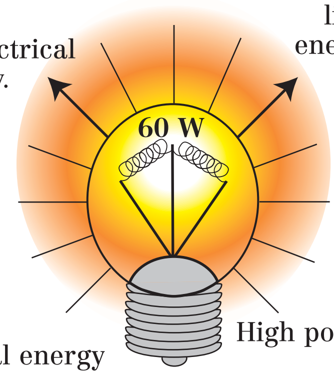
Rapid rate of doing work.

Rapid gain in gravitational potential energy.

Slow conversion of electrical to heat and light energy.



Rapid conversion of electrical to heat and light energy.



Power is the number of Joules transferred each second.

The unit of power is the Joule per second, called the Watt, W.

Power is the rate of energy conversion between forms.

$$\text{Power (W)} = \frac{\text{energy transferred (J)}}{\text{time taken (s).}}$$

'Rate' means how quickly something happens.

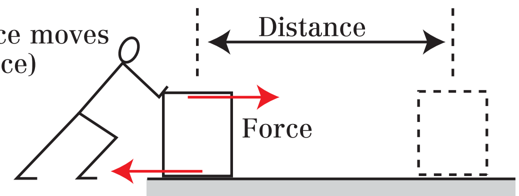
Energy transferred = work done, so

$$\text{Power (W)} = \frac{\text{work done (J)}}{\text{time taken (s).}}$$

Calculating power. Non-mechanical:

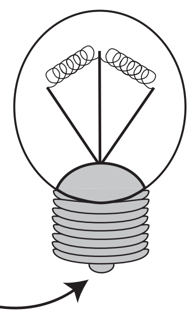
- Find out total (heat, light, electrical) energy transferred
- Find out how long the energy transfer took
- Use the formula above

Mechanical:
(i.e. where a force moves through a distance)



- Calculate the work done = force (N) × distance (m)
- Find out how long the work took to be done
- Use the formula above

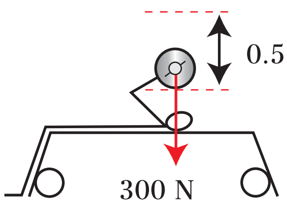
Electrical energy = 1200 J



$$\text{Power} = \frac{\text{energy transferred}}{\text{time taken}} = 1200\text{ J}/20\text{ s} = 60\text{ W}$$

Bulb is switched on for 20 s.

Compare these: imagine how tired you would get if you personally had to do all the work necessary to generate all the electrical power your house uses.



Work done = 300 N × 0.5 m
= 150 J per lift

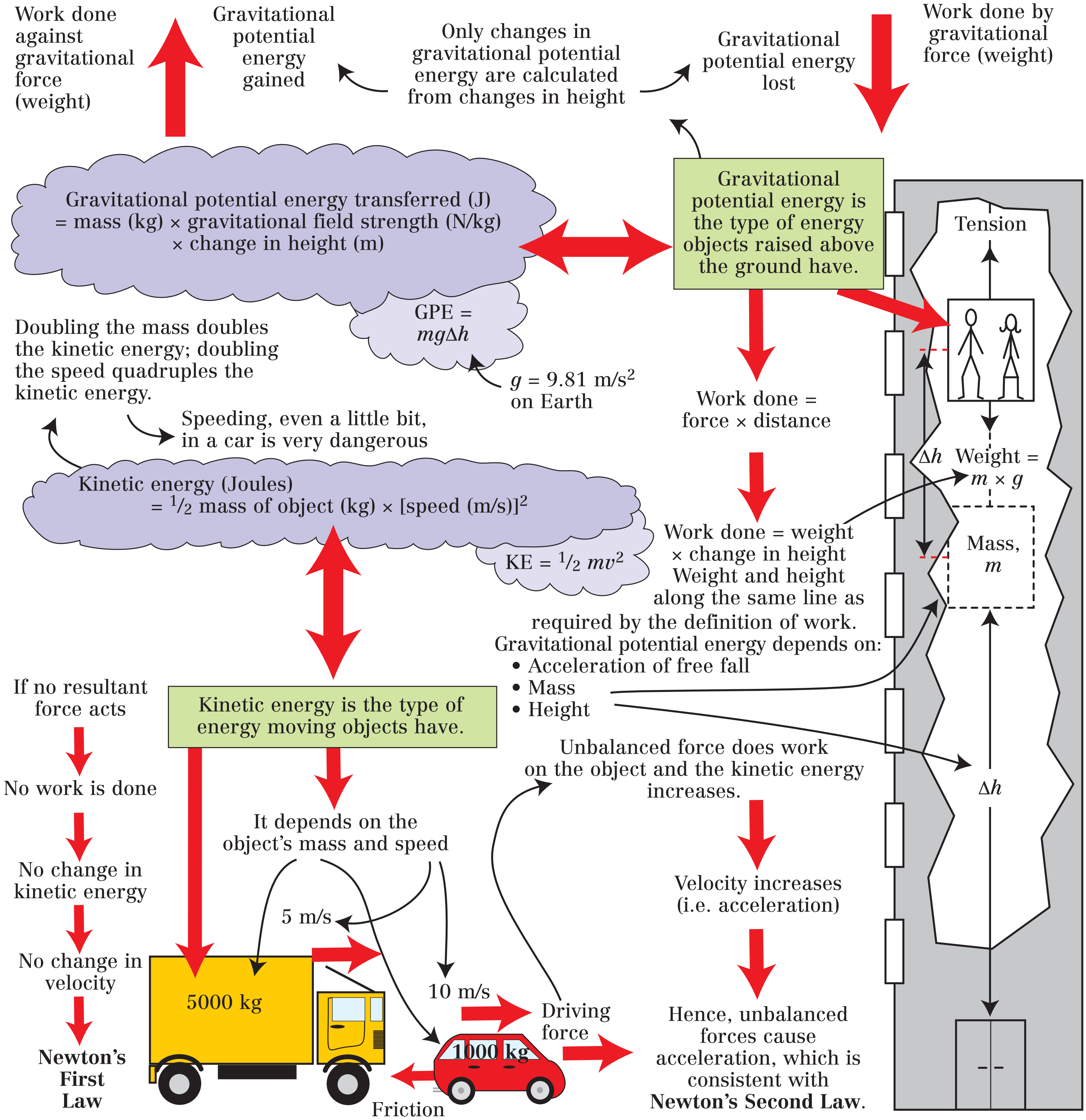
Total work done = 20 × 150 J
= 3000 J

$$\text{Power} = \frac{\text{work done}}{\text{time taken}} = \frac{3000\text{ J}}{60\text{ s}} = 50\text{ W}$$

Questions

1. A kettle converts 62,000 J of electrical energy into heat energy in 50 s. Show its power output is about 1,200 W.
2. A car travels at constant velocity by exerting a force of 1,025 N on the road. It travels 500 m in 17 s. Show that its power output is about 30 kW.
3. The power to three electrical devices is as follows: energy efficient light bulb, 16 W; the equivalent filament bulb, 60 W; a TV on standby, 1.5 W.
   a. How many more Joules of electrical energy does the filament bulb use in one hour compared to the energy efficient bulb?
   b. Which uses more energy, a TV on standby for 24 hours or the energy efficient bulb on for 1.5 hours?
4. When I bring my shopping home, I carry two bags, each weighing 50 N up two flights of stairs, each of total vertical height 3.2 m. I have a weight of 700 N.
   a. How much work do I do on the shopping?
   b. How much work do I do to raise my body up the two flights of stairs?
   c. If it takes me 30 s to climb all the stairs, show that my power output is about 170 W.

ENERGY Gravitational Potential Energy and Kinetic Energy



Questions

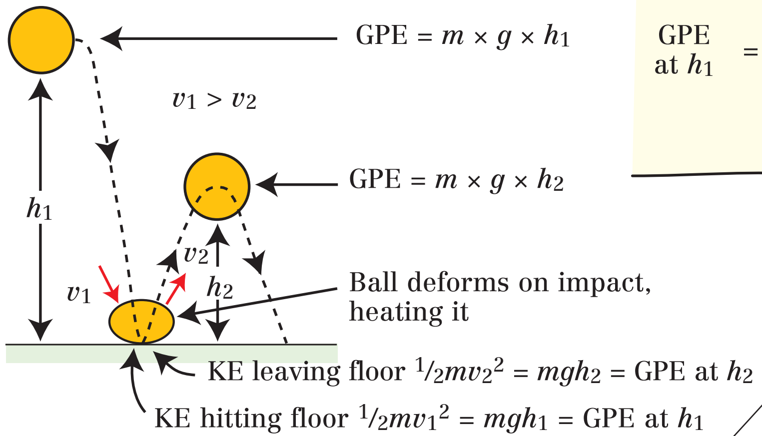
1. Make a list of five objects that change their gravitational potential energy.
2. Using the diagram above calculate the kinetic energy of the car and the lorry.
3. How fast would the car have to go to have the same kinetic energy as the lorry?
4. The mass of the lift and the passengers in the diagram is 200 kg. Each floor of the building is 5 m high.
   a. Show that the gravitational potential energy of the lift when on the eighth floor is about 80 000 J.
   b. How much gravitational potential energy would the lift have when on the third floor? If one passenger of mass 70 kg got out on the third floor, how much work would the motor have to do on the lift to raise it to the sixth floor?
   c. What is the gravitational potential energy of a 0.5 kg ball 3 m above the surface of the Moon where the gravitational field strength is about 1.6 N/kg?
5. A coin of mass 10 g is dropped from 276 m up the Eiffel tower.
   a. How much gravitational potential energy would it have to lose before it hits the ground?
   b. Assuming all the lost gravitational potential energy becomes kinetic energy, how fast would it be moving when it hit the ground?
   c. In reality, it would be moving a lot slower, why?

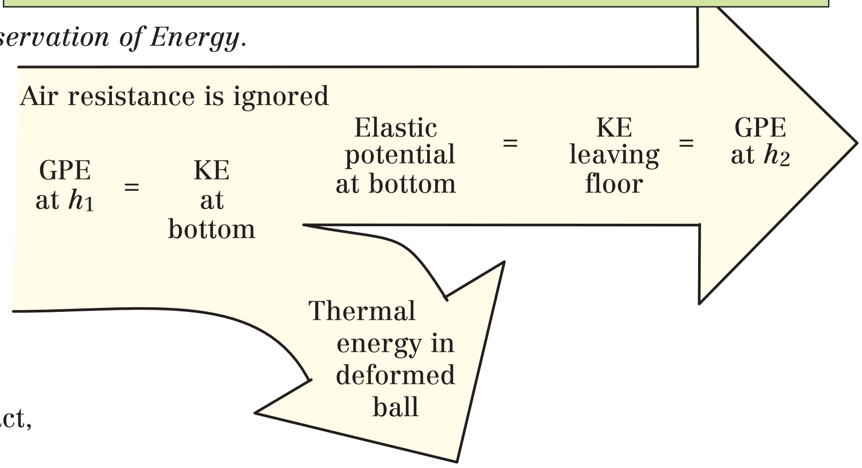
ENERGY Energy Calculations

GPE = gravitational potential energy KE = kinetic energy

All energy calculations use the *Principle of Conservation of Energy*.

E.g. Bouncing ball

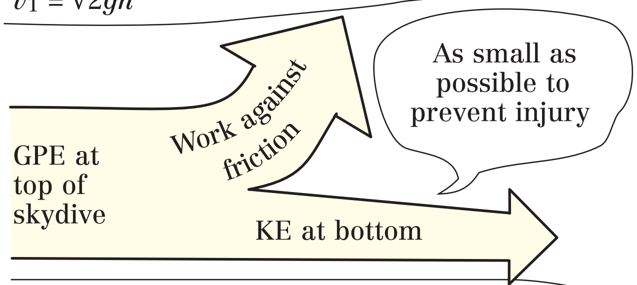




Conservation of energy
GPE at top of bounce = KE at bottom of bounce

$mg\Delta h = \frac{1}{2}mv_1^2$

$v_1 = \sqrt{2gh}$



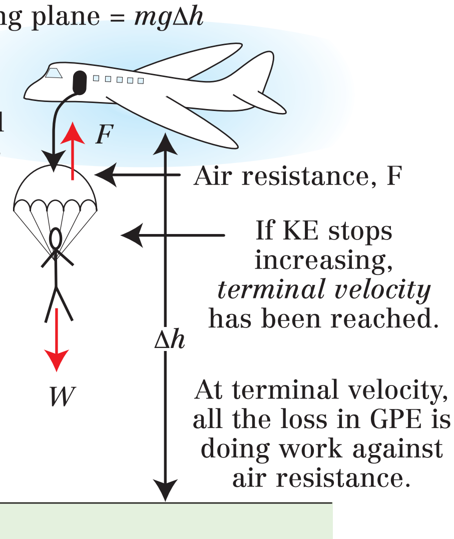
GPE on leaving plane = $mg\Delta h$

GPE at top is not equal to KE at bottom as some GPE was transferred to work against friction (air resistance).

GPE = KE + work against friction

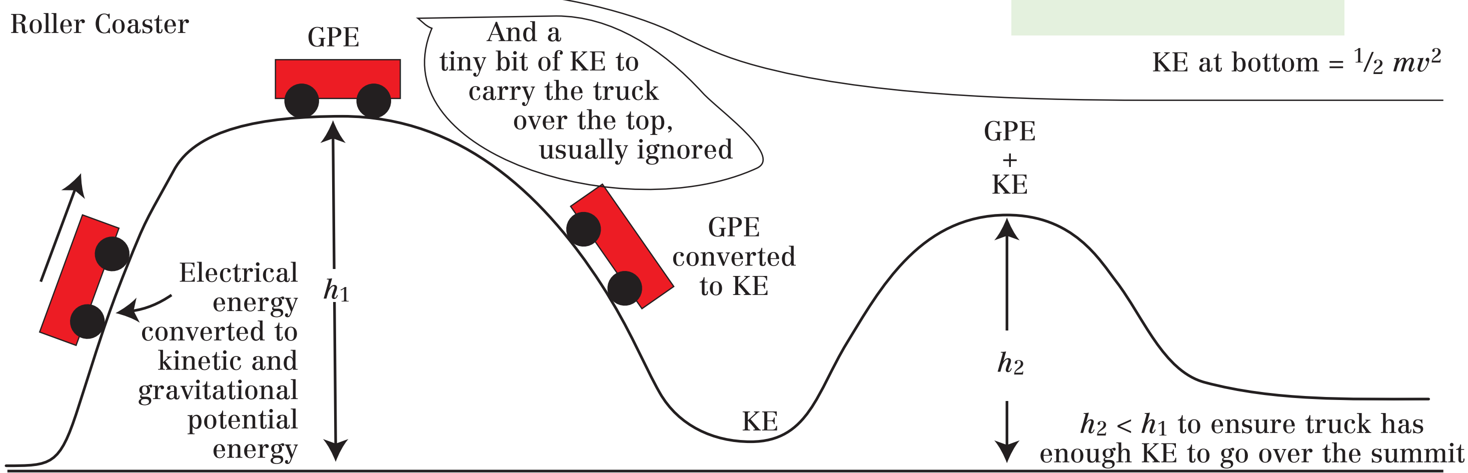
$mg\Delta h = \frac{1}{2}mv^2 + F \times \Delta h$

$$F = \frac{mg\Delta h - \frac{1}{2}mv^2}{\Delta h}$$



KE at bottom = $\frac{1}{2}mv^2$

Roller Coaster



Time to reach top of track
= GPE gain / power of motor = mgh_1 / power
The time will be greater than this as some electrical energy is converted to KE and does work against friction.

KE here = loss of GPE from top
$\frac{1}{2}mv^2 = mgh_1$
$v = \sqrt{2gh_1}$

This is an overestimate as the truck did work against friction.

Questions Take $g = 9.8 \text{m/s}^2$.

1. At the start of a squash game, a 44 g ball is struck by a racquet and hits the wall at 10 m/s.
   a. Show its KE is about 2 J.
   b. The ball rebounds at 8 m/s. Calculate the loss in KE.
   c. Where, and into what form, has this energy been transferred?
2. An acrobatics aircraft of mass 1000 kg is stationary on a runway. Its take off speed is 150 m/s.
   a. Show that the KE of the aircraft at take off is about 11×10^6 J
   b. The maximum thrust of the engines is 20 000 N. Show the aircraft travels over 500 m along the runway before it lifts off.
   c. Give two reasons why the runway will actually need to be considerably longer.
   d. The aircraft climbs to a height of 1000 m. Show it gains about 10×10^6 J.
   e. If the aircraft takes 5 minutes to reach this height, show the minimum power of the engine must be about 33 kW.
   f. Why must this be the minimum power?
   g. The aircraft then flies level at 200 m/s. What is its KE now?
   h. The pilot cuts the engine and goes into a vertical dive as part of the display. When the plane has dived 500 m what is the maximum KE the plane could have gained?
   i. Hence, what is the maximum speed the plane could now be travelling at?
   j. In reality, it will be travelling slower, why?

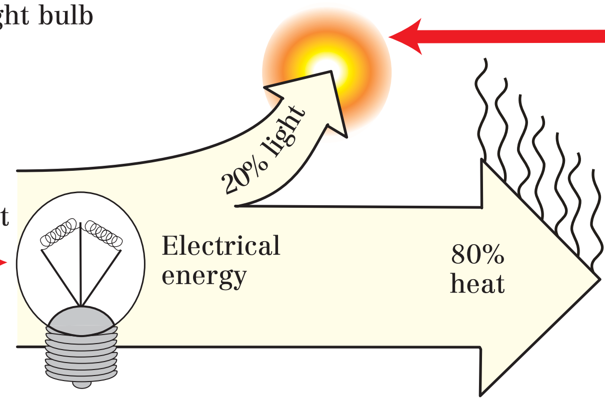
ENERGY Efficiency and the Dissipation of Energy

If energy is conserved, why do we talk about ‘wasting energy’?

Usually when energy is transferred only a proportion of the energy is converted to a useful form, the remainder is converted to other less useful forms of energy, often heat.

E.g. Light bulb

20% efficient



Useful – the type of energy we want from a light bulb.

This energy is not useful – light bulbs are not designed to be heaters. We say this energy has been ‘wasted’.

We say that this energy, that is not useful, is ‘wasted’.

compare

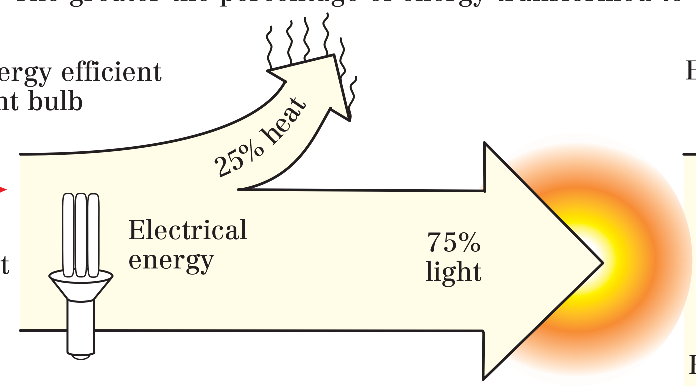
The proportion of the total energy transferred that is useful is called the *efficiency* of the system.

Efficiency (%) = useful energy output (J) / total energy input (J) × 100%

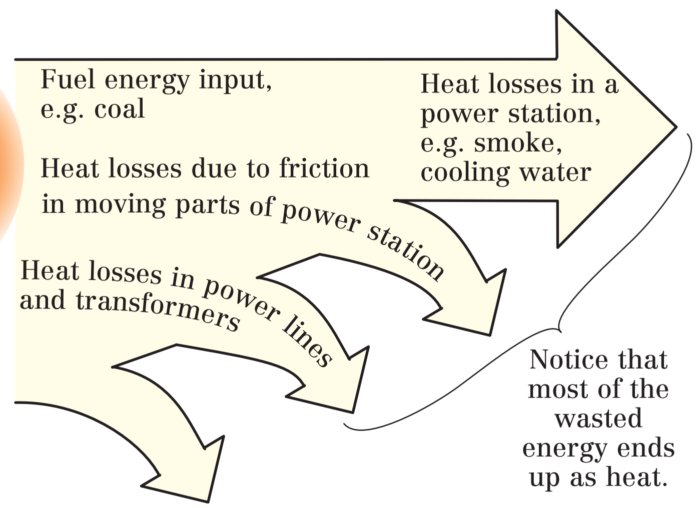
The greater the percentage of energy transformed to a useful form, the more efficient the device.

Energy efficient light bulb

75% efficient

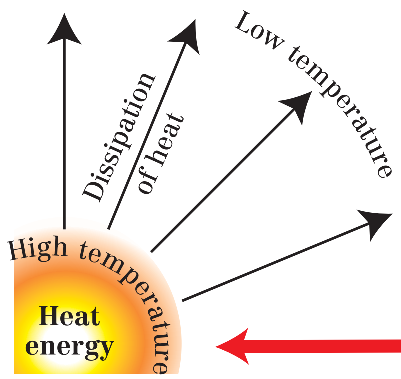


E.g. Power generation



Notice that most of the wasted energy ends up as heat.

Heat energy naturally spreads out into the environment.



Most energy that spreads out into the environment is relatively cool and therefore not useful.

Thermal energy can be efficiently transferred if it has a high temperature. } Useful

Questions

1. An electric motor on a crane raises 50 kg of bricks 10 m. If the energy supplied to the motor was 16 000 J show that the motor is about 30% efficient.
2. A rollercoaster has 250 000 J of GPE at the top of the first hill. At the bottom of the first hill, the coaster has 220 000 J of KE. Where did the rest of the energy go, and what is the overall efficiency of the GPE to KE conversion?
3. A ball of mass 30 g falls from 1.5 m and rebounds to 0.8 m. Show that the efficiency of the energy transformation is about 50%. Why do you not need to know the mass of the ball?
4. A car engine is about 20% efficient at converting chemical energy in petrol. If a car of mass 1000 kg has to climb a hill 50 m high, how much chemical energy will be required? Why in reality would substantially more chemical energy be needed than the value you calculated?
5. A filament light bulb produces a lot of waste heat. Explain why this waste heat energy cannot be put to other uses very easily.
6. What are the main sources of energy wastage in:
   a. A vacuum cleaner?
   b. A motor car?

TRANSFER OF ENERGY

WAVES Describing Waves

WAVES

All waves transfer energy from one place to another, without transferring any matter.

A wave is a periodic disturbance of a medium.

Speed = distance travelled by a wave crest or compression in one second.

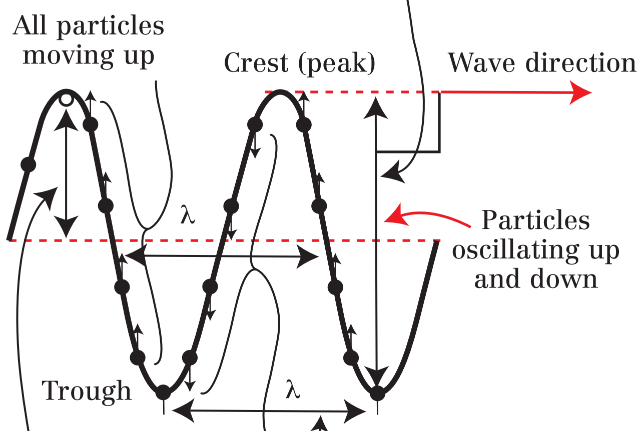
The direction of wave motion is defined as the direction energy is transferred.

The medium is the material that is disturbed as the wave passes through it.

Two types

Transverse waves

Particles of the medium oscillate about fixed positions at right angles to the direction of wave travel.

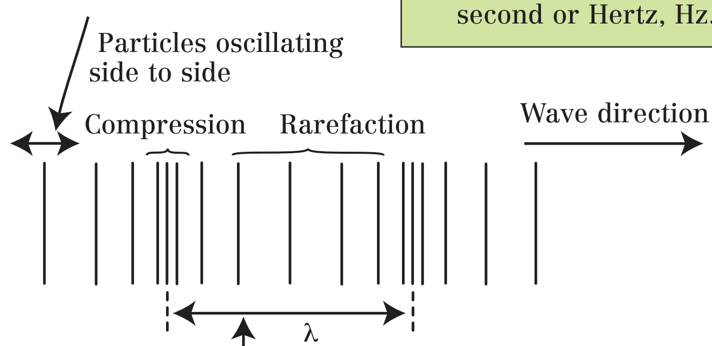


Amplitude – distance between a crest or trough and the *undisturbed position*.

Longitudinal waves

The particles of the medium oscillate about fixed positions along the same line as the wave energy travels.

Frequency is the number of waves per second produced by the source that pass through a given point in the medium. Measured in waves per second or Hertz, Hz.



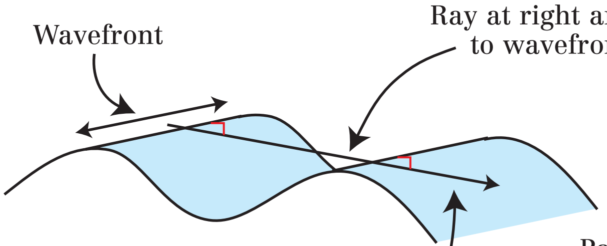
Wavelength (λ) – distance between the same point on two adjacent disturbances. Measured in metres.

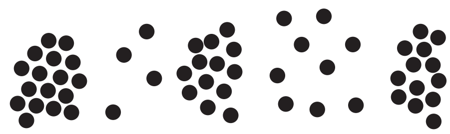
Examples longitudinal:

- Sound

Examples transverse:

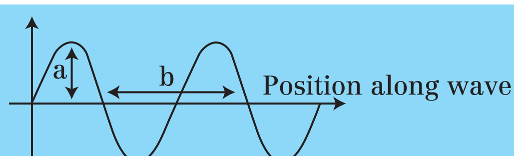
- Surface water waves
- Light
- Plucked guitar string

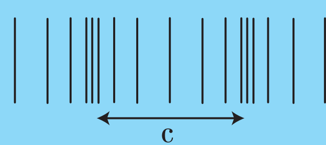




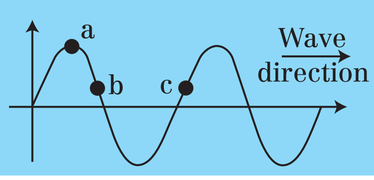
Questions

1. Identify the measurements a, b and c in the following diagrams:





2. Write a sentence to define each of the following terms:
   a. Wavelength.
   b. Frequency.
   c. Amplitude.
2. Give one similarity and one difference between a longitudinal and transverse wave and give an example of each.
3. For each of particles a, b, and c in the diagram decide if the particle is moving up, moving down, or is momentarily stationary.



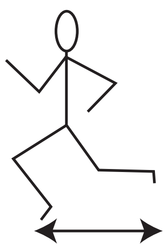
WAVES Wave Speed

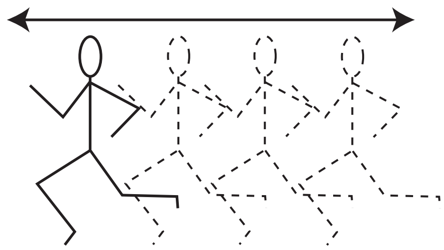
The speed of a wave is given by the equation

Wave speed (m/s) = frequency (Hz) × wavelength (m).

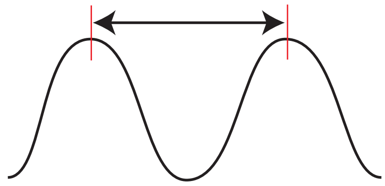
Here is how to see why

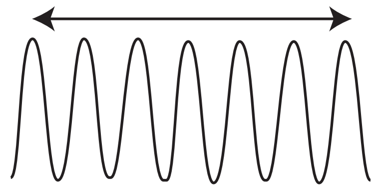
Walking speed (m/s) = stride length (m) × no of steps per second





Wave speed (m/s) = wavelength (m) × no of waves per second (frequency)

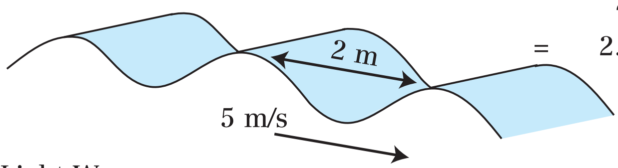




Examples

Water Wave:

$$\text{frequency} = \frac{\text{speed}}{\text{wavelength}} = \frac{5 \text{ m/s}}{2 \text{ m}} = 2.5 \text{ Hz}$$



Light Wave:

Speed of light = 3×10^8 m/s

frequency = 5×10^{14} Hz,

$$\text{wavelength} = \frac{\text{speed}}{\text{frequency}} = \frac{3 \times 10^8 \text{ m/s}}{5 \times 10^{14} \text{ Hz}} = 6 \times 10^{-7} \text{ m}$$

Common speeds:

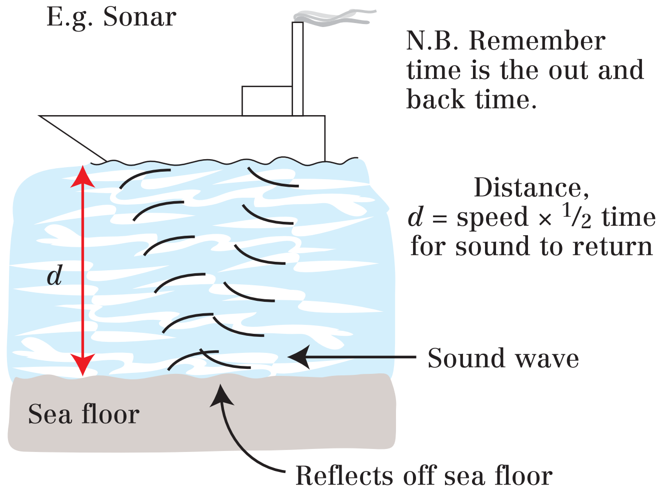
Speed of light = 3×10^8 m/s (300 000 000 m/s)

Speed of sound ≈ 340 m/s (in air at room temperature)

Wave speeds can also be calculated by

$$\text{Wave speed (m/s)} = \frac{\text{distance travelled (m)}}{\text{time taken (s)}}$$

E.g. Sonar



Questions

1. Calculate the speed of the following waves:
   a. A water wave of wavelength 1 m and frequency 2 Hz.
   b. A water wave of wavelength 3 m and frequency 0.4 Hz.
2. Rearrange the formula wave speed = frequency × wavelength to read:
   a. wavelength = _____. b. frequency = ______.
3. Calculate the frequency of a sound wave of speed 340 m/s and wavelength:
   a. 2 m. b. 0.4 m.
4. Calculate the wavelength of a light wave of speed 300 000 000 m/s and frequency:
   a. 4.62×10^{14} Hz. b. 8.10×10^{14} Hz.
5. Calculate the speed of the following waves. Why might we say that all of these waves belong to the same family?
   a. Wavelength 10 m, frequency = 3×10^7 Hz.
   b. Wavelength 4×10^{-3} m, frequency 7.5×10^{10} Hz.
   c. Wavelength 6×10^{-10} m, frequency 5×10^{17} Hz.
6. In the sonar example above, the echo takes 0.3 s to return from the sea floor. If the sea is 225 m deep, show that the speed of sound in seawater is about 1500 m/s.
7. A radar station sends out radiowaves of wavelength 50 cm and frequency 6×10^8 Hz. They reflect off an aircraft and return in 4.7×10^{-5} s. Show that the aircraft is about 7 km from the radar transmitter.

WAVES Electromagnetic Waves

Electromagnetic waves, like all waves transfer energy. They also have the following properties in common.

Electromagnetic waves

- Will travel across empty space. They do not need a medium (solid, liquid, or gas) to travel, unlike sound waves.
- They all travel at the speed of light (300 000 000 m/s) in a vacuum.
- As the speed is fixed, as wavelength increases frequency decreases and *vice versa*.
- They can all be reflected, refracted, diffracted, and interfere.
- They obey the wave speed equation: Wave speed (m/s) = frequency (Hz) × wavelength (m).
- The electromagnetic spectrum of increasing frequency and decreasing wavelength is broken up into blocks and given names. These group the wavelengths that are produced in similar ways.

Notice that ultraviolet, X-rays, and gamma rays wavelengths overlap but they are named according to their source.

	Radiowaves	Microwaves	Infrared (IR)	Visible light	Ultraviolet (UV)	X-rays	Gamma Rays
	I N C R E A S I N G F R E Q U E N C Y →						
Frequency range (Hz)	3 × 10^9	3 × 10^{11}	4.3 × 10^{14}	7.5 × 10^{14}	3 × 10^{17}	3 × 10^{20}	
	← I N C R E A S I N G W A V E L E N G T H						
Wavelength range	← → 10 cm	← → 1 mm	← → 7 × 10^{-7} m	← → 4 × 10^{-7} m	UV ← → 1 × 10^{-9} m	X-rays ← → 1 × 10^{-12} m	γ-rays ← →
Sources	Radio transmitters (electrons accelerating up and down metal aerials)	Microwave transmitters (Klystron or magnetron tube)	Any hot object →	Very hot, luminous objects → Light emitting diodes	Extremely hot gases, e.g. the Sun, UV lamps	X-ray tubes	Nuclei of radio-active atoms
Detectors	Aerials	Microwave receiver (aerial)	← (special) —— Photographic film → ; ← Charge coupled device – used in digital cameras and camcorders → ; Thermistor	Light dependent resistor	Fluorescent materials	← GM tube →	
	I N C R E A S I N G E N E R G Y →						

Detectors: Things which produce an observable response to the radiation they absorb.

Notice that light is just one of this family of radiations and that the visible spectrum, red–violet, can be extended on both sides.

Questions

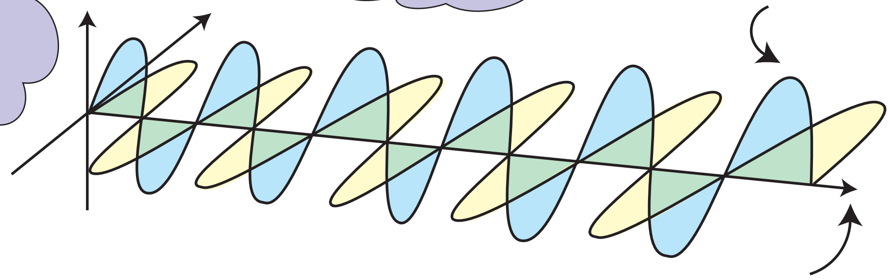
1. State three properties all electromagnetic waves have in common.
2. Calculate the wavelength of electromagnetic waves of the following frequencies:
   a. 5 × 10^9 Hz. b. 5 × 10^{14} Hz. c. 5 × 10^{15} Hz.
   d. What part of the electromagnetic spectrum does each of these waves come from?
2. Calculate the frequencies of electromagnetic waves of the following wavelengths:
   a. 1 m. b. 1 × 10^{-5} m. c. 5 × 10^{-8} m.
   d. What part of the electromagnetic spectrum does each of these waves come from?
3. List the electromagnetic spectrum in order of increasing energy.
4. Which has the longest wavelength, red or blue light? List the colours of the visible spectrum in order of increasing frequency.

WAVES How Electromagnetic Waves Travel

What is 'waving' in an electromagnetic wave?
It is formed from linked oscillating electric and magnetic fields, hence the name.

No need for a medium as electric and magnetic fields travel in empty space.

Two fields oscillate at right angles.



Electric field

Magnetic field

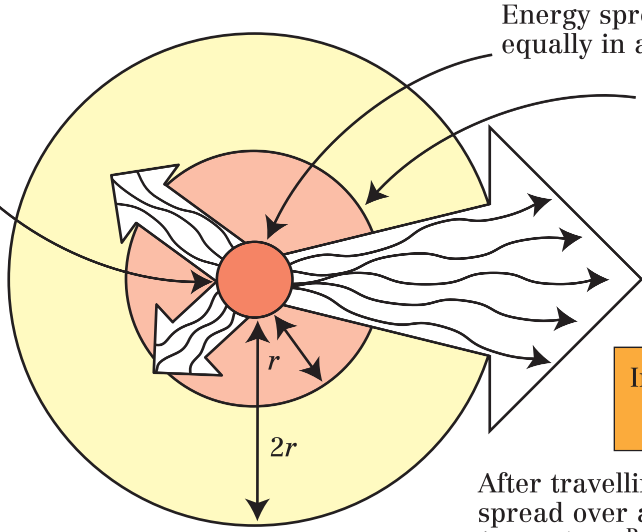
Direction of travel

Electromagnetic radiation from a point source (e.g. a star, lamp filament) obeys the inverse square law.

Source has a power output of P watts (i.e. it is losing P Joules every second by the emission of electromagnetic waves).

Energy spreads out (radiates) equally in all directions.

After travelling a distance r, it will be spread over a sphere of surface area A (Intensity, P/A).



Doubling the distance from the source reduces the intensity to a quarter.

I.e. Intensity $\propto 1/r^2$

$$\text{Intensity (W/m}^2\text{)} = \frac{\text{power (W)}}{\text{area (m}^2\text{)}}$$

After travelling a distance $2r$, it will be spread over a sphere of surface area $4A$. (Intensity, $\frac{P}{4A}$)

Laser light — Stands for '**L**ight **A**mplification by **S**timulated **E**mission of **R**adiation'

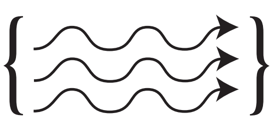
Only one wavelength from a given source.

Waves form a narrow beam with very little spreading so the light is very intense.

Laser light *vs.* **Ordinary light**

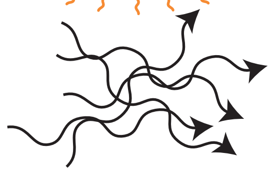
Generally a mixture of wavelengths from a source.

All waves travel together in step (in phase).



Peaks and troughs always coincide.

Waves travel in all directions.

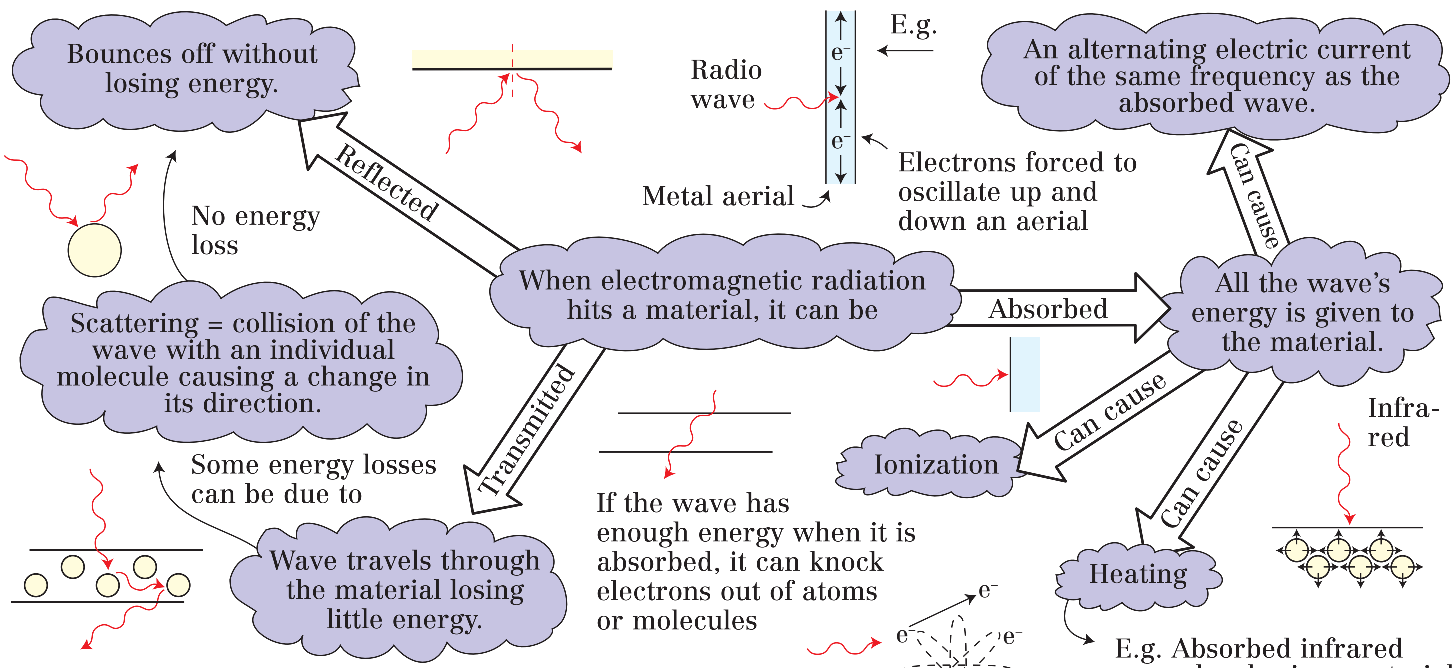


Waves do not travel in step.

Questions

1. What is waving in an electromagnetic wave?
2. A 60 W light bulb can be considered a point source of light. What is the intensity of the light:
   a. 1 m from the bulb when it has spread through a sphere of area 12.6 m^2?
   b. 2 m from the bulb when it has spread through a sphere of area 50.3 m^2?
   c. Suggest what the intensity would be 3 m from the bulb.
3. The intensity of the Sun's radiation at the Earth is about 1400 W/m^2. Jupiter is about five times further from the Sun. Show that the intensity of the Sun's radiation here is about 56 W/m^2.
4. Suggest three differences between laser light and ordinary light from a lamp.

WAVES Absorption, Reflection, and Transmission of Electromagnetic Waves



Whether a wave is absorbed, reflected, or transmitted depends on the type of radiation and the material. Here are some examples.

Radiation	Metals	Glass	Living Tissue	Water
Radiowaves	Absorbed by aerials, but otherwise reflected	Transmitted	Transmitted	Reflected
Microwaves	Reflected, e.g. satellite dishes and inside of microwave ovens	Transmitted	Transmitted except 12 cm wavelength which is absorbed by water in the tissues	12 cm wavelength absorbed, otherwise transmitted
Infrared	Absorbed by dull/black surfaces, reflected by shiny ones	Transmitted/ reflected depending on wavelength	Absorbed	Absorbed
Visible light	Absorbed by dull/black surfaces, reflected by shiny ones	Transmitted	Some wavelengths absorbed, some reflected – giving the tissue a distinctive colour	Transmitted
Ultraviolet	Absorbed	Absorbed	Absorbed and causes ionization	Absorbed
X-rays	Partially absorbed and partially transmitted. The denser the material the more is absorbed		Partially absorbed and partially transmitted. The denser the tissue the more is absorbed	Transmitted
Gamma rays			Transmitted	Transmitted

Questions

1. Define the following and give an example of a type of radiation and material that illustrates each:
   a. Transmission. b. Reflection. c. Absorption.
2. Suggest three possible results of the absorption of electromagnetic radiation by a material.
3. Copy and complete the table using words below (look ahead to p33 and 34 if you need help).

Sending signals to mobile phones. Cooking. Aerials. Broadcasting. Suntans. Sterilization. Medical X-rays. Mirrors. Walls of a microwave oven.

	Transmission	Absorption	Reflection
Radiowave			Round the globe broadcasting by bouncing off the ionosphere
Microwave			
Infrared		Cooking	
Visible light	Lenses		
Ultraviolet			
X-ray			
Gamma ray			

WAVES The Earth's Atmosphere and Electromagnetic Radiation

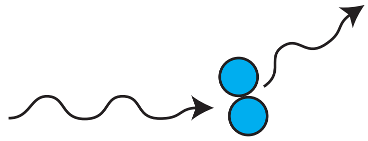
Electromagnetic waves either

pass straight through the atmosphere

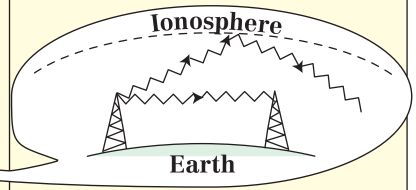
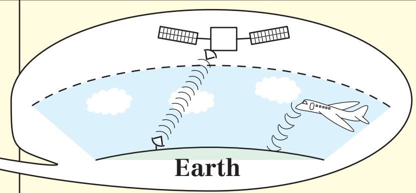
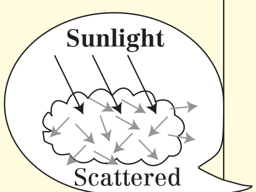
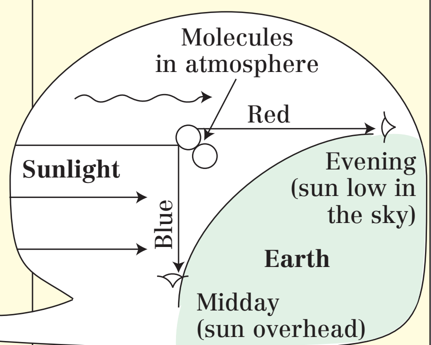
or

are absorbed by molecules in the atmosphere

or



are scattered by molecules in the atmosphere

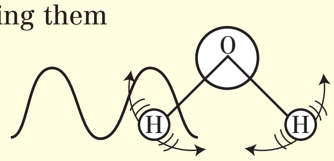
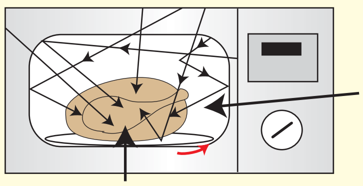
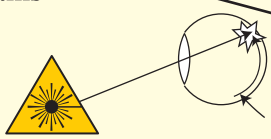
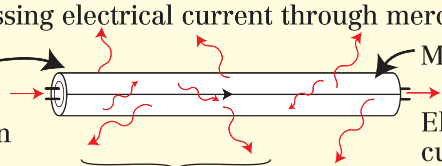
Type of radiation	Effect of the atmosphere	Potential uses	Potential problems
Radiowaves	Generally pass straight through, except some long wavelengths will be reflected by a layer called the ionosphere, high in the atmosphere	Carrying messages over long distances. Bouncing radiowaves off the ionosphere allows them to reach receivers out of the line of sight	
Microwaves	Pass through all parts of the atmosphere	Send information to and from satellites in orbit; send information to and from mobile phones; radar	
Infrared	Absorbed by water vapour and other gases such as carbon dioxide (present in small amounts) and methane (present in minute amounts)	Humans are increasing the amount of greenhouse gases in the atmosphere. Some scientists think this is causing the Earth to warm up. Possible consequences are . . . • Rising sea levels due to melting of the polar ice caps • Extreme weather conditions occurring more often • Loss of farmland (too wet, dry)	Infrared is emitted by all warm surfaces including the Earth's surface. Some is lost into space but some is absorbed by gases (water, carbon dioxide) in the atmosphere warming it. This is called the *Greenhouse effect* and those gases that absorb infrared, greenhouse gases. Too high a concentration of greenhouse gases leads to *global warming*
Visible light 	Passes through clear skies. Blue light is scattered more than red light giving blue skies during the day and red skies at dawn and dusk Randomly scattered from water vapour in clouds	Provides plants with energy for photosynthesis and hence all living things with food. Warms the Earth's surface	
Ultraviolet	Absorbed by ozone gas high in the atmosphere (the ozone layer)	Ozone layer protects plants and animals from exposure to too much ionizing ultraviolet radiation from the Sun which would harm them	Ozone layer is being destroyed by chemical reactions with man-made gases
X-rays and gamma rays	Absorbed by the atmosphere		

Questions

1. Which types of electromagnetic radiation pass straight through the atmosphere, which are scattered, and which are absorbed?
2. What is the Greenhouse effect? Suggest why the concentration of carbon dioxide in the atmosphere has been rising for the last 200 years. Suggest three consequences of global warming.
3. Why are cloudy nights generally warmer than when there are clear skies?
4. If the polar ice caps melt, will the Earth's surface absorb more or less radiation from the Sun? Hence will this increase or decrease the rate of global warming?
5. How is the ozone layer helpful to humans and why should we be concerned about a hole in it?

WAVES Uses of Electromagnetic Waves, Including Laser Light

There is an almost limitless range of uses for electromagnetic waves.
The selection below gives a flavour of some of the more common.

Type of radiation	
Radiowaves	Broadcasting (long, medium, and shortwave radio, TV [UHF]) (see pages 97, 99). Emergency services communications
Microwaves	Microwaves are strongly absorbed by water molecules making them vibrate violently. This can be used to heat materials (e.g. food) containing water.  Microwave energy penetrates more deeply than infrared so food cooks more quickly  Microwaves bounce off the metal walls until absorbed by the food Food must be rotated to ensure all parts are cooked evenly Sending signals to and from mobile phones or orbiting satellites (see p97)
Infrared	Fibre-optic cables (see p104) Remote controls Toasters and ovens Infrared cameras for looking at heat loss from buildings, night vision, and searching for trapped people under collapsed buildings
Visible light	Seeing and lighting → Fibre-optic cables (see p104) Laser light → To read CDs, DVDs, and barcodes in shops (see p107) Laser light → Surveying, as laser beams are perfectly straight Laser light → Eye surgery (can be used to 'weld' a detached retina back into place on the back of the eyeball)  Retina
Ultraviolet	Can be produced by passing electrical current through mercury vapour If the tube is coated with a fluorescent chemical this absorbs the ultraviolet radiation and emits visible light  Mercury vapour Electric current Ultraviolet radiation produced Fluorescent strip lights Security markers use fluorescent chemicals, which glow in ultraviolet radiation but are invisible in visible light Used for tanning lamps in sun beds Washing powder contains fluorescent chemicals to make clothes look 'whiter than white'
X-rays	Absorption depends on density of the material so can be used to take shadow picture of bones in bodies or objects in luggage (see p108)
Gamma rays	Used to kill cancerous cells Sterilize hospital equipment and food

Questions

1. Write a list of all the things you use electromagnetic radiation for during a typical day.
2. Food becomes hot when the molecules in it vibrate violently. Suggest one similarity and one difference between how this is achieved in a microwave oven and in a conventional thermal oven.
3. Group the uses listed in (1) under the headings:
   a. 'Electromagnetic waves used to communicate'.
   b. 'Electromagnetic waves used to cause a change in a material'.
   c. 'Electromagnetic waves used to gather information'.

WAVES Dangers of Electromagnetic Waves

When electromagnetic radiation is absorbed by the body, it deposits its energy. The more energy deposited, the greater the potential for damage. This depends on the type of radiation, its intensity, and time for which the body is exposed to it.

To reduce the hazard from electromagnetic waves you can reduce the time of exposure, reduce the intensity (for example by moving away from the source or using a lower power source), or by the use of a physical barrier to absorb the radiation.

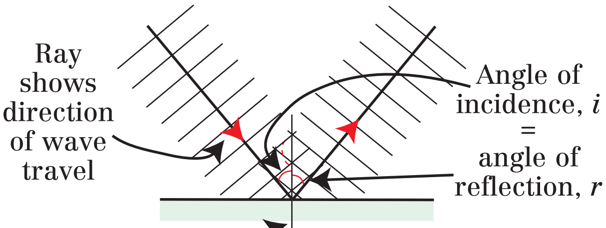
Type of radiation	Hazard	How to reduce hazard
Non-ionizing. These are a lower hazard		
Radiowaves	Minimal. These generally pass straight through the body and carry little energy	
Microwaves	Low intensity radiation from mobile phones and their transmitter masts may be a health risk, but the evidence is inconclusive Microwaves used in ovens causes a heating effect in water, which would therefore damage water-containing cells	*Reduce time of exposure:* reduce phone usage *Reduce intensity:* use a hands free kit to reduce exposure *Physical barrier:* microwave ovens have metal case and grille over the door to prevent microwaves escaping
Infrared	Absorbed infrared can lead to cell damage, which we call a burn	*Reduce time of exposure and intensity:* the body has a natural defence mechanism of instinctively moving away from sources of infrared that are uncomfortably hot
Visible light	Only laser light presents a significant hazard	*Reduce exposure:* never look into the beam *Physical barrier:* most laser products, especially if high intensity, have the beam shielded
Ionizing – able to break molecules into smaller parts (ions) which may go on to be involved in further (possibly harmful) chemical reactions. If these molecules are in the cells of the body the ions can cause changes to the DNA of the cell causing it to divide and grow incorrectly. This is called *cancer*		
Ultraviolet	Absorption may cause cell mutations (particularly in skin) which can lead to cancer Sunburn	*Physical barrier:* sun cream and sun block contain chemicals that strongly absorb ultraviolet providing a barrier between the radiation and the skin Wear clothing *Reduce time of exposure:* avoid excessive sunbathing or tanning treatment
X-rays	Some absorbed and some transmitted. Absorbed radiation may cause cell mutations leading to cancer	*Reduce time of exposure:* limit number of X-rays you are exposed to (but sometimes the medical benefits outweigh the potential risks) *Physical barrier:* health workers use lead shielding to reduce their exposure
Gamma rays	High enough energy to directly kill cells (radiation burns), or to cause cancerous cell mutation	*Physical barrier:* gamma rays from nuclear power plants are shielded from the outside by thick layers of lead, steel, and concrete *Reduce time of exposure:* nuclear industry workers have their exposure times carefully monitored and controlled

Questions

1. Suggest three ways that exposure to harmful electromagnetic waves can be reduced.
2. What is the difference between ionizing and non-ionizing radiation?
3. A parent is worried about the possible health risks of a child using a mobile phone while sunbathing in swimwear on a very sunny day. What advice would you give them?

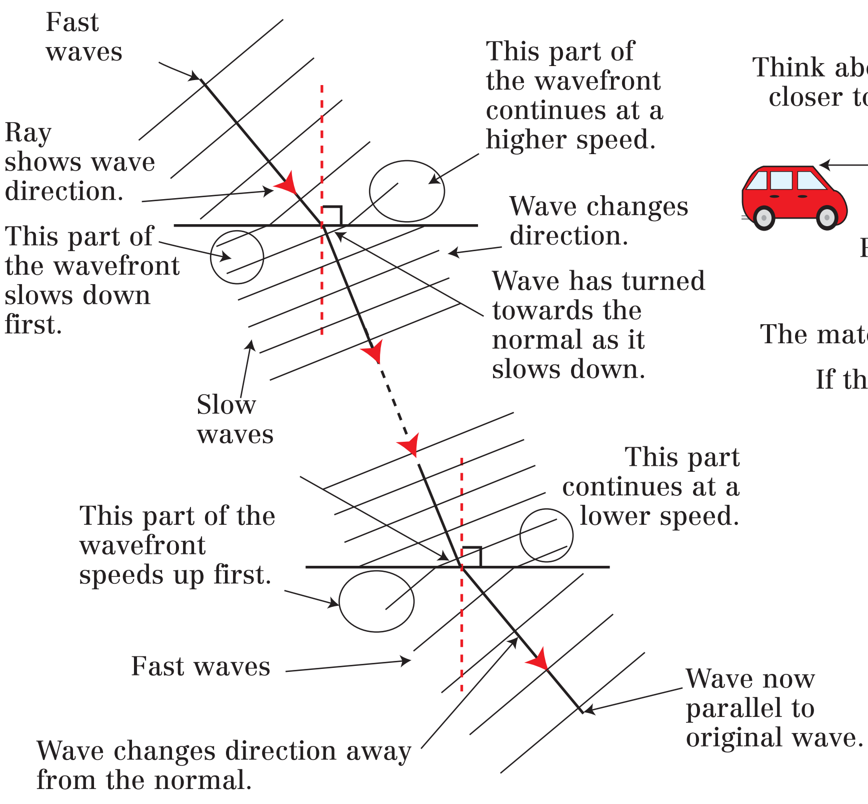
WAVES Reflection, Refraction and Total Internal Reflection

Waves *reflect* off a plane surface.



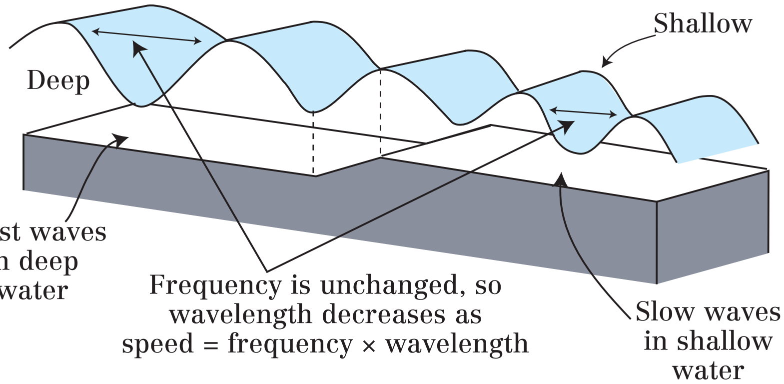
Normal – a construction line perpendicular to the reflecting / refracting surface at the point of incidence

If the waves meet the boundary at an angle . . .

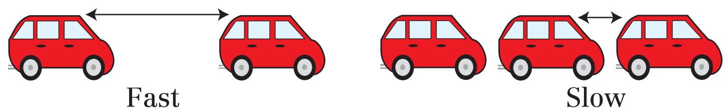


This process is called *refraction*.

Waves travel at different speeds depending on the media they are travelling in.

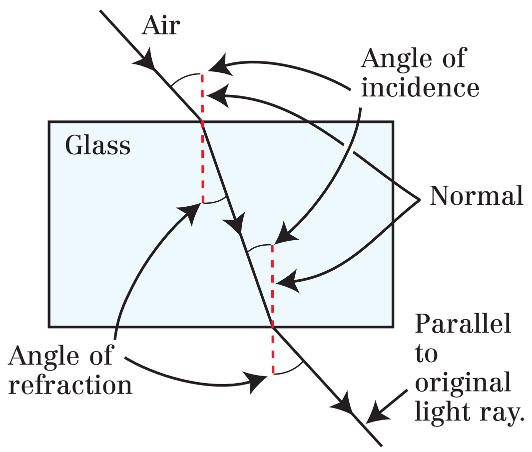


Think about cars on a road, if they slow down they get closer together but the number of cars passing each second stays the same.



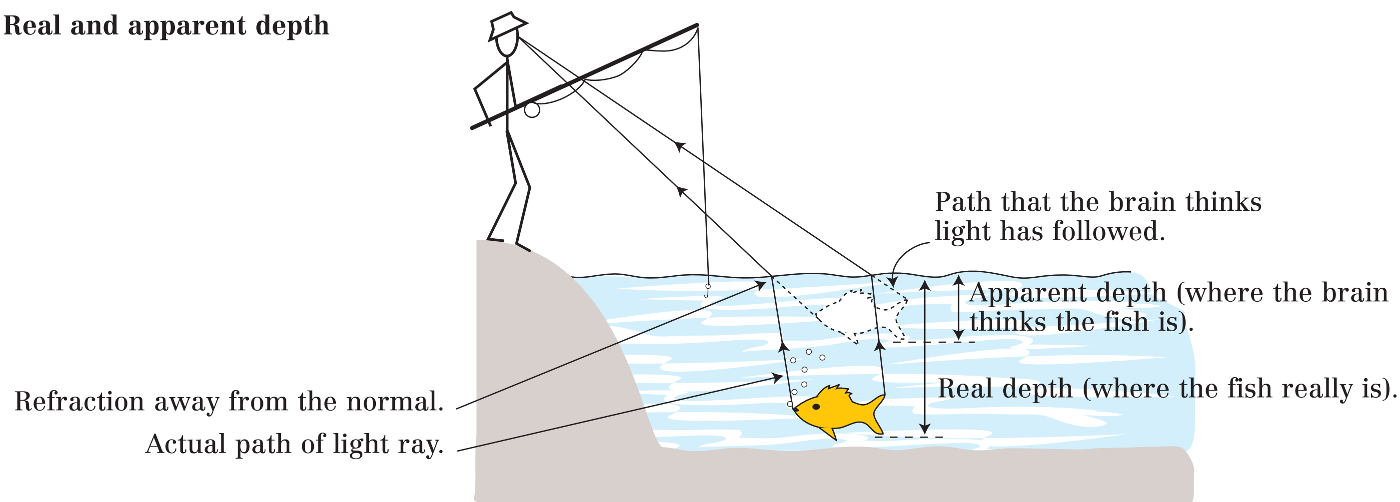
The material light passes through is called the *medium*.

If the speed of light is different in two different media, it also refracts.

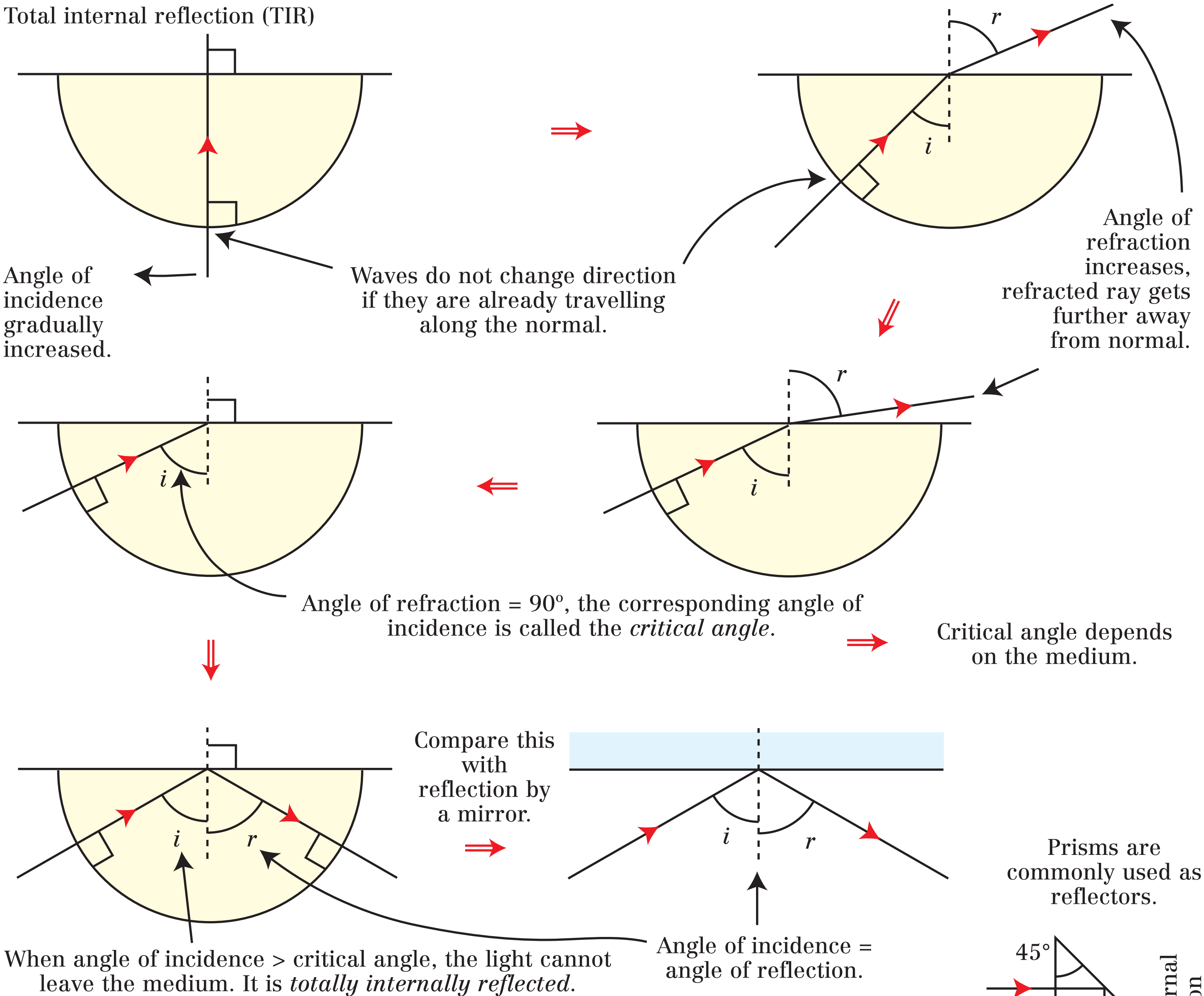


As light slows down it changes direction towards the normal (angle of incidence, *i*, > angle of refraction, *r*).
As light speeds up it changes direction away from the normal (angle of incidence, *i*, < angle of refraction, *r*).

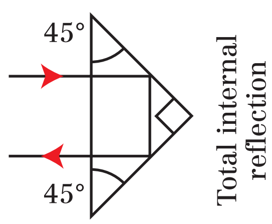
Real and apparent depth



Total internal reflection (TIR)



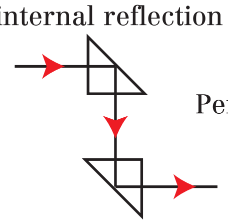
Prisms are commonly used as reflectors.



E.g. 'Cat's eyes' in roads.

Prisms are more robust than mirrors.

Total internal reflection can be used to manipulate the path of light.

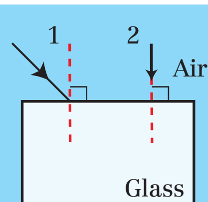


Periscope

Other uses:
- Binoculars
- Bicycle reflectors

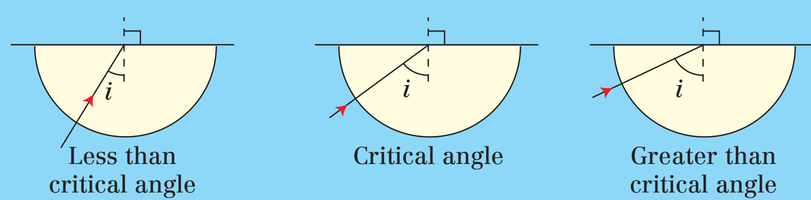
Questions

1. Explain how to decide whether a wave changes direction towards or away from the normal. In what special situation is there no change in direction?



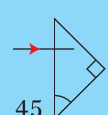
2. Copy and complete the diagram right to show the paths of the two rays through and out the bottom of the glass block.

3. Copy and complete the diagrams right to show what happens to light incident on a glass/air surface when the angle of incidence is less than, equal to, or above the critical angle.



4. Explain, with the aid of a diagram, why waves meeting a boundary where they slow down at an angle change direction.

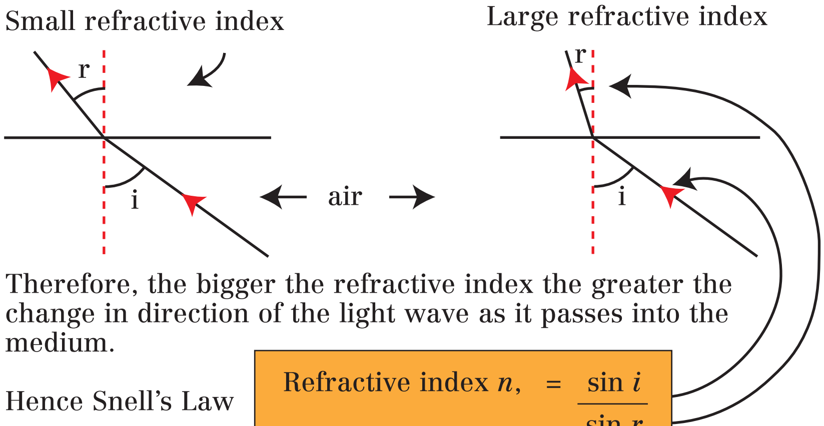
5. Complete the path of the light ray through this prism and suggest a use for such a prism.



WAVES Refractive Index and Dispersion

When light travels from a vacuum (or air since it makes very little difference to the speed) into another medium, it is slowed down. The amount of slowing is expressed by the ratio:

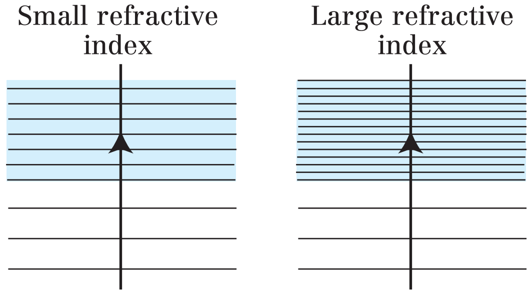
$$\frac{\text{Speed of light in vacuum (m/s)}}{\text{Speed of light in medium (m/s)}} = \text{refractive index, } n$$



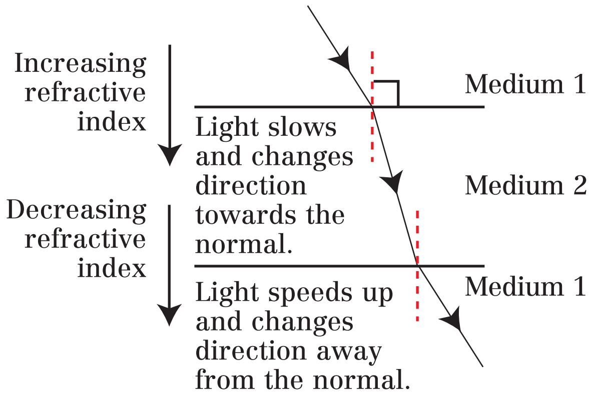
Therefore, the bigger the refractive index the greater the change in direction of the light wave as it passes into the medium.

Hence Snell's Law

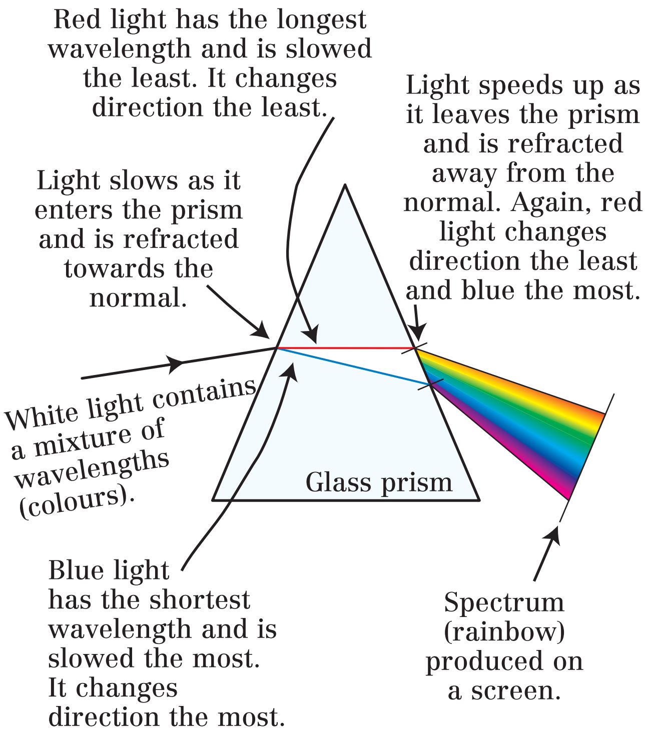
$$\text{Refractive index } n, = \frac{\sin i}{\sin r}$$



The bigger the refractive index the more the light is slowed as it passes into the medium.

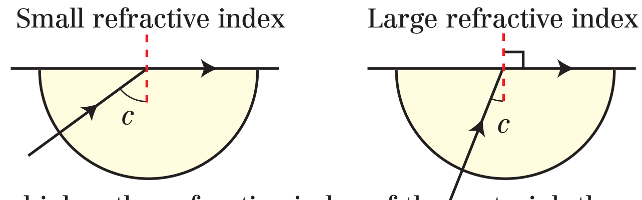


Dispersion



Total internal reflection

1. Light must change direction away from the normal so must be going from high to low refractive index.
2. Angle of incidence must be greater than the critical angle.



The higher the refractive index of the material, the greater the change of direction away from the normal and therefore, the lower its critical angle.

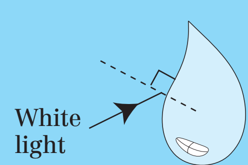
The critical angle, c, can be calculated from the ratio of the refractive indices either side of the boundary.

$$\text{Sin (critical angle)} = \frac{\text{refractive index of second material}}{\text{refractive index of first material}}$$

$$\text{Sin } c = \frac{n_r}{n_i}$$

Questions

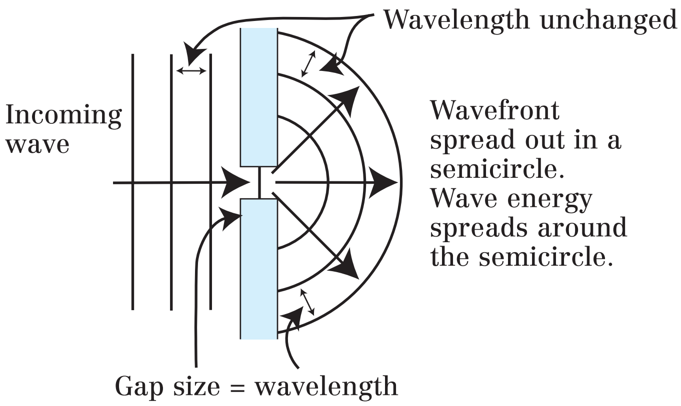
1. Which colour, blue or red, is slowed most as it enters a glass prism?
2. Copy the water droplet and complete the diagram to show how the drop splits the white light into colours. Show the order of these colours on your diagram.
3. The speed of light in a vacuum is 3×10^8 m/s. Show that:
   a. The refractive index of water is about 1.3 given the speed of light in water is 2.256×10^8 m/s.
   b. The speed of light in diamond is about 1.2×10^8 m/s given its refractive index is 2.42.
4. The refractive index of glass is about 1.52. A ray of light enters a glass block at 25° to the normal. Show that it continues through the block at about 16°.
5. What is the critical angle for light travelling from water, refractive index 1.33, to air, refractive index 1.00? Why is it not possible to calculate a critical angle for light travelling from air into water?

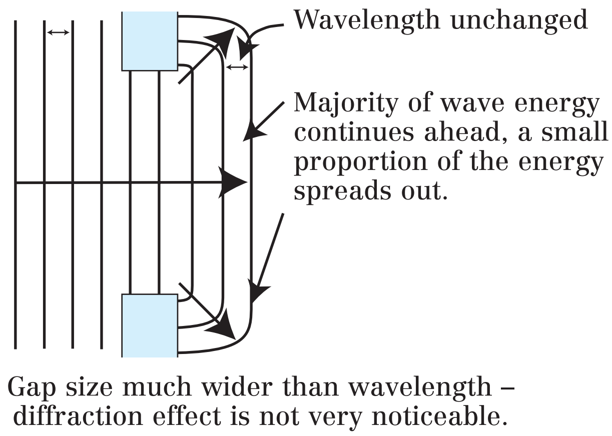


WAVES Diffraction and Interference

Both diffraction and interference are properties of waves. The fact that all electromagnetic waves display both effects is strong evidence for them having a wave nature.

Diffraction – the spreading out of wave energy as it passes through a gap or past an obstacle.

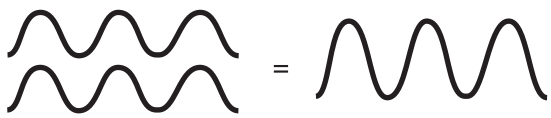




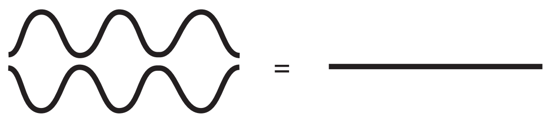
Light has a very short wavelength (about 5×10^{-7} m), so needs very small gap sizes for diffraction to be noticeable.

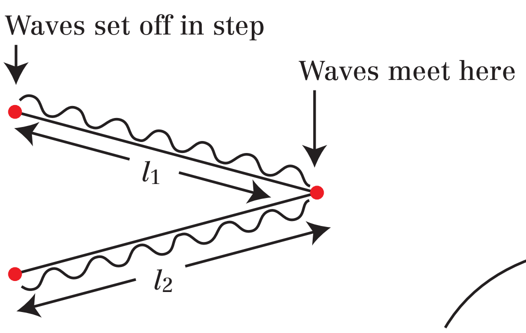
Interference – when two waves meet, their effects add.

When two waves arrive in step, they reinforce each other and this is called *constructive interference*. For light the result would be bright and for sound, loud.



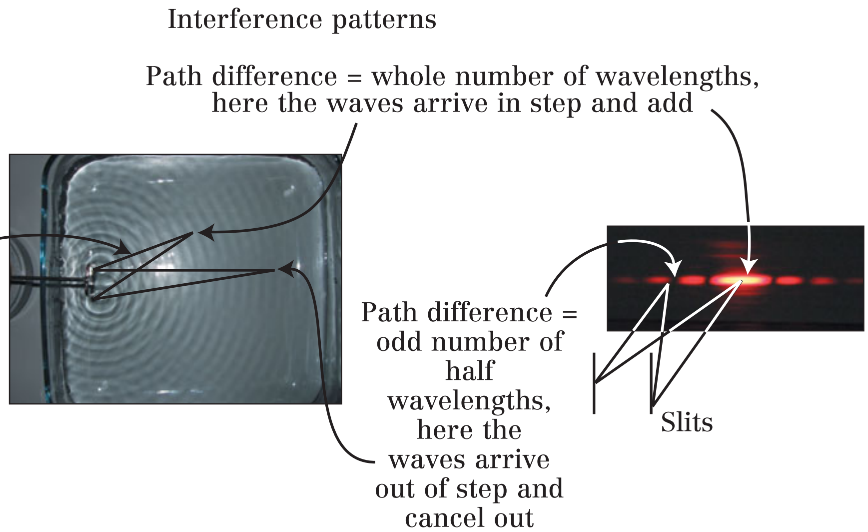
When two waves arrive out of step they cancel out and this is called *destructive interference*. For light this would be dark and for sound, quiet.





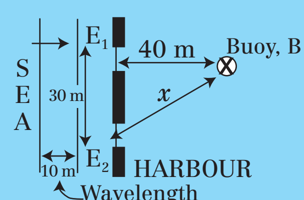
If the difference in path length ($l_1 - l_2$) is:

- A whole number of wavelengths the waves arrive in step and we have constructive interference.
- An odd number of half wavelengths, the waves arrive out of step and we have destructive interference.

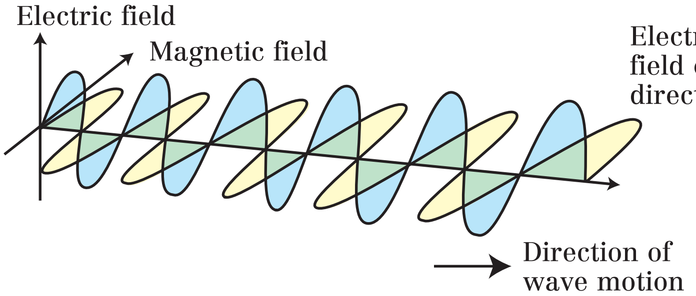


Questions

1. The speed of sound in air is about 340 m/s. Calculate wavelength of the note 'middle C', frequency = 256 Hz. Hence, explain why a piano can be heard through an open doorway, even if the piano itself cannot be seen.
2. A satellite dish behaves like a gap with electromagnetic waves passing through. Explain why the dish sending the signal to a satellite should have a much wider diameter than the wavelength of the waves, whereas a dish broadcasting a signal from a satellite over a wide area should have the same diameter as the wavelength of the waves.
3. The diagram shows a plan view of a harbour. The wavelength of the waves arriving from the sea is 10 m.
   a. How long is length x?
   b. How many waves fit in the length E_1 to B?
   c. How many waves fit in the length E_2 to B?
   d. Therefore, will the waves arrive in or out of step at the buoy, B? Hence, describe the motion of a boat tied to it.
   e. If the wavelength increased to 20 m how would your answers to b–d change?

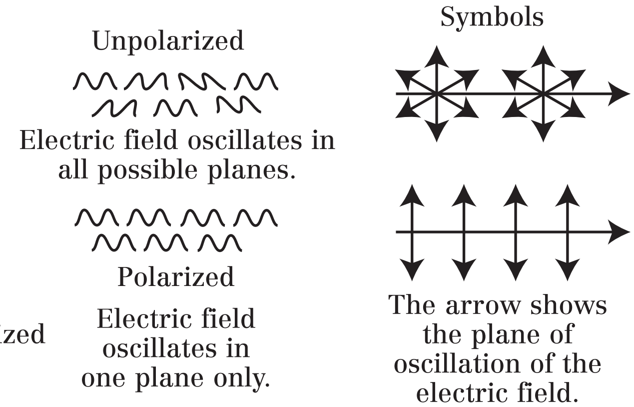


WAVES Polarization and the Photon Model of Light

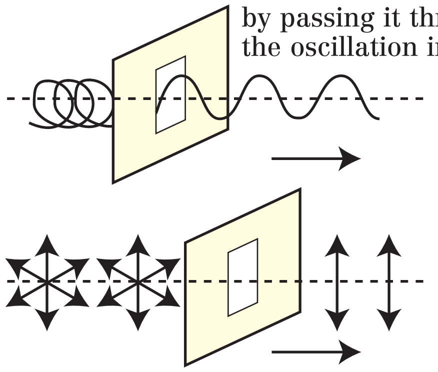


Electromagnetic waves are made from an electric and magnetic field oscillating at right angles to each other and to the direction of wave motion.

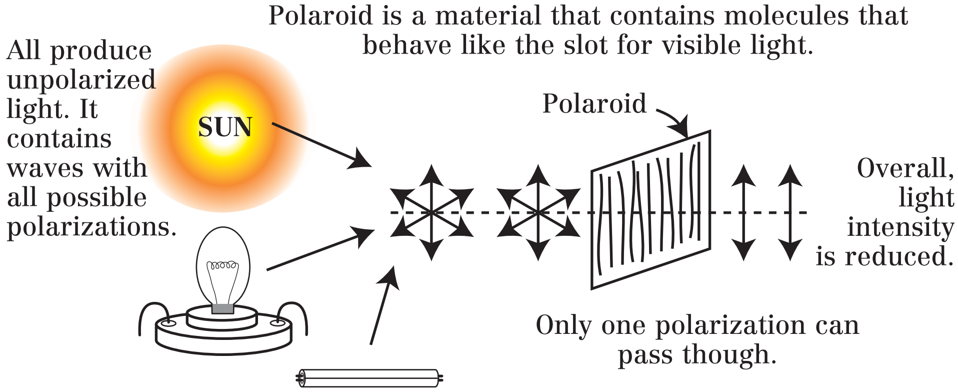
A beam of electromagnetic radiation is made up of many waves. If the electric field in all the waves only oscillates in one plane (so the magnetic field only oscillates in one plane too), the waves are said to be *polarized*.

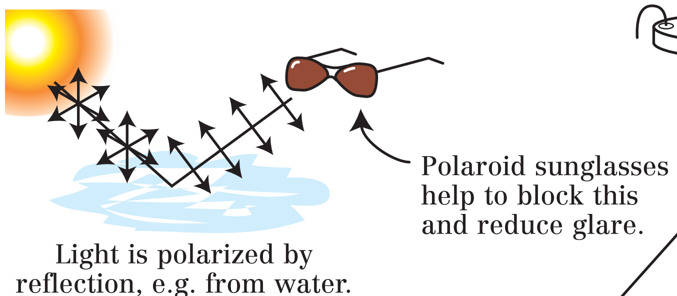


A mechanical wave on a string can be polarized by passing it through a frictionless slot; only the oscillation in one plane passes through.



Polaroid is a material that contains molecules that behave like the slot for visible light.



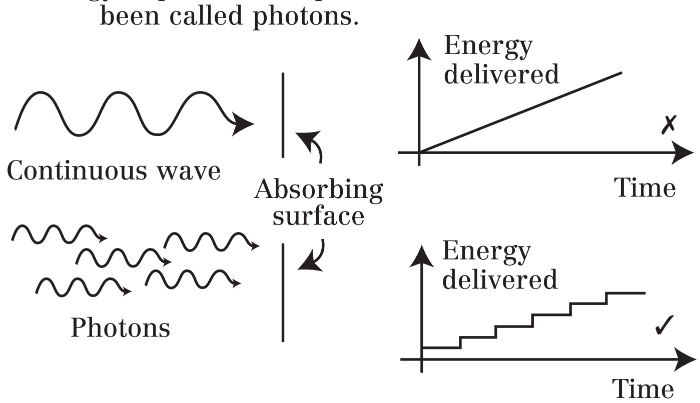


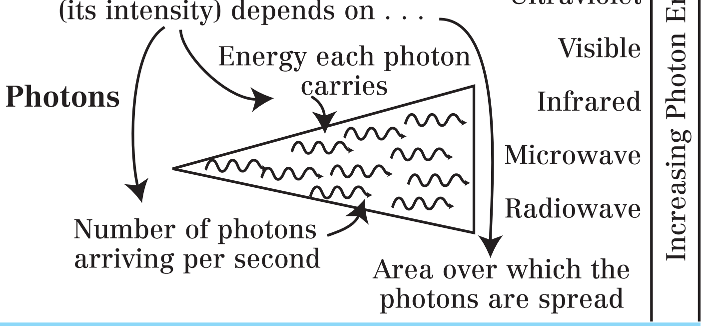
① Electromagnetic radiation always delivers energy in packets (or quanta). These have been called photons.

② The energy carried by each photon is directly proportional to the frequency of the electromagnetic wave.

③ Hence, the electromagnetic spectrum is also a scale of increasing photon energy.

④ The total energy delivered by a beam of electromagnetic radiation (its intensity) depends on . . .





Questions

1. What do we mean by a polarized wave? Draw a diagram to illustrate your answer.
2. Reflected light from a lake in summer is horizontally polarized. Which orientation of light should the Polaroid material in sunglasses allow to pass if the glasses are to cut down glare from the lake?
3. What is a photon?
4. What type of radiation delivers more energy per photon, X-rays or radiowaves?
5. Suggest why X-rays and gamma rays can knock electrons out of atoms (ionize them) but visible light and infrared cannot. What effect might this have on the human body?
6. The photons in a beam of electromagnetic radiation carry 4×10^{-17} J each. If 1×10^{18} photons arrive each second over a 2 m^2 area what is the total energy arriving per m^2?

WAVES Seismic Waves and the Structure of the Earth

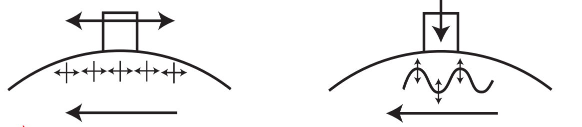
Earthquakes occur when stresses build up at fault lines where the Earth's tectonic plates are moving past each other. The energy stored can be suddenly released as the plates shift, sending out a shock or seismic wave.

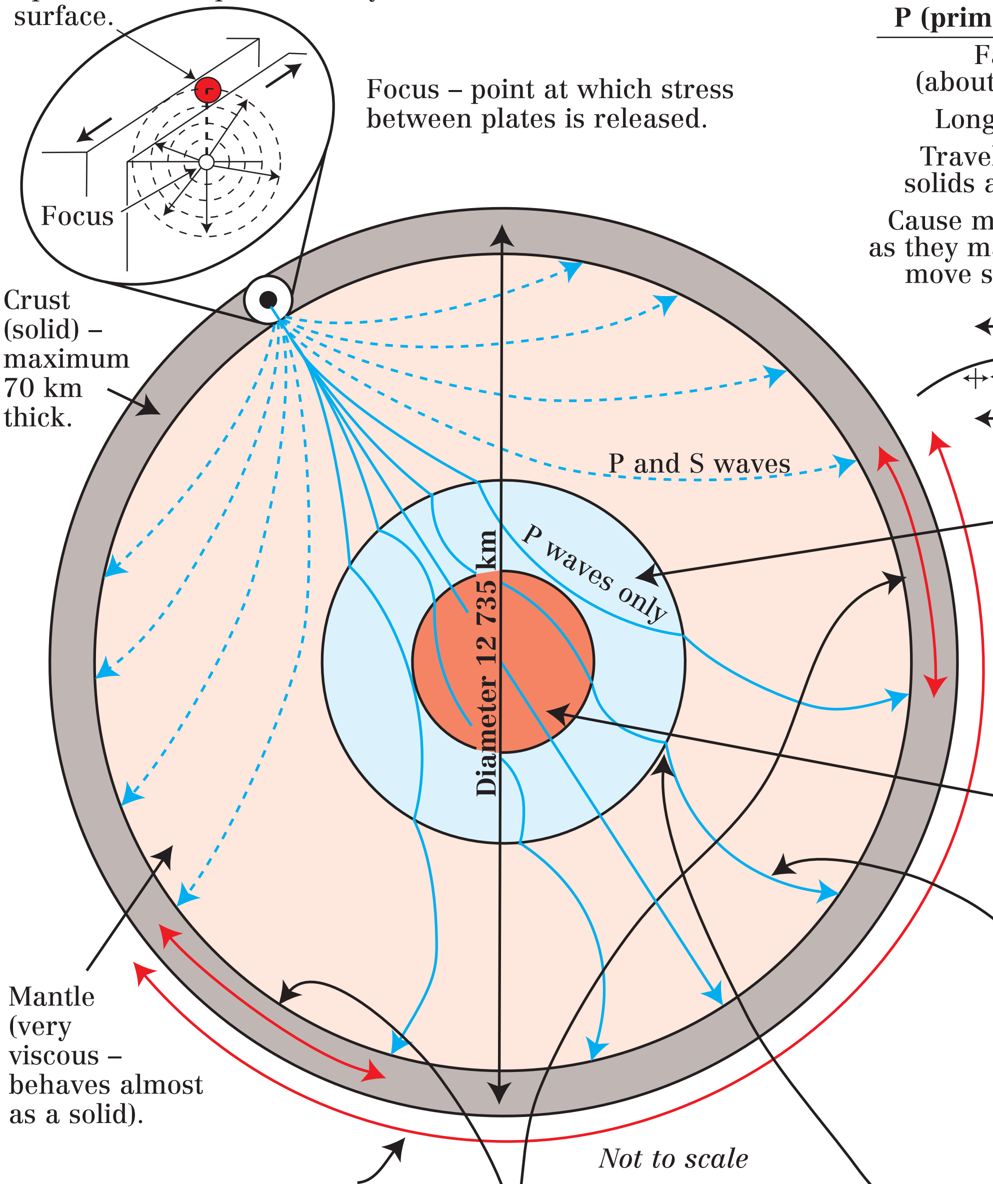
Epicentre – the point directly above the focus on the Earth's surface.

Focus – point at which stress between plates is released.

These seismic waves come in two types

P (primary) waves	S (secondary) waves
Faster (about 10 km/s)	Slower (about 6 km/s)
Longitudinal	Transverse
Travel through solids and liquids	Travel through solids only
Cause most damage as they make buildings move side to side	Cause less damage as they make buildings move up and down





Crust (solid) – maximum 70 km thick.

Outer core (molten, iron and nickel).

Inner core (solid, due to great pressure. Iron and nickel).

Mantle (very viscous – behaves almost as a solid).

Waves follow a curved path as the density of the Earth steadily increases as you go into the Earth. Therefore, their speed changes and they are steadily refracted.

S wave shadow zone. S waves cannot travel through the molten outer core so this area forms a 'shadow' of the Earth's core. Seismometers in this region do not detect S waves.

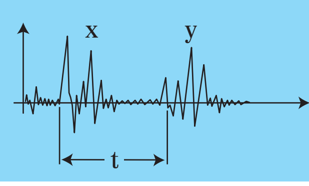
P wave shadow zone – caused by refraction as the P waves enter and leave the core. Seismometers here pick up no waves.

The distance to the epicentre can be estimated by the time lag between the P and S waves arriving.

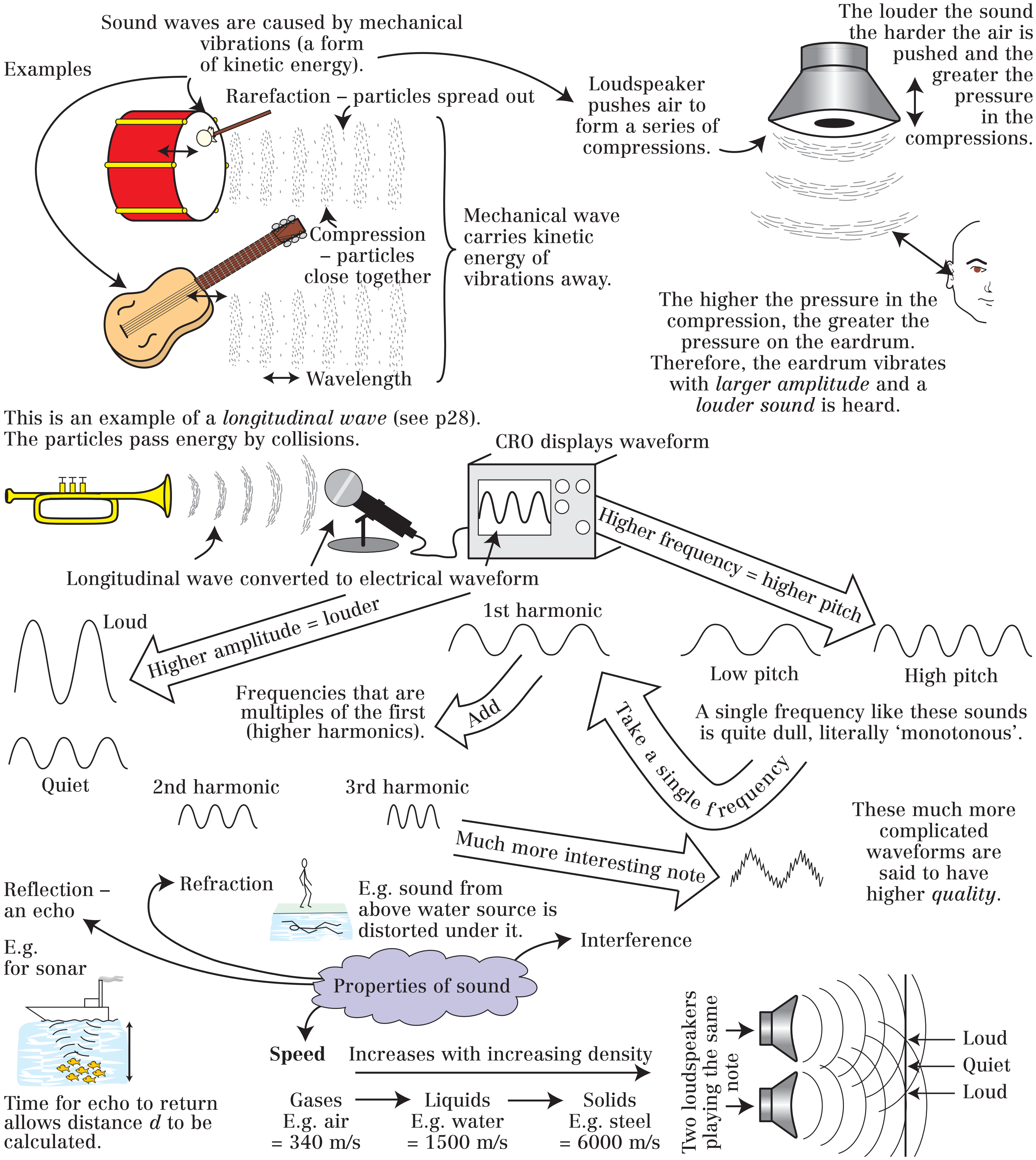
Sudden change in direction at join between layers, because the density of the material suddenly changes so there is a sudden change in wave speed and hence direction by refraction (see p36).

Questions

1. What is the difference between an Earthquake's epicentre and its focus?
2. Draw a labelled diagram of the layers in the Earth. If the crust is a maximum of 70 km thick, what percentage of the total radius of the Earth is made up of crust?
3. Write down two similarities and three differences between P and S waves.
4. Explain how scientists know that the outer core of the Earth is molten.
5. Here is a seismometer trace for an earthquake:
   a. Which trace, X or Y, shows the arrival of the S waves and which the P waves?
   b. If the speed of the P waves is 10 km/s and they took 150 s to arrive, how far away was the earthquake?
   c. If the speed of the S waves is 6 km/s, how long should they take to arrive?
   d. Hence, what is the time interval t marked on the graph?

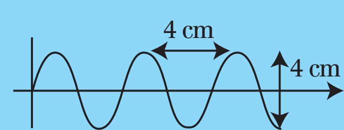


WAVES Sound Waves



Questions

1. What causes sound? Explain how the sound from a loudspeaker reaches your ear.
2. Explain why sound cannot travel in a vacuum.
3. Use the formula speed = frequency × wavelength to calculate the range of wavelengths of sound the human ear can hear in air where the speed of sound is about 340 m/s.
4. Why does sound travel faster in solids than in gases?
5. What does the pitch of a sound wave depend on?
6. What does the loudness of a sound wave depend on?
7. What is a harmonic?
8. Copy this waveform and add:
   a. A waveform of twice the frequency but the same amplitude.
   b. A waveform of half the amplitude but the same frequency.
   c. A waveform of the same amplitude and frequency but of a higher quality.

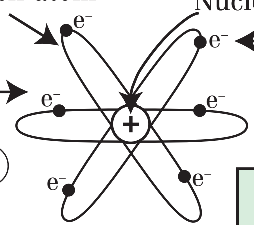


ELECTRICAL ENERGY Static Electricity

The positively charged nucleus is orbited by negatively charged electrons. These do not escape because opposite charges attract.

All materials are made of atoms

Normally the number of positive and negative charges is equal in each atom



Nucleus – has positive charge

Electrons – have negative charge

Measured in Coulombs, C.

Like charges repel

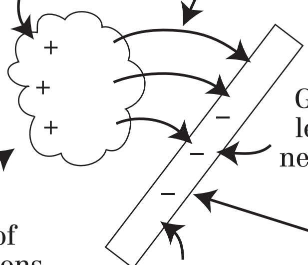
Unlike charges attract

Static electricity is formed when electrical charges are trapped on an insulating material that does not allow them to move. You can charge up a material by . . .

1) Friction

Wool duster

Electrons (negative charge) rubbed off the wool onto the polythene rod.



Gain of electrons leaves an overall negative charge.

Loss of electrons leaves an overall positive charge.

Polythene rod

In all charging processes, it is always electrons that move as they can be removed from or added to atoms.

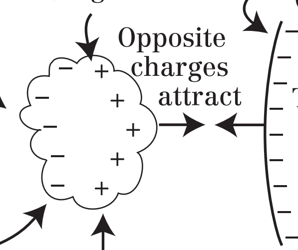
2) Induction

Overall neutral particle, e.g. dust.

Negatively charged surface (e.g. a TV screen).

Electrons repelled away.

Opposite charges attract



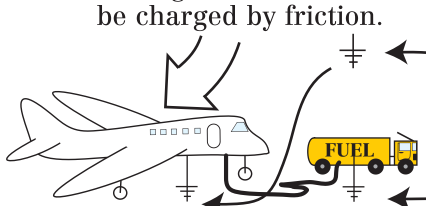
This explains why TV screens tend to get very dusty.

Surplus of positive charges on this surface

E.g. polish

Antistatic sprays contain a conducting chemical to avoid the build up of charge.

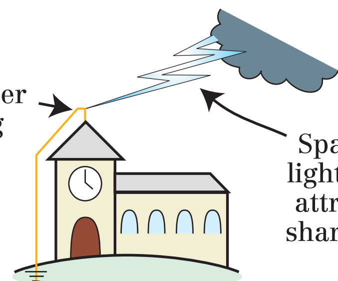
Clothing and aircraft can be charged by friction.



Static electricity will flow to Earth if a conducting path is provided, as the charges can get further apart by spreading over the Earth.

Both plane and fuel tanker are connected to Earth before fuelling to prevent any sparks.

Copper lightning conductor



Sparks like lightning are attracted to sharp points.

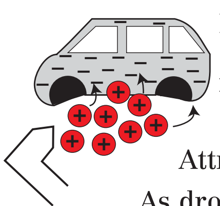
Large metal plate

E.g.

Danger of explosions – flammable vapours or dust ignited by sparks – earthing needed in these environments

Uses and dangers of static electricity

Spraying paint and pesticides

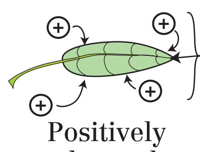


Negatively charged metal object.

Attraction

Spray gun is positively charged.

As drops all have the same charge, they repel giving a fine spray.

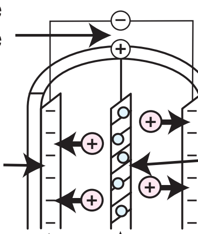


Negative charge induced on leaf by positive drops.

Positively charged droplets are attracted to leaf.

Electrostatic precipitator

Large voltage



Chimney

Negatively charged plate

Positively charged grid.

Smoke attracted and sticks to negative plates.

Smoke particles positively charged by contact with the grid.

When large particles are collected on the plates, they fall down the chimney due to their weight.

Prevents dirty smoke entering the atmosphere.

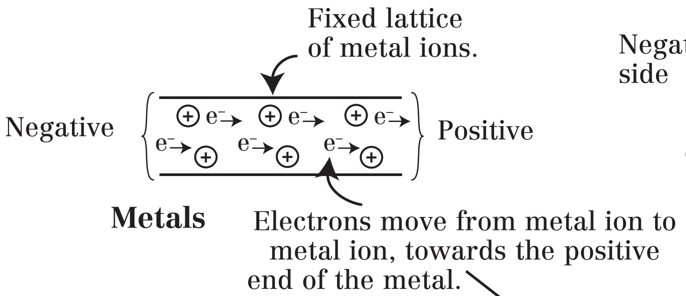
Questions

1. Complete the following sentences. Like charges ________, unlike (opposite) charges ________.
2. What is the unit of electrical charge?
3. What is the difference between an insulator and a conductor?
4. Why would it not be possible to charge a copper rod by rubbing it, no matter how furiously you rubbed?
5. Explain in as much detail as possible how a balloon rubbed on a woolly jumper sticks to a wall.
6. Make a list of all the examples of static electricity in action mentioned in this page. Divide your list into cases where static electricity is useful, where it is a nuisance, and where it is dangerous. Try to add your own examples to the list.

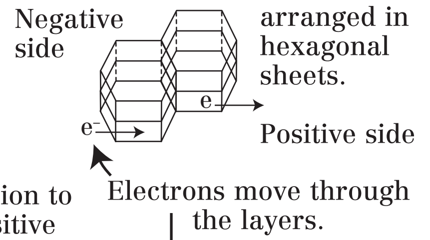
ELECTRICAL ENERGY Electric Currents

An electric current is a flow of charged particles.

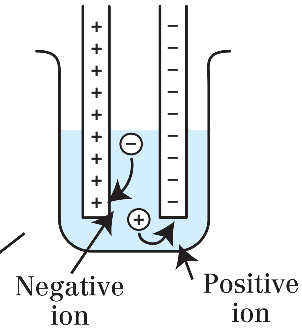
Solids



Graphite



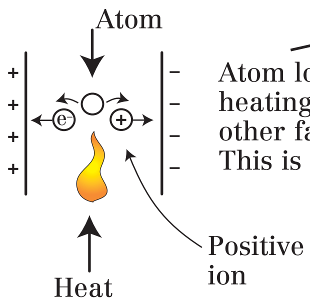
Liquids



Molten or dissolved *ionic* solids.

What do all these have in common?

Gases



Atom loses electrons due to heating (or by collision with other fast moving atoms). This is called ionization.

Current flows between plates.

Three conditions for an electric current to flow:

1. There must be charge carriers (electrons or ions).
2. They must be free to move.
3. There must be a potential difference to repel them from one side and attract them to the other.

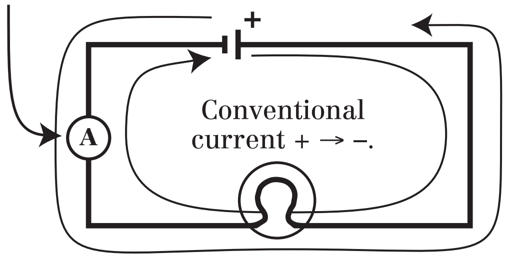
Current (in Amps) is the rate of flow of charge; the number of Coulombs of charge flowing past a point per second.

$$\text{Current (A)} = \frac{\text{Charge (C)}}{\text{time (seconds, s)}}$$

1 Amp = 1 coulomb per second

In equations we usually use I for current and Q for charge. Hence $I = Q/t$.

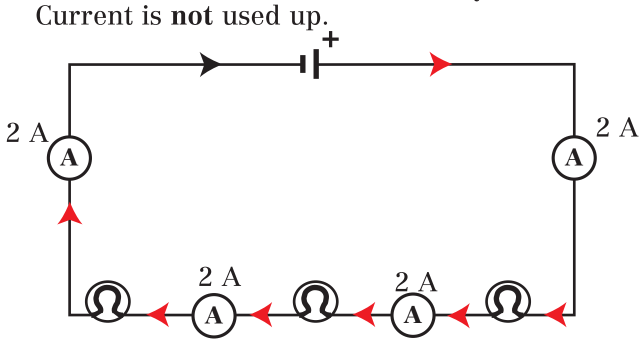
Electric current is always measured with an ammeter, always placed in series.



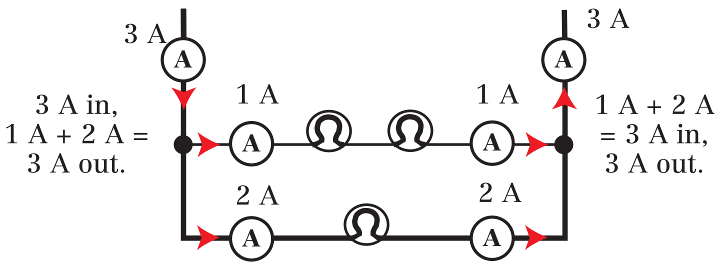
Electron current – → +.

Current rules

1. The current is the same all the way round a series circuit. Current is **not** used up.



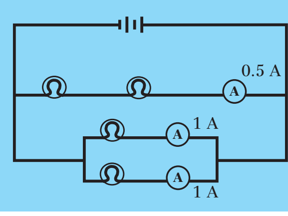
2. The current flowing into a junction = current flowing out.



These rules mean that charge is conserved. It does not 'pile up' anywhere in the circuit.

Questions

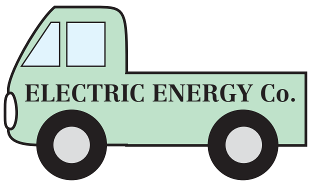
1. Why must ionic solids be molten or dissolved to conduct an electric current?
2. In a circuit 4 C of charge passes through a bulb in 2.5 s. Show that the current is 1.6 A.
3. An ammeter in a circuit shows a current of 1.2 A.
   a. The current flows for 2 minutes. Show the total charge passing through the ammeter is 144 C.
   b. How long would it take 96 C to pass through the ammeter?
4. In the following circuit, how many Amps flow through the battery?
5. The laws of circuit theory were all worked out in the 1800s. The electron was discovered in 1897. Discuss why we have conventional direct current flowing from positive to negative, when we know that the electrons actually flow from negative to positive.



ELECTRICAL ENERGY Potential Difference and Electrical Energy

What actually happens in an electric circuit?

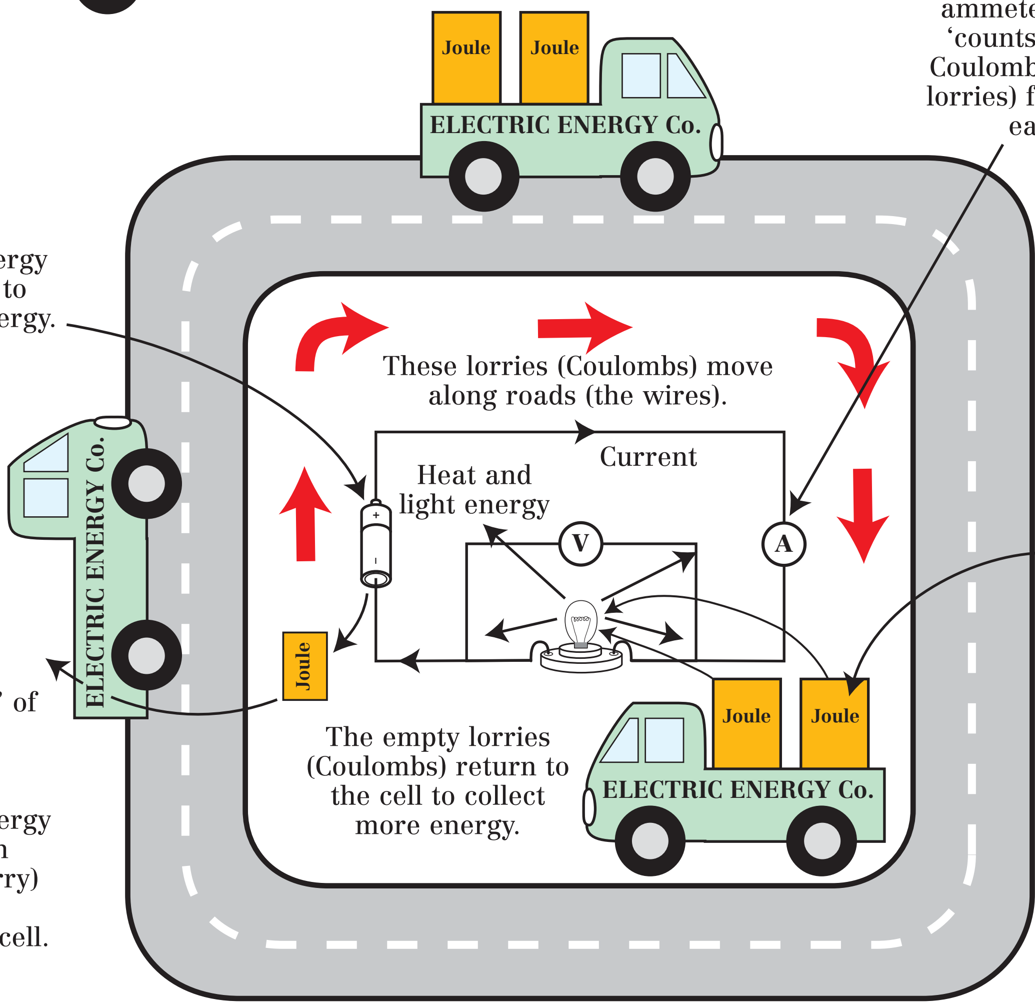
We can use a model to help us understand what is happening.



An electric current is a flow of charges, measured in Coulombs. We can imagine each Coulomb to be represented by a lorry.

We measure the current flowing in a circuit in Amps using a device called an ammeter. The ammeter 'counts' the number of Coulombs (the number of lorries) flowing through it each second.

In the cell, chemical energy is converted to electrical energy.



When the lorries get to a bulb, they unload their energy, which then comes out of the bulb as heat and light energy.

The current is the same going into the bulb as coming out of it, so electric charge (the lorries) are not 'used up' in a circuit.

The 'voltage' of a cell is the number of Joules of electrical energy given to each Coulomb (lorry) that passes through the cell.

We can measure the energy difference between the loaded lorries going into the bulb and the empty ones leaving it using a voltmeter. The voltmeter is connected *across* the bulb to measure how much energy has been transferred to the bulb by comparing the energy (Joules) carried by the lorries (Coulombs) before and after the bulb. *Each Volt represents one Joule transferred by one Coulomb*. The proper name of this is potential difference (because the current has more potential to do work before the bulb than after it) but is often called the voltage.

Questions Use the lorry model to explain:

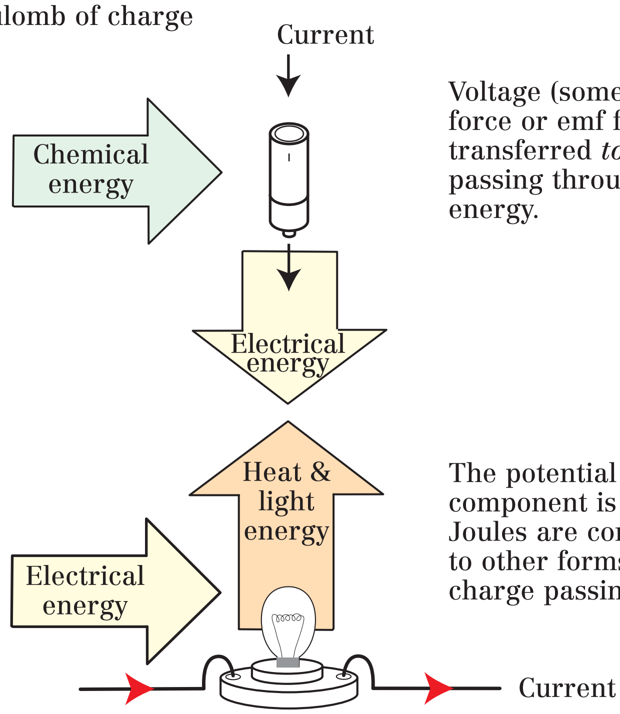
1. Why the ammeter readings are the same all the way round a series circuit.
2. Why the total current flowing into a junction is the same as the total current flowing out.
3. Why all the bulbs in a parallel circuit light at full brightness.
4. Why the bulbs get dimmer as you add more in a series circuit.
5. Why the cell goes 'flat' more quickly if you add more bulbs in parallel.
6. Should a 'flat' battery be described as discharged or de-energized? Discuss.
7. This model cannot explain all the features of a circuit. Try to explain:
   a. How the lorries know to save some energy for the next bulb in a series circuit.
   b. Whether it takes time for the first full lorries to reach the bulb and make it light up.
   c. Whether there are full lorries left in the wires when you take the circuit apart.

ELECTRICAL ENERGY Energy Transfers in Series and Parallel Circuits

1 Volt = 1 Joule of energy per Coulomb of charge

The voltage of a cell is a measure of how many Joules of chemical energy are converted to electrical energy per Coulomb of charge passing though it.

Voltage (sometimes called electromotive force or emf for short) is the energy transferred *to* each Coulomb of charge passing through a source of electrical energy.



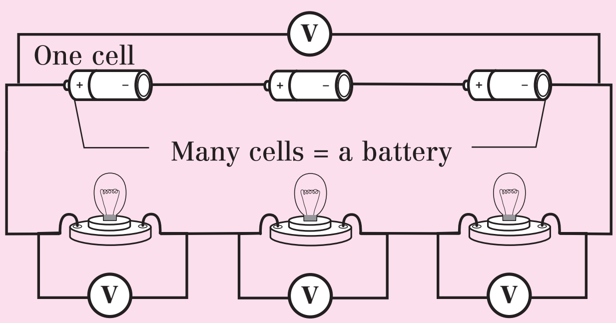
Potential difference is the energy given to a device *by* each Coulomb of charge passing through it.

The potential difference across a component is a measure of how many Joules are converted from electrical energy to other forms of energy per Coulomb of charge passing though the component.

A bulb converts electrical energy to thermal and light energy.
A motor converts electrical energy to kinetic energy.
A resistor converts electrical energy to thermal energy.
A loudspeaker converts electrical energy to sound energy.

As energy cannot be created or destroyed all the electrical energy supplied by the cell must be converted into other forms of energy by the other components in the circuit.

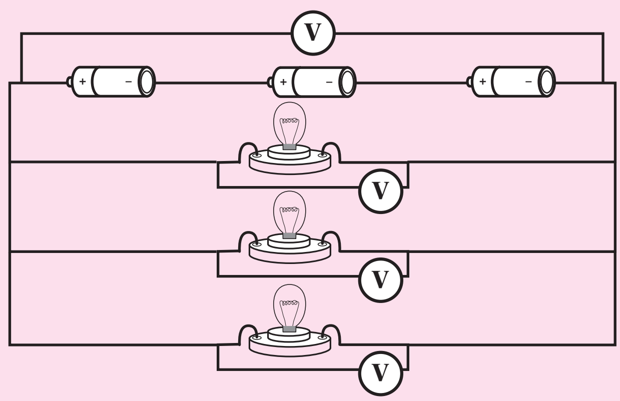
N.B. Voltmeters connected in *parallel*.



This means that in a *series* circuit the sum of the voltages across the components must equal the voltage across the cell.

The current is the *same* through all components, the potential difference is *shared* between components.

N.B. Voltmeters connected in *parallel*.



In a *parallel* circuit, each Coulomb of charge only passes through one component before returning to the cell. Therefore, it has to give all the energy it carries to that component. Therefore, the potential difference across each component is the same as the potential difference of the cell.

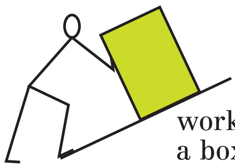
Potential difference is the *same* across all components, current is *shared* between components.

Questions

1. What is a Joule per Coulomb more commonly called?
2. A cell is labelled 9 V, explain what this means.
3. Explain whether or not voltage splits at a junction in a circuit.
4. A 1.5 V cell is connected in series with a torch bulb. The bulb glows dimly. Explain why adding another cell, in series, will increase the brightness of the bulb.
5. Considering the same bulb as in question 2, adding a second cell in parallel with the first will make no difference to the brightness. Why not?
6. When making electrical measurements we talk about the *current through* a component, but the *voltage across* a component, explain why.
7. Try to write down a formula relating voltage, energy, and charge.

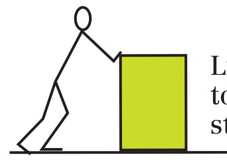
ELECTRICAL ENERGY Resistance

Resistance is a measure of how much energy is needed to make something move or flow.



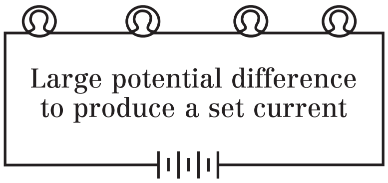
Large amount of work needed to move a box at steady speed

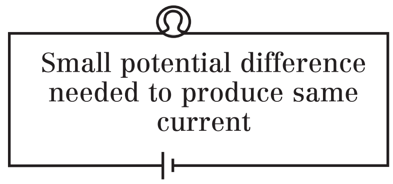
High resistance



Little work needed to move a box at steady speed

Low resistance





We *define* resistance as the ratio of the potential difference across a component to the current flowing through it.

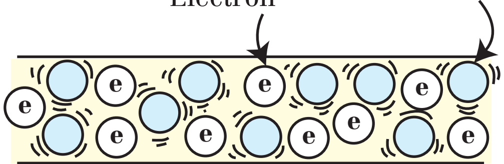
$$\text{Resistance } (\Omega) = \frac{\text{potential difference (V)}}{\text{current (A)}}$$

Unit = Ohms, Ω

i.e. if we have a high resistance then a bigger push is needed to push the current round the circuit. Note that this is not Ohm's Law, just the definition of resistance.

What causes resistance in wires?
In the lorry analogy on p45, the lorry had to use some energy (fuel) to move along the roads (wires). This represents the resistance of the wires.

Wires have resistance because the electrons moving through the wire bump into the positive metal ions that make up the wire.

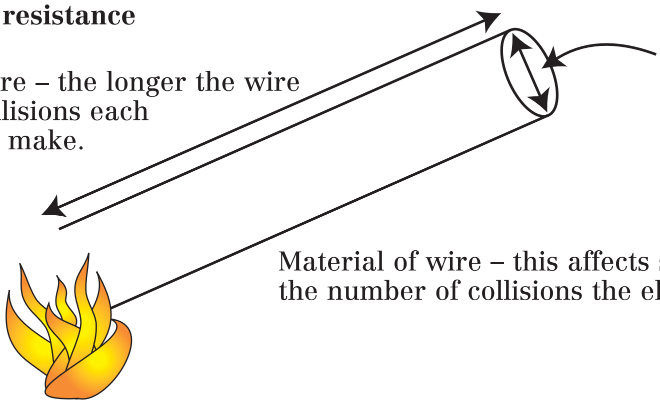


The electrons give some of their kinetic energy to the metal ions, which makes them vibrate so electrical energy is converted to thermal energy and the wire gets warm.

The same process happens in a resistor, but the materials are chosen to increase the number of collisions making it more resistant to charge flow.

Factors affecting resistance

Length of wire – the longer the wire the more collisions each electron will make.



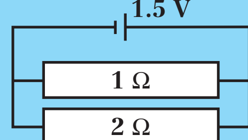
Width of wire – the wider the wire the more electrons can flow at any one time, hence you get a bigger current for the same potential difference, so a lower resistance.

Material of wire – this affects size and layout of the metal ions and so the number of collisions the electrons make.

Temperature – the hotter the wire the more the metal ions vibrate and so the more likely electrons are to collide.

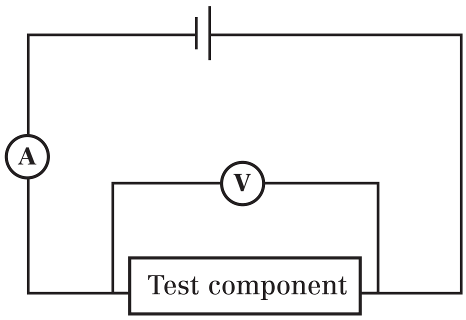
Questions

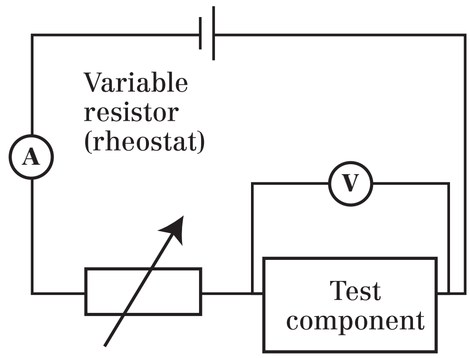
1. Show that a resistor with 5 V across it and 2 A flowing through it has a resistance of 2.5 Ω.
2. A 12 Ω resistor has 2.4 V across it. Show that the current flowing is 0.2 A.
3. A lamp has a resistance of 2.4 Ω and 5 A flows through it. Show the potential difference is 12 V.
4. The potential difference across the lamp in (3) is doubled. What would you expect to happen to a. the filament temperature, b. the resistance, c. the current?
5. In the following circuit, which resistor has the largest current flowing through it?
6. Why do many electronic devices, e.g. computers, need cooling fans?



ELECTRICAL ENERGY Electrical Measurements and Ohm's Law

Experimental technique for measuring resistance





Finding the resistance of a component for a given current

Use meter readings and the formula Resistance (Ω) = potential difference (V) / current (A) to find the resistance.

Datalogging could be used to do this

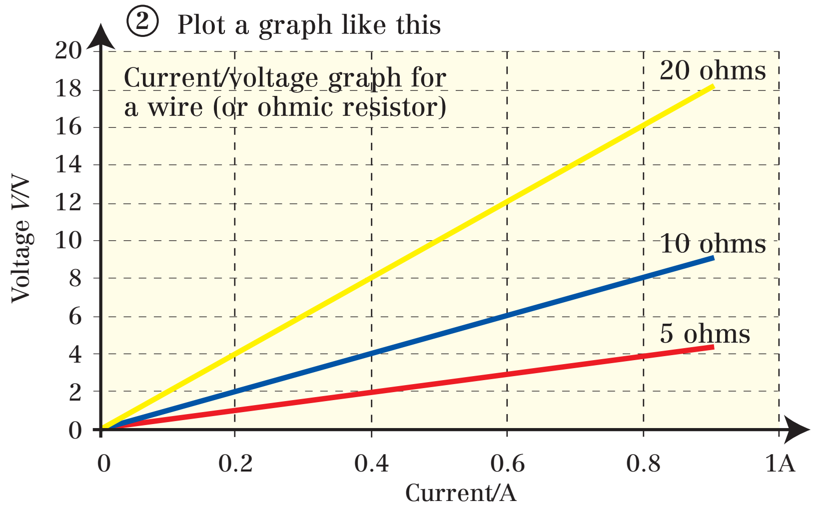
Use voltmeter and ammeter sensors.
Computer software automatically plots voltage vs. current as the variable resistor is altered.

Finding the resistance of a component for a range of currents

① Record voltmeter and ammeter readings for many different settings of the variable resistor in a table.

Voltage across component (Volts)	Current through component (Amps)

② Plot a graph like this



③ Gradient of graph $= \dfrac{\text{change in } y}{\text{change in } x}$

$= \dfrac{\text{change in potential difference, V}}{\text{change in current, A}}$

= Resistance, Ω

The steeper the line the greater the resistance.

N.B. Beware, sometimes these graphs are plotted with the axes reversed. Then the resistance is not the gradient, it is $^1/_{\text{gradient}}$.

Ohm's Law

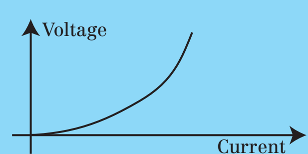
A component where the current is directly *proportional* to the voltage is said to obey Ohm's Law and is called *ohmic*.

This means:
1. A graph of *V vs. I* is a straight line through the origin.
2. $V = I \times R$ where *R is constant whatever the value of the current or voltage*.

Note that the definition of resistance applies to all components; they are only ohmic if their resistance does not change as the current changes.

Questions

1. Calculate the gradients of the three lines in the graph above and confirm they have the resistances shown.
2. 1.5 A flows in a 1 m length of insulated wire when there is a potential difference of 0.3 V across it.
   a. Show its resistance is 0.2 Ω.
   b. If 0.15 A flows in a reel of this wire when a potential difference of 3 V is placed across it, show that the length of the wire on the reel is 100 m.
3. Current and voltage data is collected from a mystery component using the method above. When plotted the graph looks like this:
   Is the resistance of the component increasing, decreasing, or staying the same as the current increases?



ELECTRICAL ENERGY Power in (Ohmic) Electrical Circuits

The general definition of power is : Power (W) $= \dfrac{\text{energy transferred (J)}}{\text{time taken (s).}}$

We also know that 1 Volt = 1 Joule per Coulomb.

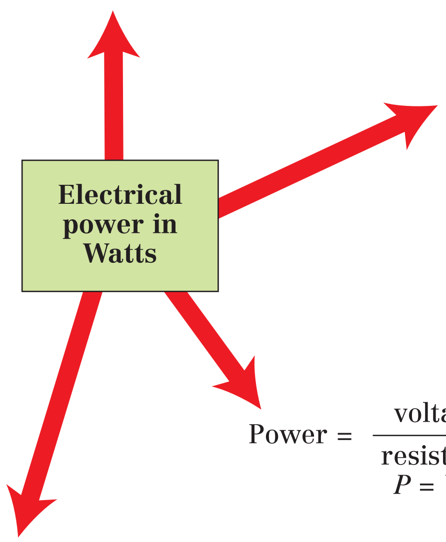
As a formula we represent this as potential difference (Volts) $= \dfrac{\text{energy transferred (Joules)}}{\text{charge passing (Coulombs).}}$

We also know that current (Amps) $= \dfrac{\text{charge passing (Coulombs)}}{\text{time taken (seconds).}}$

Then current × voltage $= \dfrac{\text{charge passing}}{\text{time taken}} \times \dfrac{\text{energy transferred}}{\text{time taken}} = \dfrac{\text{energy transferred}}{\text{time taken}}$ = Power

Also as voltage = current × resistance then

Power = current^2 × resistance
$P = I^2R$

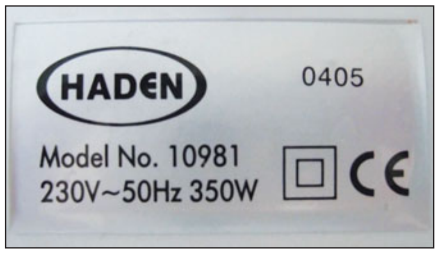


Rate of transfer of electrical energy to other forms

Power $= \dfrac{\text{voltage}^2}{\text{resistance}}$
$P = V^2/R$

Power = current × voltage
$P = IV$

Mains appliances use 230 V and always have a power rating.

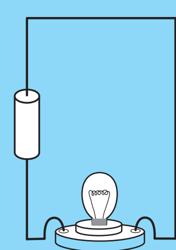


We can use this information to calculate the current that flows through them when working normally.

Device	**Voltage (V)**	**Power (W)**
Filament bulb	230	60
Energy efficient lamp	230	9
Kettle	230	1500
Microwave oven	230	1600
Electric cooker	230	1000–11 000
TV set	230	30

Questions

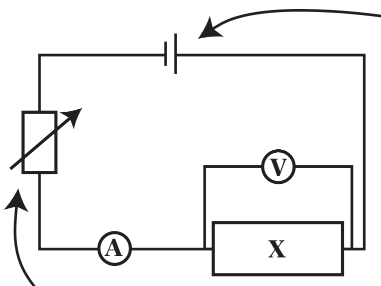
1. Redraw the circuit using standard circuit symbols adding voltmeter to measure the potential difference across the lamp and an ammeter to measure the current through it.
   a. The voltmeter reads 6 V. How many Joules of energy are transferred per Coulomb?
   b. The ammeter reads 2 A. How many Coulombs pass through the lamp each second?
   c. Hence, how many Joules per second are transferred to the lamp?
   d. If the voltmeter now reads 12 V and the ammeter still reads 2 A then how many Joules are transferred to the lamp each second?



2. A 1.5 V cell is used to light a lamp.
   a. How many Joules does the cell supply to each Coulomb of electric charge?
   b. If the current in the lamp is 0.2 A, how many Coulombs pass through it in 5 s?
   c. What is the total energy transferred in this time?
   d. Hence, show the power of the lamp is 0.3 W.
3. A 6 V battery has to light two 6 V lamps fully. Draw a circuit diagram to show how the lamps should be connected across the battery. If each draws a current of 0.4 A when fully lit, explain why the power generated by the battery is 4.8 W.
4. Use the data in the table above to show that the current drawn by an ‘energy efficient’ lamp is over 6× less than the current drawn by a normal filament bulb.
5. Show that a 60 W lamp with a potential difference of 240 V across it has a resistance of 960 Ω.

ELECTRICAL ENERGY Properties of Some Electrical Components

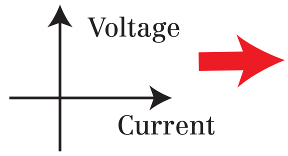
A graph of voltage against current (or *vice versa*) for a component is called its characteristic.
This circuit can be used to measure the characteristic of component X.



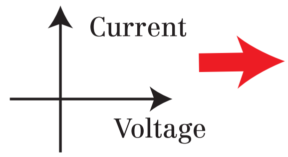
The cell can be reversed to measure negative values of current and voltage.

The current and voltage are recorded for a wide range of settings of the variable resistor.

N.B. Check carefully whether current or voltage is plotted on the x axis.

If 

gradient = resistance

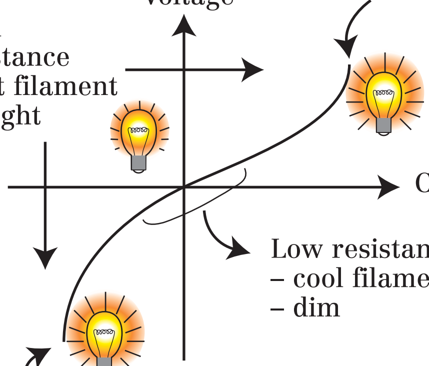
If 

gradient = $^1/_{\text{resistance}}$

All the following components are *non-ohmic* as their resistance is not independent of the current flowing through them.

1. Filament lamp

Symbol 



High resistance
– hot filament
– bright

As the current increases the resistance increases.

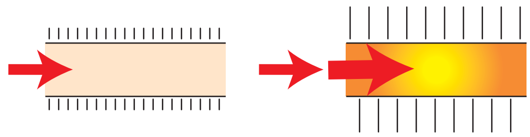
Power = current^2 × resistance

Power output = brightness increases as current increases

Low resistance
– cool filament
– dim

Eventually the filament gets so hot it melts and the bulb fails (if the potential difference exceeds the design potential difference).

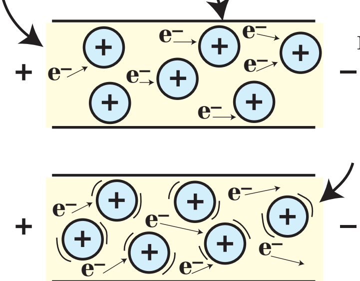
As the current increases, the filament wire in the bulb becomes hotter.



Eventually it glows red, and then white, hot.

The more collisions the electrons make the more energy they transfer to the wire and the hotter it gets.

Increasing current in the wire means the electrons make more collisions with fixed ions in the wire.



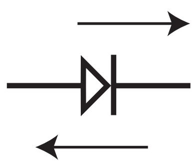
This in turn makes the ions vibrate more increasing the number of collisions still further.

Electrons find it harder to move; you need a greater potential difference to drive the same current so the resistance increases.

2. Diode

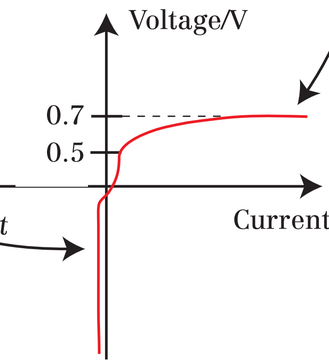
Symbol

A diode only allows current to flow in one direction.



Forward bias – very low resistance, high current flow

Reverse bias – extremely high resistance, negligible current flow



Small gradient

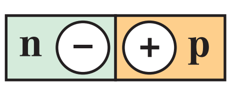
Large gradient

In the reverse direction, the current is almost negligible until very large voltages are reached when the diode may fail.

The forward current 'turns on' at about 0.5 V and very large currents can be achieved by 0.7 V when there is almost no resistance in the diode.

Diodes are made from two types of semiconductor

n-type – excess of negative charges

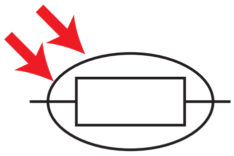


p-type – shortage of negative charge. The spaces left are called holes and behave as positive charges.

Electrons will flow n → p and holes p → n. Therefore, the diode will conduct when the n-type end is negative and the p-type end is positive.

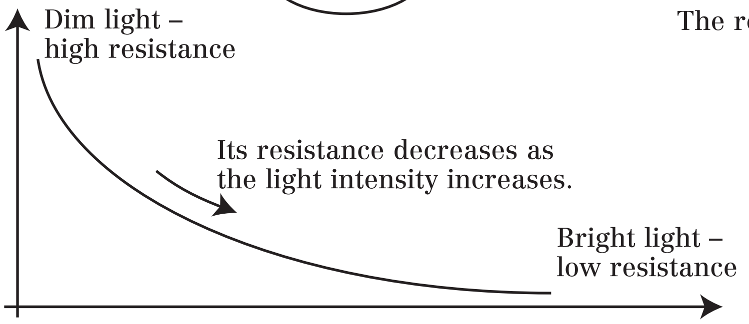
3. Light dependent resistor (LDR)

Symbol



As its name suggests this is a resistor whose resistance changes depending on the intensity of the light falling on it.

Resistance



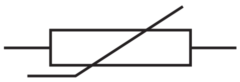
Light intensity

The resistance changes in a non-uniform way.

Used to control electrical circuits that need to respond to varying light levels, e.g. switching on lights automatically at night.

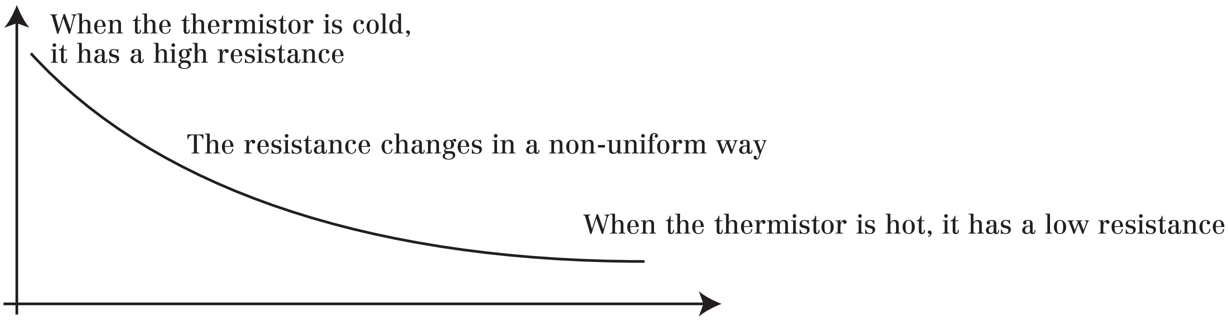
4. Thermistor

Symbol



This is a resistor whose resistance varies depending on temperature. Its resistance decreases as temperature increases.

Resistance



Temperature

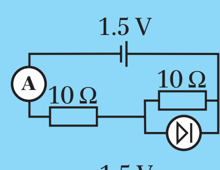
Notice that this is the opposite behaviour to a wire, whose resistance increases with increasing temperature.

Thermistors are used to control circuits that need to respond to temperature changes, e.g. to switch off a kettle.

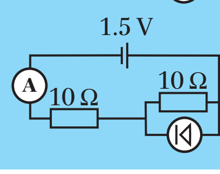
Questions

1. Draw the circuit symbols for: a. A filament lamp. b. An LDR. c. A thermistor. d. A diode.
2. Sketch a graph of current against voltage for a filament lamp. Explain in terms of the motion of electrons through the filament the shape of the graph.
3. Show that a thermistor with a potential difference of 3 V across it and a current of 0.2 A flowing through it has a resistance of 15 Ω. If the temperature of the thermistor was raised, what would you expect to happen to its resistance?
4. Show that an LDR with a potential difference of 1.5 V across it and a current of 7.5×10^{-3} A (7.5 mA) flowing through it has a resistance of 200 Ω. If the LDR is illuminated with a brighter light, with the same potential difference across it what would you expect to happen to the current flowing in it and why?
5. Sketch a graph of current against voltage (both positive and negative values) for a diode. Use it to explain why a diode only passes current in one direction.
6. Consider the following circuits. In which circuit will the ammeter show the greatest current?
7. A student plans to use a thermistor to investigate how the temperature of the water in a kettle varies with time after it is switched on.
   a. Draw a circuit involving an ammeter and voltmeter the student could use.
   b. Explain how they would use the ammeter and voltmeter readings together with a graph like the one printed above on this page, to find the temperature of the water at any given time.

a)

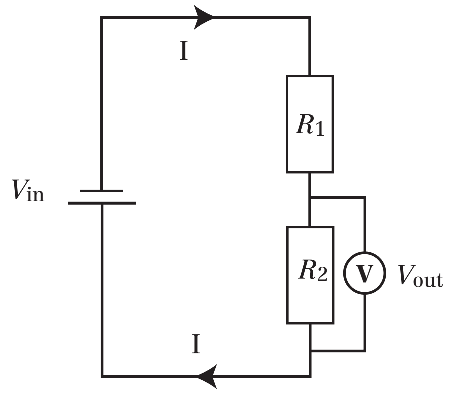


b)



ELECTRICAL ENERGY Potential Dividers

Two resistors in series form a potential divider.



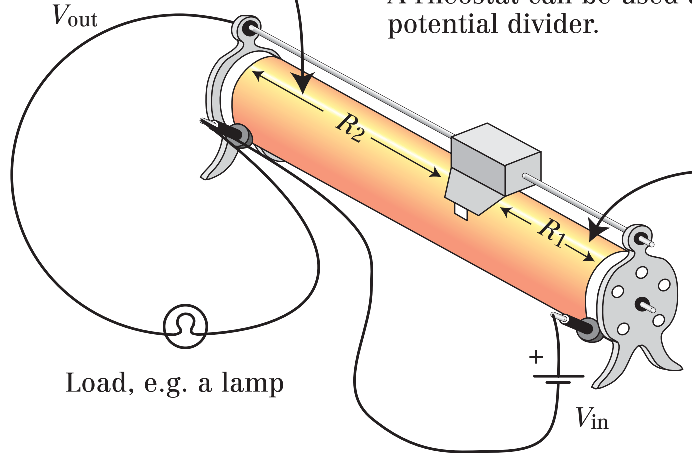
The potential difference of the cell, V_{in}, is divided between the two resistances in the ratio of their resistances.

The output voltage can be calculated using the formula:

$$V_{out} = V_{in} \times \left(\frac{R_2}{R_1 + R_2} \right)$$

V_2 (output potential difference) across here

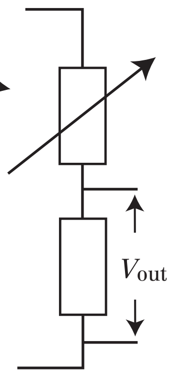
A rheostat can be used as a potential divider.



Slider divides the resistance into two separate resistors, R_1 and R_2. The position of the slider determines the relative size, hence ratio, of the two resistances.

The current in both resistors is the same as they are in series. The resistor with the greater value will take more voltage to drive the current through it so has the greater potential difference across it.

If one of the resistors is a variable resistor, the ratio of the resistances can be altered. This means you can have a variable output voltage.



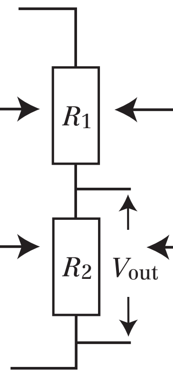
If one of the resistors is an LDR, the output voltage depends on the light level. LDR has a large resistance in the dark.

If one of the resistors is a thermistor, the output voltage depends on temperature.

Thermistors have a high resistance in the cold.

Placed here the output will be high in the light, low in the dark.

Placed here the output will be low in the light, high in the dark.

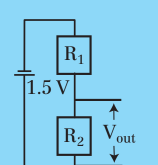


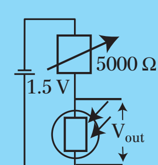
Placed here the output will be high when hot, low when cold.

Placed here the output will be high when cold, low when hot.

Questions

1. Use the formula above to calculate V_{out} if R_1 and R_2 in the circuit provided have the following values:
   a. R1 = 10 Ω, R2 = 20 Ω. b. R1 = 20 Ω, R2 = 10 Ω. c. R1 = 1 kΩ, R2 = 5 kΩ.
   d. R1 = 1.2 kΩ, R2 = 300 Ω.
2. For each of the pairs of resistors in question 1, decide whether R1 or R2 has the greater potential difference across it.
3. An LDR has a resistance of 1000 Ω in the light and 100 000 Ω in the dark. In the circuit, the variable resistor is set to 5000 Ω. Calculate V_{out} in the light and in the dark. If the resistance of the variable resistor is reduced, will the values of V_{out} increase or decrease?
4. Draw a potential divider circuit where the output rises as the temperature rises. Suggest a practical application of this circuit.

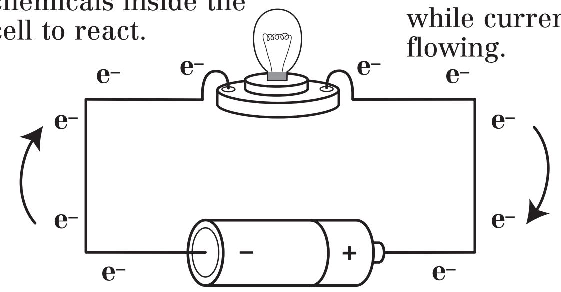




ELECTRICAL ENERGY Electric Cells, Alternating and Direct Current

Electron flow allows chemicals inside the cell to react.

Chemicals only react while current is flowing.



Eventually the reaction is complete and no further stored chemical energy can be released from the cell.

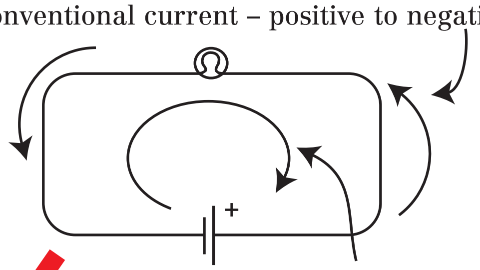
Electric cells convert stored chemical energy into electrical energy.

Circuit symbols

A number of cells joined are a battery.

Current produced by cells only ever flows one-way.

Conventional current – positive to negative



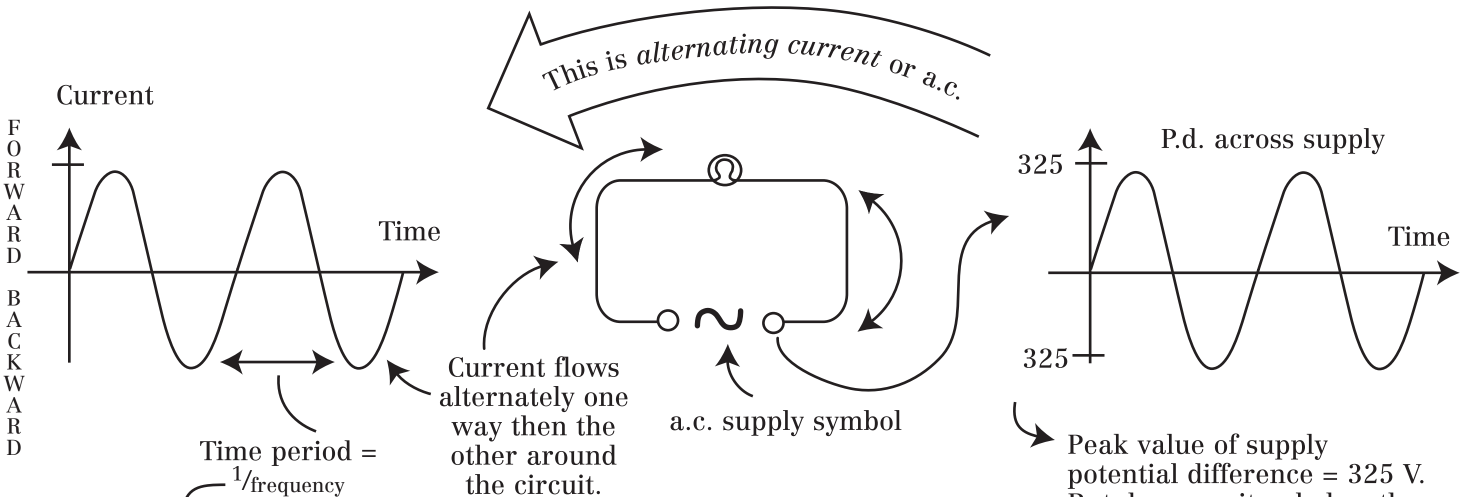
Electron current – negative to positive

Both these currents are *direct* currents (or d.c.). They flow consistently in one direction.

Compare this with mains electricity.

The capacity of a cell is measured in *Amp-hours*. 1 Amp-hour means the cell can deliver a current of 1 Amp for 1 hour. Since 1 Amp-hour = 3600 C the energy stored (Joules) in a cell can be calculated from voltage (V) × capacity (Amp-hours) × 3600 C.

'Rechargeable' cells use another source of electricity, often the mains, to force the electrons the 'wrong way' around the circuit. This, in a specially designed cell, reverses the chemical reaction, storing the electrical energy as chemical energy. It would be more correct to say the battery has been 're-energized'.



Peak value of supply potential difference = 325 V. But, because it only has the peak value for a short time the supply transfers an equivalent power to a 230 V direct current supply.

In the UK, the frequency is 50 Hz (cycles per second).

Alternating currents are widely used because:

- They are easier to generate (p83–85).
- They are easier to distribute (p86–7) than direct currents.

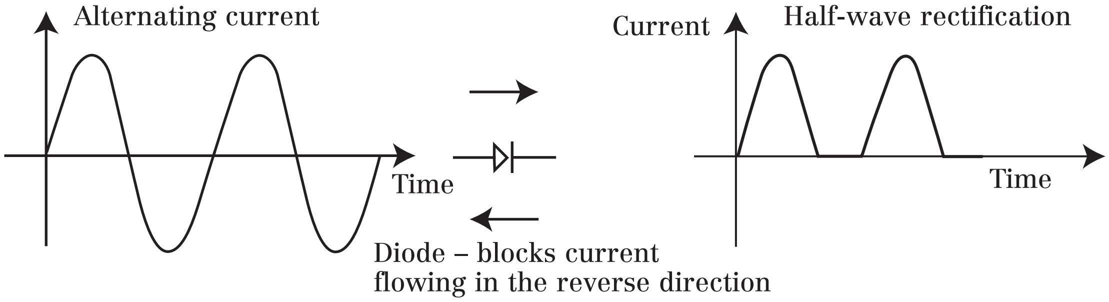
Many devices need direct current to work so alternating current often has to be converted to direct current (p54).

Questions

1. Sketch a labelled graph of the variation of supply potential difference with time (for 10 seconds) for alternating current of frequency 2 Hz, and peak value 3 V. Add to the graph a line showing the output from a battery of terminal potential difference 2 V.
2. The capacities of two cells are AA = 1.2 Amp-hours and D = 1.4 Amp-hours. How long will each cell last when supplying:
   a. A current of 0.5 A to a torch bulb? b. 50 mA to a light emitting diode?
3. Some people claim that battery powered cars do not cause any pollution. A battery is just a store of electrical energy so where do battery-powered cars really get their energy from? Hence, are they really non-polluting, or is the pollution just moved elsewhere?
4. Draw up a table of advantages and disadvantages of batteries compared to mains electricity. Consider relative cost, how they are used, potential power output, and impact on the environment.

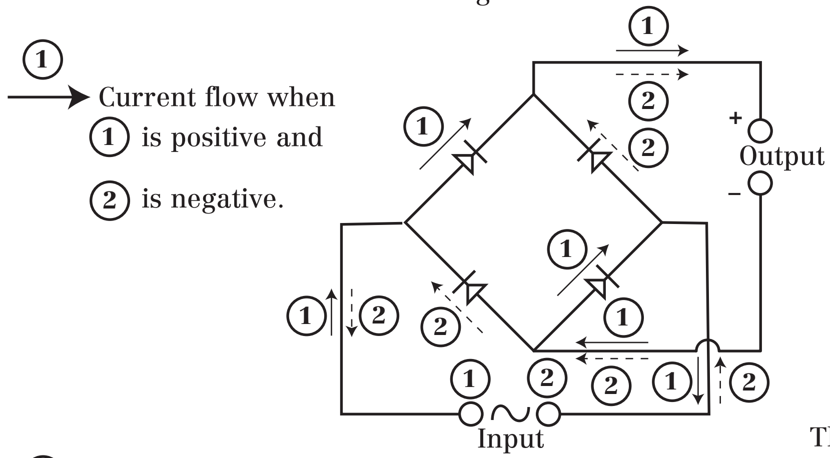
ELECTRICAL ENERGY Diodes, Rectification and Capacitors

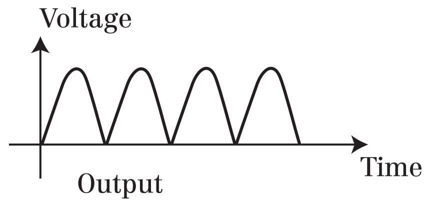
Although alternating current is easier to generate and distribute, many appliances, especially those with microchips, need direct current. The process of converting alternating to direct current is called *rectification*.

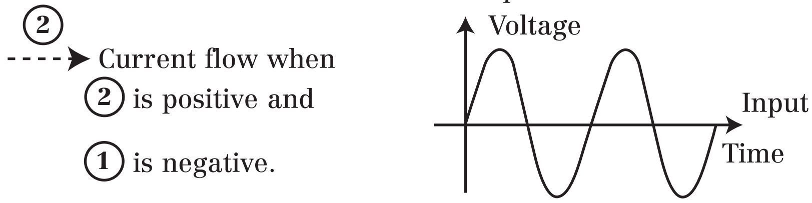


We now have direct current that flows one way around a circuit, but it is only flowing for half the time, and even then the voltage is rising and falling.

A better result is obtained with a bridge circuit.



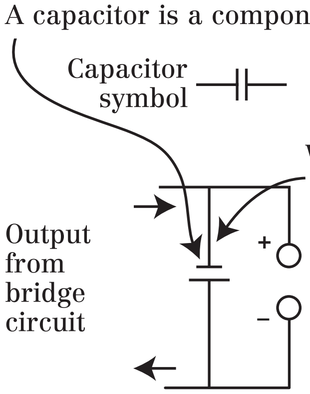




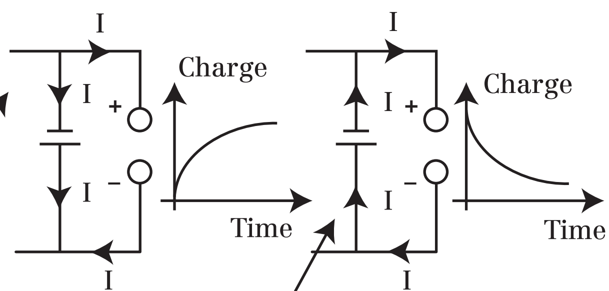
This makes use of both the forward and reverse current and is called *full wave rectification*.

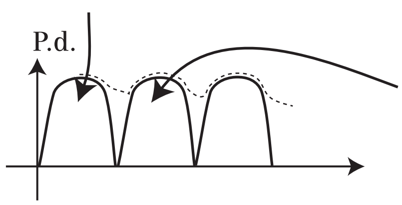
The direct current produced still has a rising and falling voltage. We say it is *unsmoothed*.

A capacitor is a component that can store charge.



When the potential difference is high, it stores some of the charge.

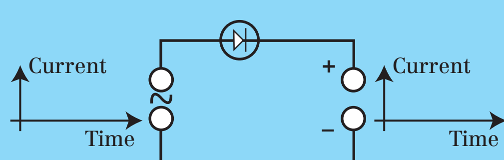




As the potential difference starts to fall it releases the charge. This helps to keep the current and potential difference up and we say the direct current is smoothed.

Questions

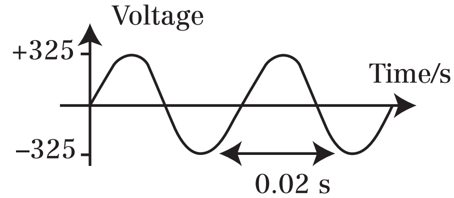
1. What is a diode?
   a. Complete the graphs in the circuit below to show the effect of the diode.
   b. Why is the output an example of direct current? Why do we say it is 'unsmoothed'?
   c. If the diode were reversed what would be the effect, if any, on the direct current output?
2. What name do we give a device that stores charge?
3. Explain the difference between full wave rectification and half-wave rectification. Illustrate your answer with voltage–time graphs.
4. Draw a circuit that produces full wave rectification. Show how the current flows through the circuit.



Mains Electricity and Wiring

N.B. Never inspect any part of mains wiring without first switching off at the main switch next to the electricity meter.

The UK mains electricity supply is alternating current varying between +325 V and –325 V with a frequency of 50 Hz. It behaves as the equivalent of 230 V direct current.

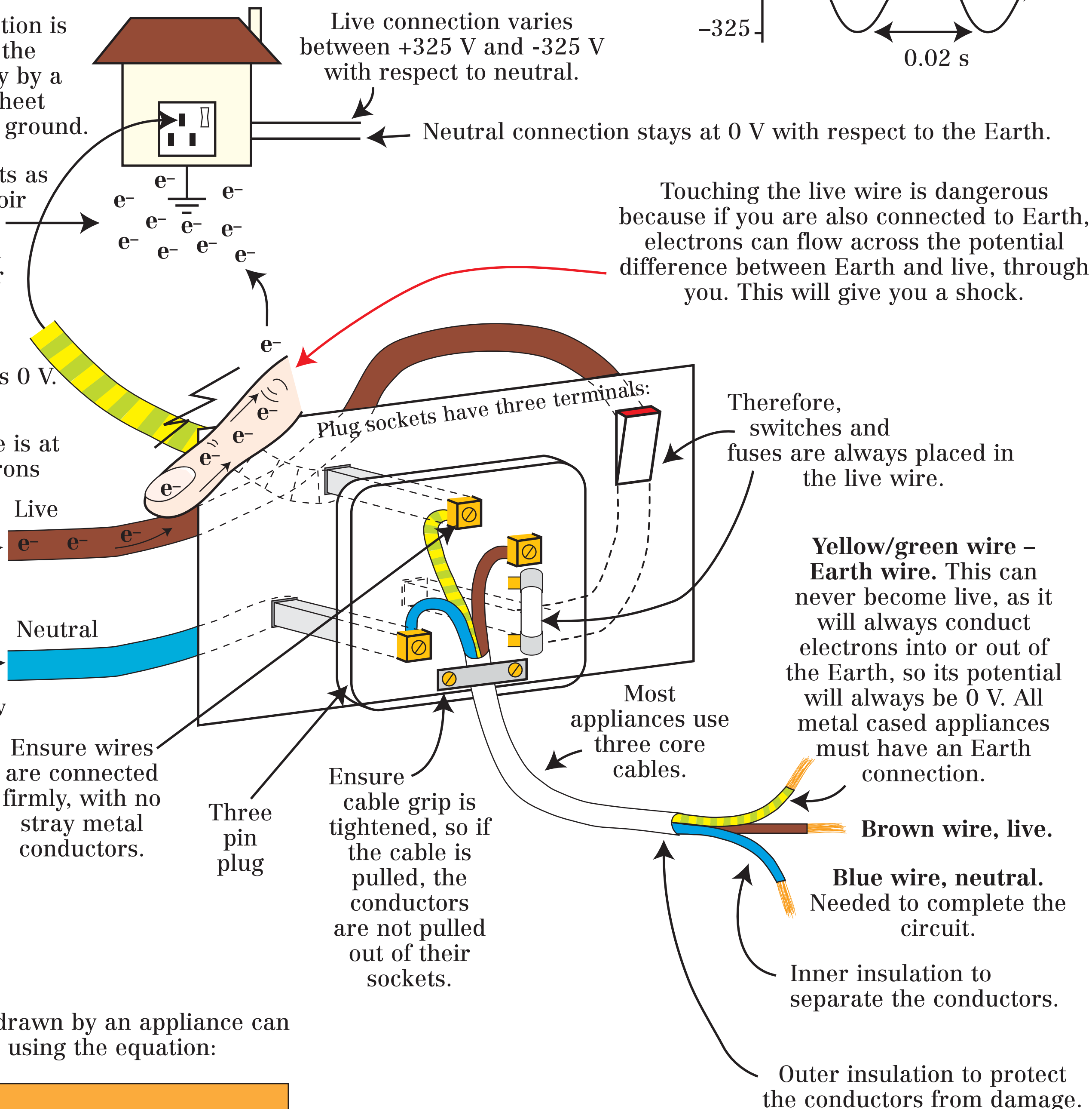


Earth connection is connected to the Earth, usually by a large metal sheet buried in the ground.

The Earth acts as a vast reservoir of charge; electrons can flow into it or out of it easily. Therefore, its potential is 0 V.

When the live is at +325 V electrons flow from neutral to live.

When the live is at –325 V electrons flow from live to neutral.



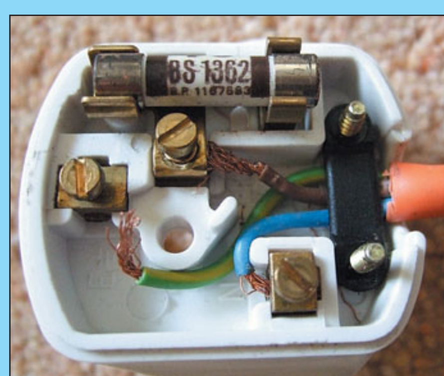
The current drawn by an appliance can be calculated using the equation:

$$\text{Current} = \frac{\text{Power}}{\text{voltage}} = \frac{\text{Power}}{230\ \text{V}}$$

Power ratings can be found on the information label on the appliance.

Questions

1. What colours are the following electrical wires: live, neutral, Earth?
2. My kettle has a power output of 1 kW and my electric cooker 10 kW. What current will each draw? Why does the cooker need especially thick connecting cables?
3. Some countries use 110 V rather than 230 V for their mains supply. Suggest how the thickness of the conductors in their wiring would compare to the conductors used in the UK. How will this affect the cost of wiring a building? What advantages does using a lower voltage have?
4. Study this picture of a three-pin plug – how many faults can you find?
5. Placing a light switch in the neutral wire will not affect the operation of the light but could make changing a bulb hazardous. Why?



ELECTRICAL ENERGY Electrical Safety

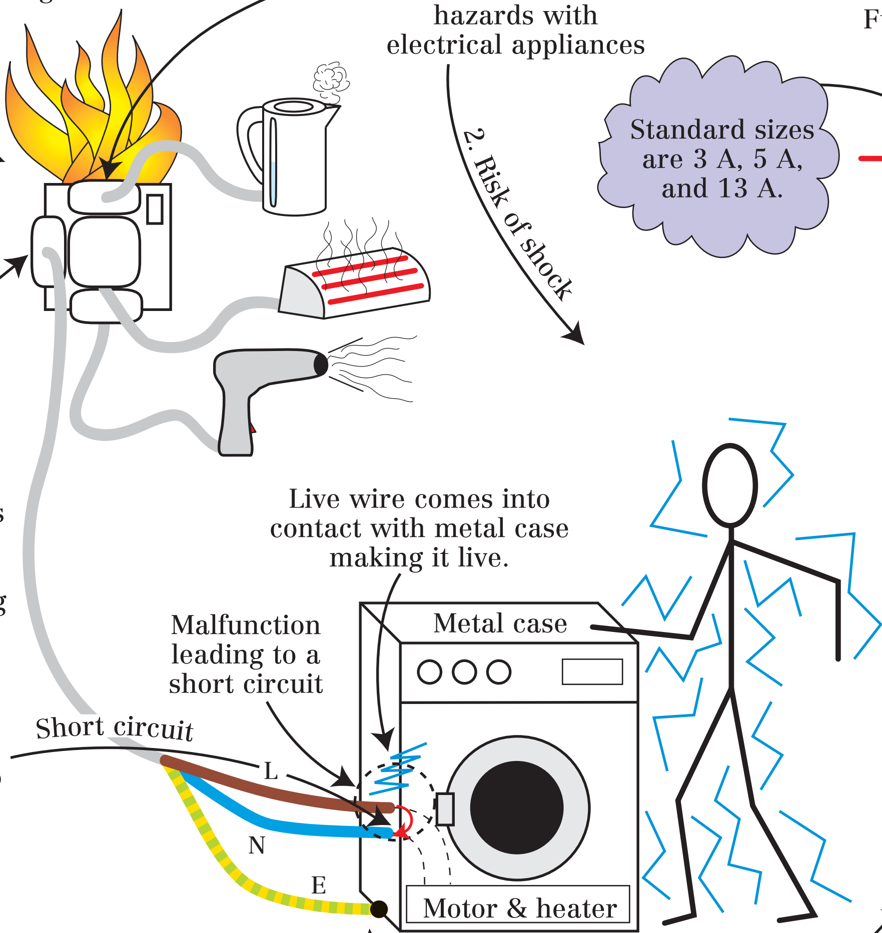
N.B. Never inspect any part of mains wiring without first switching off at the main switch next to the electricity meter.

There are two main hazards with electrical appliances

1. Risk of fire – due to overheating if too much current flowing.

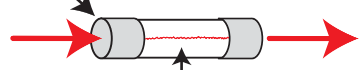
Stacking too many appliances into one socket.

If current flows directly from live to neutral without passing through the appliance. This occurs if there is a very low resistance path leading to very large current.



Fuses and the Earth wire prevent this.

Standard sizes are 3 A, 5 A, and 13 A.



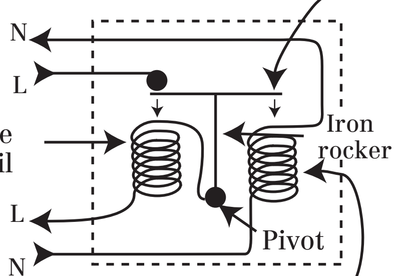
A fuse is a very thin piece of wire, a weak link in the circuit. If too much current is drawn, it overheats and melts, breaking the circuit, before the wires become very hot and become a fire risk.

If a malfunction occurs, a very large current flows from live to Earth directly.

The very large current in the live wire melts the fuse and breaks the circuit. The case is no longer live so cannot give a shock.

Fuses need to have a higher rating than the normal working current of the appliance but not so high that they may not fuse if a fault develops.

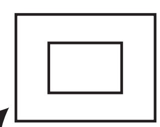
Residual current devices (r.c.d) can act like an Earth wire and fuse.



If the current in both coils is the same, the rocker stays level. If a fault develops, current in the neutral wire falls and the iron rocker is attracted magnetically to the live coil breaking the circuit.

Advantages:
1. Acts faster than a fuse, which has to melt.
2. Trips even if not all the current goes to Earth.
3. Easily resettable once the fault is corrected.

Some appliances have a completely insulated (e.g. plastic) outer case so cannot become live even if a fault develops. They are *double insulated*. An Earth wire is not needed but fuses are still used to prevent too much current flowing causing a fire.



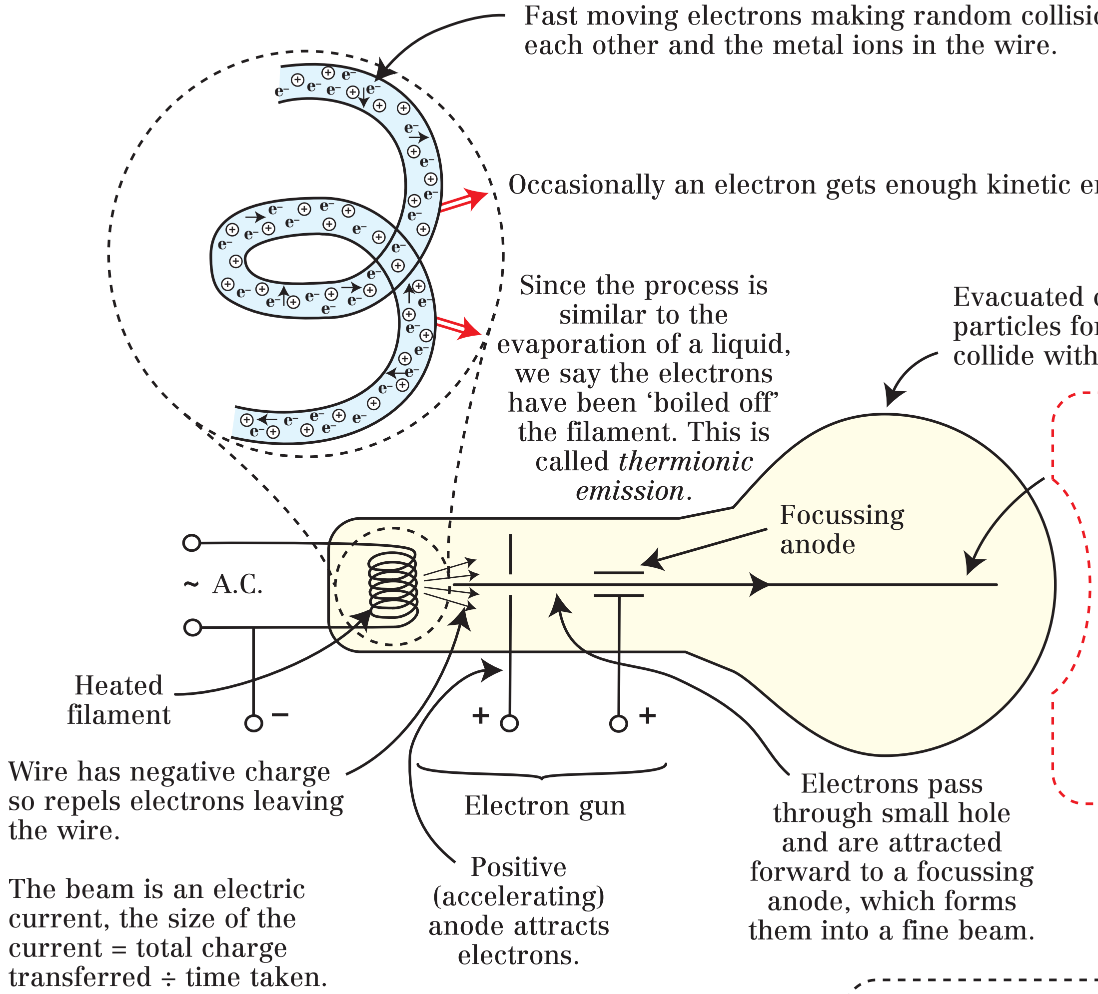
Symbol on case

Questions

1. Choose (from 3 A, 5 A, and 13 A) the most appropriate fuse for the following:
   a. An electric iron of power output 800 W.
   b. A table lamp of power output 40 W.
   c. A washing machine of total power 2500 W.
2. Explain why a fuse must always be placed in the live wire.
3. Explain why a double insulated appliance does not need an Earth wire, but does need a fuse.
4. The maximum current that can be safely drawn from a normal domestic socket is 13 A. At my friend’s house, I notice a 2.5 kW electric fire, an 800 W iron, and three 100 W spot lamps all connected to a single socket. What advice should I give my friend? Use a calculation to support your answer.
5. While using my electric lawnmower I cut the flex, and the live wire comes into contact with the damp grass. An r.c.d will make this wire safe very quickly. What is an r.c.d and how does it work in this case?

ELECTRICAL ENERGY Electron Beams

Not all electric currents flow in wires. It is possible to produce a beam of electrons travelling through a vacuum.



Kinetic energy of the electrons = electronic charge × accelerating voltage between anode and cathode.

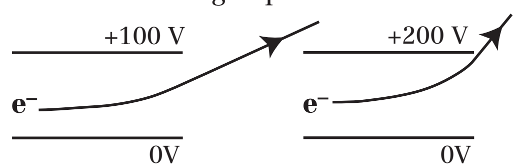
N.B. Voltage is energy per unit charge.

Hence KE (J) = e × V

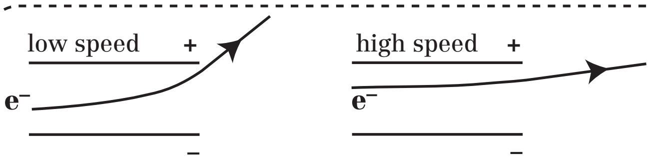
The beam is an electric current, the size of the current = total charge transferred ÷ time taken.

$$\text{Therefore current} = \frac{\text{rate of flow of electrons} \times \text{electronic charge}}{\text{time.}}$$

The beam can be deflected by charged plates.



The larger the charge on the plates (i.e. the potential difference across them) the greater the deflection.



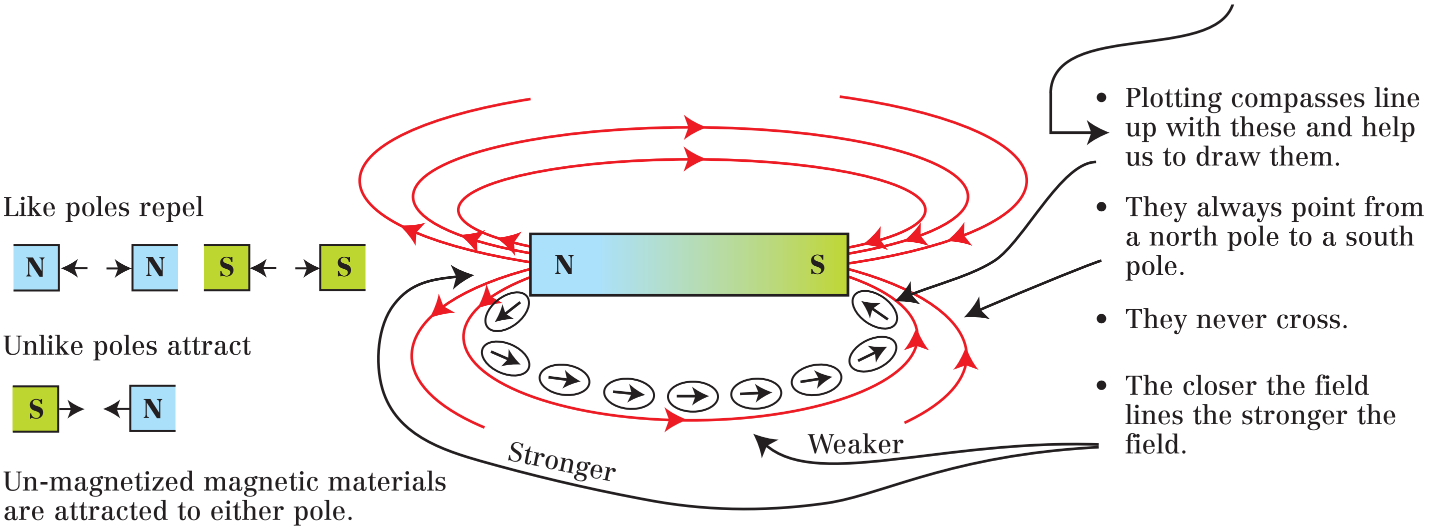
The greater the kinetic energy of the electrons, i.e. the faster they are moving, the less time they spend between the plates and the smaller the deflection.

Questions

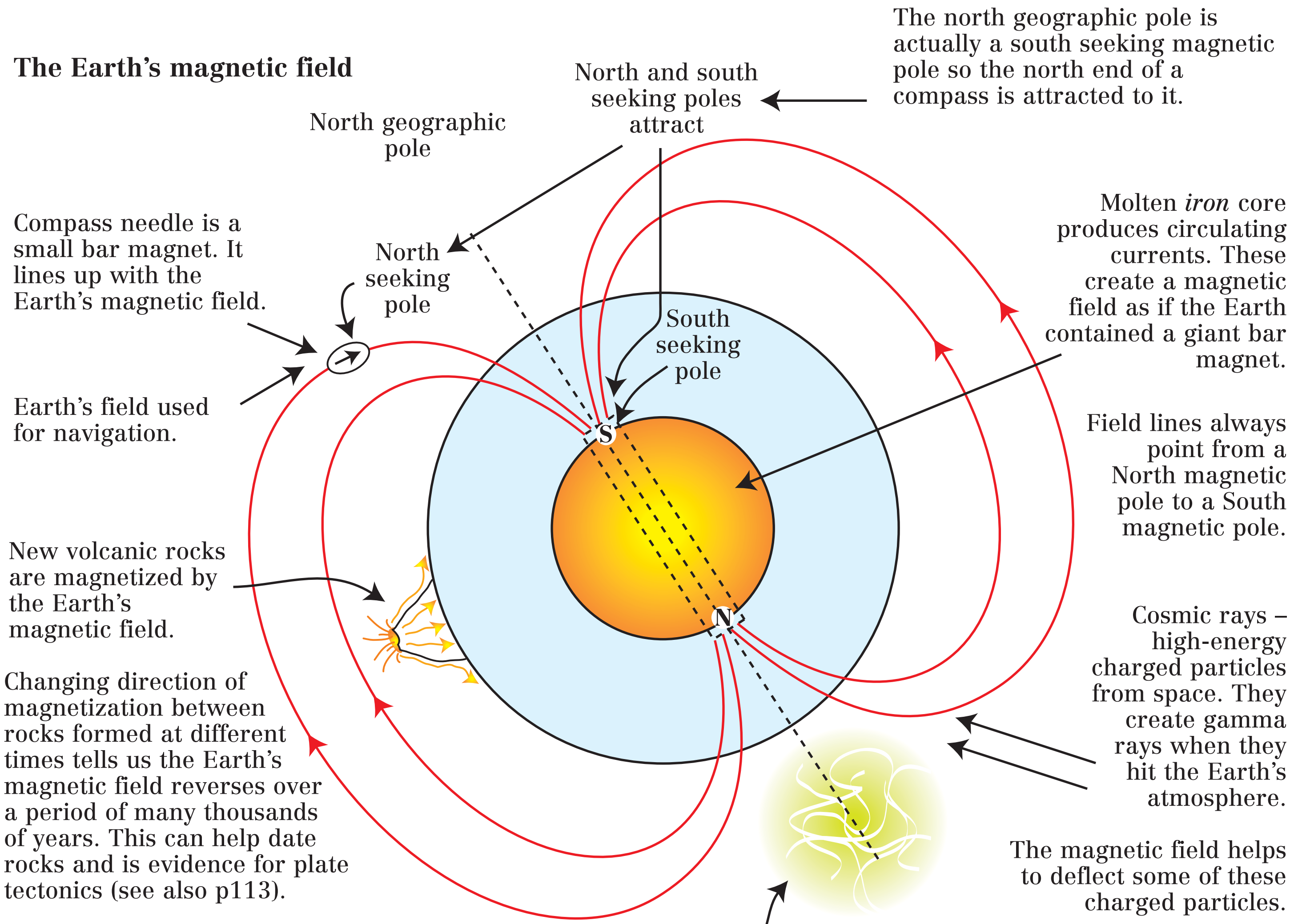
1. Describe the process of thermionic emission. Why is it important that the electron beam be produced in a vacuum?
2. What would happen to the kinetic energy of the electrons produced by an electron gun if the potential difference between the heated filament and the accelerating anode was increased?
3. What would happen to the charge transferred per second (the current) in the electron beam if the heater temperature was increased but the accelerating potential was not changed? Would the kinetic energy of the electrons change?
4. Given that the charge of one electron is 1.6×10^{-19} C, show that the kinetic energy of an electron in the beam is 3.2×10^{-17} J when the accelerating potential is 200 V.
5. If the current in the electron beam is 2 mA, show that the number of electrons boiled off the filament each second is about 1.3×10^{16} [charge on the electron = 1.6×10^{-19} C].
6. Use the answers to questions 4 and 5 to show that the total energy delivered by the beam per second (i.e. its power) is 0.4 W.
7. An electron beam passes through two charged plates as shown in the diagram. What would be the effect on the deflection of:
   a. Increasing the potential difference across the deflecting plates?
   b. Decreasing the accelerating voltage across the electron gun?

MAGNETIC FIELDS Magnetism and the Earth's Magnetic Field

A magnetic field is a region of space in which magnets and magnetic materials feel forces. The only magnetic materials are iron, steel, nickel, and cobalt. We represent magnetic fields by drawing magnetic field lines.



The Earth's magnetic field



The Earth's magnetic field interacts with charged particles from the Sun. They are channelled to the poles where they interact with molecules in the atmosphere making them glow. This is the aurora.

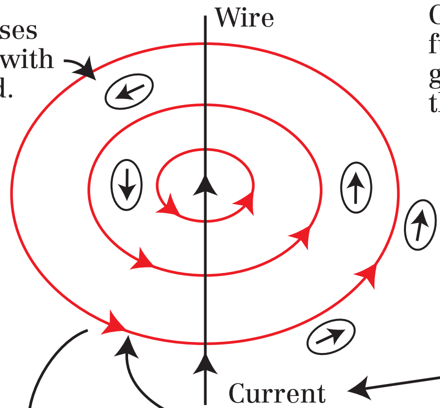
Questions

1. What is a magnetic field? Make a list of three properties of magnetic field lines.
2. Make a list of the four magnetic materials. How could you test an unknown material to discover whether it is one of the four in the list?
3. Using a magnet how would you tell if a piece of steel was magnetized or un-magnetized?
4. If the Earth's magnetic field were to disappear, it would be very bad news for our health. Explain why. (You might need to look at p69.)
5. Why might a magnetic compass not work very well close to the North or South Pole?

MAGNETIC FIELDS Electromagnetism and The Motor Effect

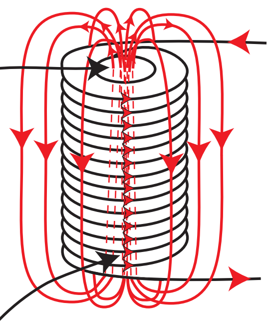
A current carrying wire produces a magnetic field around it.

Plotting compasses line up with the field.



Circular field lines (getting further apart as the field gets weaker further from the wire).

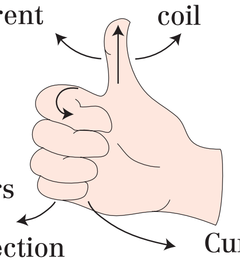
A coil (or solenoid) produces a magnetic field through and around it.



Right Hand Grip Rule

Thumb points in the direction of current

Field inside coil

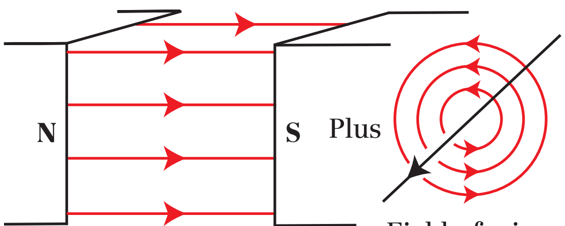


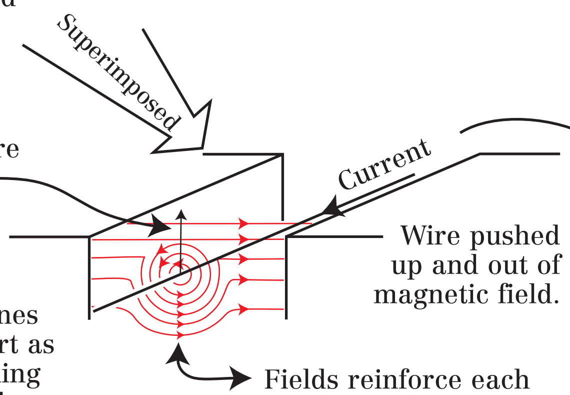
Fingers curl in direction of field lines

Current around the coil

The more turns on the coil, a bigger current and adding a soft iron core all strengthen the magnetic field.

The magnetic field of a wire can be made to interact with another magnetic field to produce a *catapult field*, which exerts a force on the wire.





Fields cancel out as they are in opposite directions.

Wire pushed up and out of magnetic field.

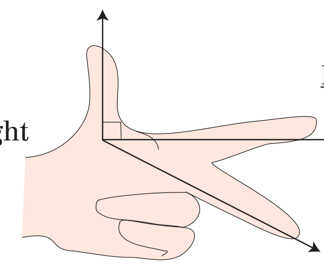
Magnetic field lines try to get as short as possible by pushing the wire out of the field and removing the distortion.

Fields reinforce each other as they are in the same direction.

The directions of the external field, current, and the resulting force (and hence motion of the wire) are remembered by Fleming's **Left Hand Rule**.

Thumb = motion (force)

All at right angles



First finger = external field

Second finger = current

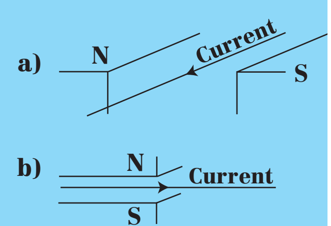
Reversing **either** current *or* field will reverse direction of the force.

If the current is parallel to the external magnetic field the two magnetic fields are at right angles to each other and cannot interact so no force is produced.

Size of the force can be increased by:
- Using a larger current
- Using a stronger external field

Questions

1. In what ways are the fields around a bar magnet and around a long coil (solenoid) similar and in what ways are they different?
2. What would happen to the direction of the magnetic field lines around a wire, or through a coil, if the current direction reverses?
3. Make a list of five uses for an electromagnet and suggest why electromagnets are often more useful than permanent magnets.
4. What happens to the direction of the force on a current carrying wire if both the field and current directions are reversed?
5. Copy the diagrams (right) and add an arrow to show the direction of the force on the wire.

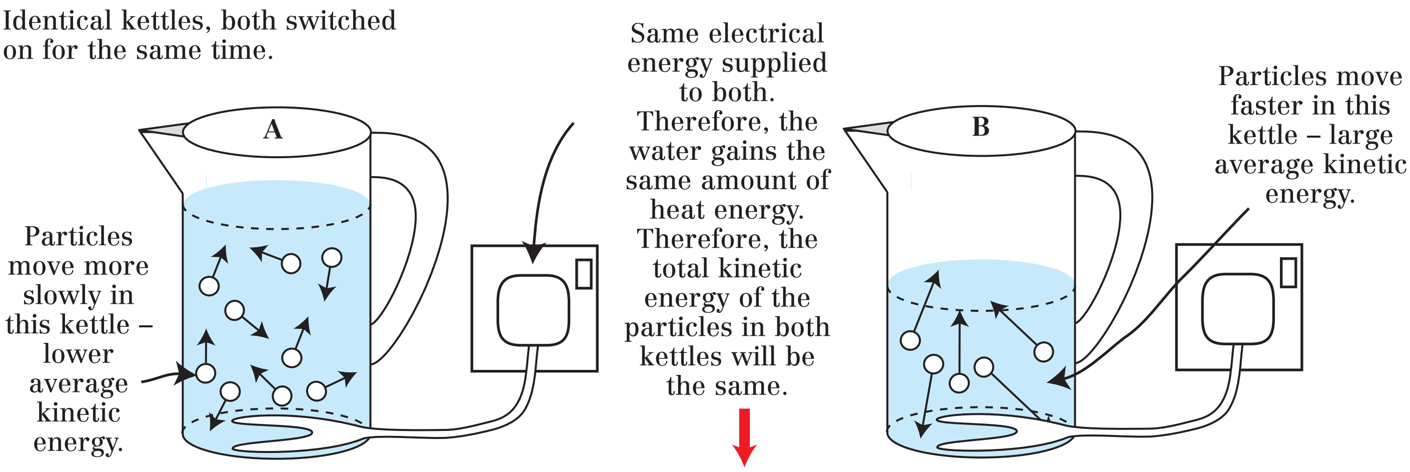


THERMAL ENERGY Heat and Temperature – What is the Difference?

All energy ultimately ends up as heat. In most energy transfers, a proportion ends up as heat energy, and often this is not useful. Sometimes we want to encourage heat transfers, in cooking for example, and sometimes discourage them, in preventing heat losses from your home for example. Therefore, understanding heat energy and how it is transferred is important.

Are heat and temperature the same thing?

> We define heat energy as the total kinetic energy of the particles in a substance (in Joules).



This kettle has half the number of particles so to make a fair comparison we measure the average energy per particle.

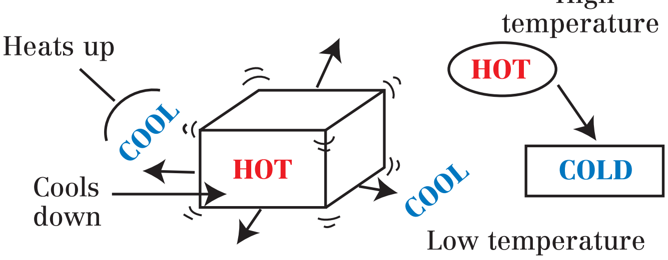
We have a special name for this average; we call it *temperature*.

> Temperature (in Kelvin) is proportional to the average kinetic energy of the particles.

Experience tells us that kettle B is hotter than A. This means that the particles in B have a higher average kinetic energy than those in A. This is reasonable because the same amount of energy is spread over fewer particles in B than in A.

Temperature differences tell us how easily heat is transferred. The bigger the temperature *difference* between an object and its surroundings the more easily heat will be transferred.

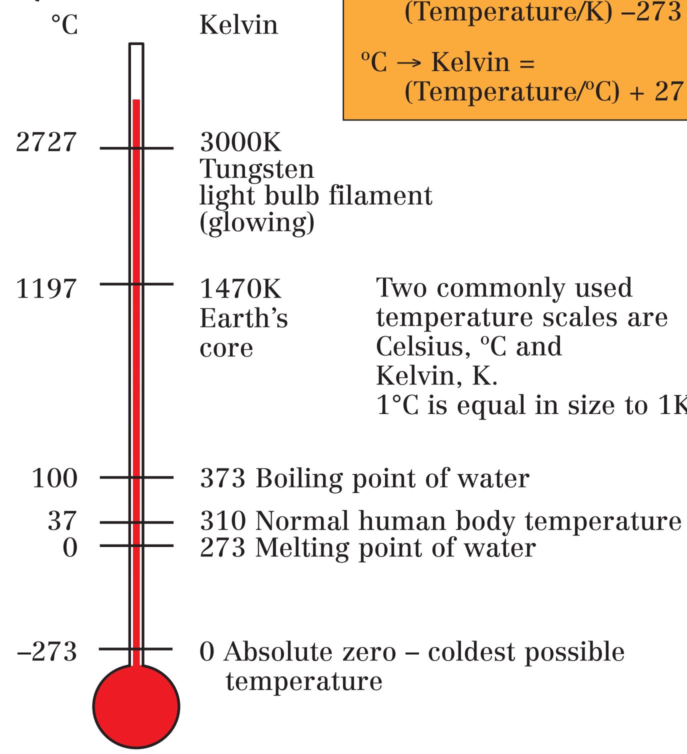
Heat always flows from hot to cold



Temperature Scales

Kelvin → °C = (Temperature/K) −273

°C → Kelvin = (Temperature/°C) + 273



Two commonly used temperature scales are Celsius, °C and Kelvin, K.
1°C is equal in size to 1K

Questions

1. Explain how a bath of water at 37°C can have more heat energy than an electric iron at 150°C.
2. A red-hot poker placed in a small beaker of water will make the water boil, but placed in a large bucket of water the temperature of the water only rises a few degrees, why?
3. Which should lose heat faster, a mug of tea at 80°C in a fridge at 5°C, or the same mug of tea at 40°C, placed in a freezer at −10°C?

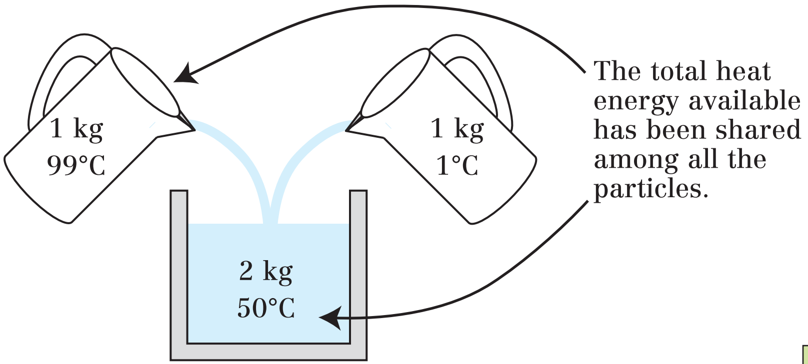
Questions

1. Convert the following into Kelvin: 42°C, 101°C, −78°C, −259°C.
2. Convert the following into °C: 373K, 670K, 54K, 4K.

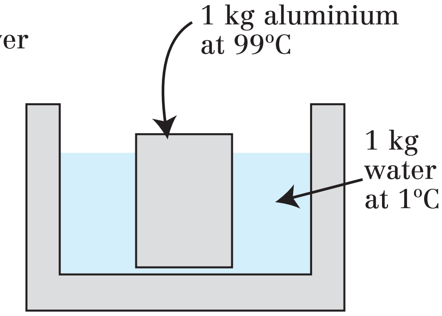
THERMAL ENERGY Specific and Latent Heat

When an object cools, it transfers heat to its surroundings.

Consider



However



Temperature of water / aluminium when they come to equilibrium <50°C (and no heat has been lost from the container).

This tells us that 1 kg of aluminium has less heat energy stored in it than 1 kg of water, so the average kinetic energy (temperature) of the particles when mixed is less. We say aluminium has a lower specific heat capacity than water.

Since temperature is proportional to the average kinetic energy of the particles we are actually measuring the energy needed to increase the average kinetic energy of the particles by a set amount. This will depend on the structure of the material, i.e. what it is made of and whether it is a solid, liquid, or gas. Therefore, *all materials have their own specific heat capacities.*

Specific heat capacity is a measure of how much heat energy 1 kg of a material can hold, defined as:

The energy needed to be supplied to raise the temperature of 1 kg of a material by 1K.

Units J/kgK

Energy supplied (J) = mass (kg) × specific heat capacity (J/kgK) × temperature change (K).

$$\Delta E = m \times shc \times \Delta T$$

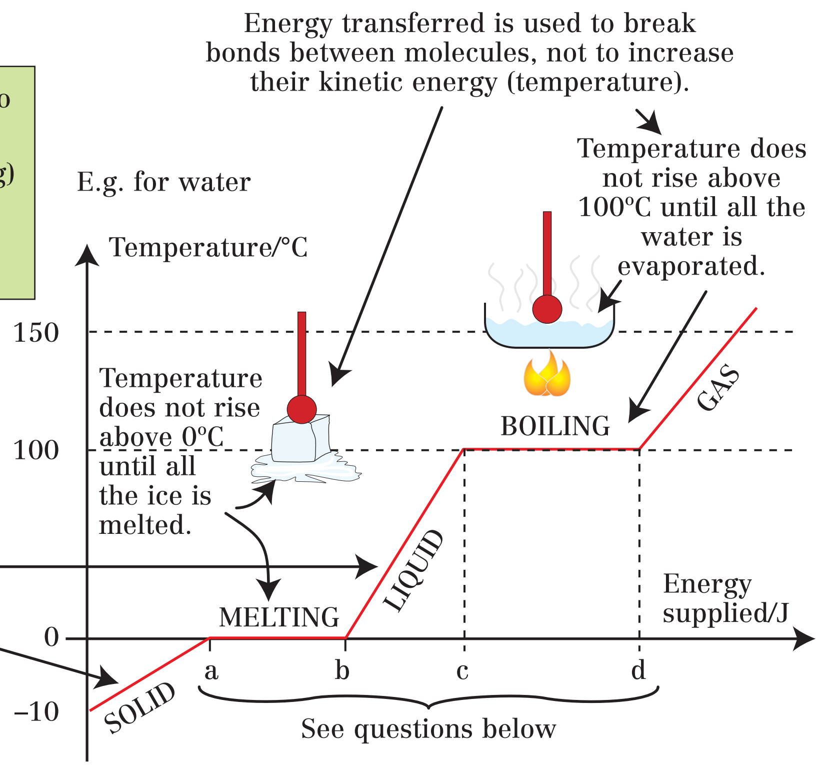
Latent heat is a measure of the energy needed to completely melt or boil 1 kg of a material.

Energy (J) = mass (kg) × specific latent heat (J/kg)

$$\Delta E = m \times slh$$

Units J/kg

Specific latent heat depends on the strength and number of intermolecular bonds between molecules, so depends on the material and its state.

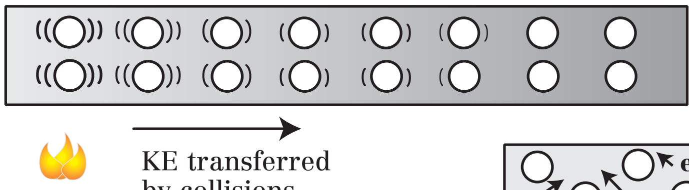


Questions

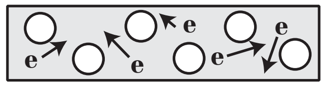
1. What happens to the average kinetic energy of the particles in material when the temperature rises?
2. A pan of boiling water stays at 100°C until all the water has evaporated. Why?
3. Explain why adding ice to a drink cools it down.
4. Given that specific heat capacity of water = 4200 J/kgK and of steam = 1400 J/kgK and that the specific latent heat for melting ice is 334 000 J/kg and for boiling water = 2 260 000 J/kg show that if the graph in the text above represents 2.5 kg of water:
   a. The energy supplied between a and b is 835 000 J.
   b. The energy supplied between b and c is 1 050 000 J.
   c. The energy supplied between c and d is 5 650 000 J.
5. A student finds that it takes 31 500 J to heat a 1.5 kg block of aluminium from 21°C to 44°C. Show that the specific heat capacity of aluminium is about 900 J/kgK.

THERMAL ENERGY Heat Transfer 1 – Conduction

Conduction is the transfer of thermal energy from a high temperature region to low temperature region by the transfer of kinetic energy between particles in a material.



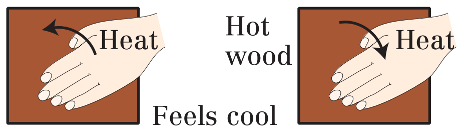
This is especially effective in solids where the particles are firmly bonded together.

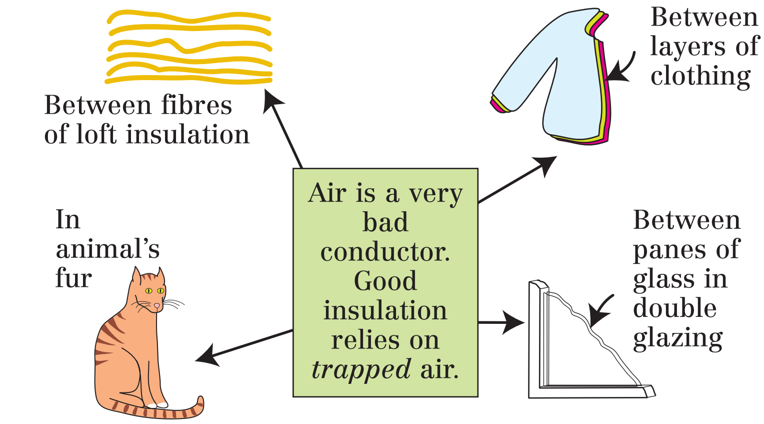


Metals and graphite have free electrons, which can move and carry heat energy. They are very good conductors.

Good conductors transfer heat energy well.

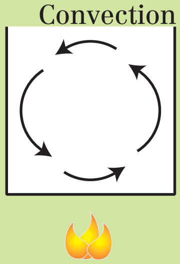
Insulators do not transfer heat well.

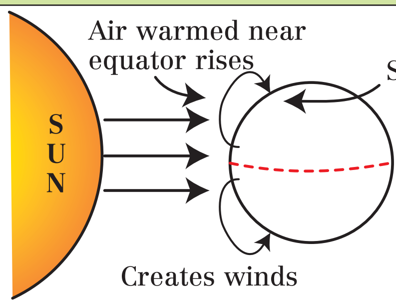


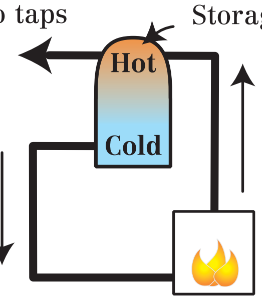


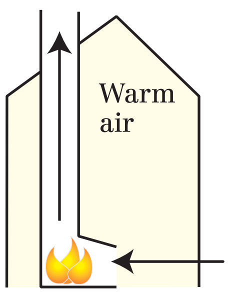
Heat Transfer 2 – Convection

Convection happens in *fluids* because the particles can move and carry heat energy away from the source. Hot fluids have a lower density than cool fluids.

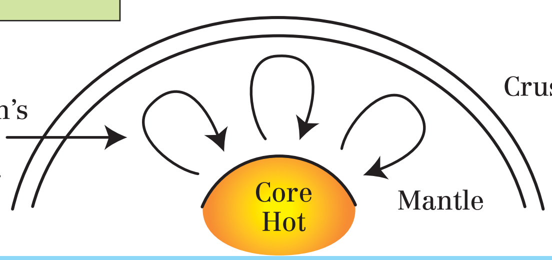








Examples of convection

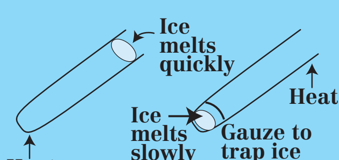


Questions – conduction

1. Using the idea of particles explain why metals are such good conductors of heat and why air is a bad conductor.
2. Air is often trapped, for example between layers of clothing, to reduce conduction. Make a list of five places where air is trapped to prevent conduction.
3. Stuntmen can walk (quickly) across a bed of burning coals without injury, yet briefly touching a hot iron causes a painful burn, why?

Questions – convection

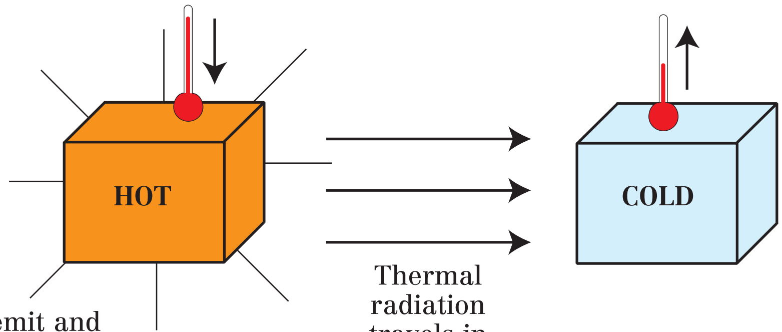
1. Explain the result opposite using the ideas of conduction and convection:



2. Why is the heating element at the bottom of a kettle?
3. Suggest what causes currents in the oceans (in detail).

THERMAL ENERGY Heat Transfer 3 – Radiation

Thermal radiation is the transfer of heat energy by (infrared) electromagnetic waves (see p30 and 32).

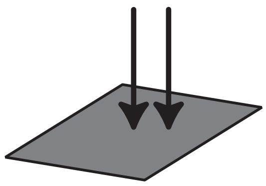


All bodies emit and absorb thermal radiation, the hotter they are the more energy they radiate.

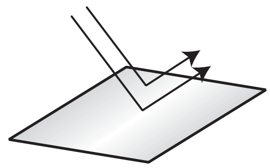
Thermal radiation travels in straight lines.

Whenever thermal radiation is absorbed, the energy it carries makes the substance that absorbs it hotter.

Thermal radiation does not need a medium, it can travel across a vacuum.

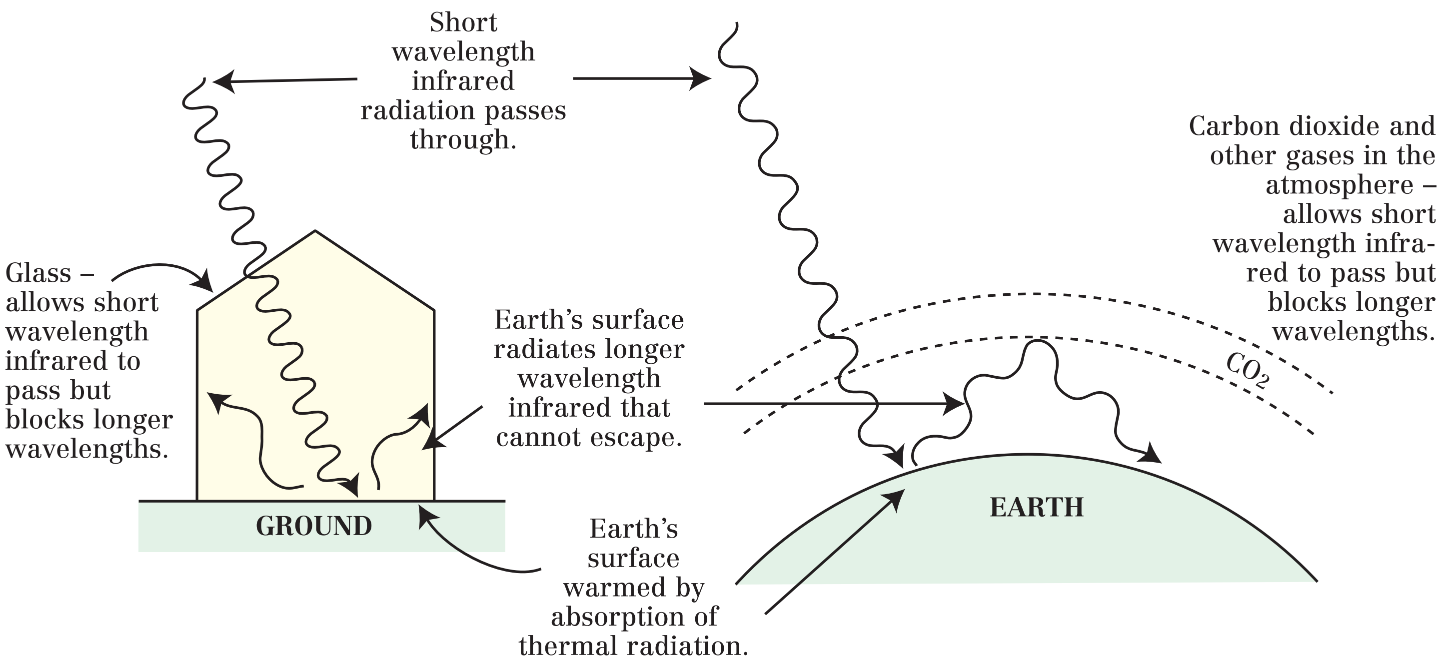


Dark, matt surfaces are good absorbers and emitters of thermal radiation.



Light, shiny surfaces are poor absorbers and emitters of thermal radiation.

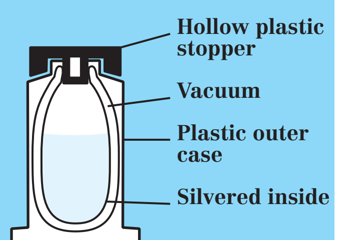
The greenhouse effect



Temperature rises due to the reabsorption of the trapped heat radiation. This leads to global warming.

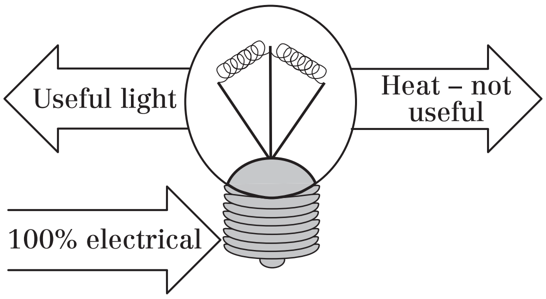
Questions

1. By which method of heat transfer does the heat from Sun reach Earth? How can you tell?
2. Why are solar panels fixed to roofs and designed to heat water painted black?
3. Why are many teapots made of shiny steel?
4. Explain why it is important to reduce the amount of carbon dioxide we pump into the atmosphere.
5. Look at the following diagram of a thermos flask and explain why:
   a. There is a vacuum between the walls of the flask.
   b. The walls of the flask are shiny.
   c. The drink stays hotter longer if the stopper is put in.
   d. Liquid nitrogen (boiling point 77K, –196°C) stays as a liquid in the flask for a long time, but rapidly boils and evaporates if poured out.



THERMAL ENERGY Reducing Energy Wastage in Our Homes

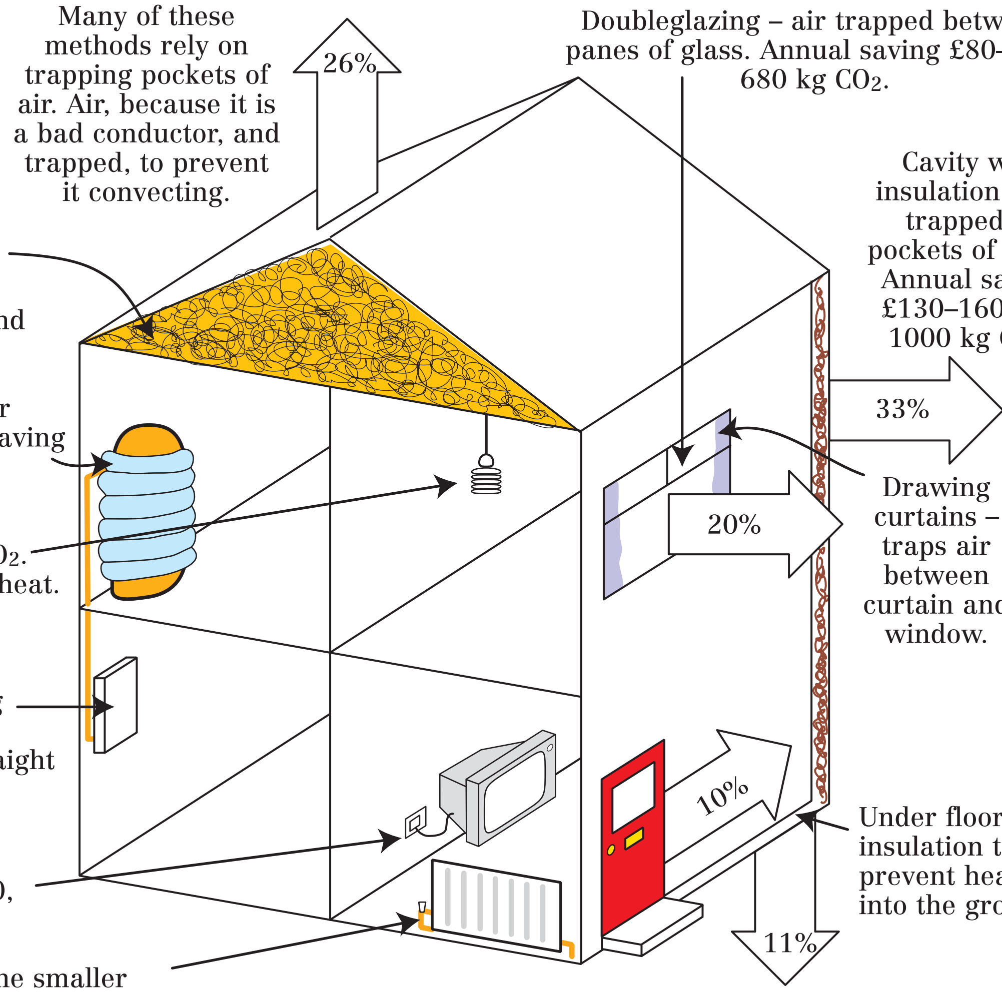
Reducing our demand for energy is as important in reducing greenhouse gas emissions as finding renewable energy resources. Although energy is conserved, we often convert it to forms that are not useful. For example:



To reduce our demand for energy there are many practical steps we can take, many involving the reduction of heat transfer. However, householders must also consider payback time.

$$\frac{\text{Cost of installing}}{\text{annual saving}} = \text{payback time in years.}$$

Many of these methods rely on trapping pockets of air. Air, because it is a bad conductor, and trapped, to prevent it convecting.



Doubleglazing – air trapped between panes of glass. Annual saving £80–100, 680 kg CO_2.

Cavity wall insulation – air trapped in pockets of foam. Annual saving £130–160 and 1000 kg CO_2.

Loft insulation made of fibreglass or mineral wool. Annual saving £180–220 and 1500 kg CO_2.

Hot water tank jackets – air trapped in fibres. Annual saving £10–20, 50 kg CO_2.

Energy saving light bulb. Annual saving £9, 40 kg CO_2. Produces much less waste heat.

Drawing curtains – traps air between curtain and window.

A condensing boiler condenses hot waste gas from the burnt fuel making it give up its latent heat rather than pumping it straight into the atmosphere.

Under floor insulation to prevent heat loss into the ground.

Not leaving appliances on standby. Annual saving £20, 40 kg CO_2.

Turn down thermostats – the smaller the temperature difference between inside and outside the slower the rate of loss of thermal energy. 1°C reduction has an annual saving of £50 and 300 kg CO_2.

Draught proofing – prevents warm air convecting from a warm room into a colder one through gaps in doors and windows. Annual saving £10–20, 120 kg CO_2.

Saving energy also reduces carbon dioxide emissions because carbon dioxide is a waste product of burning any fossil fuel, either directly such as gas in a boiler, or indirectly to generate electricity in a power station.

(Data correct (2006) Energy Saving Trust www.est.org.uk.)

Questions

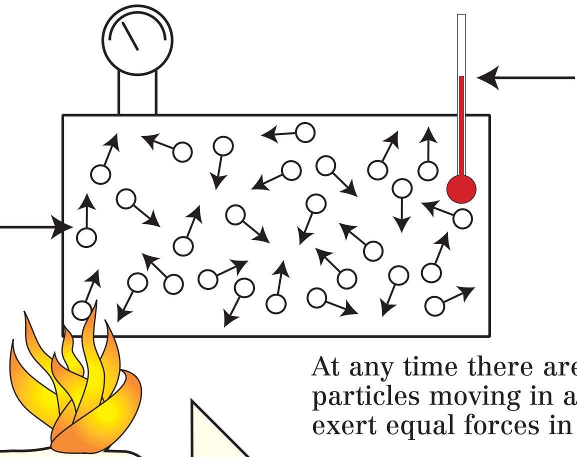
1. A householder could spend £230 on loft insulation that would save £180 in fuel bills each year, or they could spend £75 on draughtproofing and save £20 each year. Which would you recommend they do and why?
2. Why do we talk about wasting energy when physics tells us energy is conserved?
3. Which of the energy saving measures above are free?
4. The annual savings quoted above are both in terms of money and CO_2 saved. Which do you consider to be more important and why?

THERMAL ENERGY Kinetic Model of Gases

The kinetic model of gases is the name we give to the idea that a gas is made up of microscopic particles moving randomly, colliding with each other and the walls of the container.

The pressure is a measure of the rate and force of the collision of the gas molecules with the sides of the container.

The volume of the particles is insignificant compared to the volume of the container.



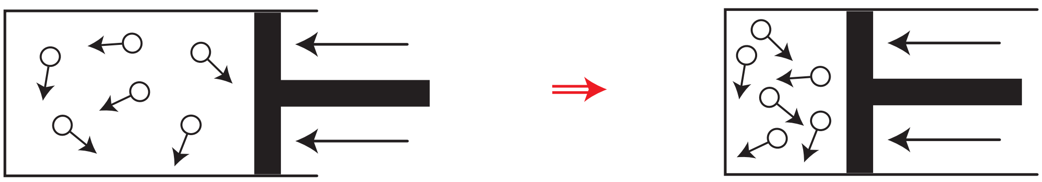
The temperature (in Kelvin) is *directly proportional* to the average kinetic energy of the molecules.

As the temperature rises, so does the average kinetic energy and, therefore, speed of the gas particles.

At any time there are on average equal numbers of gas particles moving in any direction. This explains why gases exert equal forces in all directions.

Heating the gas increases the average kinetic energy of the molecules, i.e. raises the temperature.

The gas particles travel faster and hit the sides of the container faster, and more often. Therefore, the pressure rises. We assume the particles do not lose any kinetic energy during collisions.

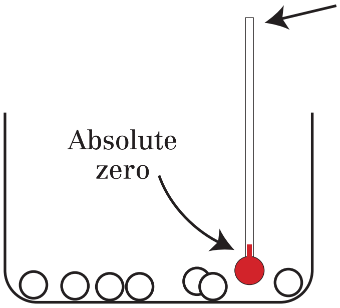


Gas pressure increases.

Gases are very compressible because there are large spaces between the molecules.

Reducing the volume of a container means that the molecules collide with the sides more often as they do not have so far to travel.

No pressure exerted at absolute zero, as there are no collisions.



Thermometers read a temperature because gas particles collide with it and transfer kinetic energy to the material of the thermometer.

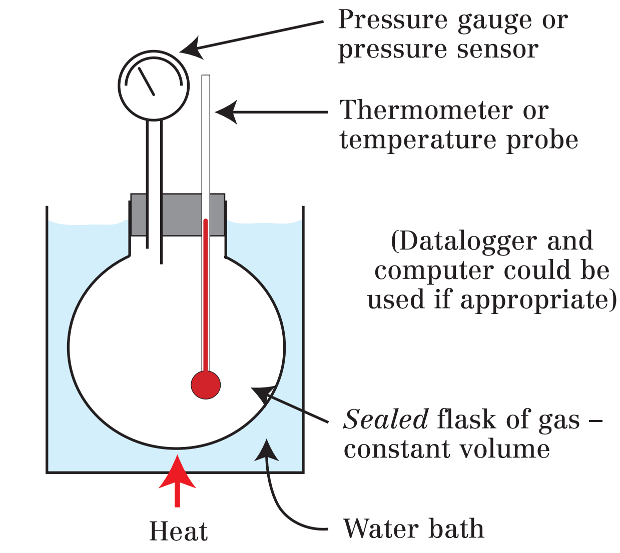
If the molecules stopped moving, then they would have no kinetic energy – therefore, we would say they had no temperature. This is called *absolute zero* because you cannot get any colder.

Questions

1. Explain carefully why heating a gas in a sealed container raises the pressure. Why might this not be very safe?
2. A motorist checks his tyre pressures before a long journey. At the end of the journey, he notices his tyres are warm and that their pressure has risen, why?
3. A toy balloon containing helium is released accidentally by a child. The balloon rises high into the atmosphere where the air pressure is a lot lower. Eventually it bursts. Why?
4. When you breathe in your lung volume increases. What happens to the air pressure in your lungs, and why does air rush in through your nose?
5. When petrol burns in a car engine it gets very hot very quickly. Why does this force the cylinder out?
6. When carbon dioxide is released rapidly from a fire extinguisher, it makes the nozzle get very cold, why?

THERMAL ENERGY Gas Laws

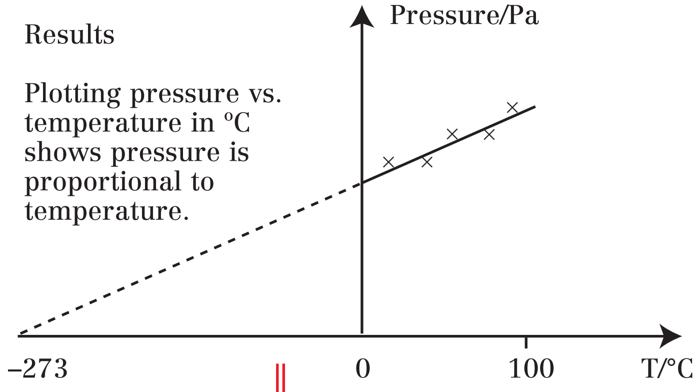
Measuring the variation of gas pressure with temperature:



Pressure is measured in Pascals, Pa. 1 Pa = 1 N/m^2.

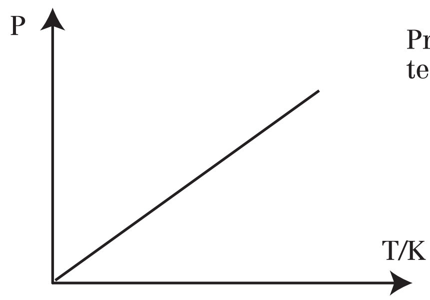
Results

Plotting pressure vs. temperature in °C shows pressure is proportional to temperature.



Extrapolating the line back, we see that the pressure would be zero when the temperature is –273°C. This is absolute zero, because all the gas particles would have stopped moving (see p65).

It would make sense to start a temperature scale here – we call this the Kelvin scale.



Pressure is *directly* proportional to temperature (measured in Kelvin) i.e.

$$\frac{\text{Pressure}}{\text{temperature (Kelvin)}} = \text{constant}$$

$$\frac{P}{T} = \text{constant}$$

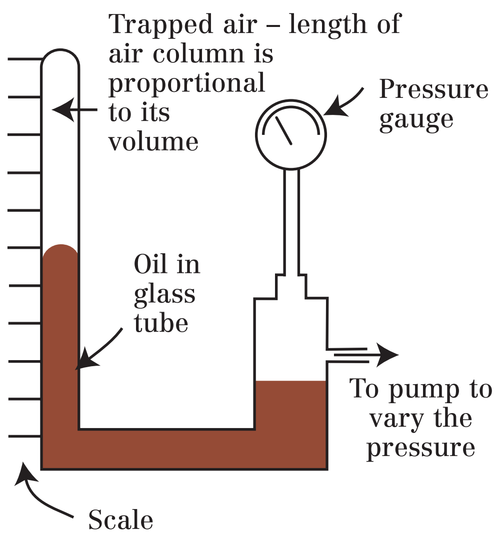
Pressure × volume = constant

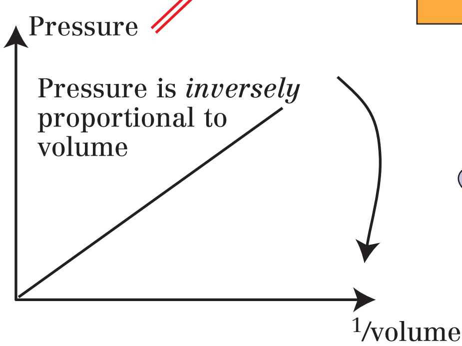
P × V = constant

Hence combining the two equations

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Measuring the variation of gas pressure with volume:





N.B.
All gas law calculations must be carried out with Kelvin temperatures.

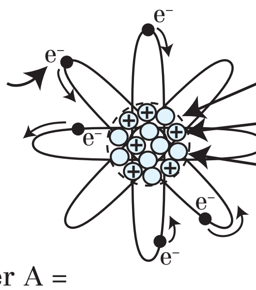
Questions

1. The pressure of air in a sealed container at 22°C is 105 000 Pa. The temperature is raised to 85°C. Show that the new pressure is about 130 000 Pa assuming that the volume of the container remains constant.
2. A bubble of air of volume 2 cm^3 is released by a deep-sea diver at a depth where the pressure is 420 000 Pa. Assuming the temperature remains constant show that its volume is 8 cm^3 just before it reaches the surface where the pressure is 105 000 Pa.
3. A sealed syringe contains 60 cm^3 of air at a pressure of 105 000 Pa and at 22°C. The piston is pushed in rapidly until the volume is 25 cm^3 and the pressure is 315 000 Pa. Show that the temperature of the gas rises to about 95°C.
4. When a star forms a gas cloud in space is attracted together by gravity compressing it. As the volume of the gas reduces what happens to its pressure and hence temperature?

RADIOACTIVITY Atomic Structure

All atoms have the same basic structure:

Electrons are held in orbit around the nucleus by electrostatic attraction.



In all atoms the number of protons = number of electrons. This makes atoms uncharged, or *neutral*.

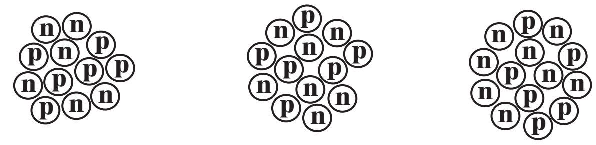
Naming atoms:

$^{A}_{Z}X$

- Atomic (proton) number Z = number of protons in the nucleus
- Mass (nucleon) number A = total number of protons plus neutrons in the nucleus
- X: Symbol for the element

Each element has a unique number of protons. Therefore, the atomic number uniquely identifies the element.

Some atoms of the same element have different numbers of neutrons.



E.g. all these atoms are carbon as they all have 6 protons, but they have different numbers of neutrons. They are called isotopes of carbon.

> Isotopes are always the same element, i.e. same atomic number but have different numbers of neutrons (and so mass number).

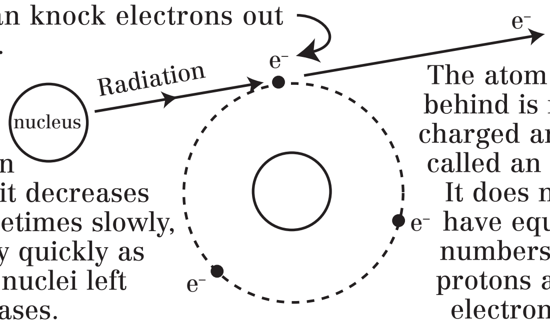
The relative masses of protons, neutrons, and electrons and their relative electric charges are:

	Mass	Charge
Proton	1	+1
Neutron	1	0
Electron	$\frac{1}{1870}$	–1

What is Radioactivity?

Some elements give out random bursts of radiation. Each individual nucleus can only do this once, and when it has happened, it is said to have decayed. As even a tiny sample of material contains billions of atoms, many bursts of radiation can be emitted before all the nuclei have decayed.

Ionizing – it can knock electrons out of other atoms.



The emission of this radiation is random but it decreases over time, sometimes slowly, sometimes very quickly as the number of nuclei left to decay decreases.

The atom left behind is now charged and is called an *ion*. It does not have equal numbers of protons and electrons.

Elements that behave like this are called *radioactive*.

We can measure the radioactivity as the number of decays (and, therefore, bursts of radiation emitted) per second.

> 1 decay per second = 1 Becquerel, Bq

Questions

1. Copy and complete the table.

	No. of protons	No. of electrons	No. of neutrons
Carbon $^{12}_{6}C$			
Barium $^{137}_{56}Ba$			
Lead $^{\_\_}_{\_\_}Pb$		82	125
Iron $^{56}_{\_\_}Fe$	26		
Hydrogen $^{1}_{1}H$			
Helium $^{4}_{2}He$			
Helium $^{3}_{2}He$			
Element X $^{A}_{Z}X$			

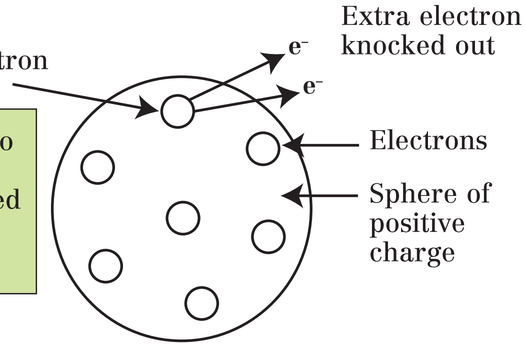
2. a Draw a diagram to show all the protons and neutrons in the nuclei of $^{35}_{17}Cl$ and $^{37}_{17}Cl$.
   b. What word do we use to describe these two nuclei?
   c. Why is there no difference in the way the two types of chlorine atoms behave in chemical reactions?
   d. If naturally occurring chlorine is 75% $^{35}_{17}Cl$ and 25% $^{37}_{17}Cl$ explain why on a periodic table it is recorded as $^{35.5}_{17}Cl$?
3. What is a Becquerel?
4. If ionizing radiation knocks electrons out of atoms, will the ions left behind be positively or negatively charged? Why?
5. Explain what you understand by the term 'radioactive element'.

RADIOACTIVITY A History of Our Understanding of the Atom

In 1803, John Dalton noted that chemical compounds always formed from the same ratio of elements, suggesting particles were involved. He called these atoms from the Greek, meaning indivisible.

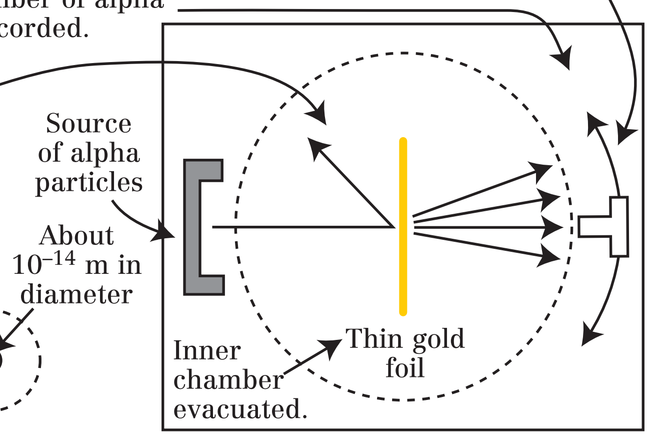
J.J. Thomson (1897) discovered the electron, a particle that could be knocked out of an atom. He suggested a 'plum pudding' model of the atom.

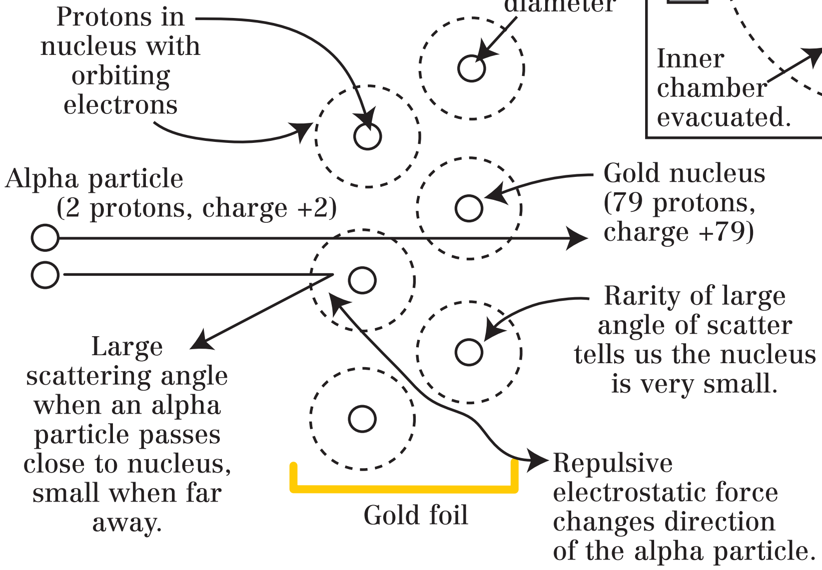
The model was so named as the electrons appeared like the fruit in a pudding.



Rutherford, Geiger, and Marsden investigated this in 1910. They decided to probe the nucleus further with alpha particles. These are particles with two positive charges, which they considered to be like little bullets.

1. Detector detects the alpha particles that have travelled through the foil. It can be moved to any angle round the foil so that the number of alpha particles in any direction can be recorded.
2. The majority of alpha particles travelled through the foil with very little change in direction.
3. A *very* small number were turned through angles greater than 90°.
4. Plum pudding model cannot explain this since as the positive and negative charges were reasonably evenly distributed no alpha particles should get scattered through large angles.
5. Rutherford proposed the nuclear model.





Summary

The alpha scattering experiment proves that:
1. Atoms have massive, positively charged nuclei.
2. The majority of the mass of the atom is the nucleus.
3. Electrons orbit outside of the nucleus. Most of the atom is empty space.

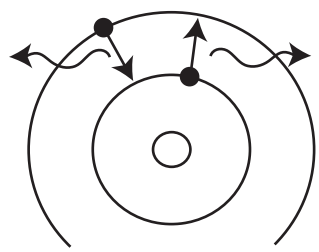
Bohr further developed the atomic model by suggesting that the electrons were arranged in energy levels around the nucleus.

Kinetic energy is transferred to potential energy in the electric field round the nucleus as the alpha particle does work against the repulsive force. This is returned to kinetic energy on leaving the region near the nucleus.

- The larger the charge on the nucleus the greater was the angle of scatter.
- The thicker the foil the greater the probability that an alpha particle passes close to a nucleus.
- Slower alpha particles remain in the field around the nucleus for longer – increases the angle of scattering.

To move up a level it has to absorb precisely the right amount of energy from an electromagnetic wave.

If an electron moved down a level, it has to get rid of some energy in the form of an electromagnetic wave.



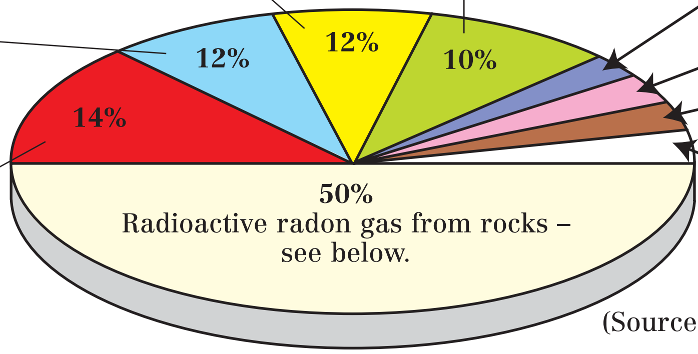
Questions

1. List the main conclusions of the alpha scattering experiment.
2. What evidence did Thomson have for the plum pudding model?
3. Suggest why the alpha scattering apparatus has to be evacuated (have all the air taken out of it).
4. Suggest why the gold foil used in the alpha scattering experiment needs to be very thin.
5. The diameter of an atom is about 10^{-10} m and of a gold nucleus 10^{-14} m. Show that the probability of directly hitting a nucleus with an alpha particle is about 1 in 108. What assumptions have you made?

RADIOACTIVITY Background Radiation

Radioactive elements are naturally found in the environment and are continually emitting radiation. This naturally occurring radiation is called *background radiation*, which we are all exposed to throughout our lives.

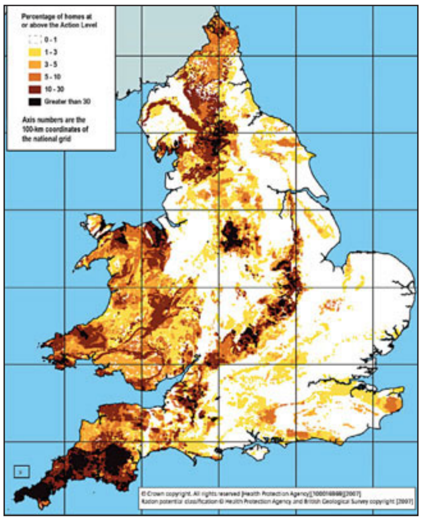
Background radiation comes from a number of sources. (Note that these are averaged across the population and may differ for different groups, for example depending on any medical treatment you may have, or whether you make many aeroplane flights.)

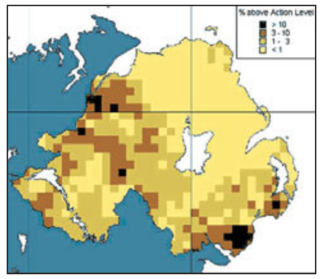


(Source: Health Protection Agency, 2006.)

One of the major sources of background radiation is radon gas. This is produced by minute amounts of uranium, which occurs naturally in rocks, and is present in all parts of the country. It disperses outdoors so is only a problem if trapped inside a building. Exposure to high levels of radon can lead to an increased risk of lung cancer.

Since we all inhale radon throughout our lives it accounts for about half our annual radiation dose in the UK.

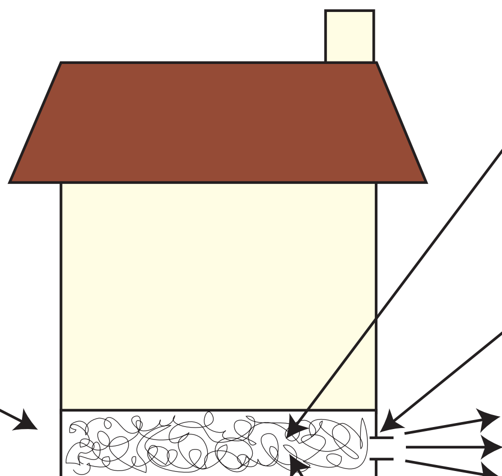




Maps courtesy of the Health Protection Agency and the British Geological Survey

For more information go to: www.ukradon.co.uk

Geological conditions in some areas produce higher than average radon concentrations as shown in the map.

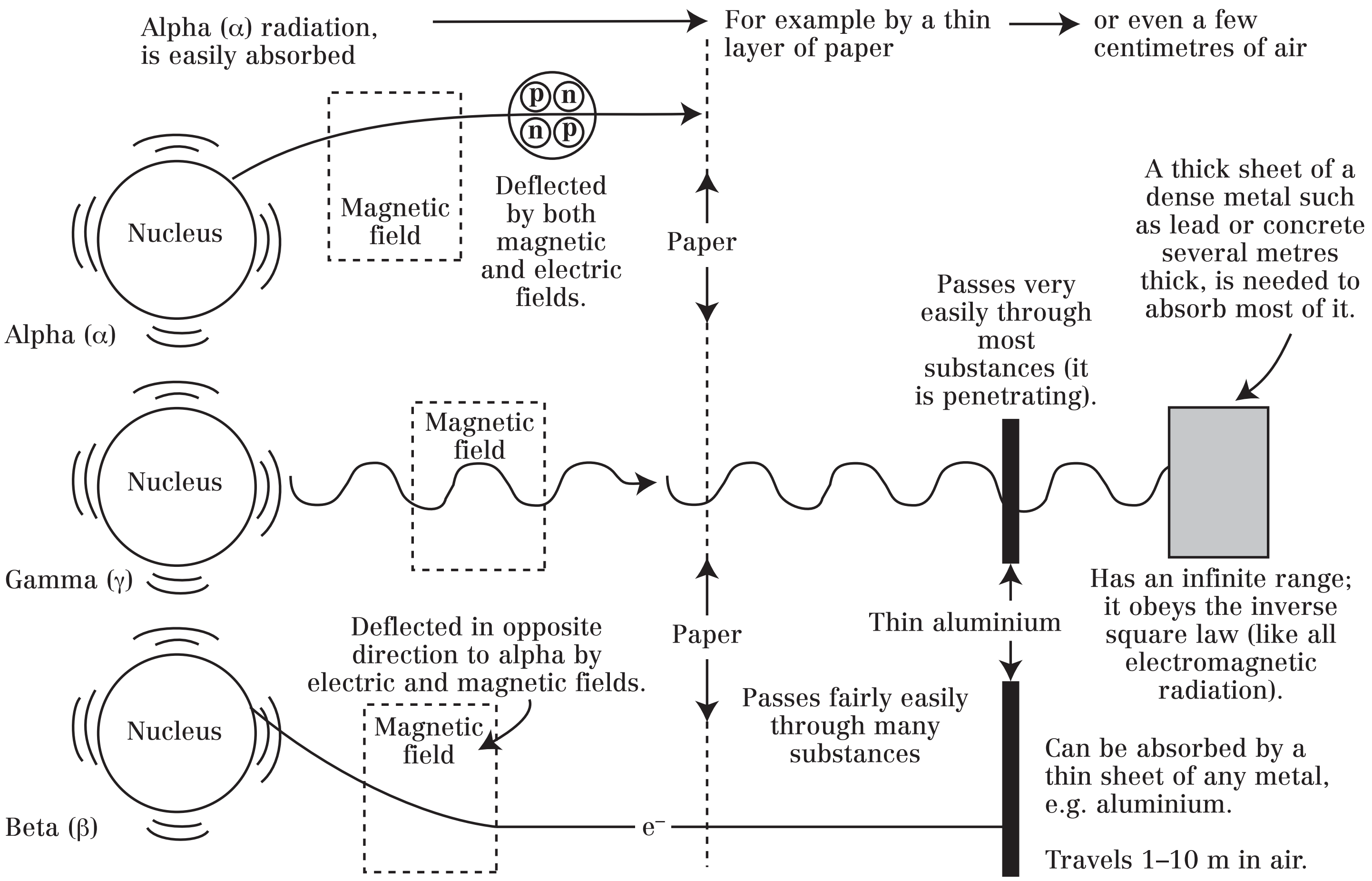


Questions

1. Make a list of sources of background radiation.
2. Give at least two reasons why the percentages shown above in the sources of background radiation are only averages and will differ for different people.
3. On average what percentage of the total background radiation is man-made?
4. Should we worry about background radiation?

RADIOACTIVITY Three Types of Nuclear Radiation

There are three types of radiation emitted by radioactive materials. They are all emitted from unstable *nuclei*:



Name	Identity		Mass	Charge	
Alpha (α)	Helium *nucleus*	p n n p $^{4}_{2}$He	4	+2	Massive and highly charged. Therefore, interacts strongly with other matter causing ionization, and loses energy rapidly. Easily stopped and short range
Beta (β)	Fast moving electron ejected from the *nucleus*. Note that it is not an atomic orbital electron	e^-	$\frac{1}{1870}$	–1	Nearly 8000 × less massive than alpha and only half the charge. Therefore, does not interact as strongly with other matter causing less ionization, and loses energy more gradually. Harder to stop and has a longer range
Gamma (γ)	Electromagnetic wave		0	0	No mass or charge so only weakly interacts with matter. Therefore, very difficult to stop

Questions

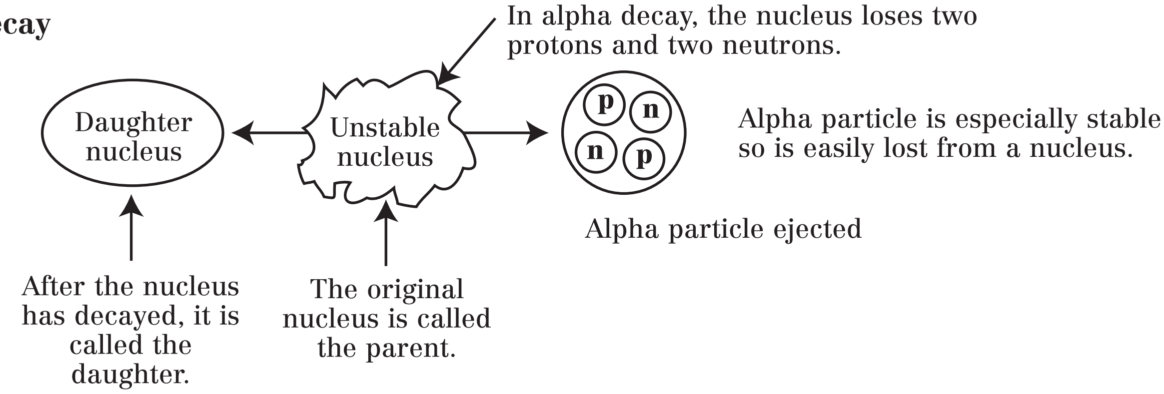
1. Describe the differences between alpha, beta, and gamma radiation. What materials will stop each one?
2. Alpha and beta particles are deflected in both electric and magnetic fields but gamma is not. Explain why. Why are alpha and beta deflected in opposite directions?
3. A student has a radioactive source. When the source is placed 1 cm in front of a GM tube connected to a ratemeter it counts 600 counts per minute.
   - Moving the source back to 10 cm the count drops to 300 counts per minute.
   - Replacing the source at 1 cm and inserting 2 mm thickness of aluminium foil gives 300 counts per minute.
   - Moving the source back to 5 cm and inserting 2 cm of lead gives 150 counts per minute.

   Explain how you know what type(s) of radiation the source emits.
4. Many smoke alarms contain a small radioactive source emitting alpha particles. This is inside an aluminium box, and placed high on a ceiling. Use the properties of alpha particles to explain why smoke alarms do not pose any health risk.

RADIOACTIVITY Radioactive Decay and Equations

Most nuclei never change; they are stable. Radioactive materials contain unstable nuclei. These can break up and emit radiation. When this happens, we say the nucleus has *decayed*. The result for alpha and beta decay is the nucleus of a different element. For gamma decay, it is the same element but it has less energy.

Alpha decay



Mass number decreases by 4 (2 protons + 2 neutrons lost). Atomic number decreases by 2 (2 protons lost).

Atomic number

$^{A}_{Z}X \rightarrow \, ^{(A-4)}_{(Z-2)}Y + \, ^{4}_{2}He$ Or $^{A}_{Z}X \rightarrow \, ^{(A-4)}_{(Z-2)}Y + \, ^{4}_{2}\alpha$

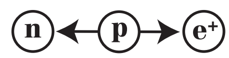
Beta decay

Beta-minus 

Neutron becomes a proton and electron.

Daughter nucleus has one more proton than the parent so the atomic number increases by one.

Overall number of protons plus neutrons is unchanged so the mass number does not change.

Beta-plus 

Proton becomes a neutron and a positron (an anti-electron with all the same properties as an electron but the opposite charge).

Daughter nucleus has one less proton than the parent so the atomic number decreases by one.

Overall number of protons plus neutrons is unchanged so the mass number does not change.

$^{A}_{Z}X \rightarrow \, ^{A}_{(Z+1)}Y + \, ^{0}_{-1}e^{-}$

Or

$^{A}_{Z}X \rightarrow \, ^{A}_{(Z+1)}Y + \, ^{0}_{-1}\beta^{-}$

$^{A}_{Z}X \rightarrow \, ^{A}_{(Z-1)}Y + \, ^{0}_{+1}e^{+}$

Or

$^{A}_{Z}X \rightarrow \, ^{A}_{(Z-1)}Y + \, ^{0}_{+1}\beta^{+}$

Gamma decay

Often after either alpha or beta decay the nucleons have an excess of energy. By rearranging the layout of their protons and neutrons, they reach a lower energy state and the excess energy is emitted in the form of a gamma ray.

$$^{A}_{Z}X \rightarrow \, ^{A}_{Z}X + \gamma$$

Rules for nuclear equations

The total mass number must be the same on both sides of the equation.

The total atomic number on both sides of the equation must be the same.

The total charge must be the same on both sides of the equation.

Questions

Copy and complete the following nuclear equations:

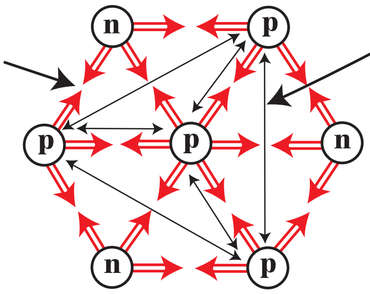
1. $^{215}_{84}Po \rightarrow \, ^{211}_{82}Pb + \_\_\_$.
2. $^{228}_{90}Th \rightarrow \, ^{\_\_}_{\_\_}Ra + \, ^{4}_{2}\alpha$.
3. $^{214}_{82}Pb \rightarrow \, ^{214}_{83}Bi + \_\_\_$.
4. $^{15}_{8}O \rightarrow \, ^{15}_{7}N + \_\_\_$.
5. $^{\_\_}_{\_\_}Si \rightarrow \, ^{27}_{13}Al + \, ^{0}_{+1}\_^{+}$.
6. $^{238}_{\_\_}U \rightarrow \, ^{\_\_}_{90}Th + \, ^{4}_{2}\alpha$.
7. $^{74}_{33}As \rightarrow \, ^{\_\_}_{\_\_}Se + \, ^{0}_{-1}\_^{-}$.
8. $^{227}_{89}Ac \rightarrow \, ^{\_\_}_{87}Fr + \_\_\_$.

RADIOACTIVITY N/Z Curve

Nuclei have positive charge due to the protons in them. All the protons repel, so why does the nucleus not explode?

There is another force acting called the *strong nuclear force*.
This acts between all nucleons, both protons and neutrons.

Strong nuclear attraction only acts between adjacent nucleons.



Electrostatic repulsion between all protons.

For small nuclei, a proton:neutron ratio of 1:1 is sufficient for the strong nuclear force to balance the electrostatic force. For larger nuclei, we need more neutrons to provide extra strong nuclear force, without increasing the electrostatic repulsion, so the ratio rises to 1.6:1.

Plotting the number of protons vs. number of neutrons in stable nuclei gives this graph.

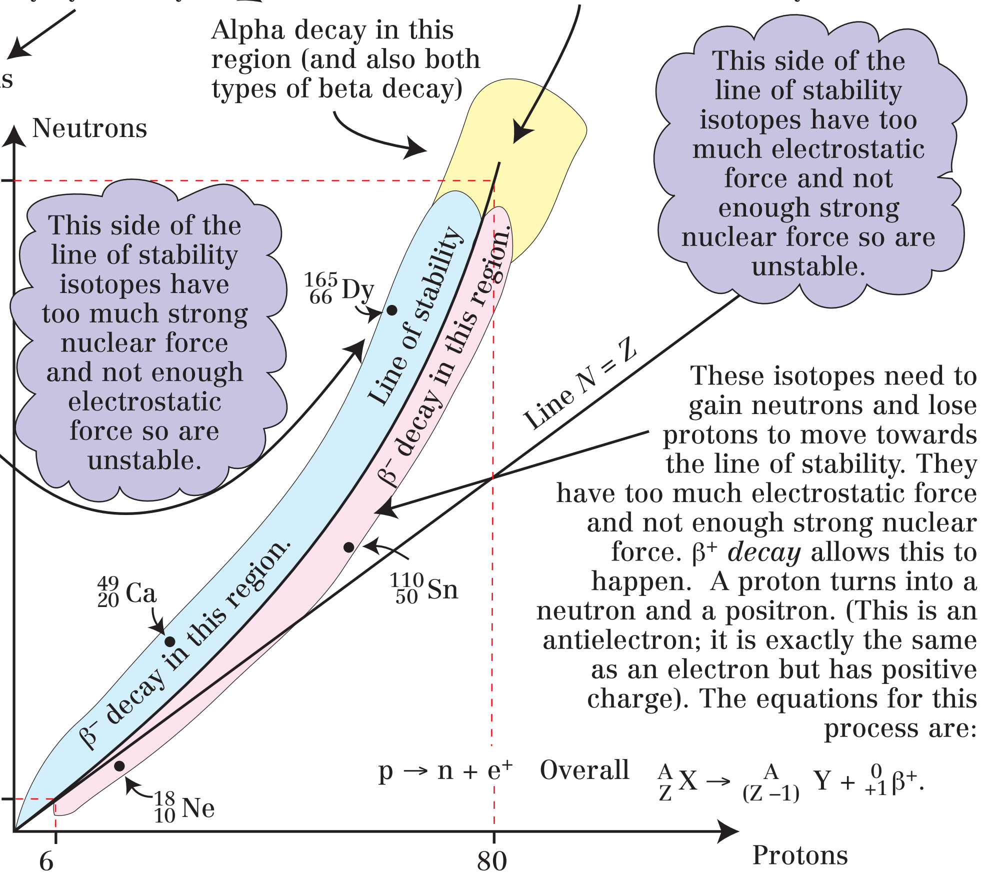
For elements where $Z > 80$ these decay by α decay.

If a nucleus has a proton:neutron mixture close to this line it is stable and does not decay.

Alpha particles consist of two protons and two neutrons.
Therefore, the atomic number falls by two and the mass number by four.

$$^{A}_{Z}X \rightarrow {}^{(A-4)}_{(Z-2)}Y + {}^{4}_{2}He$$

N.B. Remember alpha particle is $^{4}_{2}He$.



These isotopes need to gain protons and lose neutrons to move towards the line of stability. They have too much strong nuclear force and not enough electrostatic force. β^- *decay* allows this to happen.
A neutron turns into a proton and an electron. The equations for this process are:

$n \rightarrow p + e^-$

Overall $\quad ^{A}_{Z}X \rightarrow {}^{A}_{(Z+1)}Y + {}^{0}_{-1}\beta^-$.

These isotopes need to gain neutrons and lose protons to move towards the line of stability. They have too much electrostatic force and not enough strong nuclear force. β^+ *decay* allows this to happen. A proton turns into a neutron and a positron. (This is an antielectron; it is exactly the same as an electron but has positive charge). The equations for this process are:

$p \rightarrow n + e^+$ $\quad$ Overall $\quad ^{A}_{Z}X \rightarrow {}^{A}_{(Z-1)}Y + {}^{0}_{+1}\beta^+$.

N.B. remember the beta particle is an electron.

E.g.

$^{49}_{20}Ca \rightarrow {}^{49}_{21}Sc + {}^{0}_{-1}\beta^-$. $\qquad$ $^{165}_{66}Dy \rightarrow {}^{165}_{67}Ho + {}^{0}_{-1}\beta^-$.

Parent $\qquad$ Daughter

E.g.

$^{110}_{50}Sn \rightarrow {}^{110}_{49}In + {}^{0}_{+1}\beta^+$.

$^{18}_{10}Ne \rightarrow {}^{18}_{9}F + {}^{0}_{+1}\beta^+$.

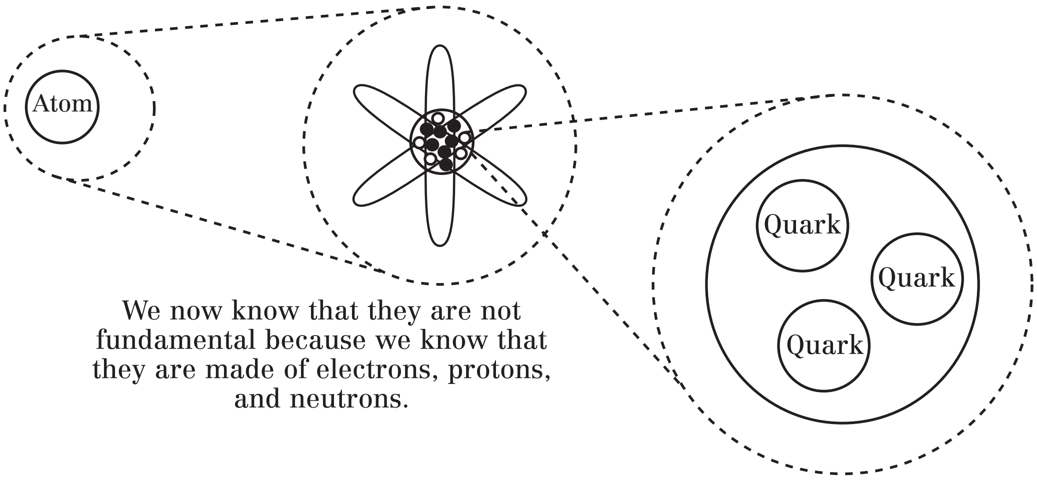
Questions

1. Explain why proportionately more neutrons are needed in larger nuclei?
2. Using the graph above, calculate the ratio $Z{:}N$ when $Z = 6$ and when $Z = 80$. Comment on your answer. Why does the line on the graph curve away from the line $Z = N$?
3. What type of decay occurs in isotopes with too much strong nuclear force? How do these changes help the nucleus to become more stable?
4. Repeat question 3 for isotopes with too much electrostatic force.
5. Nuclei do not contain electrons, so where does the electron emitted from a nucleus in beta-minus decay come from?
6. Balance the equation $^{11}_{6}C \rightarrow {}^{11}_{\_\_}B +$ ____. (Hint: are there too many protons or too many neutrons in the carbon nucleus?), hence will β^+ or β^- decay occur?

RADIOACTIVITY Fundamental Particles

A fundamental particle is one that cannot be split into anything simpler.

The word atom means 'indivisible' because scientists once thought atoms were fundamental particles.



We now know that they are not fundamental because we know that they are made of electrons, protons, and neutrons.

Similar experiments to Rutherford's alpha scattering using electrons fired at protons and neutrons reveals that they are made up of smaller particles – *quarks*.

Scientists now think that quarks, together with electrons and **positrons** are examples of fundamental particles.

An example of antimatter. All particles have antiparticles; they are identical in mass but opposite in charge. Our Universe is made of matter. Antimatter is made in particle accelerators or as the result of some nuclear processes such as beta-plus decay.

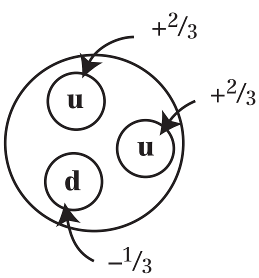
There are actually six types of quark given odd names. They also have fractional charges as shown below.

Up	Charge	Charm	Charge	Top	Charge
u	$+\frac{2}{3}$	c	$+\frac{2}{3}$	t	$+\frac{2}{3}$
Down	Charge	Strange	Charge	Bottom	Charge
d	$-\frac{1}{3}$	s	$-\frac{1}{3}$	b	$-\frac{1}{3}$

Normally we are not allowed fractional charges, but quarks never occur on their own, only in combinations that add up to a whole charge.

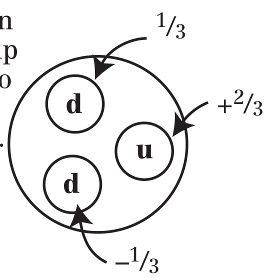
Protons and neutrons are made of just two types of quark, the up and the down. Other particles have to be created in special machines called particle accelerators.

Proton – two up and one down quarks.



Charge = $(+\frac{2}{3}) + (+\frac{2}{3}) + (-\frac{1}{3}) = +1$

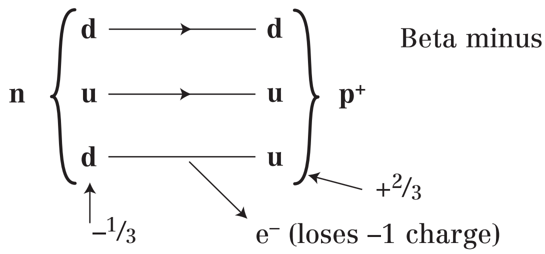
Neutron – one up and two down quarks.

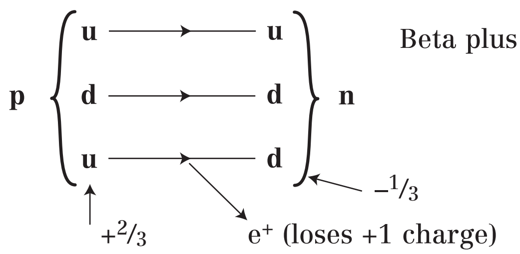


Charge = $(+\frac{2}{3}) + (-\frac{1}{3}) + (-\frac{1}{3}) = 0$

Beta decay

In beta decay, one of the up quarks changes to a down quark or *vice versa*.





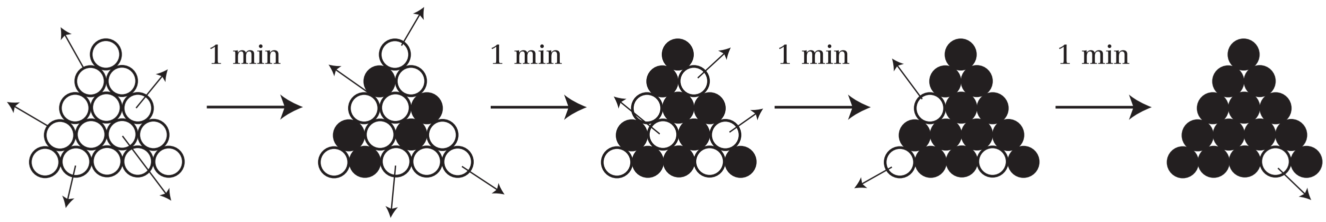
Questions

1. What is meant by the statement 'an electron is a fundamental particle'?
2. How many different types of quark make up protons and neutrons?
3. What quarks are found in a neutron?
4. Describe the changes in quarks when a proton decays to a neutron by beta-plus decay.
5. What is antimatter?

RADIOACTIVITY Half-Life

Most types of nuclei never change; they are stable. However, radioactive materials contain unstable nuclei. The nucleus of an unstable atom can break up (decay) and when this happens, it emits radiation.

A nucleus of a different element is left behind.

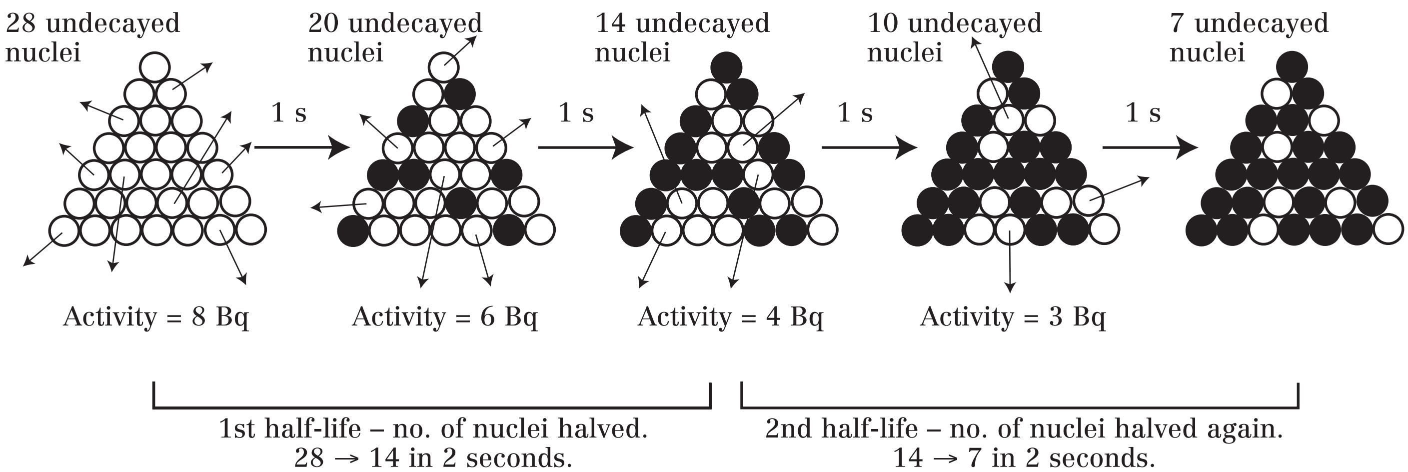


As time goes by radioactive materials contain fewer and fewer unstable atoms and so become less and less radioactive and emit less and less radiation.

There is no way of predicting when an individual nucleus will decay; it is a completely random process. A nucleus may decay in the next second or not for a million years. This means it is impossible to tell how long it will take for all the nuclei to decay.

Like throwing a die, you cannot predict when a six will be thrown. However, given a very large number of dice you can estimate that a certain proportion, $^1/_6$th, will land as a six.

We define *activity* as the number of nuclei that decay per second (N.B. 1 decay per second = 1 Bq). The time it takes for the activity of a radioactive material to halve (because half of the unstable nuclei that were originally there have decayed) is called the **half-life**.



We see the activity falling as there are fewer nuclei available to decay. However, note that the time taken to halve is independent of the number of nuclei, in this case 2 seconds. Half-lives are unique to each individual isotope and range from billions of years to fractions of a second.

The half-life of a radioactive isotope is formally defined as:

> 'The time it takes for half the nuclei of the isotope in a sample to decay, or the time it takes for the count rate from a sample containing the isotope to fall to half its initial level.'

Calculations

1. Numerically e.g. a radioisotope has an activity of 6400 Bq and a half-life of 15 mins.

After 15 mins the activity will be $\frac{6400\text{ Bq}}{2} = 3200$ Bq.

After 30 mins the activity will be $\frac{3200\text{ Bq}}{2} = 1600$ Bq.

After 45 mins the activity will be $\frac{1600\text{ Bq}}{2} = 800$ Bq.

After 1 hour the activity will be $\frac{800\text{ Bq}}{2} = 400$ Bq.

Alternatively, consider the number of half-lives, e.g. $1^1/_2$ hrs = 6 × 15 mins = 6 half-lives.
Therefore

$$\text{activity} = \frac{\text{original activity}}{(2 \times 2 \times 2 \times 2 \times 2 \times 2)}$$

(i.e. divide by 2, six times)

$$= \frac{\text{original activity}}{2^6}$$

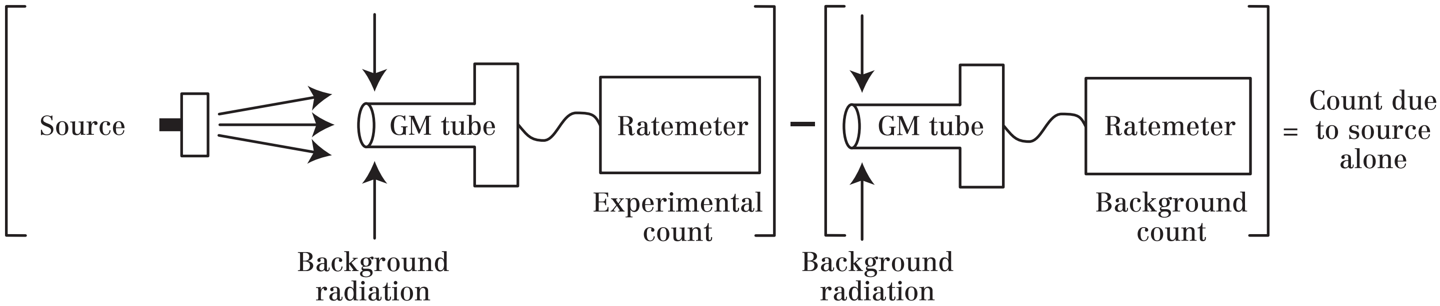
In general,

$$\text{activity} = \frac{\text{original activity}}{2^{\text{no. of half-lives}}}$$

Therefore after 6 half-lives, in this case,

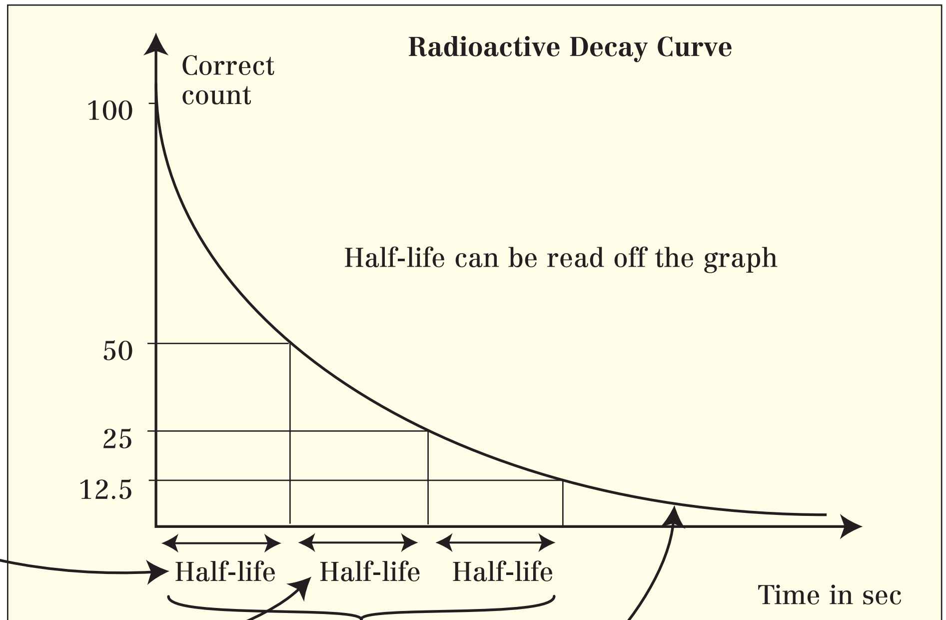
$$\text{activity} = \frac{6400\text{ Bq}}{2^6} = 100\text{ Bq.}$$

2. Graphically A graph of activity vs. time can be plotted from experimental measurements. We must remember to subtract the background count from the actual count to find the count due to the source alone. We call this the *corrected count rate*.



Results:

As long as the sample is large enough, this curve is smooth, because although the process is random, probability tells us half the atoms will decay in a certain time, but not which.



1st half-life, time taken to drop from 100 to 50 counts.

2nd half-life, time taken to halve again from 50 to 25 counts.

Half-life is constant, irrespective of starting count.

Nuclear radiation never completely dies away, but eventually drops to a negligible level, close to the background. At this point, a source is considered safe. Consideration of half-life therefore, has importance when considering which isotopes to use for various applications and the disposal of radioactive waste – see section on applications of radioactivity.

Questions

1. What is the activity of a radioactive source?
2. Write down a definition of half-life. Suggest why we can measure the half-life of a substance, but not its 'full life' (i.e. the time for all the atoms to decay).
3. $^{99}_{43}$Tc (Technetium) has a half-life of 6 hrs. A sample of technetium has an initial count rate of 128 000 Bq
   i. What will the count rate be after: a. 6 hrs? b. 18 hrs?
   ii. How many hours will it take the count rate to fall to: a. 32 000 Bq? b. 8000 Bq? c. 1000 Bq?
4. A student has a sample of $^{137}_{56}$Ba (Barium). They record the count rate every 60 s and record the following results:

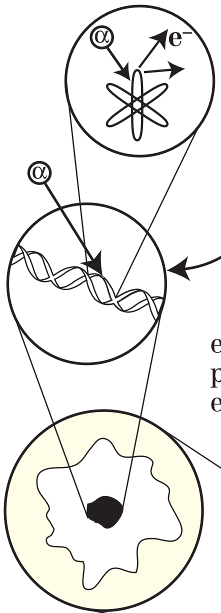
Time in seconds	0	60	120	180	240	300	360	420	480	540	600	660	720
Count rate (decays/s)	30.8	23.8	18.4	14.2	11.1	8.7	6.9	5.4	4.4	3.5	2.9	2.4	2.0

The background count rate, with no source present, was 0.8 counts per second.
   a. Copy the table and include a row for the corrected count rate.
   b. Draw a graph of count rate vs. time and use it to show that the half-life is approximately 156 s.
   c. Do you think this isotope would present significant disposal problems, why or why not?
5. A student has a sample of radioactive material. In one lesson the activity recorded was 2000 Bq. The next day, at the same time, the count rate was just over 500 Bq. Which of the following isotopes is the sample most likely to be?
   a. $^{135}_{53}$I (iodine) half-life = 6.7 hrs.
   b. $^{87}_{38}$Sr (strontium) half-life = 2.9 hrs.
   c. $^{42}_{19}$K (potassium) half-life = 12.5 hrs.
   d. $^{187}_{74}$W (tungsten) half-life = 24 hrs.

RADIOACTIVITY Is Radiation Dangerous?

All nuclear radiation is ionizing. It can knock electrons out of atoms, or break molecules into bits. If these molecules are part of a living cell, this may kill the cell.

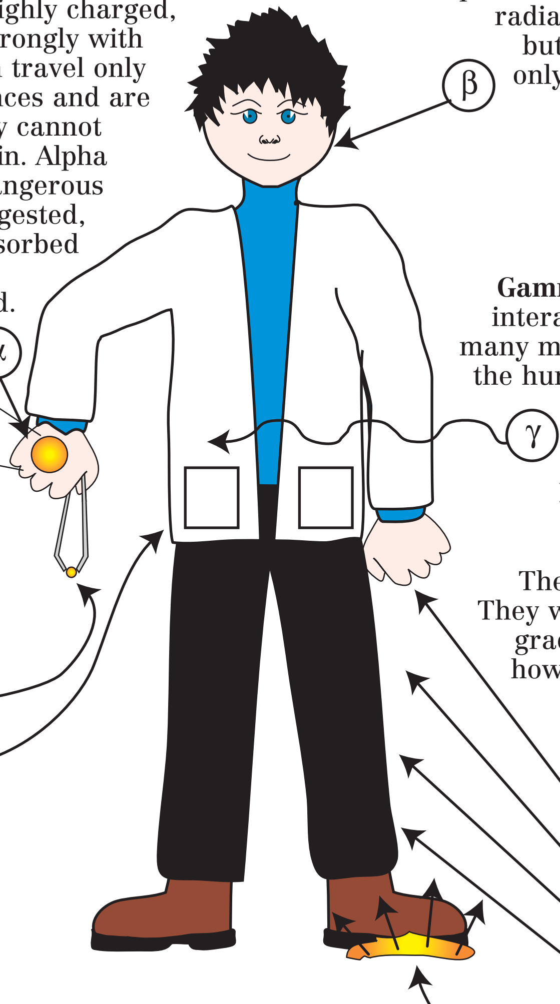
Radiation dose is measured in Sieverts. This unit measures the amount of energy deposited in the tissue by the radiation, and takes account of the type of radiation, because some particles are more effective at damaging cells than others. It is a measure of the possible harm done to your body.



If the molecule is DNA, the damage caused by the radiation may affect the way it replicates. This is called *mutation*. Sometimes this leads to *cancer*.

Alpha particles are heavy and highly charged, and interact strongly with atoms. They can travel only very short distances and are easily stopped. They cannot penetrate human skin. Alpha emitters are only dangerous when inhaled, ingested, injected, or absorbed through a wound.

Beta particles are also charged, but interact less strongly than alpha particles, so travel further and penetrate more: they can penetrate skin. Clothing provides some protection. They can cause radiation burns on prolonged exposure but are hazardous to internal organs only when inhaled, ingested, injected, or absorbed.



Gamma rays are uncharged, so do not interact directly with atoms, and travel many metres in air. They easily penetrate the human body, causing organ damage. Their effects can be reduced by concrete or lead shielding.

Many people work with radiation, e.g. radiologists in hospitals, and nuclear power plant workers. Their exposure is carefully recorded. They wear a film badge, which becomes gradually more fogged, depending on how much exposure they have had. If their exposure is too high in a set period, they will usually be given other jobs away from radiation sources, temporarily.

Radioactive materials have to be handled safely. Various precautions to adopt include:

- Keeping source as far from body as possible – usually using tongs.
- Protective clothing – usually only for highly active sources.
- Keeping exposure time as short as possible.
- Keeping the source in appropriate storage, usually shielded, e.g. lead, and labelled.

Irradiation occurs when the emitted radiation hits an object. Moving away will reduce the exposure.

Something is *contaminated* if the radioactive atoms are in contact with it. Moving away will spread the contamination.

All exposure to radiation is potentially hazardous, but consider

- Type of radiation
- Activity of source
- Contamination or irradiation
- Length of exposure
- Benefits – e.g. medical treatment

Questions

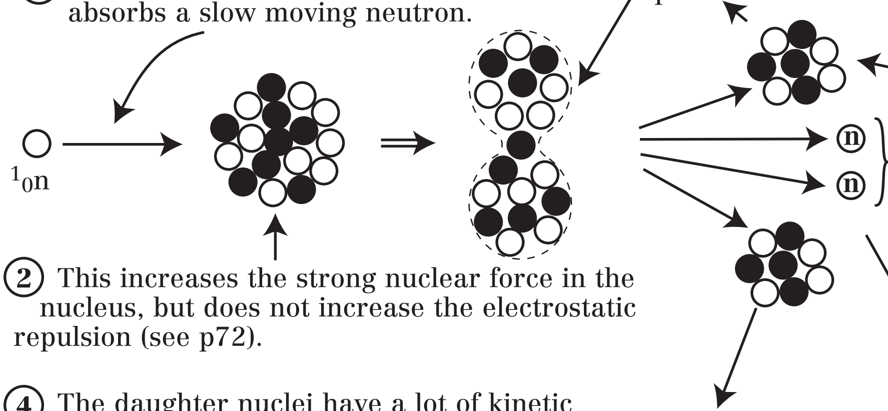
1. Explain which type of radiation is most harmful:
   a. Outside the body.
   b. Inside the body.
2. Explain the difference between contamination and irradiation. Which would you consider a more serious problem?
3. How does nuclear radiation cause damage to living tissues?
4. What is a Sievert?
5. Explain three precautions you should take if you had to handle a low activity radioactive source.

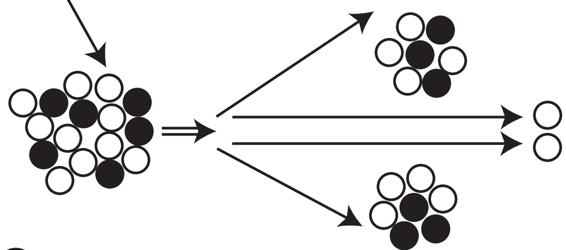
Nuclear Fission

Nuclear fission is the splitting of an atomic nucleus.

A large parent nucleus, such as 235-uranium or 239-plutonium, splits into two smaller daughter nuclei, of approximately equal size. This process also releases energy (heat) which can be used to generate electricity (see p111). Normally, this will happen spontaneously but can be speeded up by inducing fission.

1. Parent nucleus (^{239}Pu or ^{235}U) absorbs a slow moving neutron.
2. This increases the strong nuclear force in the nucleus, but does not increase the electrostatic repulsion (see p72).
3. The forces in the nucleus are unbalanced and the nucleus splits.
4. The daughter nuclei have a lot of kinetic energy, the energy released by the fission process. This causes heating of the material.
5. The smaller daughter nuclei do not need so many neutrons to be stable (see p72) and spare neutrons (two or three) are released with large kinetic energies.



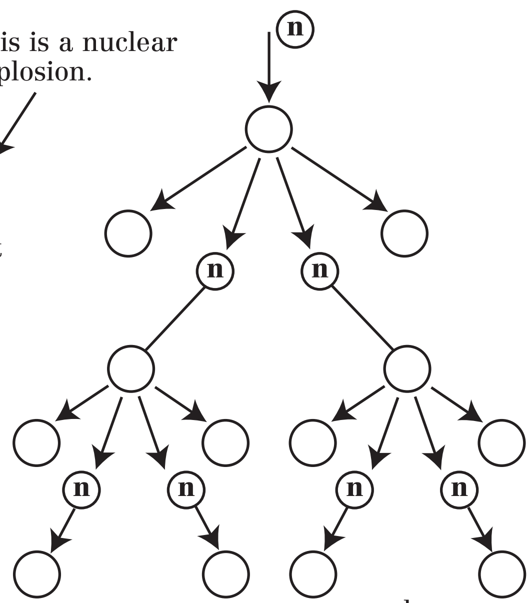


6. These excess neutrons may go on to be absorbed by other ^{239}Pu or ^{235}U nuclei causing them to split.
7. If all the spare neutrons were to go on to cause further fissions, this would rapidly build up into an uncontrolled *chain reaction*.

If uranium were burned chemically to uranium oxide, it would release about 4500 J/g. The equivalent energy release from nuclear fission is 8.2×10^{10} J/g.

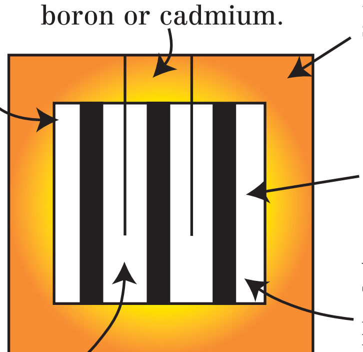
The daughter products themselves are radioactive because they still tend to be neutron rich (i.e. lying above the *N/Z* curve), and decay, releasing more thermal energy and nuclear radiation. They have a wide range of half-lives. These factors need to be taken into account when considering their disposal, (see p112).

This is a nuclear explosion.



and so on . . .

Nuclear reactors are designed to control the chain reaction and prevent an explosion.



Fuel rods of uranium or plutonium.

Control rods made of boron or cadmium.

Lead/concrete shielding.

Reactor core gets hot due to heat released in the fuel rods by the nuclear fission reaction.

Core made of graphite or heavy water to slow down the neutrons. This is called the moderator and makes the neutrons more likely to be absorbed by further nuclei.

Control rods absorb neutrons before they can cause further fissions.

Lowering the control rods absorbs more neutrons and slows the reaction, raising the control rods speeds it up.

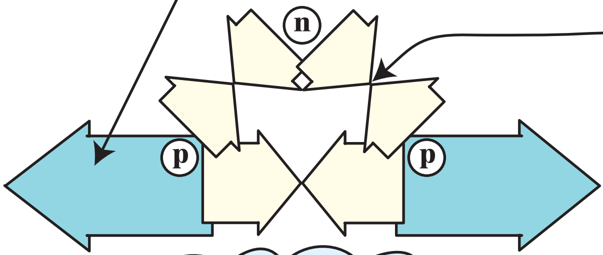
Questions

1. Balance this equation, a fission reaction of uranium producing the daughter nuclei barium and krypton.
   $^{235}_{92}U + ^{1}_{0}n \rightarrow$ ____$_{56}Ba + ^{90}_{__}Kr + 2\,^{1}_{0}n$.
2. In what form is the majority of the energy released by a nuclear reaction?
3. Why do the products of fission reactions need careful handling?
4. How do the control rods in a reactor control the rate of the nuclear reaction?
5. For a stable chain reaction, neither speeding up nor slowing down, suggest how many neutrons from each fission should go on to cause a further fission.
6. Use the data above to show that the energy released from the fission of 1 g of ^{235}U is about 20 million times as much as when the same gram is burnt in oxygen to form uranium oxide.

RADIOACTIVITY Nuclear Fusion

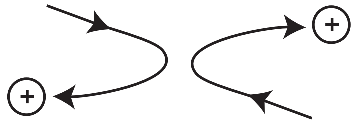
Nuclear fusion is the joining of two light nuclei to form a heavier nucleus. It is the process by which energy is released in stars.

In the nucleus, the STRONG NUCLEAR FORCE attracts protons and neutrons together; it is stronger than the ELECTROSTATIC REPULSION between the protons but it is a very short-range force.

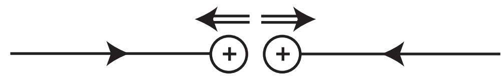


To fuse two nuclei they must be brought very close together so the strong nuclear force can bind their protons and neutrons together.

To do this you have to overcome the electrostatic repulsion between the nuclei.



Therefore, the nuclei have to travel very fast so they have a lot of kinetic energy to do work against the repulsive force.



This means that the gas containing the nuclei has to be very hot, dense, and under high pressure.

The gas is so hot that none of the electrons now orbits the nuclei. This is called plasma.

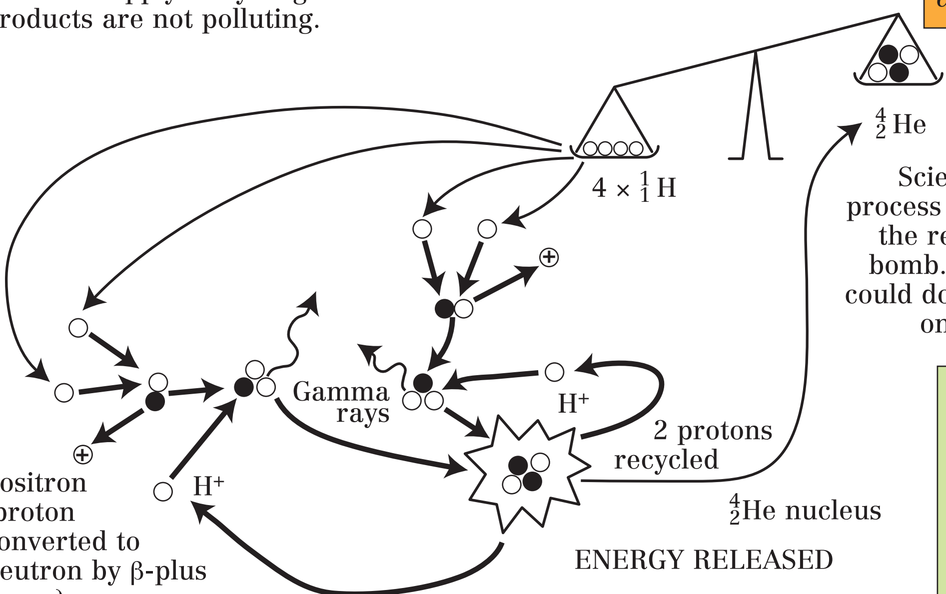
This is very difficult to do on Earth as this plasma would melt any container. Confining plasma is a major area of research because for the same mass of fuel, fusion of hydrogen to helium releases much more energy than fission and is the reaction occurring in the core of stars. We have a plentiful supply of hydrogen in water on Earth and the products are not polluting.

When the nuclei join, energy is released as the kinetic energy of the product nucleus.

The nucleus formed has less mass than the total mass of the nuclei that fused to create it. The missing mass (or mass defect) has been converted to energy by Einstein's famous relationship

$\Delta E = \Delta mc^2$

ΔE = energy released in J
Δm = mass loss in kg
c = speed of light = 3×10^8 m/s



Scientists still have not achieved the process under control. They can do it where the reaction is explosive, in a hydrogen bomb. Some scientists once claimed they could do fusion at room temperature, but no one has been able to repeat this.

Key

- ○ H^+ proton
- ○● Deuterium nucleus (1n + 1p)
- ●○○ $^3_2$ He nucleus
- ⊕ Positron (β^+ particle)

Questions

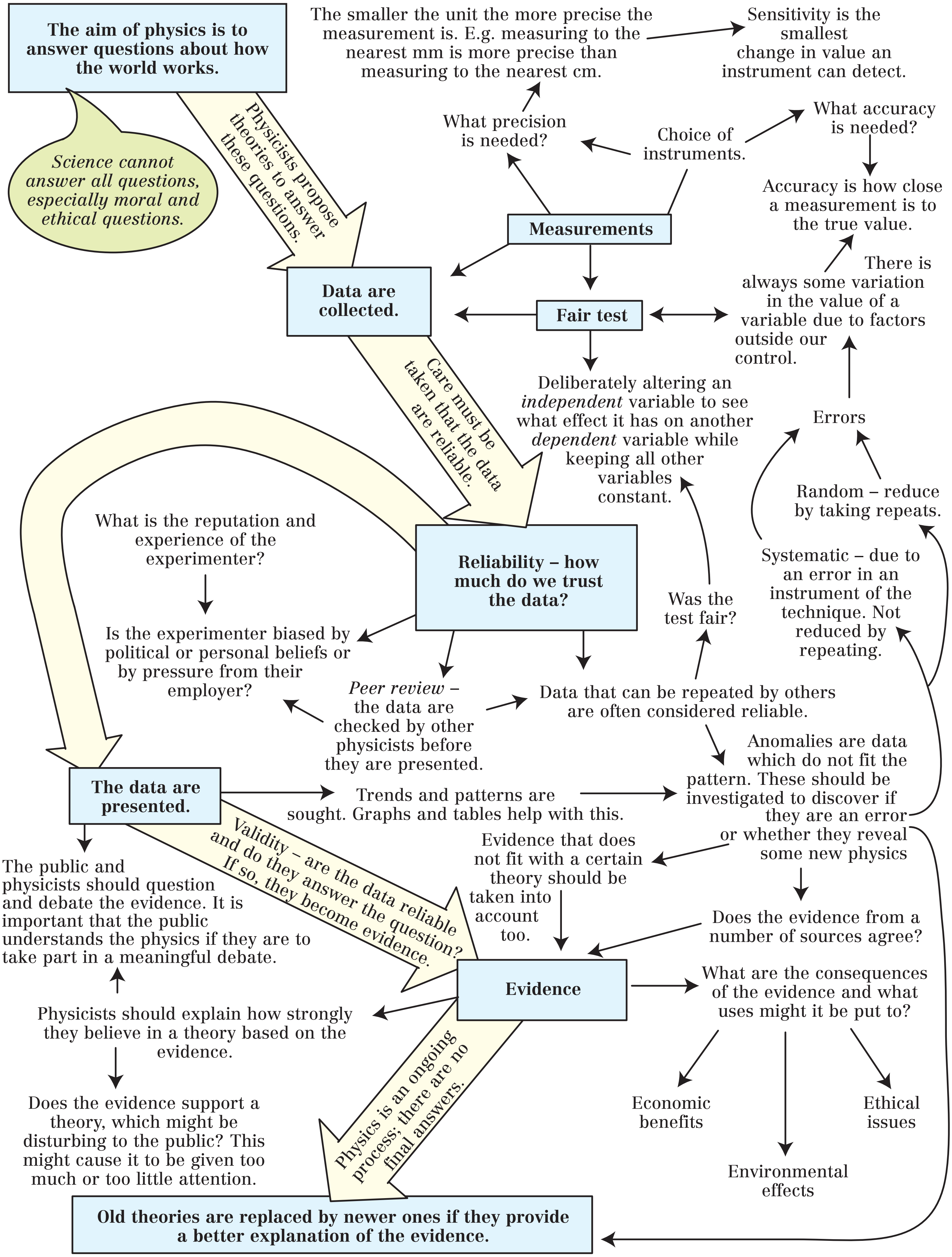
1. Explain the differences between nuclear fission and fusion.
2. What are the two forces that must be kept in balance in a stable nucleus?
3. What is plasma?
4. Why does fusion require such high temperatures and what problems may occur as a result?
5. Explain why scientists are working hard to achieve controlled fusion on Earth.
6. A helium-4 nucleus is only 99.3% of the mass of the 4 hydrogen nuclei from which it was formed. The other 0.7% of its mass is converted into energy. Use Einstein's equation $\Delta E=\Delta mc^2$ to show that the energy released from the fusion of 1 kg of hydrogen nuclei, is about 6.3×10^{14} J (c = speed of light = 3×10^8 m/s).

APPLICATIONS OF PHYSICS

The previous pages have outlined some of the main ideas that physicists believe. Physicists hold these ideas because they have collected evidence.

How Science Works

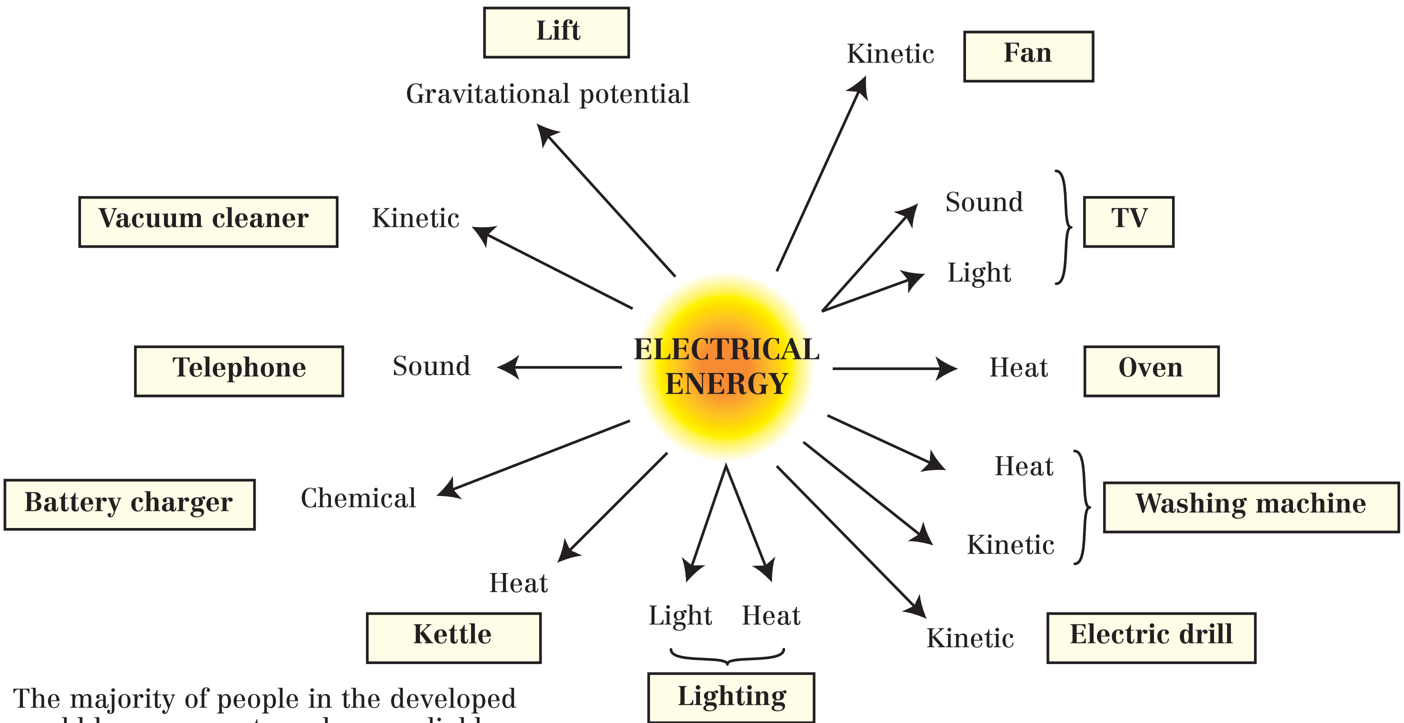
The remainder of this book outlines some of the ways that these ideas have been put to use. The link between these two aspects is how science works.



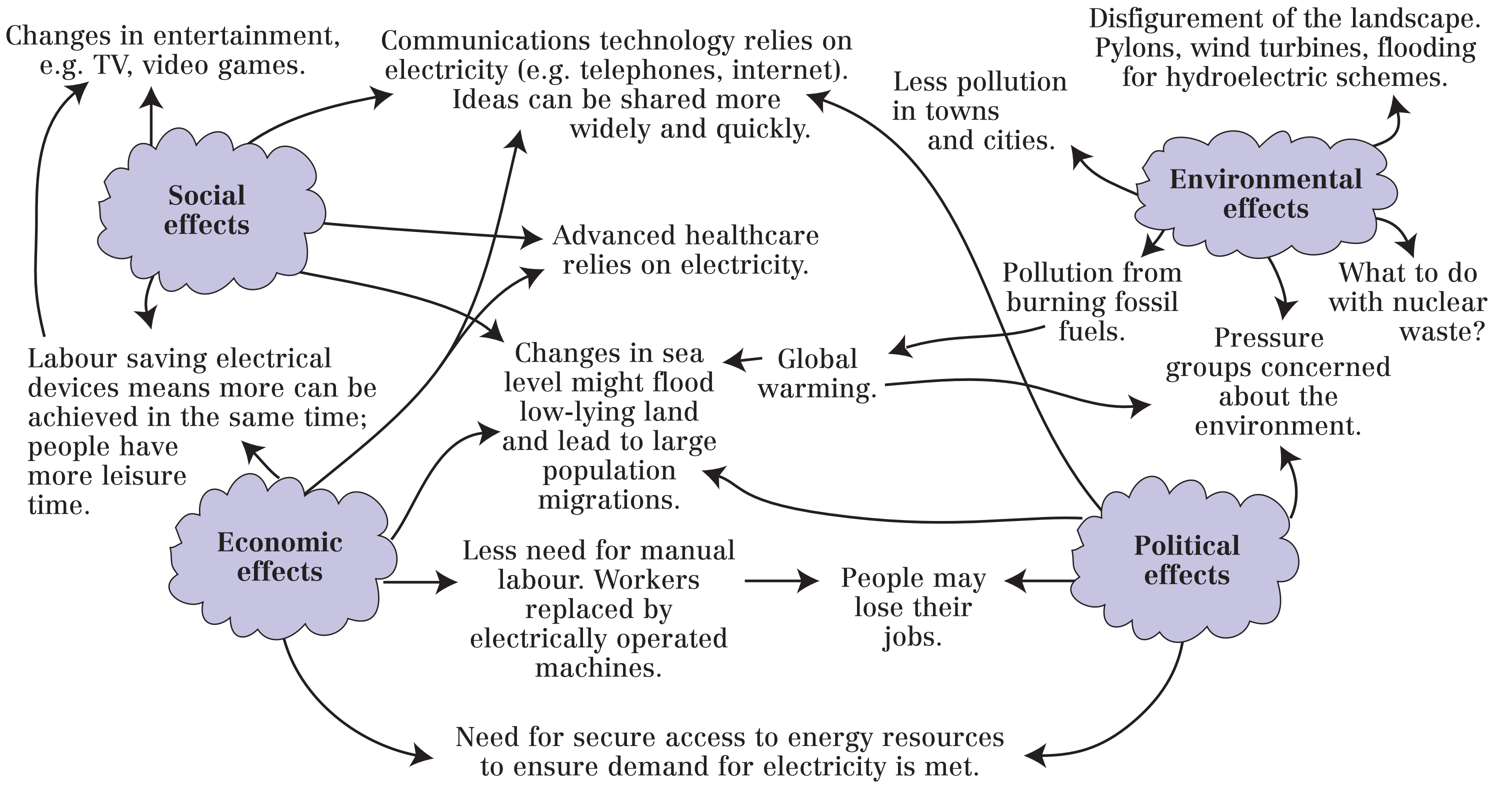
THE SUPPLY AND USE OF ELECTRICAL ENERGY

Examples of Energy Transformations Involving Electrical Devices and the Impact of Electricity on Society

Electricity supplies the majority of the energy we use in our daily lives. It is clean and very easy to control. Most houses contain many appliances that work by transforming electricity into other forms.



The majority of people in the developed world have access to a cheap, reliable electricity supply. The majority of people in the developing world do not.
The fact that we have electricity so easily available has had a huge impact on all aspects of our lives and society. Here is a flavour.



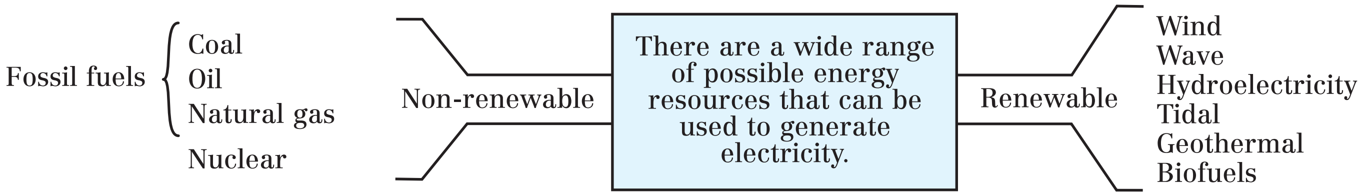
Questions

1. One hundred years ago open coal fires heated many homes. Now electric heaters heat many houses. Suggest some reasons why.
2. Draw an energy flow diagram for three more electrical devices found in your home not shown above.
3. Make a list, with justification of each, of one positive and one negative impact of electricity socially, politically, environmentally and economically not shown above.

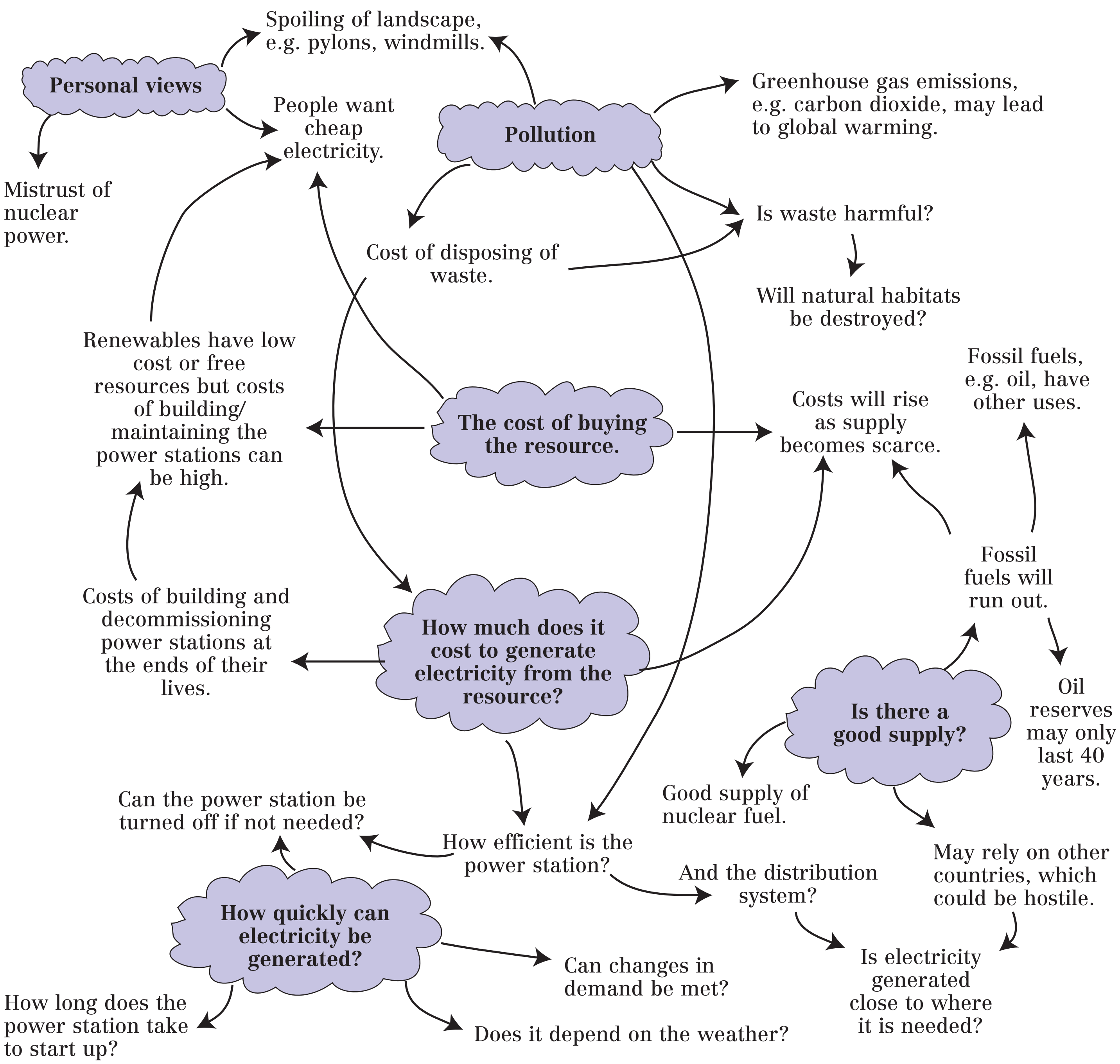
THE SUPPLY AND USE OF ELECTRICAL ENERGY

What Influences the Energy Resources We Use?

Electricity provides the majority of the energy needs of the UK. The demand for electricity is predicted to continue to rise. Electricity is a secondary energy source; another (primary) energy source is needed to generate it.



The following pages outline how electricity is generated from these resources, but how do we decide what resources to use? There are a huge number of questions to be answered, and many of the answers may be contradictory.



Questions

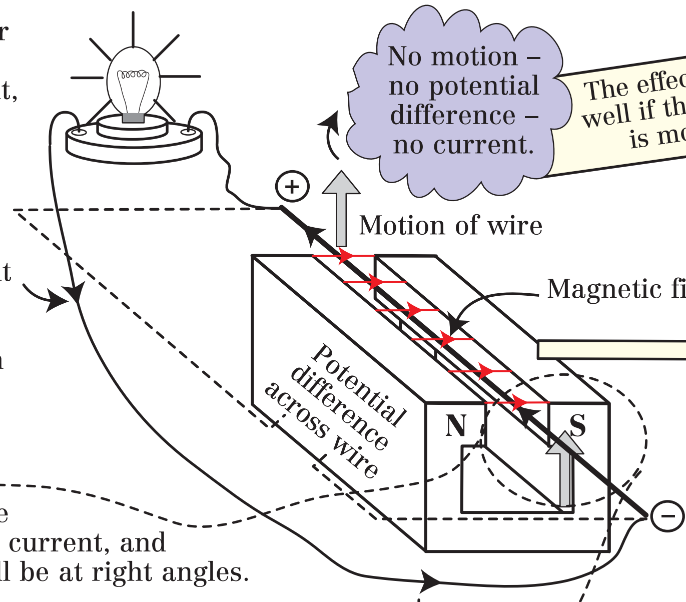
1. Make a list of energy resources we use to generate electricity and divide your list into the renewable and non-renewable resources.
2. The type of energy resources that the UK should use to generate electricity in the future is very controversial. Why do you think this is? Do you think that there are any 'right' answers to the question, 'What energy resources should the UK use in the future?'?

Electricity Generation – Electromagnetic Induction

Moving an electrical conductor through a magnetic field produces a potential difference across the conductor. This is called *electromagnetic induction*.

If the conductor forms part of a complete circuit, the potential difference will drive a current through it.

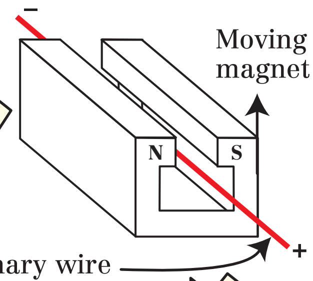
Induced current – the wire in the field behaves like an electric cell in the circuit.



Magnetic field line

No motion – no potential difference – no current.

The effect works equally well if the magnetic field is moved instead.



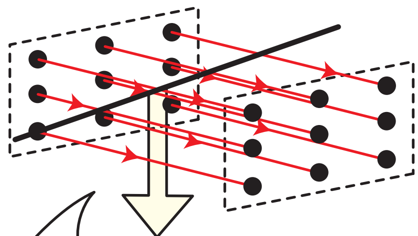
Moving magnet

Stationary wire

Whenever a conductor is exposed to a *changing magnetic field*, a potential difference is created (induced).

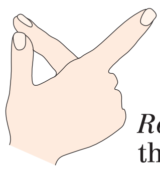
Direction of the magnetic field, current, and motion must all be at right angles.

Conventional current in the circuit – flows positive to negative.



Second finger – current

Thumb – motion



First finger – magnetic field

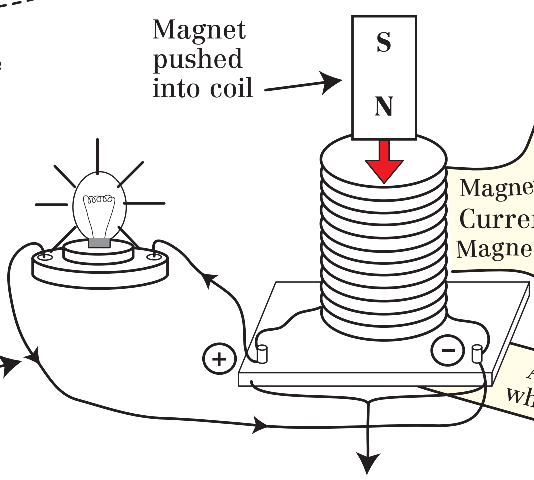
The *Right Hand Rule* relates the field, current, and motion. (compare with the Left Hand Rule on p59).

Reversing any one of these three quantities will *reverse* one other.

Alternatively consider the rate the conductor is cutting through lines of magnetic force. The faster it cuts, the greater the potential difference induced.

Induction also works with coils.

Magnet pushed into coil



Induced potential difference (and current) increased by:

- Using more coils.
- Moving the magnet faster.
- Using a stronger magnet.
- Using a coil with a larger cross sectional area.

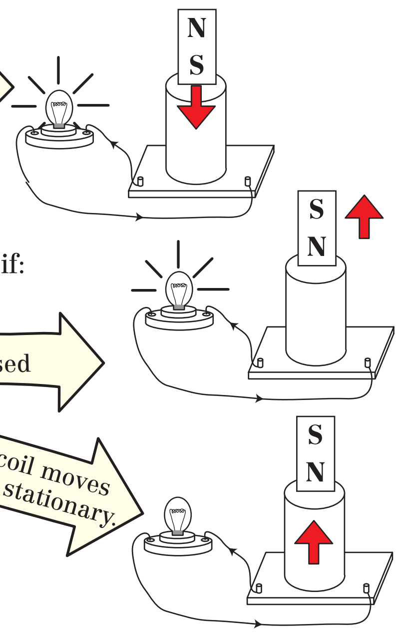
Conventional current flows if the coil terminals are connected.

Current reversed if:

Magnetic polarity reversed

Magnet motion reversed

Also works if coil moves while magnet is stationary.

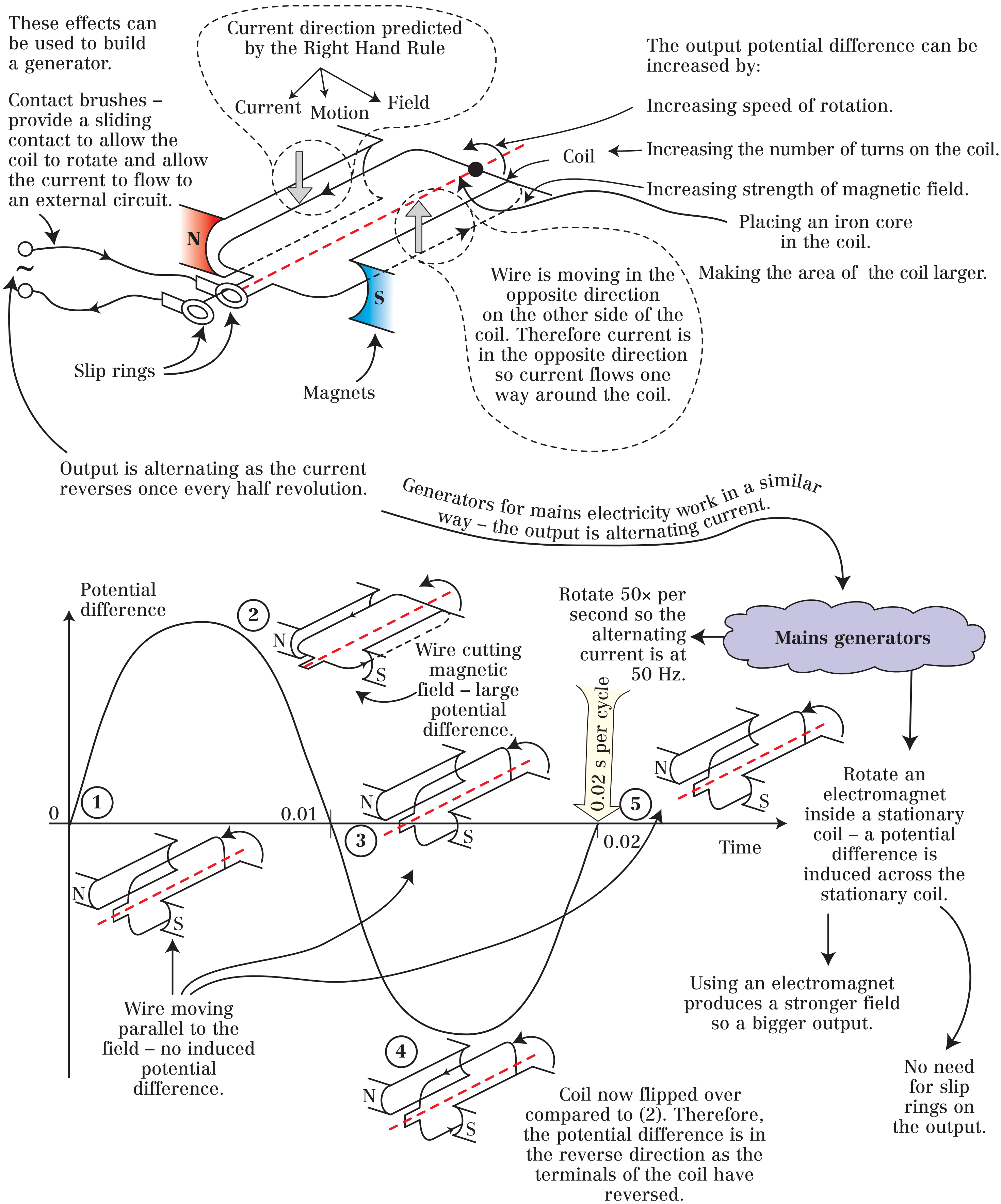


The electrical energy transferred by the circuit comes from the work done to push the magnet into the coil.

Potential difference induced across ends of coil.

Questions

1. A wire is moved at right angles to a magnetic field. What would happen to the size of the potential difference across the wire if:
   a. The wire was moved faster?
   b. The magnet was moved instead of the wire, but it was moved at the same speed as the wire?
   c. A weaker magnetic field was used?
   d. The wire stopped moving?
   e. Two magnets were used end to end so more wire was in the field?
   f. The wire moved from a north pole to a south pole along the magnetic field lines?
2. When pushing a magnet into a coil how could you make the size of the induced potential difference bigger (3 ways)? How could you reverse the direction of the potential difference (2 ways)?
3. When generating electricity by induction where does the energy that is converted into electrical energy come from?



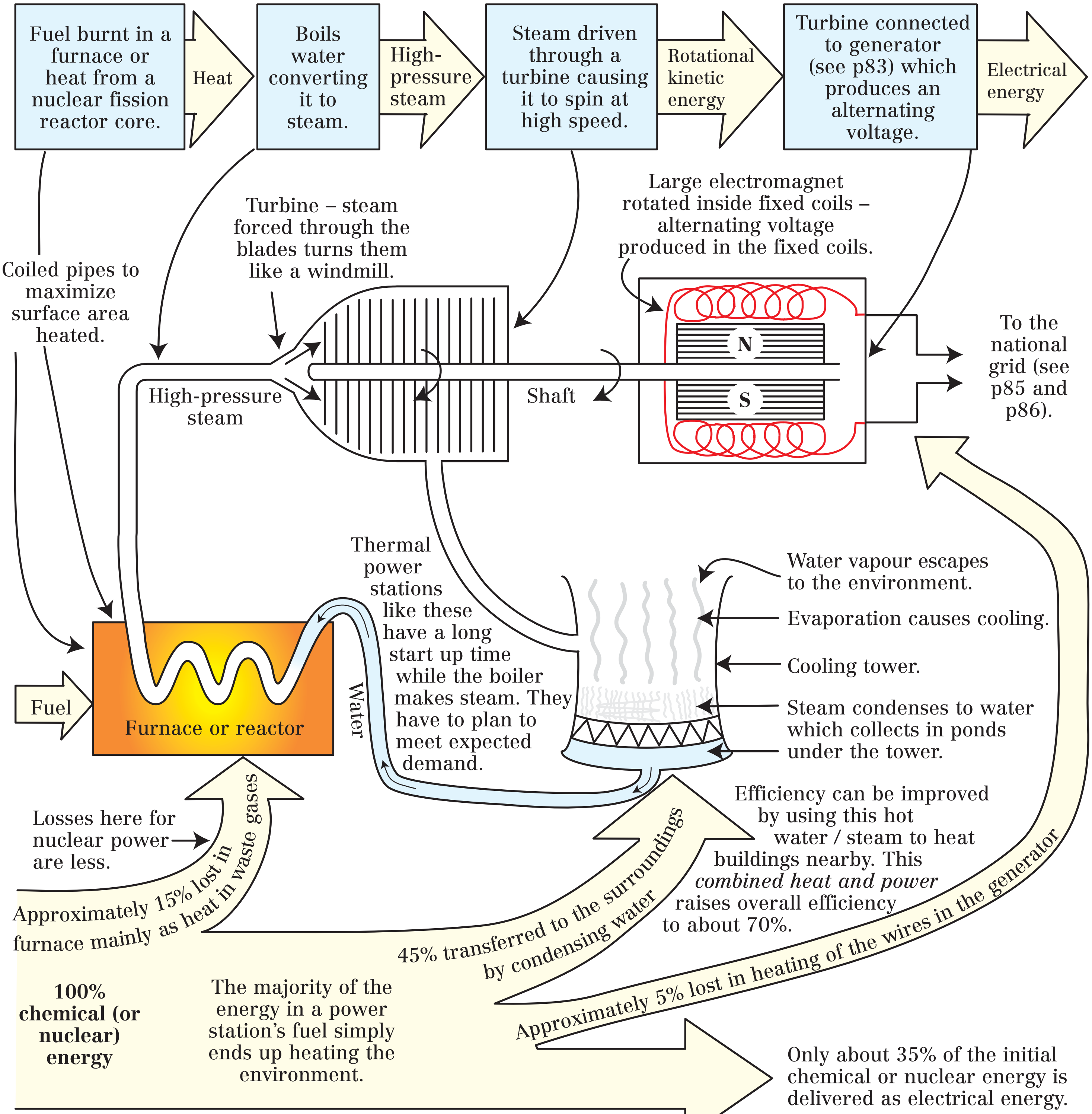
Questions (continued)

4. List five ways the output of an alternating current generator can be increased.
5. The mains electricity in the UK alternates through 50 complete cycles per second. What does this tell us about the rate of rotation of the generators in power stations in the UK?
6. Suggest two differences between the simple generator shown above and the generators used to generate mains electricity.
7. Why is the potential difference produced by a generator zero twice every revolution?
8. Draw a labelled diagram of an alternating current generator and use it to explain why the current it produces is alternating.

THE SUPPLY AND USE OF ELECTRICAL ENERGY How Power Stations Work

Electricity is very useful energy source because it is easy to distribute and control. However, it is a *secondary energy source* because another primary energy source has to be used to generate it. In conventional power stations, that energy source is either fossil fuels (coal, oil. or natural gas) or nuclear energy stored in uranium or plutonium (see p77 and p111). Increasingly renewable energy resources (see p88 and p89) are also being used.

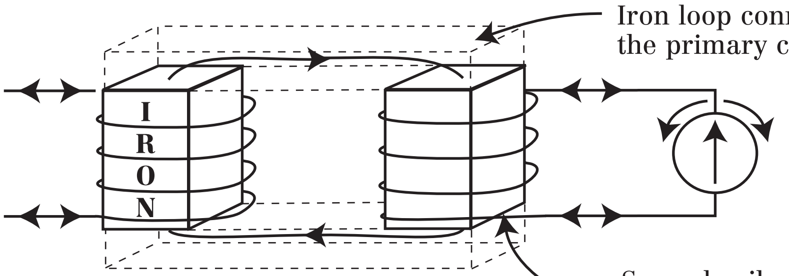
Here we focus on conventional power stations.



Power stations are situated in the country to reduce pollution in towns. They are often close to rivers or the sea for their cooling water supply.

Questions

1. Name energy sources used to generate electricity in thermal power stations.
2. Draw an energy flow diagram for a coal-fired power station. Start with chemical energy in the coal and end with electrical energy produced.
3. What is combined heat and power?
4. Why are thermal power stations built near rivers or the sea?
5. What is the typical efficiency of conversion of chemical energy to electricity in a thermal power station? To what form of energy is most of the chemical energy converted?



Iron loop connects the two coils. It forces the magnetic field of the primary coil to pass through both coils.

Second coil experiences rising and falling magnetic field of the first coil so an alternating current is *induced* in it.

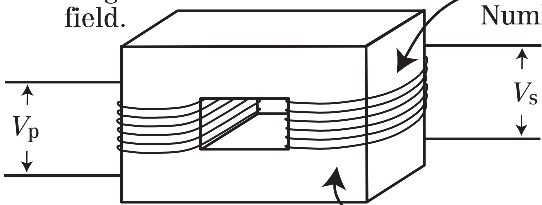
Current in coil produces an electromagnet. Alternating current produces alternating magnetic field in the core.

Energy transferred between coils by the magnetic field.

Transformers only work with alternating current.

Primary coil.
Number of turns = N_p.
Connected to power supply.

Primary voltage



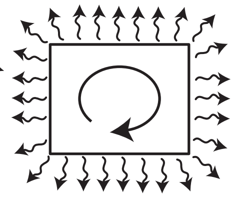
Secondary coil.
Number of turns = N_s. Output to device.

Secondary voltage

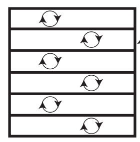
Iron core – usually made of thin layers of iron separated by an insulator.

Energy losses
Heating in coils
Heating in core, by eddy currents induced

Large eddy current – large heat loss (inefficient).



Small eddy current – less heating (more efficient).



Transformer formula

$$\frac{N_{primary}}{N_{secondary}} = \frac{V_{primary}}{V_{secondary}}$$

If $V_p > V_s$ (so $N_p > N_s$) = step-down transformer.

Transformer for laptops, mobile phone chargers, stereo systems etc. are step-down. The reduce 230 V mains to a few volts for the device.

In an isolating transformer $V_p = V_s$, e.g. for a bathroom shaver socket. These do not change voltage but isolate the device from a direct connection to the mains.

If $V_p < V_s$ (so $N_p < N_s$) = step-up transformer.

Mainly used to increase voltage of electricity generated in a power station for transmission in the national grid.

Questions

1. Copy and complete the following table, giving answers to the nearest whole number:

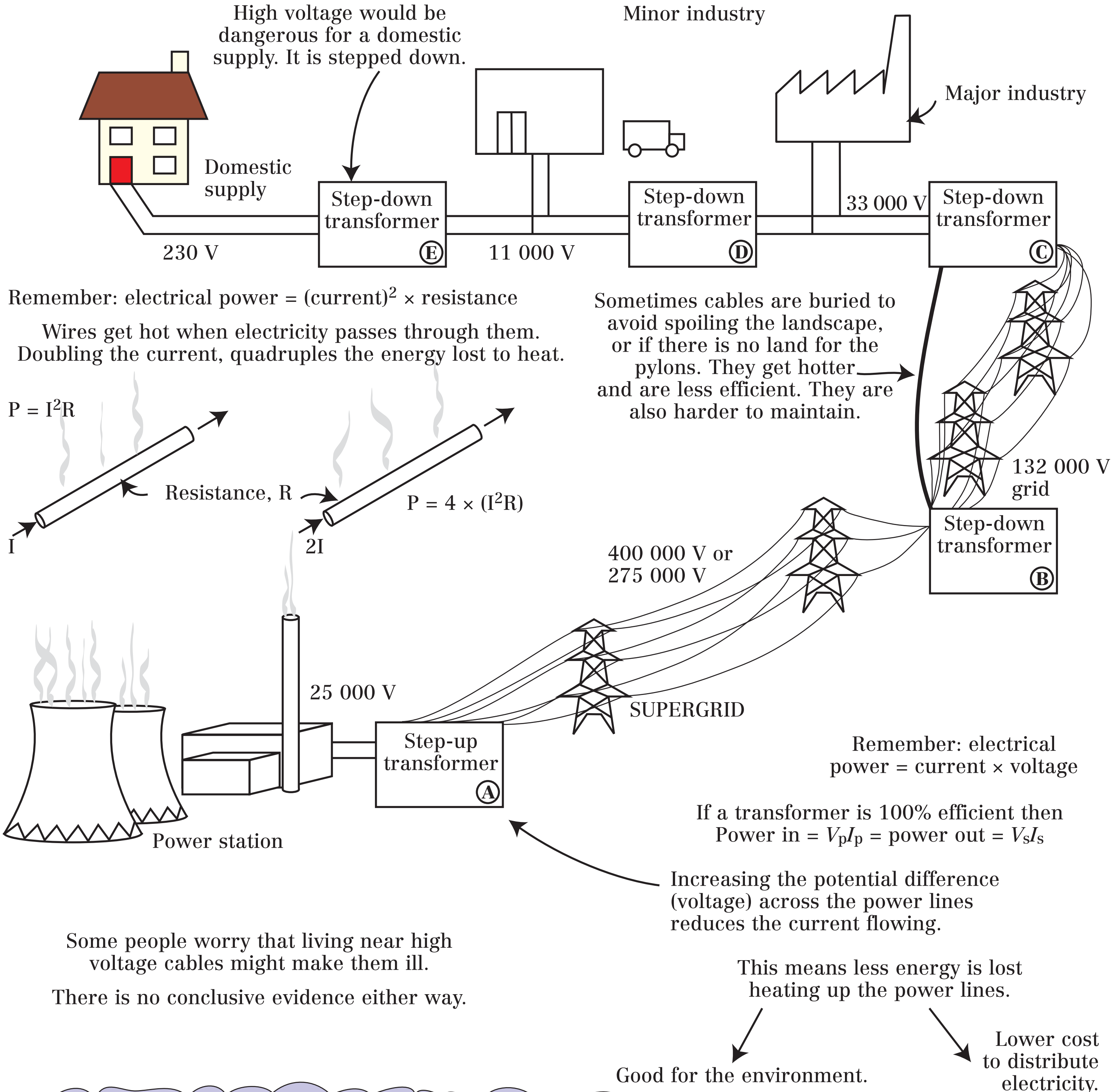
Transformer	Primary turns	Secondary turns	Primary voltage	Secondary voltage
A		120	240	12
B	625	10 000		400 000
C	20 000		11 000	240
D	2180	1000	240	

Which transformers are step-up and which are step-down?

2. Explain why a transformer needs AC not DC current to work.
3. Remember that electrical power = current × voltage.
   a. If a transformer is supplied with 0.2 A at 240 V, what is the input power?
   b. Assuming the transformer is 100% efficient, what is the output power?
   c. If the ratio $N_p:N_s$ = 2400:60 what is the output voltage?
   d. Hence, what current can be drawn from it?
4. Many people leave mobile phone chargers, containing transformers, plugged in when not in use. The primary coil is connected to the mains, but no current is drawn from the secondary coil by the phone since it is not connected.
   a. How, and from where, does the charger still waste energy?
   b. Even though the energy wasted is small, why should people be encouraged to unplug chargers when not in use?
5. DC electricity is more useful for many applications, but the mains electricity is supplied as AC. Suggest why.

THE SUPPLY AND USE OF ELECTRICAL ENERGY The National Grid

Electricity is supplied from power stations to consumers by a 'national grid' of interconnected cables and transformers. They allow energy to be sent where it is needed anywhere in the country, and diverted around any faults that develop.



As transformers are essential to the national grid and they only work with alternating current this is a key reason for generating and distributing electricity as alternating current.

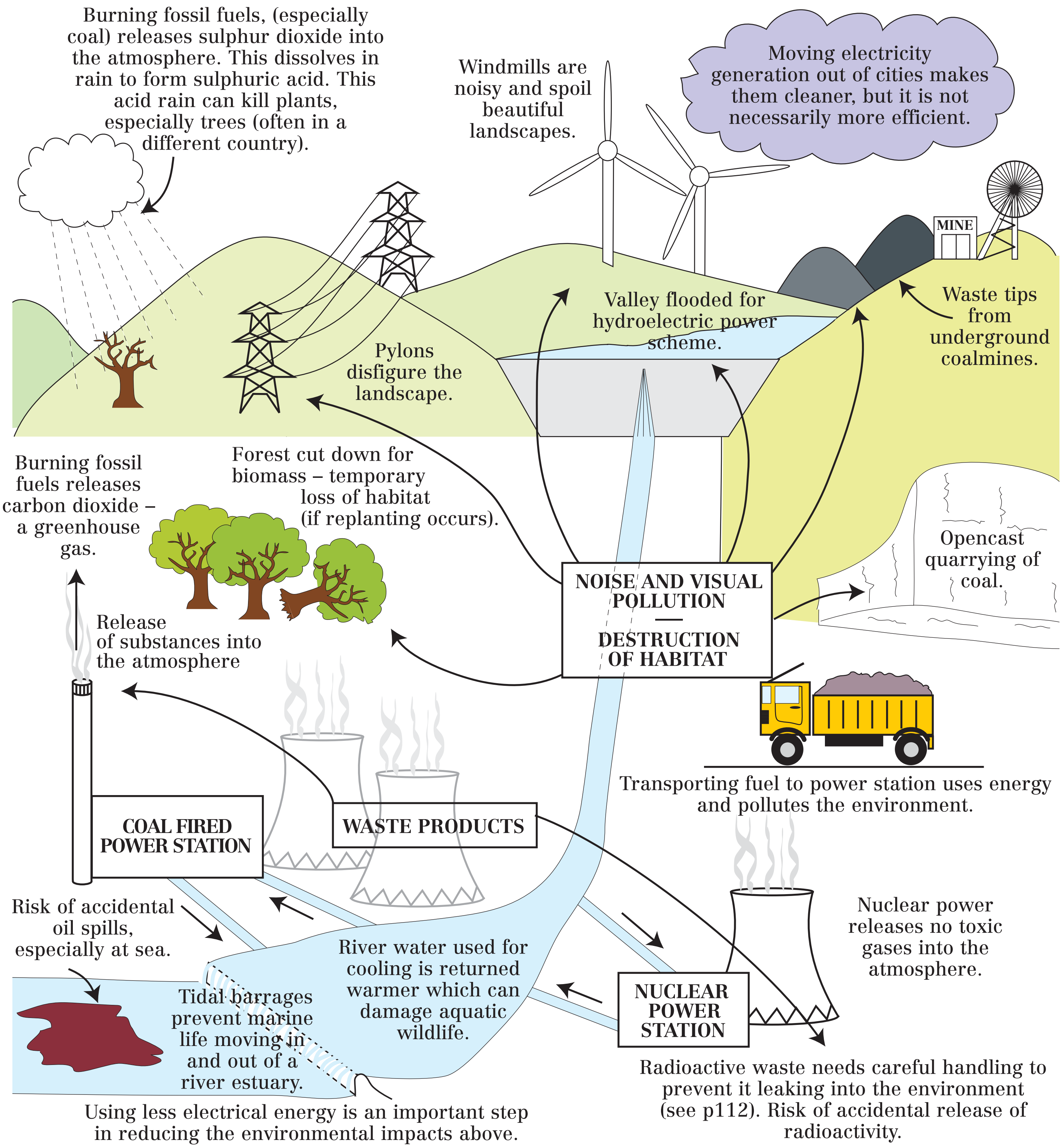
Questions

1. Suggest two reasons for a 'national grid' to supply electricity, rather than each town having its own power station.
2. Assuming the super-grid power lines operate at 400 000 V, calculate the ratio N_p:N_s for each of the transformers in the diagram above.
3. Why do we use very high voltages to distribute electricity when a lower voltage would be a lot safer?
4. Step-down transformer B (above) has an output of 300 A at 132 000 V, what is the current flowing into it assuming the input voltage is 400 000 V and it is 100% efficient?
5. Explain (using a formula) the statement, 'Doubling the current in a wire, quadruples the energy loss from it as heat'.
6. Draw up a table of advantages and disadvantages of underground vs. overground cables.

THE SUPPLY AND USE OF ELECTRICAL ENERGY

The Environmental Impact of Electricity Generation

All electricity generation has some impact on the environment.

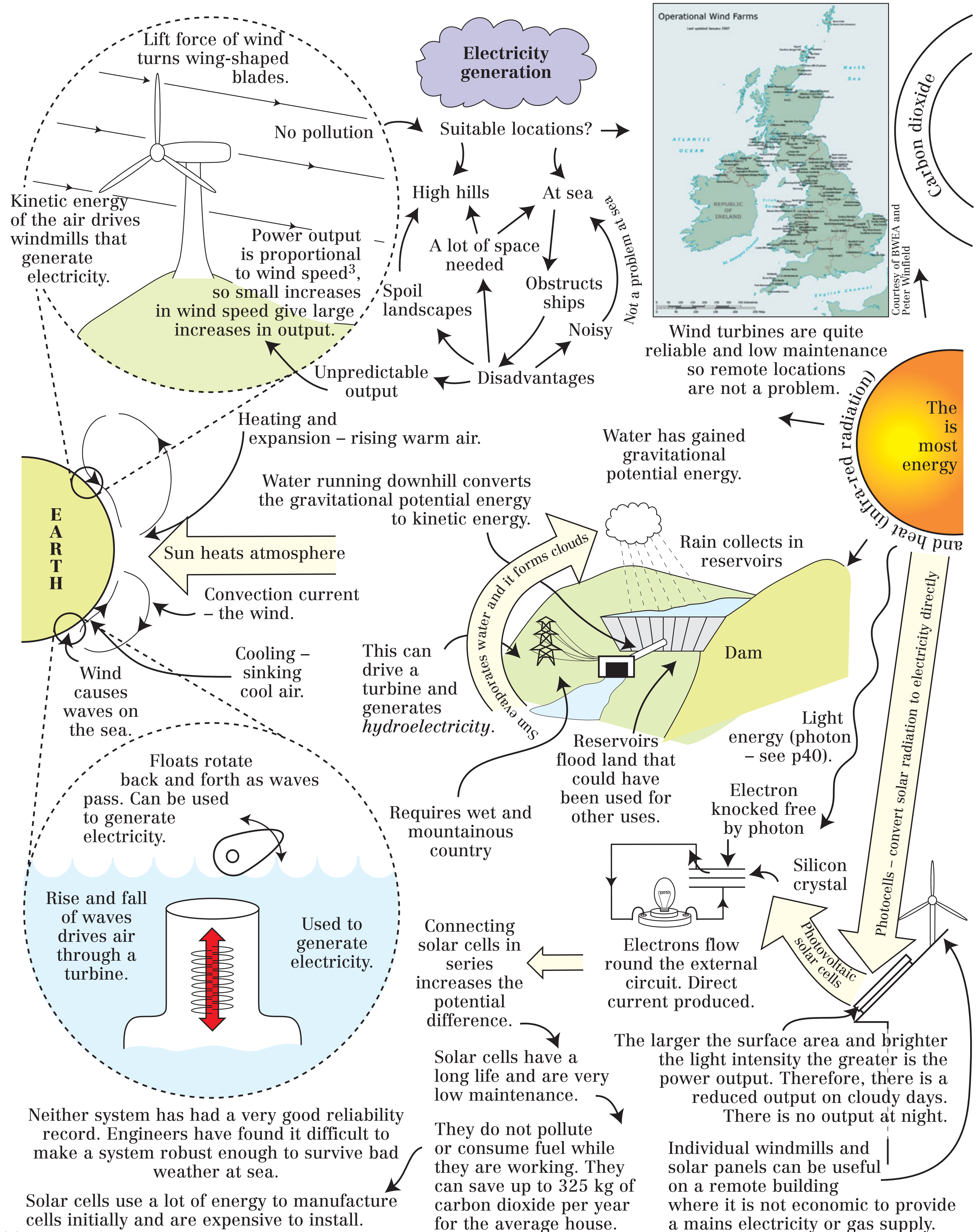


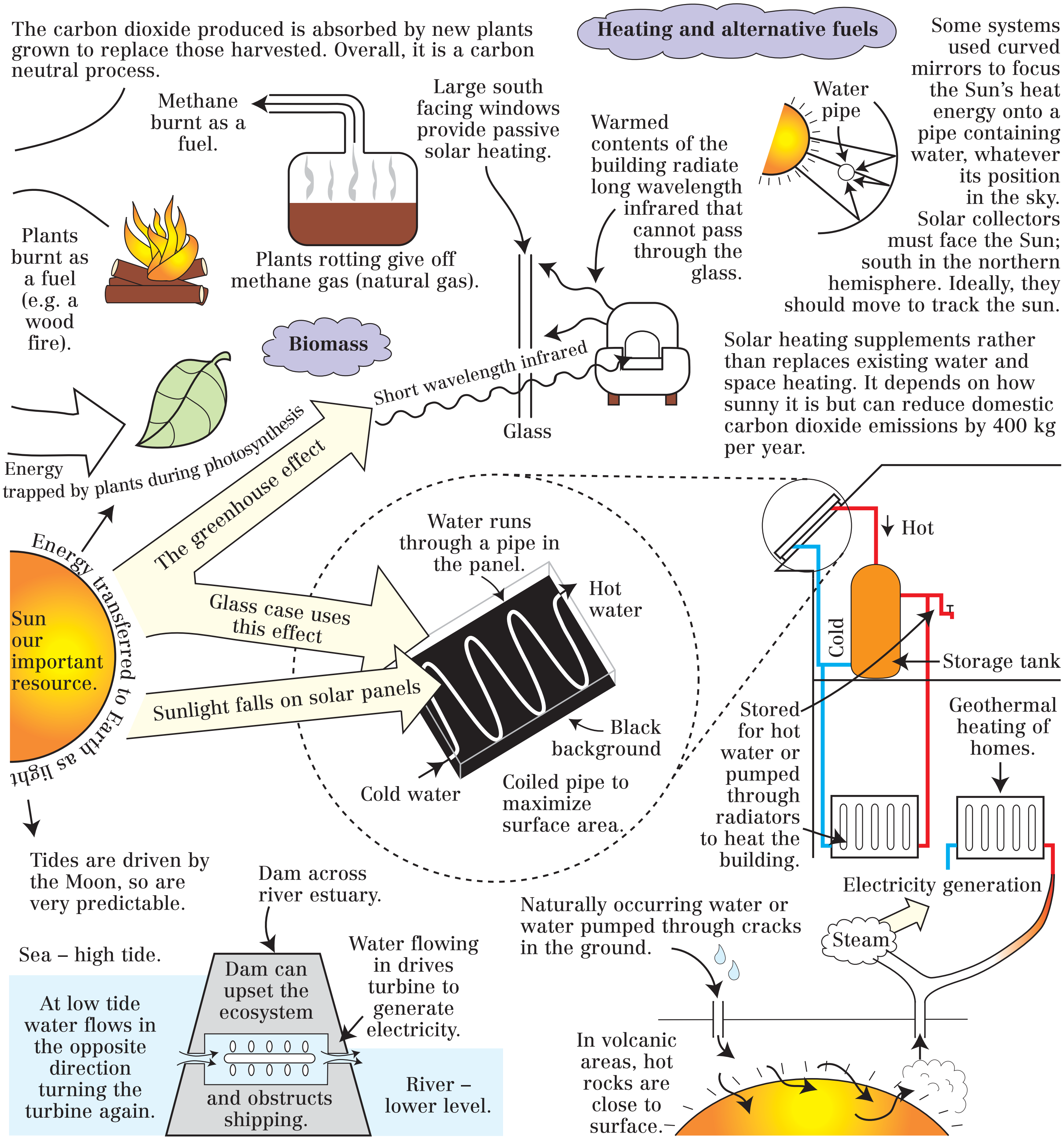
Questions

1. Make a list of 5 ways you could reduce electricity consumption in your house.
2. In the UK in 2007 there are 1200 wind turbines producing a total of 772 megawatts.
   a. On average how many megawatts does one turbine produce?
   b. All the fossil fuel power stations in the UK combined produce about 60 000 megawatts. How many turbines would be needed to replace all the fossil fuel power stations?
   c. Solar cells produce free electricity without any pollution. Suggest some reasons why they are not very widely used in Britain.
3. The environmental impact of electricity generation is an international problem. Give three examples from above where the impact on the environment could affect more than just the country generating the electricity.
4. Some people say the destruction of a wildlife habitat to build a new dam is not justified. If the dam replaced a coal-fired power station do you agree or not? Justify your argument.

THE SUPPLY AND USE OF ELECTRICAL ENERGY Renewable Energy Resources

Renewable energy resources are those that are *not used up* like fossil fuels. They can be used on a large scale, mainly to generate electricity, or for individual buildings either to provide heating or to generate electricity. All of these resources have advantages and disadvantages. To use renewable resources effectively a combination of different resources must be used, both on a national and local scale.





Questions

1. What is our most significant source of energy on Earth?
2. Look at the map of wind farms in the UK. The most common wind direction in the UK is from the southwest. Scotland, Wales and northern England are hilly. Hence, explain why there are very few wind farms in southeast England.
3. Summarize all the information in this chapter in a table as shown.

Source of renewable energy	How it works (you might include a diagram here)	Advantages	Disadvantages or problems

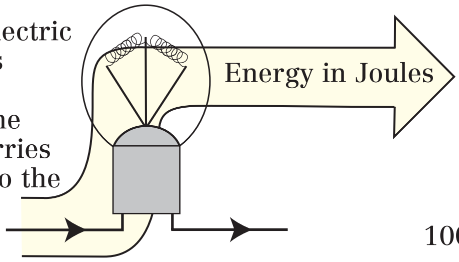
You should be able to include at least eight separate rows.

4. For each of the following, why might people object to having them built near their local area? How might you persuade them to accept the proposal?
   a. A wind farm of twenty large windmills.
   b. A hydroelectric power scheme involving flooding a valley by building a dam across it.
   c. Building a barrage across a river estuary to generate tidal power.
5. UK receives 40% of Europe's total available wind energy but only generates 0.5% of its power from it. Discuss some of the possible reasons why.

THE SUPPLY AND USE OF ELECTRICAL ENERGY

Energy is the ability to do *work*. Electrical energy is a convenient way to distribute it to houses, shops, schools, offices, and factories. Like any product, electricity has a *cost* and the more you use the more you pay. Therefore, the amount used has to be measured.

Whenever electric charge flows through an appliance, the energy it carries is given up to the appliance.



The number of Joules used by an appliance every second = power.

1 Joule every second = 1 Watt.

1000 Joules per second = 1 kilowatt, kW.

Calculating the Cost of the Electrical Energy We Use

Cost depends on

How long it is switched on for.

Power rating – how quickly the appliance converts electrical energy.

Energy (J) = power (W) × time (s).

Electrical power (W) = current (A) × voltage (V).

Consider a typical device such as a kettle. 4.35 A flows when it is connected to the 230 V mains supply.

Electrical power = 4.35 A × 230 V = 1000 W = 1 kW.

Switched on for 2 mins to boil some water.

Electrical energy = 1000 W × 2 mins × 60 s = 120 000 J.

This would give a huge number of Joules on an electricity bill. A more sensible unit is needed.

If a 1 kW appliance is switched on for 1 hour it uses 1000 W × 3600 s = 3.6 million Joules
We call this a kilowatt-hour or kWh.

Electricity companies call this a unit.

Electrical energy (kWh) = power (kW) × time (h)

N.B. Be careful with the units: power must be in kilowatts not watts.

Electricity meter reading

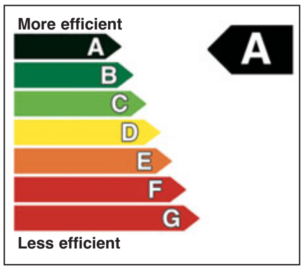
The cost of the electricity will be
Number of kilowatt-hours × cost per kilowatt-hour

Energy efficiency

Remember Efficiency = $\dfrac{\text{useful energy output}}{\text{total energy input}}$

Higher efficiency means:

- Cheaper bills.
- Less pollution.



Some people can buy cheaper electricity during the night (midnight–8am).

Advantages

Can be used to heat water or 'storage' heaters overnight, which give out their heat during the day.

Disadvantages

You need to use over 20% of your electricity at night, to be cost effective as the daytime rate is usually more expensive than normal. The heat in the water or heaters may have dissipated by the evening – just when you need it most.

Questions

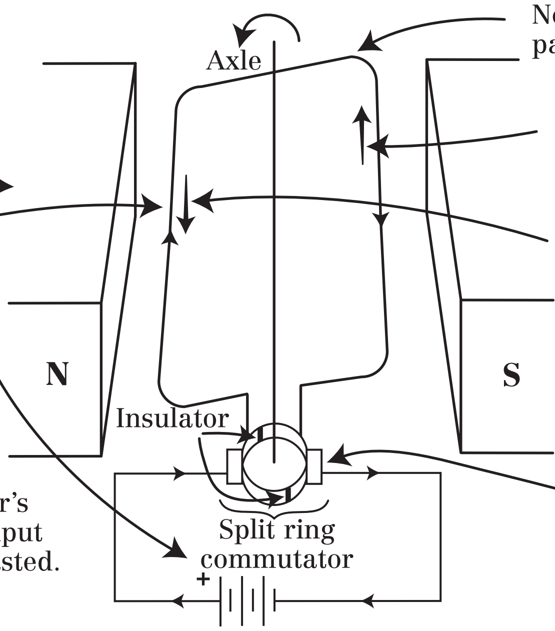
1. Calculate how many Joules each of the following uses:
   a. A 100 W light bulb on for 10 s.
   b. A 500 W TV on for 30 s.
   c. A 1 kW kettle on for 60 s.
   d. A 2 kW fire on for 5 mins.
   e. A 1 kW iron on for 1 hour.
2. Is a kWh a unit of power or energy? How many Joules are there in a kWh? How many kWh is 14.4 million Joules?
3. Copy and complete the following table:

Appliance	Current (A)	Voltage (V)	Power (kW)	Time (hours)	Energy (Joules)	Units used (kWh)	Cost of electricity at 10 p per unit
Storage heater		230	2	2		2 × 4 = 8	8 × 10 = 80
Cooker	26	230		2			
CD player	0.048	230		2.0			
Kettle		230	2			0.2	
Iron	2	230		1.2			
Fridge		230	0.12			2.88	
Lamp		230	0.06		432 000		

4. Give two advantages of buying more energy efficient devices. Where can you look to find energy efficiency information when shopping for new household appliances?
5. Why do you think electricity companies offer cheap electricity overnight?

THE SUPPLY AND USE OF ELECTRICAL ENERGY The Motor and Dynamo

The motor effect from p59 can be used to make a practical electric motor.



No force here as current is parallel to the magnetic field.

Wire forced up

Wire forced down

This forms a turning force (or torque) on the coil.

Motor can be made more powerful by . . .

- Stronger magnets.
- More coils.
- Larger current.

The coils get warm due to the current heating them.

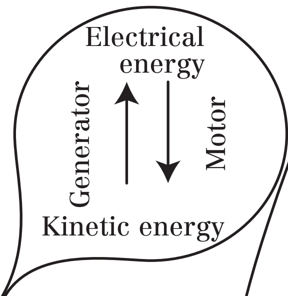
This reduces the motor's efficiency as a lot of input electrical energy is wasted.

Sliding contacts (usually made of carbon) called brushes allow current to flow into the coil as it moves. The arrangement also automatically changes the direction of the current every half turn.

E.g. by measuring the weight a motor can lift through a set distance.

$$\text{Efficiency} = \frac{\text{useful work output}}{\text{electrical energy input}}$$

Current × voltage × time

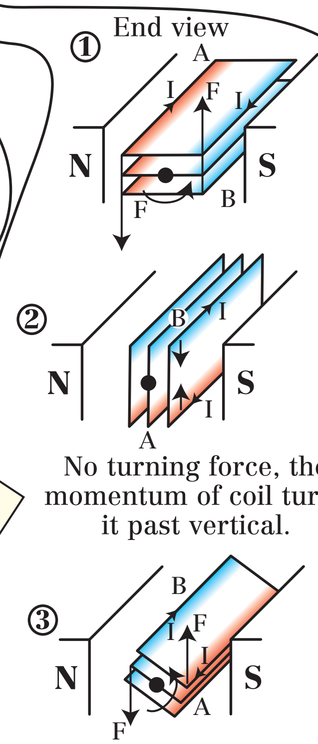


Notice that the motor is effectively the reverse of the generator on p79.

Most practical motors and generators are made more efficient by . . .

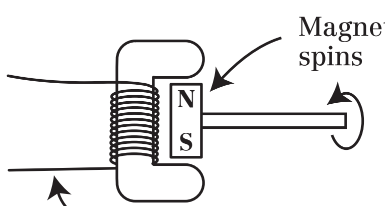
- Using electromagnets rather than permanent magnets to create stronger magnetic fields.
- Using more coils at different angles to the axle.

Avoids this



Current direction has to reverse to keep the twisting force in the same direction. Compare current directions in sides A and B between pictures 1 and 3.

A dynamo is a small generator used, for example, to light a bicycle headlight.



Magnet spins

Current induced in coil.

The advantage of spinning the magnet is that no moving connections, such as slip rings are needed. This makes it more robust.

Questions

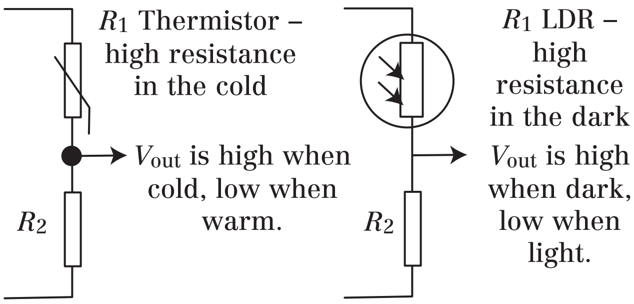
1. How can an electric motor be made more powerful?
2. What would happen to a motor if there was no way of reversing the current direction every half turn? How does a split ring commutator avoid this situation?
3. What are the energy changes in an electric motor? Therefore, why are electric motors not 100% efficient?
4. A motor can lift a weight of 20 N through 3 m in 10 s. If the current flowing is 1.79 A when the voltage of the electricity supply is 12 V, show that the motor is about 30% efficient.
5. What is a dynamo? Explain how it works in as much detail as possible using the ideas from this page and p82–83.

THE SUPPLY AND USE OF ELECTRICAL ENERGY Logic Gates

A logic gate is a circuit that can make decisions depending on the signals it receives.

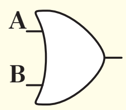
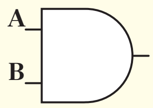
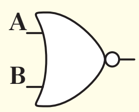
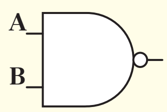
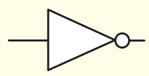
The input signal for a logic gate can either be high (about 5 V) or low (about 0 V). The high input is always denoted by 1, and low input by 0. Signals between these values are not counted. The gate's output is either high or low depending on whether the input signals are high or low.

Potential divider circuits are used to provide the input voltage for a logic gate that can be either high or low depending on the conditions.



$V_{out} = R_1 / (R_1+R_2) \times$ supply p.d.

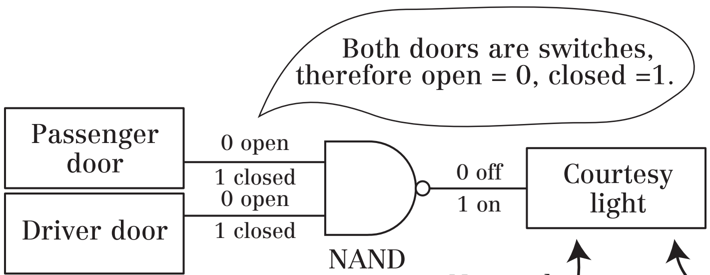
If R_2 is a variable resistor the temperature or light level at which V_{out} becomes large or small enough to trigger a high or low input at the logic gate can be set. This allows the light level or temperature that the sensor will respond to, to be set.

Name	Symbol	Truth table Input		Truth table Output
		A	B	
OR Output high (1) when either input (A or B) is high (1)		0 1 0 1	0 0 1 1	0 1 1 1
AND Output high (1) when both inputs (A and B) are high (1)		0 1 0 1	0 0 1 1	0 0 0 1
NOR Output high (1) when neither input (A nor B) is high (1)		0 1 0 1	0 0 1 1	1 0 0 0
NAND Output high (1) unless both inputs (A and B) are high (1)		0 1 0 1	0 0 1 1	1 1 1 0
NOT Reverse the input		0 1		1 0

Reversing the position of the LDR or thermistor with the fixed resistor, reverses the output.

Logic gates can be used to activate a certain output when required input conditions are met. This can be shown in a *block diagram*.

E.g. A courtesy light switches on in a car when either driver or passenger door, or both, are opened.

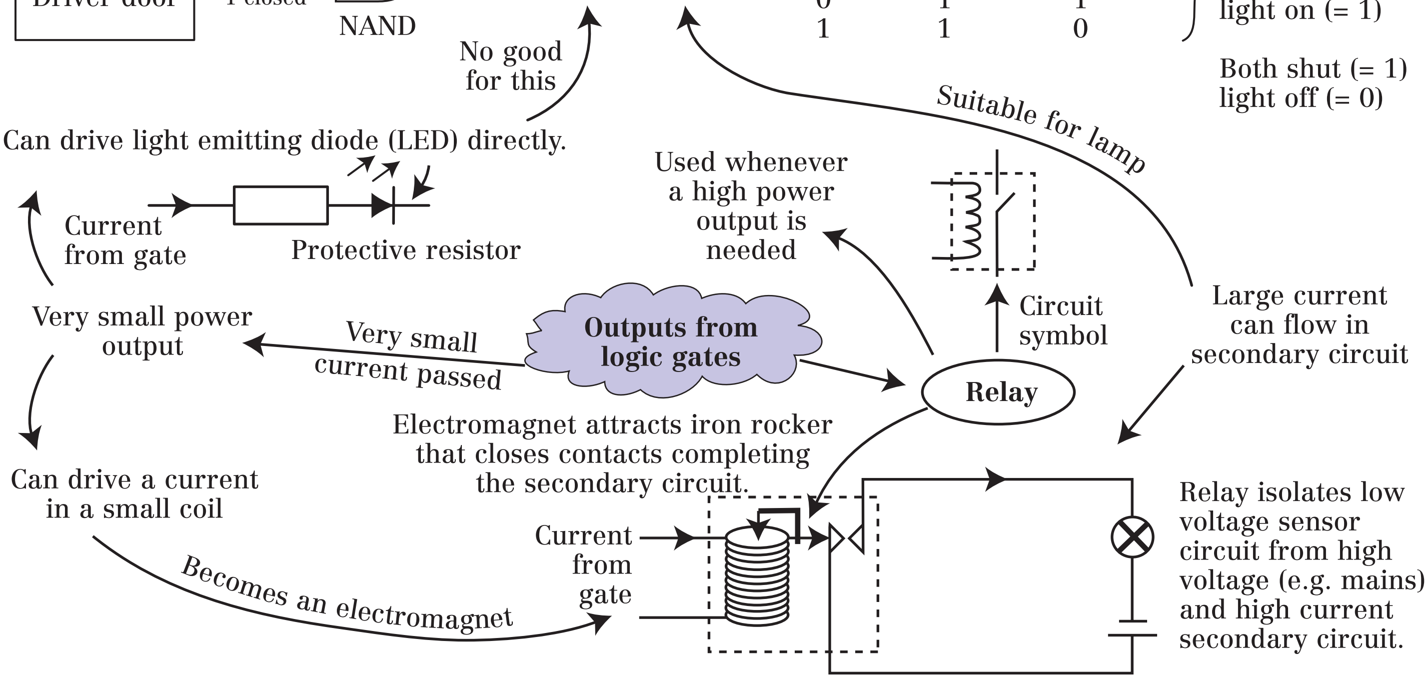


Truth table

P	D	Light
0	0	1
1	0	1
0	1	1
1	1	0

Either or both doors open (= 0) light on (= 1)

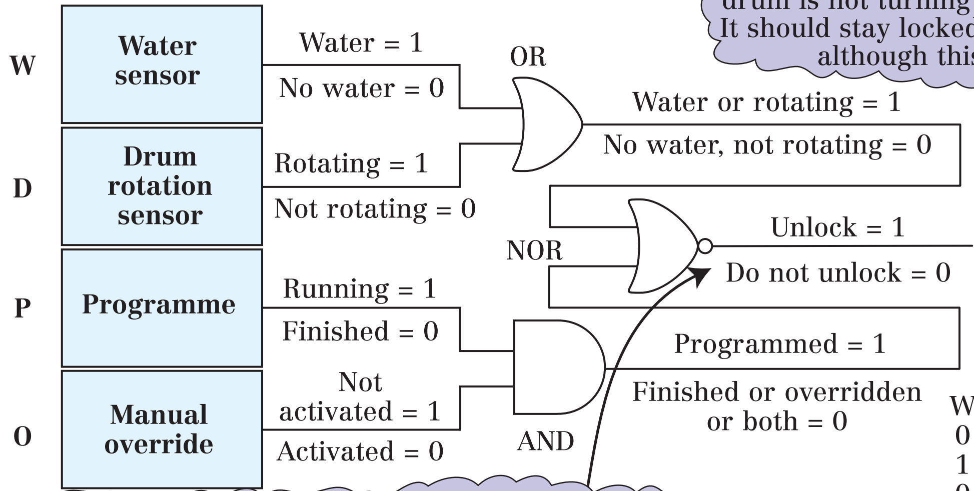
Both shut (= 1) light off (= 0)



Designing a logic system:

1. Draw up a block diagram with logic gates

E.g. A washing machine door must only unlock if the drum is not turning and there is no water in the drum. It should stay locked until the programme has finished, although this should have a manual override.



Only unlocks if no water and drum not rotating
OR output = 0
And if programme has finished or override pressed
AND output = 0

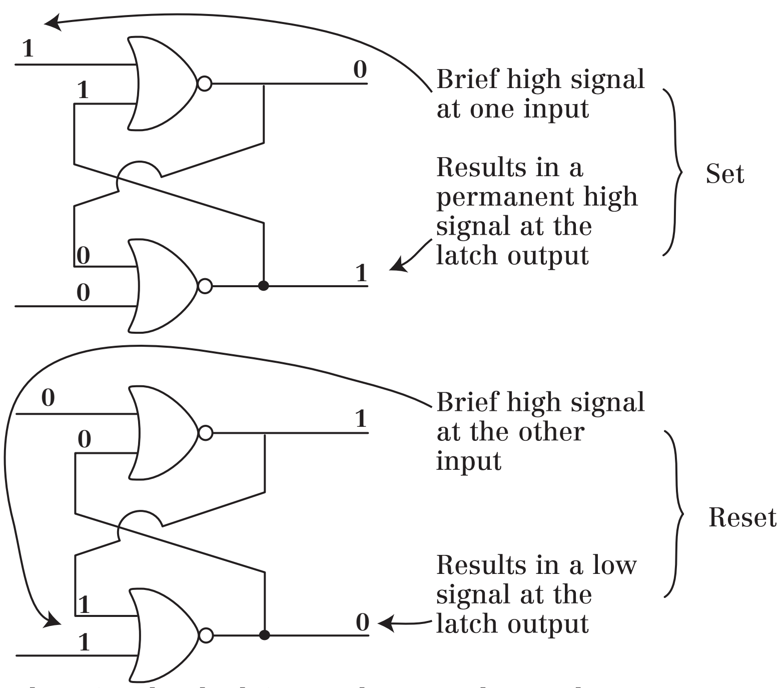
2. Draw a truth table and check it gives the desired output.

W	D	OR output
0	0	0
1	0	1
0	1	1
1	1	1

W	D	AND output
0	0	1
1	0	0
0	1	0
1	1	0

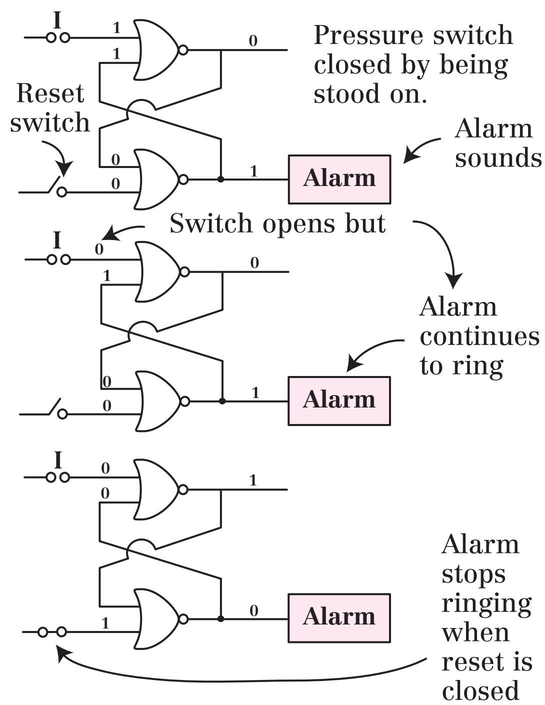
OR output	AND output	NOR output
0	0	1
1	0	0
0	1	0
1	1	0

Latching circuits Sometimes an output is needed which does not change even if the input is removed, e.g. an alarm that continues to ring even if the input that triggered it is removed.



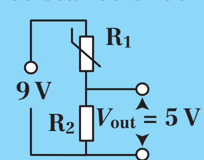
A low signal at both inputs does not change the output. This circuit is called a *bistable* – it has two stable states.

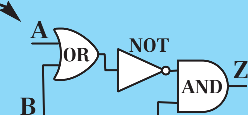
E.g. burglar alarm



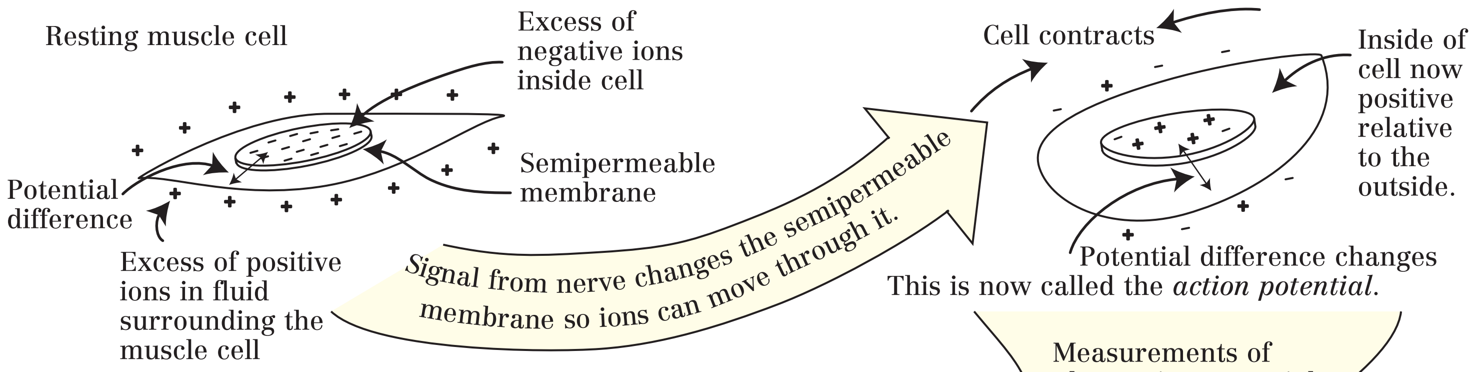
Questions

1. What do the numbers '1' and '0' represent in a truth table?
2. A microwave oven must not start unless the door is closed and the timer is set. Draw a block diagram with a suitable logic gate for this, and include the truth table.
3. In the following circuit, the resistance of the thermistor (R_1) at 100°C is 1.2 kΩ. What resistance should the variable resistor R_2 be set to so V_{out} = 5 V when the temperature reaches 100°C?
4. What is a relay and where are they used? Draw a labelled diagram.
5. In a greenhouse, automatic shades should be drawn if the soil around the plants becomes too dry and if the light level or the temperature rises too much. Draw a suitable block diagram using logic gates and give its truth table.
6. Draw a truth table for the circuit shown:
7. A water pipe may burst if the temperature drops below freezing. Draw a suitable block diagram using two logic gates for a system that will shut off the water to a house if the temperature falls below freezing and not switch it back on until it is reset by a plumber who has inspected the pipes for damage. Draw a truth table for your system.

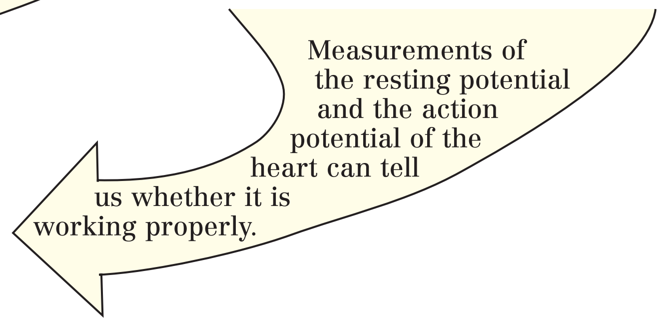




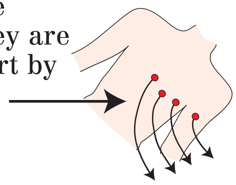
The body sends electrical signals, via nerves from the brain to stimulate muscles.



The heart is a muscle and the signals that control it come, not from the brain via nerves, but from some special cells in the heart, called the sinoatrial node. This means that the heart works automatically without us having to think about it.

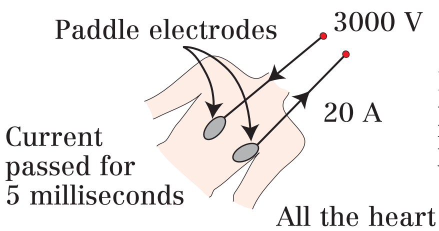


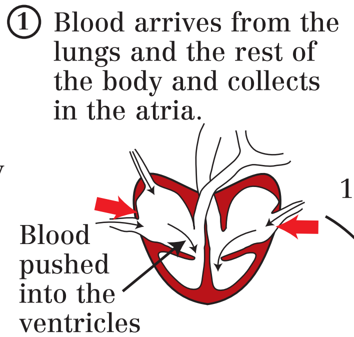
Potentials detected on the surface of the body as they are transmitted from the heart by conducting body tissues.

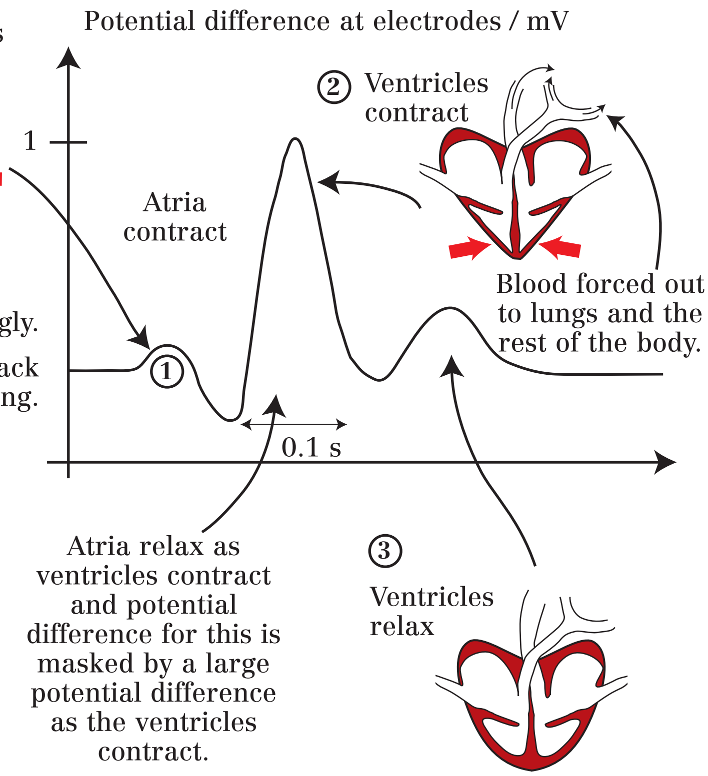


The measurement of these very small potential differences is called an *electrocardiogram* or ECG.

Defibrillation
Fibrillation occurs when a patient's heart does not beat rhythmically but quivers. Blood is not pumped and the patient will soon die.







All the heart muscles contract strongly.

Usually when they relax, they settle back into a regular rhythm of beating.

Care must be taken not to shock the operator.

Pacemakers

- Cells producing stimulus to the heart stop functioning.
- Electrical devices are fitted producing tiny, but regular, shocks to the heart.
- It is placed under the skin and a wire fed through a vein to the heart.
- Fitted with long-life batteries.

Questions
1. Using the figures above show:
   a. That the energy delivered to the heart during defibrillation is about 300 J.
   b. That the resistance of the body is about 150 Ω.
2. When electrodes are attached to a patient for an ECG or defibrillation, a conducting paste or pad is applied between the skin and the electrode. Why?
3. Often when a person receives an electric shock muscles contract violently, sometimes even breaking bones. Why do electric shocks often have this effect?
4. A normal resting heartbeat is about 70 beats per minute. Draw an ECG trace to scale showing 5 beats. A patient who has tachycardia has a fast heart rate. Add this ECG trace to your original and label it. A patient who has arrhythmia has an irregular heartbeat. Add a third trace showing this.

TRANSPORT Stopping Distances

Reaction time is the time it takes a driver to see a hazard, recognize they need to take action, decide on the action, and use the vehicle's controls.

E.g. a child runs into the road, the driver sees the child and considers braking or swerving. They decide to brake and press the brake pedal. Normally all these stages happen in about 1 second.

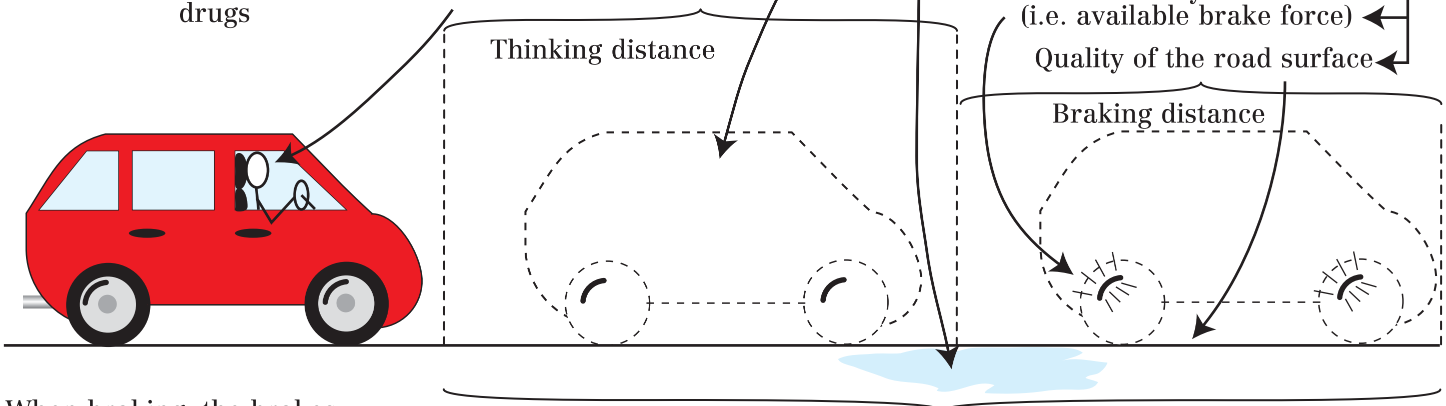
Affected by:
- Driver tiredness
- Distractions – for example using a mobile phone
- Influence of alcohol or drugs

Thinking distance – distance travelled during driver's reaction time.

Affected by:
- Reaction time
- Vehicle speed

Braking distance is the distance travelled between the driver first pressing the pedal and the vehicle stopping.

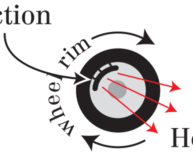
Affected by:
- The speed the vehicle was travelling at
- The mass of the vehicle
- Weather conditions – a wet or icy road for example
- The condition of the tyres and brakes (i.e. available brake force)
- Quality of the road surface



The total stopping distance of the vehicle = thinking distance + braking distance.

When braking, the brakes do work against friction.

Friction



Heat

This converts the kinetic energy of the vehicle into heat energy.

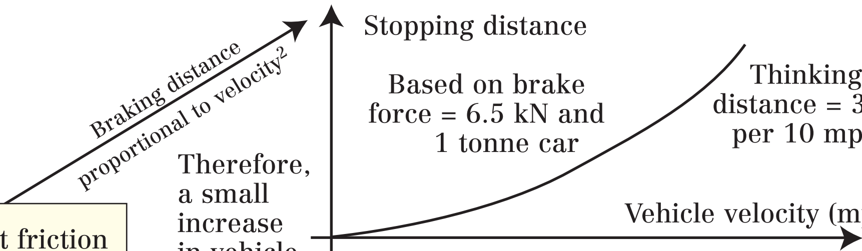
Hence kinetic energy = work done against friction

$\frac{1}{2}$ (mass of vehicle) × (velocity of vehicle)^2 = brake force × distance travelled while braking.

$$\frac{1}{2} mv^2 = F \times d.$$

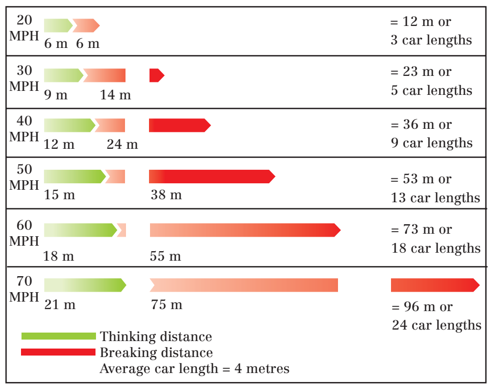
Therefore minimum braking distance = $\frac{1}{2} mv^2/F$

Braking distance is proportional to the mass of the vehicle assuming the same brake force. Therefore, large vehicles need brakes that can exert a larger force.



Therefore, a small increase in vehicle speed gives a large increase in braking distance.

Notice the braking distance is proportional to the square of the velocity. This is reflected in the stopping distances given in the Highway Code. (Crown copyright)



Questions

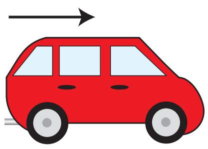
1. Write a list of factors that affect braking distance.
2. As the speed of a vehicle increases what happens to the size of the brake force needed to stop it in a certain distance?
3. Explain why each of the following is a driving offence that the police might stop you for in terms of their effect on the thinking distance or braking distance of a vehicle. The first one has been done as an example:
   a. Driving faster than the speed limit. Answer – increases both thinking distance and braking distance so a vehicle is less likely to be able to stop in the distance the driver can see to be clear.
   b. Having bald tyres. c. Driving under the influence of alcohol. d. Using a mobile phone while driving.
4. Copy and complete the following table:

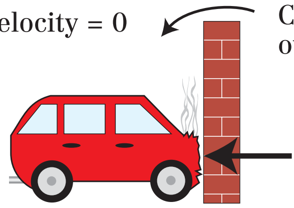
Mass of vehicle (kg)	Initial velocity (m/s)	Maximum braking force (N)	Minimum braking distance (m)
1000	13.3 (= 30 mph)	6500	
1000	31.1 (= 70 mph)	6500	
5000	13.3 (= 30 mph)	6500	

Explain why the braking distances you calculated are minimum distances.

TRANSPORT Road Safety

Most car safety features are designed to reduce the force of any collision on the passengers, which reduce the injuries they may suffer.





Change in momentum = mv

Deceleration = change in velocity / time taken

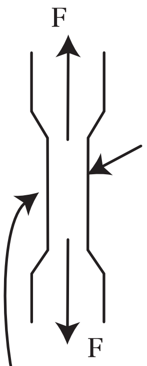
$= (v - 0)/t$

Therefore as force = mass × deceleration

$= m(v - 0)/t$

$F = mv/t$

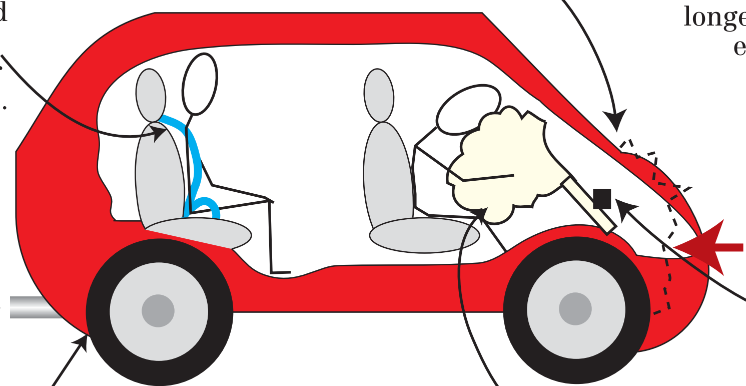
Force (N) × time (s) = change of momentum (kgm/s) (see p16)



Seatbelts are designed to extend during a collision, making the collision last longer and reducing the force. They also restrain the passengers, preventing them hitting hard surfaces such as the dashboard or other passengers.

Once a seatbelt has been in a crash it has been permanently stretched, by absorbing some of the kinetic energy of the passenger wearing it. It will not absorb kinetic energy as effectively again so has to be replaced.

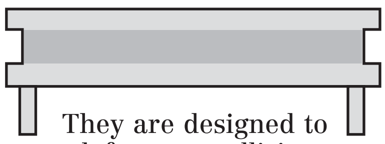
A crumple zone is a specially weakened part of the vehicle's chassis. This deforms in a collision making the collision last longer and reducing the forces exerted on the passengers.



All of these features also absorb kinetic energy by deforming (changing shape).

Antilock brakes (ABS) automatically, briefly, release the brakes if the wheels stop turning (lock) during braking. This helps to prevent skidding.

Crash barriers beside roads prevent vehicles crossing into the path of oncoming traffic.

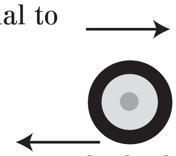


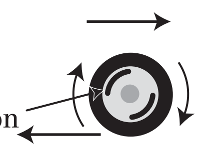
They are designed to deform on collision absorbing the kinetic energy of the vehicle.

An airbag is designed to make the passenger stop moving more gradually, increasing the time of collision. This reduces the force.

Airbag is triggered by an acceleration sensor. A very large deceleration, such as in a collision triggers a small explosive device producing a lot of gas very quickly. This inflates the bag. The gas escapes from small holes in the back of the bag as the passenger sinks into it, cushioning them.

From p95, braking distance is inversely proportional to brake force.





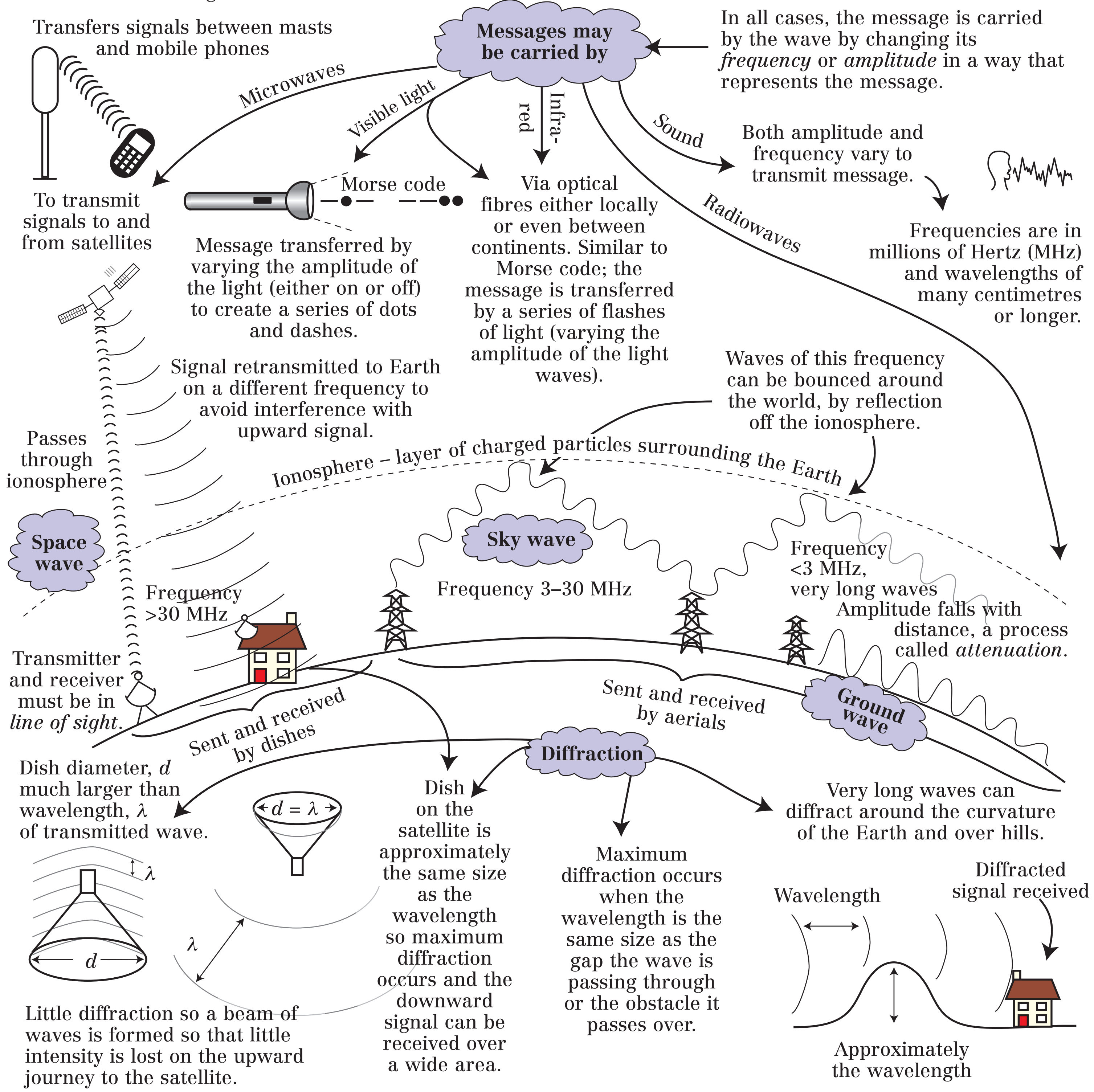
Skid – large stopping distance.

Questions

1. Using the words 'force', 'deceleration', 'momentum', 'energy' in your answers explain:
   a. How motorcycle and cycle helmets made of a material that deforms on impact with a hard surface, reduce the severity of head injuries to the rider in a collision.
   b. Why crash barriers alongside roads are often made of deformable material like steel tube rather than a rigid material like concrete.
   c. An escape lane (a pit full of deep sand) is provided at the bottom of steep hills for drivers to steer into if their brakes fail.
2. A car passenger of mass 70 kg is travelling at 13.3 m/s (30 mph). Show that their momentum is 931 kgm/s. In a collision, they hit the dashboard and stop in 0.01 s. Show that the force exerted is about 93 kN. In another collision, the passenger is cushioned by an air bag and stops in 0.1 s. Show the force is now only 9.3 kN.
3. A car of mass 1000 kg travelling at 13.3 m/s hits a brick wall and stops in 0.1 s. Calculate the deceleration. What force is exerted on the car by the wall? The same car is now fitted with a crumple zone and stops in 0.5 s. What force is exerted by the wall now?
4. Explain how antilock brakes (ABS) can help to reduce stopping distances when a driver brakes hard.

WAVES AND COMMUNICATIONS Using Waves to Communicate

The long distance transmission of information, other than by a message on paper or via an electrical signal in a wire, relies on using waves.



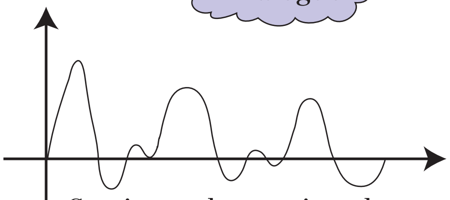
Questions

1. Name four types of electromagnetic waves used to send messages. Suggest why the other types of electromagnetic radiation are unsuitable.
2. Explain three ways radiowaves can be used to send messages over long distances. Use diagrams to help your explanation.
3. i. Use the formula wave speed = frequency × wavelength to calculate the wavelength of radiowaves of frequency:
   a. 3 MHz (3×10^6 Hz). b. 1800 MHz (1.8×10^9 Hz). c. 30 GHz (3×10^{10} Hz).
   ii. Explain which of the above frequencies would be most useful for:
   a. Diffracting around large obstacles like hills. b. Sending to a satellite using a dish.
   c. Mobile telephone communication.
4. A signal is to be sent from the UK to America across the Atlantic. Explain:
   a. Why a signal sent by a ground wave would be very weak by the time it reached America.
   b. Why the ionosphere is needed if the signal is to be sent by a sky wave.
   c. Why a satellite is needed if the signal is to be sent by a space wave.

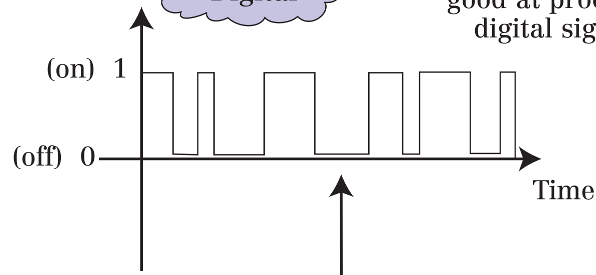
WAVES AND COMMUNICATIONS
Analogue and Digital Signals

Communication signals are either

Analogue Or **Digital**



Continuously vary in value, e.g. speech

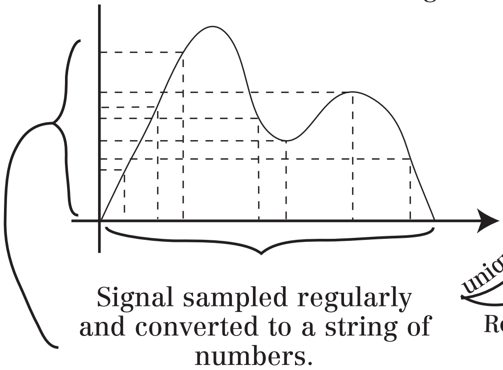


Computers work with binary code, a series high or low voltages representing 1 and 0. They are particularly good at processing digital signals.

Two distinct values only. Usually on and off represented by 1 (on) and 0 (off).

- Pulses of current in a wire.
- Flashes of visible or infrared light in fibre-optic cables.
- Pulses of radio or microwaves.

Conversion:
Sample too often and the process is too slow.
Sample too few times and not enough information is available to reconstruct the original signal.



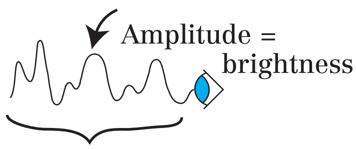
Signal sampled regularly and converted to a string of numbers.

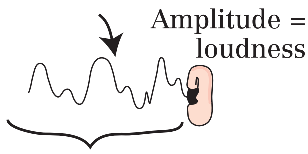
Each value represented by a unique string of 1s and 0s called binary code

Reverse of this process

When digital signals are received, they need to be converted back to analogue.

Humans cannot directly interpret digital signals. Our senses respond to analogue signals.

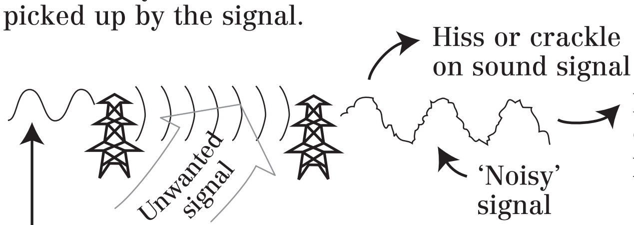




Advantages of digital signals:

1) Less noise

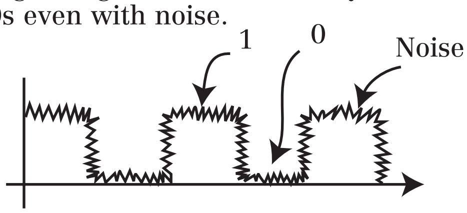
Noise is any unwanted interference picked up by the signal.



Any amplification also amplifies the noise.

With analogue signals it is hard to remove noise.

Digital signals are still clearly 1s and 0s even with noise.

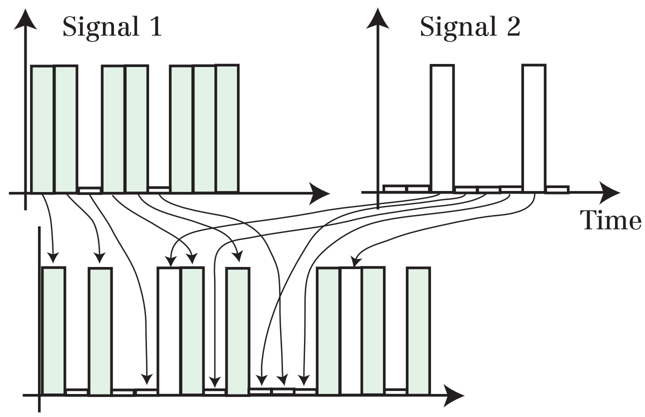


When decoded the noise is removed.

Therefore, digital radio and TV have better sound and picture quality.

2) More information can be transmitted at once.

Signals can be interleaved, (called *multiplexing*).



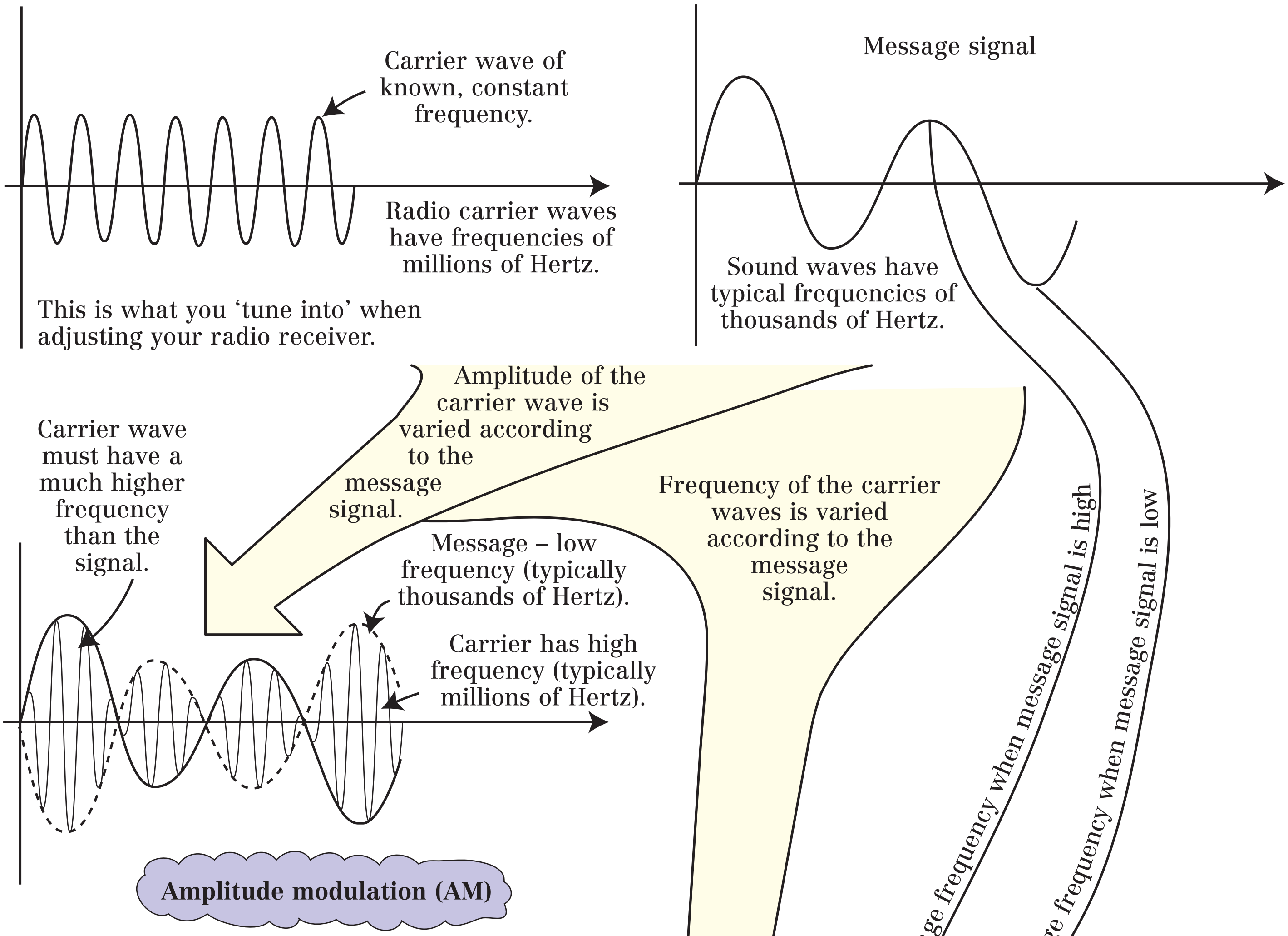
Therefore, lots of information can be sent on one signal. Hence, this is why you can have so many digital TV and radio stations but relatively few analogue ones.

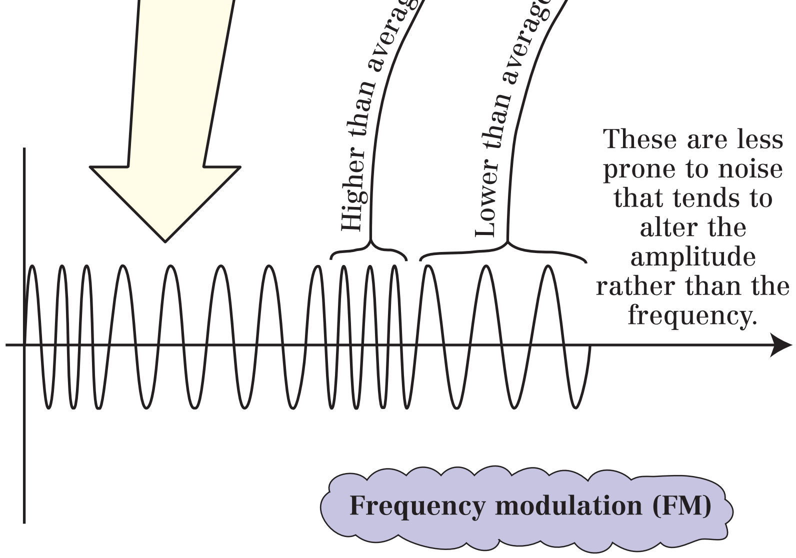
Questions

1. Use diagrams to illustrate the difference between a digital and an analogue signal.
2. When listening to a radio station a hissing sound is heard. What is likely to have caused this and is the signal most likely to have been analogue or digital?
3. Morse code is transmitted as a series of pulses of electricity in a wire or flashes of light representing dots and dashes. Explain whether it is an analogue or digital signal.
4. How are analogue signals converted to digital?
5. What is multiplexing?
6. Explain two advantages of digital signals compared to analogue.
7. When signals are amplified, noise is also amplified. Why is this less of a problem for digital signals?

WAVES AND COMMUNICATIONS AM/FM Radio Transmission

When you tune to a given radio or TV station, you select a particular frequency of radiowave to be received. This wave is called a *carrier wave*, but how is the message added to the carrier wave? There are two methods by which the carrier wave is *modulated* (or varied) by the message signal.





Both types of signal are analogue as they vary continuously.

Radio stations use different carrier frequencies so they do not interfere.

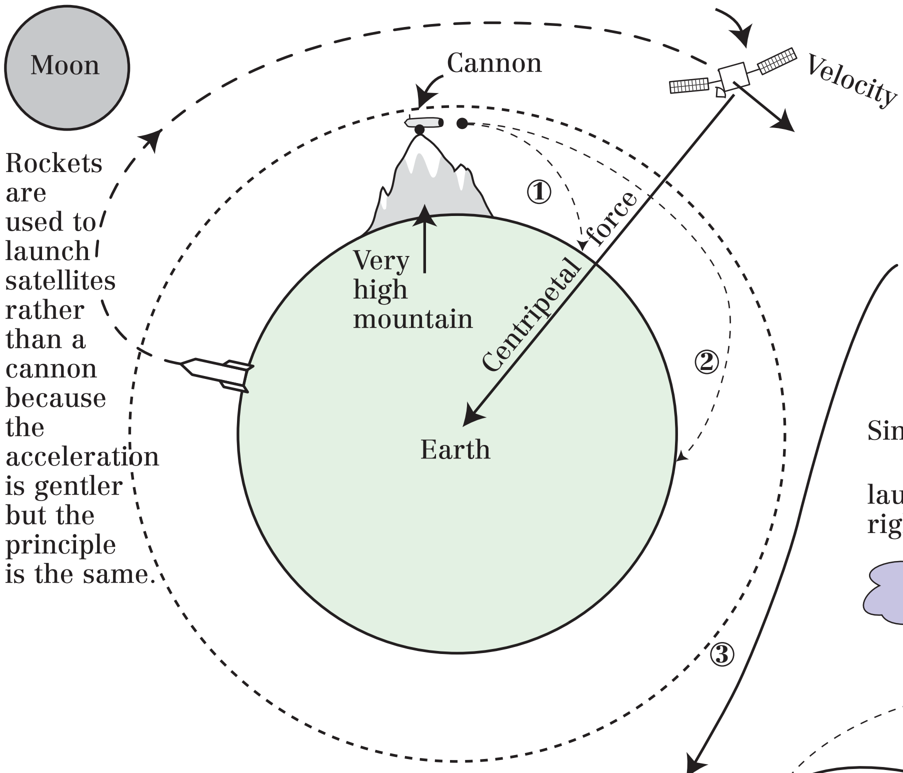
Local radio stations can use the same frequencies as long as they are located a long way apart so the signal from one is too weak to interfere with another.

Questions

1. What is a carrier wave?
2. What do you understand by the term 'modulation' in the context of radiowaves?
3. What do the abbreviations AM and FM stand for?
4. Use diagrams to explain the difference between AM and FM radio transmissions.
5. Which type of transmission, AM or FM suffers less from noise?
6. Can two different national radio stations covering the whole of the UK use the same carrier wave frequency? What about two local stations?

Satellite Orbits and Their Uses

Satellites are objects that orbit larger objects in space. They can be natural, like the moon orbiting the Earth or artificial (man-made).



Rockets are used to launch satellites rather than a cannon because the acceleration is gentler but the principle is the same.

The gravitational attraction between the two objects provides the necessary centripetal force to keep the satellite moving in a circular path (see p19). Without this force, satellites would move off in a straight line into space. The gravitational attraction provides the centripetal acceleration towards the centre of the Earth that causes the satellite's direction of motion to change continuously.

Since centripetal force = $\frac{\text{mass} \times \text{velocity}^2}{\text{radius}}$

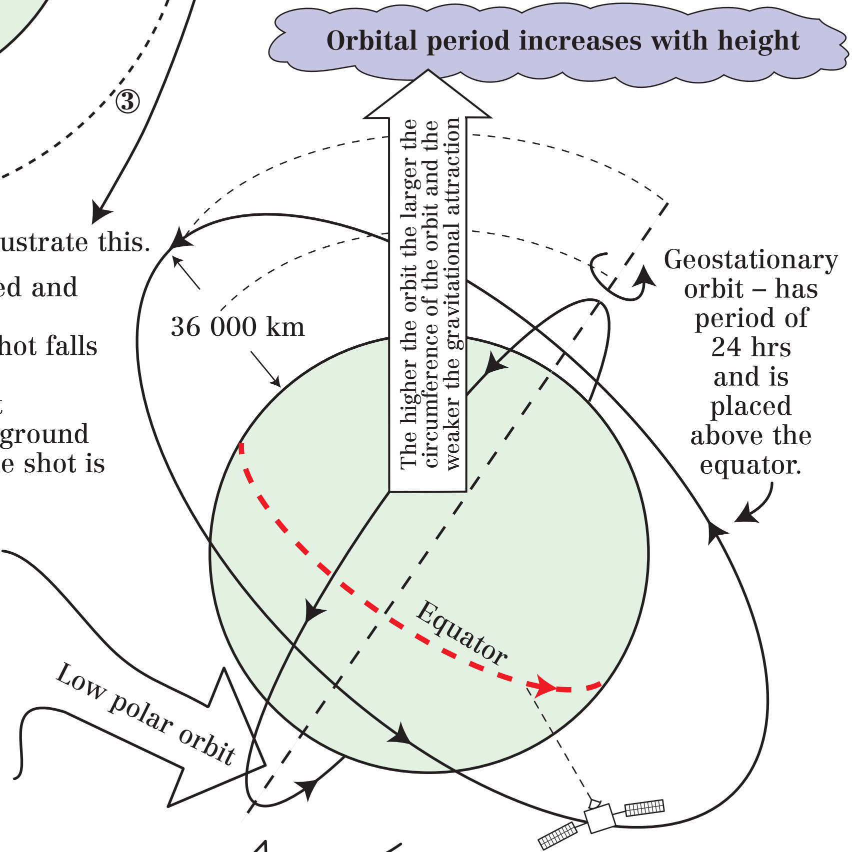
launching a satellite involves getting it to the right height, at the right speed.

Newton used a thought experiment to try to illustrate this.

1. Little gunpowder in cannon. Low initial speed and shot falls to Earth quickly.
2. More gunpowder. Higher initial speed and shot falls further before hitting ground.
3. Given enough gunpowder, the shot will orbit because it is travelling fast enough that the ground is 'falling' away under it at the same rate the shot is accelerating towards it.

Satellites in a low orbit make many orbits of the Earth per day. If they orbit over the poles and the Earth spins beneath them, they can observe many different parts of the Earth's surface each day.

Useful for:
- Weather forecasting.
- Imaging the Earth's surface (e.g. for spying, to monitor crops or pollution).



Communications – as they stay in the same place in the sky, satellite dishes only need to point in one fixed position.

Satellite stays over the same point, as the Earth and satellite are turning at the same rate.

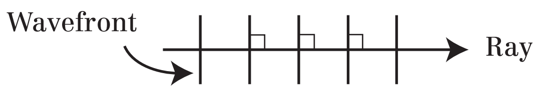
Questions

1. State and explain two reasons why satellite orbit period increases with height above the Earth.
2. Using diagrams state and explain as many differences as possible between geostationary and polar orbits.
3. For each type of orbit, geostationary and polar:
   a. State a use for a satellite in that orbit.
   b. Explain why that orbit is used.
4. A geostationary satellite orbits 36 000 km above the surface of the Earth. The radius of the Earth is 6400 km.
   a. How many hours does it take a geostationary satellite to orbit the Earth? What is this in seconds?
   b. Show that the circumference of the satellite's orbit is about 270×10^6 m.
   c. Hence show that its orbital speed is about 3080 m/s.
   d. Use the formula centripetal force = mass × velocity^2 / radius to find the resultant force on a 10 kg satellite.
   e. What provides this resultant force?

WAVES AND COMMUNICATIONS Images and Ray Diagrams

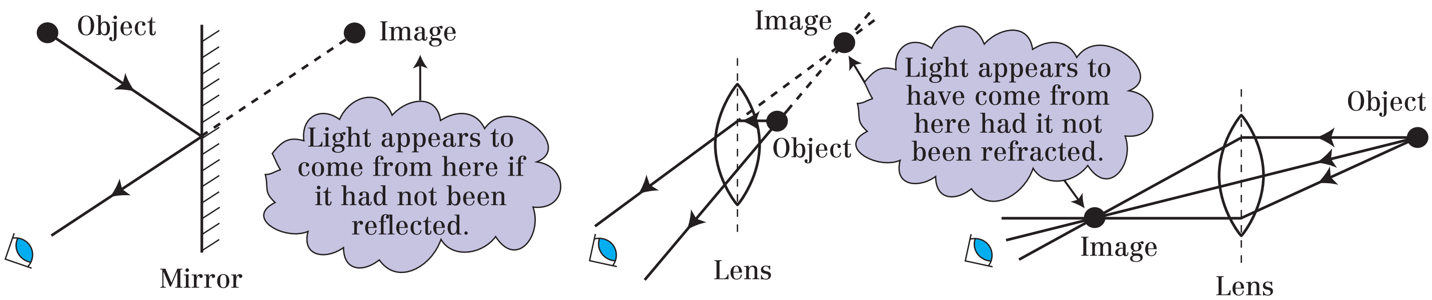
Light follows straight lines, or rays, from a source of light to an observer unless it is reflected, by a mirror, or refracted, by a lens, on route.

Mirrors and lenses come in a variety of shapes to manipulate the light rays in various useful ways. Ray diagrams help us to understand their effects.



Rays show the direction the light waves are travelling in. Light rays always travel in straight lines (as light waves travel in straight lines) except when reflected or refracted when they change direction.

An image is formed at a point where the light rays from an object appear to come from, had their direction not been changed by a mirror or lens.



Virtual images

The light rays do not pass through the image before entering the eye.

Cannot be projected onto a screen.

Always upright.

The nature of an image

Virtual or real?

Upright or inverted (upside down)?

Magnification.

Real images

The light rays pass through the image before entering the eye.

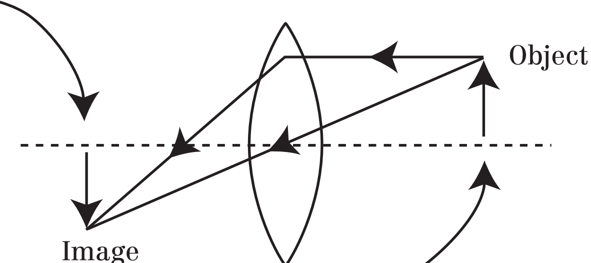
Can be projected onto a screen.

Always inverted (upside down).

Greater than 1 – *magnified* (image larger than object).

$$\text{Magnification} = \frac{\text{image height}}{\text{object height}}$$

Smaller than 1 – *diminished* (image smaller than the object).



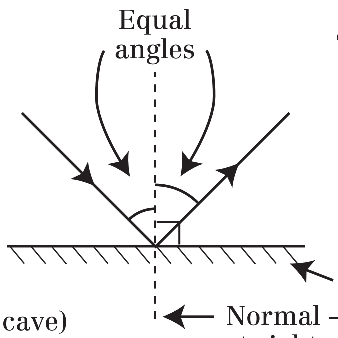
Questions

1. Make a list of three properties of an image that describe the 'nature of an image'.
2. State three differences between a real and virtual image.
3. Is the image in a plane (flat) mirror real or virtual?
4. What is a light ray?
5. What is the formula for magnification? If the magnification of a lens is less than 1, would the image be larger or smaller than the object?
6. A tree has a height of 20 m. In a photograph, it has a height of 20 cm. What is the magnification?
7. A letter 'I' in a book has a height of 5 mm. When viewed through a magnifying glass with a magnification of 1.9, how high will it appear?

Mirrors

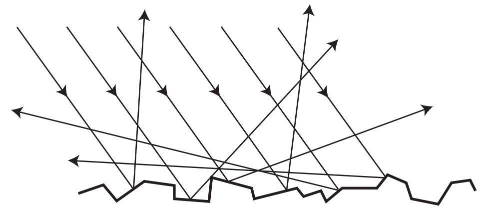
(1) Plane (flat)

Nature of image
Virtual
Upright
Same size as object



Law of reflection (applies to all mirrors):

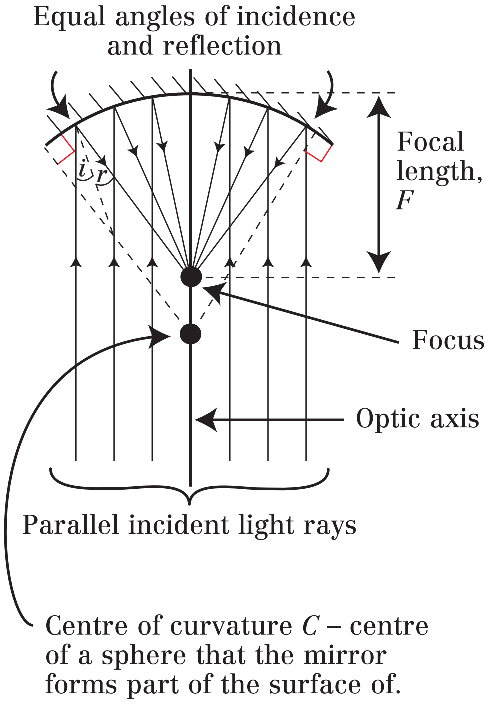
Angle of incidence, *i* = angle of reflection, *r*



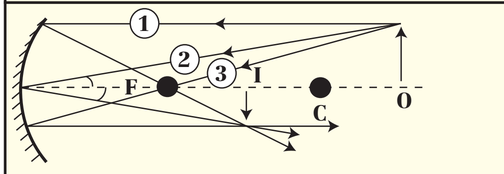
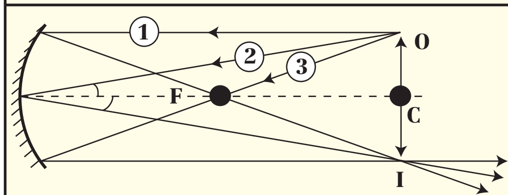
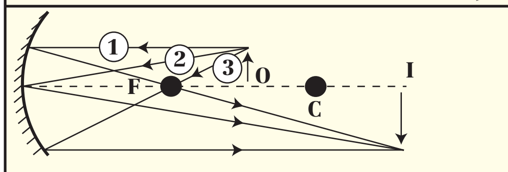
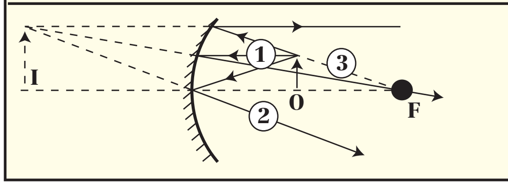
Diffuse reflection from a rough surface – no image formed.

(2) Concave – curving in (like a cave)

Brings light to a focus so is a *converging* mirror.



Nature of images

	Object	Image
	Beyond C	Between C and F Real Inverted Diminished
	At C	At C Real Inverted Same size
	Between C and F	Beyond C Real Inverted Magnified
	Closer than F	Virtual Upright Magnified

Rules for drawing ray diagrams for concave mirrors

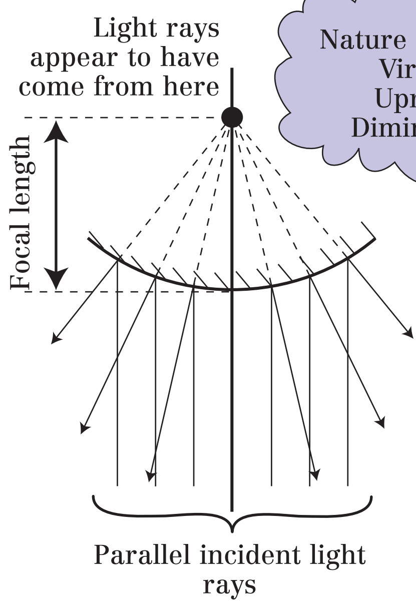
Ray from the object

1. Parallel to optic axis – reflects through *F*.
2. To centre of mirror is reflected, forming equal angles with optic axis.
3. Through F is reflected parallel to the optic axis.

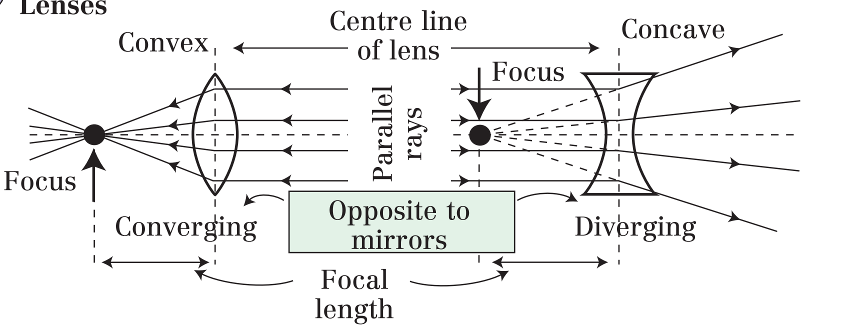
(3) Convex – bulges out

Spreads light rays out so is a *diverging* mirror.

Nature of image
Virtual
Upright
Diminished



Lenses

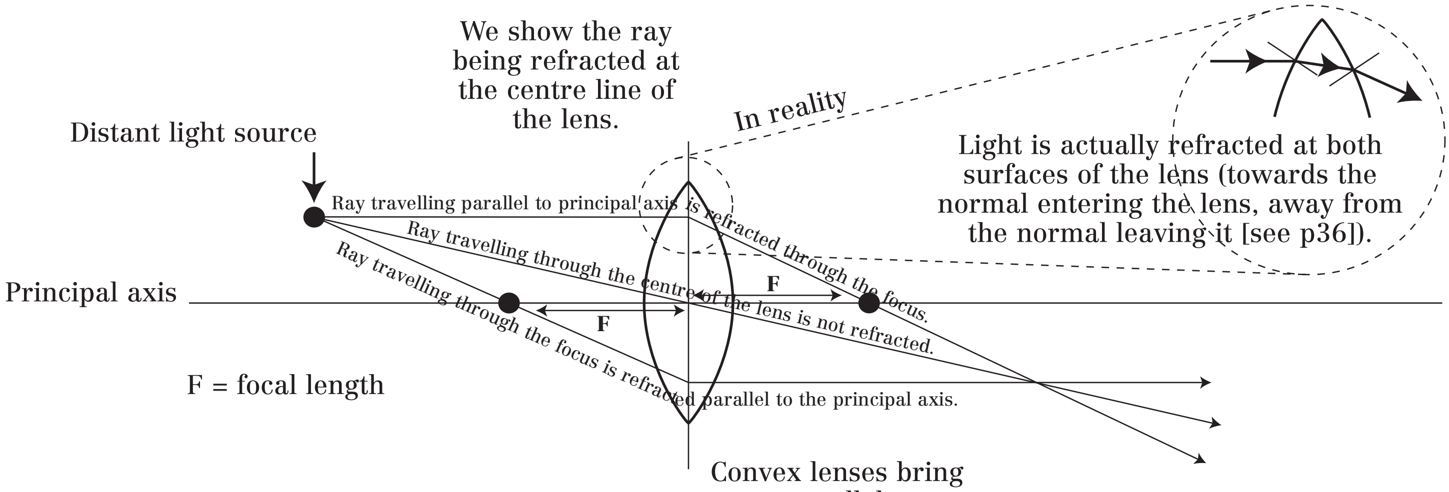


The more powerful a lens, the greater the change in direction of the light rays, and therefore the closer the focus is to the centre line of the lens.

Power of lens (dioptre) = 1/focal length (m)

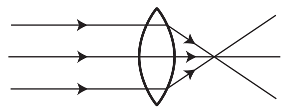
The more curved the surface the greater the refraction of the light. Therefore, fat lenses have short focal lengths and are more powerful.

1. Convex (converging) lens

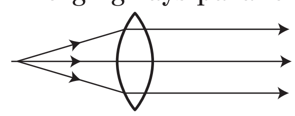


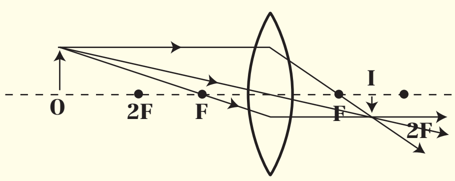
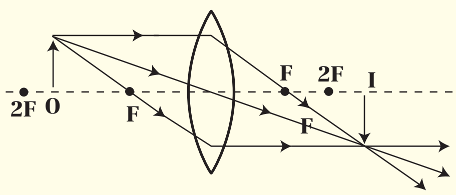
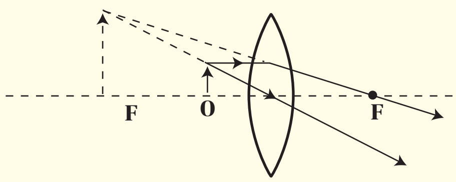
The nature of the image formed by a convex lens depends on how far the object is from the lens.

Convex lenses bring parallel rays to a focus.

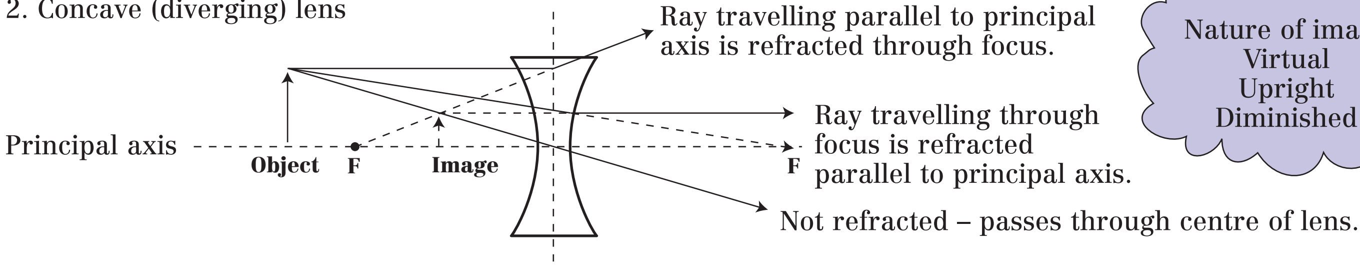


Diverging rays parallel



	Object	Image	Uses
	Further than 2F	Between F and 2F Real Inverted Diminished	Camera: convex lens focuses light from a distant object to form a diminished image on the film close to the lens
	Between F and 2F	Further than 2F Real Inverted Magnified	Projector: convex lens focuses light from a nearby object to form an enlarged image on a distant screen
	Closer than F	Upright Virtual Magnified	Magnifying glass

2. Concave (diverging) lens



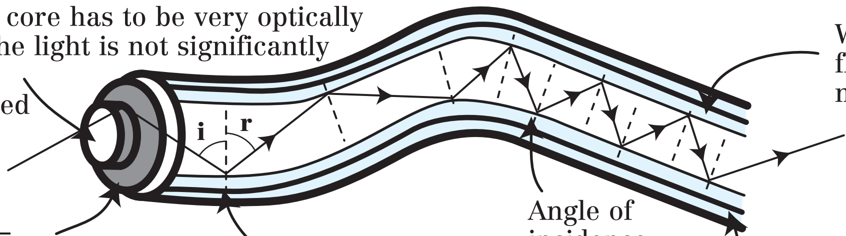
Nature of image
Virtual
Upright
Diminished

Questions

1. Describe what we mean by the term 'focal point'.
2. Draw the shapes of convex and concave mirrors and lenses. Show with ray diagrams which will bring parallel light waves to a focus, and which will diverge them.
3. What three rays are drawn in a ray diagram for:
   a. A convex lens? b. A concave mirror?
4. Does a powerful lens have a short or long focal length? What unit is the power of a lens measured in?
5. A lens has a focal length of 0.1 m. What is its power?
6. Draw a ray diagram for an object placed at 2F from a convex lens and at F from a convex lens.
7. Draw a ray diagram for a camera and a projector; include the object, image, and lens.

WAVES AND COMMUNICATIONS Optical Fibres

An optical fibre is a thin strand of very clear glass through which visible light or infrared radiation can be guided.



The glass core has to be very optically clear so the light is not significantly scattered or absorbed inside it.

Whole cable is very thin and therefore, flexible; the core is typically only a few micrometres thick.

Visible light or infrared ray

Cladding – lower refractive index than the core. Light is refracted away from the normal.

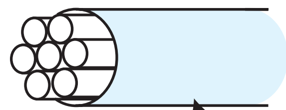
Angle of incidence is greater than the critical angle.

Angle of incidence = angle of reflection.

Protective sheath (plastic)

Conditions necessary for total internal reflection (see p38).

Light passes down fibre by repeated *total internal reflection*.



Bundle of fibres

Outer sheath

Cladding layer ensures no light transfers between fibres as it is all internally reflected.

Uses and advantages of optical fibres

Replacing copper wires to send messages

- Light and thinner so more cables will fit in the same space. More messages can be sent.
- It is very difficult to split a fibre optic and join another cable so it is very hard to intercept messages.
- No electrical interference. → Light in cables cannot escape and interfere with light in an adjacent cable. Therefore, there is no interference between messages.
- The loss of signal is less than in copper wire so lower power transmitters can be used.
- Signals can be 'multiplexed'. Many messages are sent at once by breaking them up and sending the parts in turn.

Messages sent as pulses of light. Ideal for digital communications.

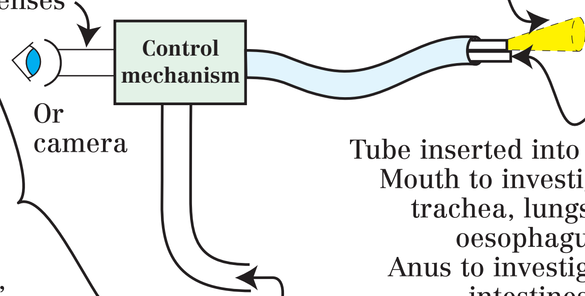
Viewing inaccessible places

Endoscope

Surgical instruments can be attached to carry out minor operations or to collect tissue samples.

Light illuminates the inside of the body.

Eyepiece and lenses



Or camera

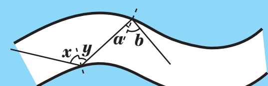
Light returns to the eyepiece.

Light from lamp

Similar instruments are used in industry to examine the insides of machines, engines, plumbing etc. without dismantling them.

Tube inserted into an orifice.
Mouth to investigate the trachea, lungs, and oesophagus.
Anus to investigate the intestines.
Through the wall of the abdomen to investigate the internal organs.

Questions

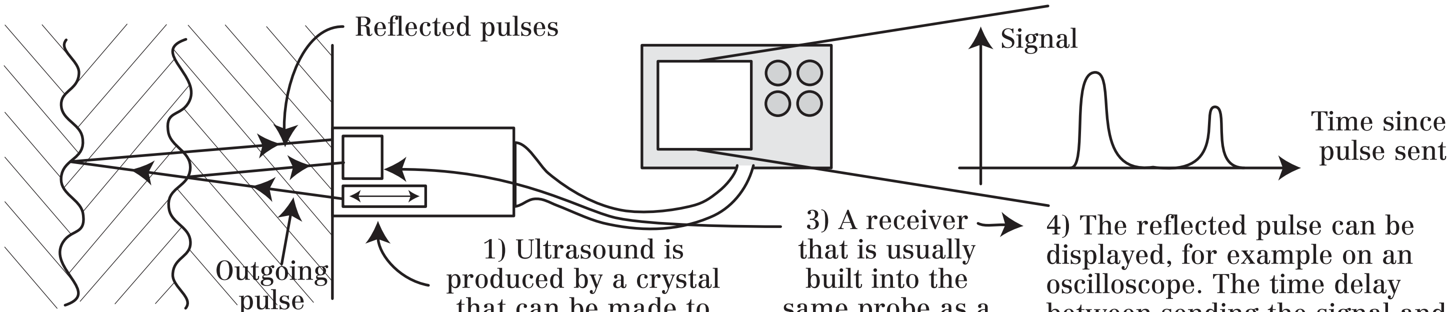


1. Copy and complete the following diagram as accurately as possible showing the path of the light along the fibre-optic cable. What can you say about the size of the pairs of angles a and b, and x and y?
2. What types of electromagnetic radiation are commonly used with fibre optics?
3. Outline some benefits of using fibre optics rather than copper wires for sending messages.
4. The light in a fibre optic gradually gets less intense as it travels along the fibre due to impurities in the glass absorbing some of the light energy. What is the electrical equivalent of this?
5. What is an endoscope? Suggest two possible uses for one.
6. Suggest why doctors often prefer to see inside people using an endoscope rather than carrying out an operation to open up the patient.

WAVES AND COMMUNICATIONS Ultrasound and its Applications

Ultrasound is a sound wave with a frequency of greater than 20 000 Hz. This is above the upper limit of hearing for humans, so we cannot hear it, although in all other respects it behaves in exactly the same manner as normal sound.

Ultrasound can be used to detect the distance between the boundaries of two objects.



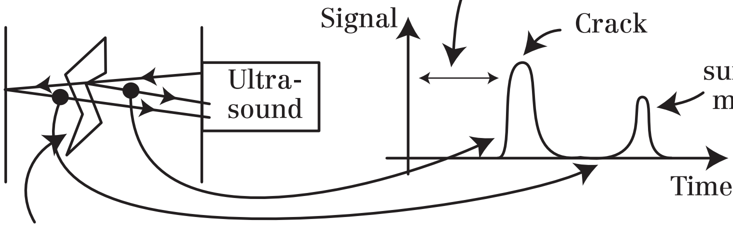
1) Ultrasound is produced by a crystal that can be made to oscillate electrically at a very high frequency.

2) Ultrasound travels through a material. If the density of the material changes the speed of the sound changes and some (usually a small fraction) of the ultrasound is reflected from the boundary to

3) A receiver that is usually built into the same probe as a transmitter.

4) The reflected pulse can be displayed, for example on an oscilloscope. The time delay between sending the signal and its echo can be used to measure the distance to the boundary, especially if the speed of the ultrasound in the material is known.

In industry



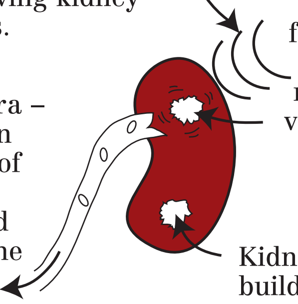
Crack in casting – for example in the turbine blade of a jet aircraft. If undetected the crack could grow until the part breaks.

Cleaning delicate mechanisms by shaking dirt free.

Mechanical effect

Advantages of ultrasound vs. X-rays
Ultrasound is not ionizing like X-rays so causes less cell damage. X-rays pass straight through soft tissues without reflection so cannot image them.

Removing kidney stones.



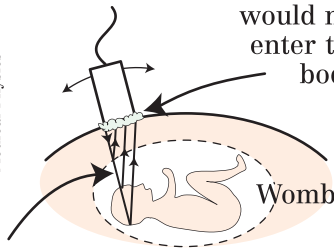
High intensity ultrasound focussed on the stone. The resulting rapid vibrations cause the stone to shatter.

Urethra – broken parts of stone passed in urine

Kidney stone – build up of mineral deposits

In medicine

Pre-natal scanning (frequencies of 1–10 MHz).

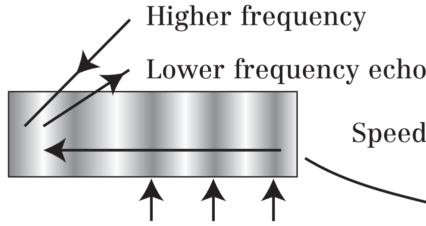


Gel to ensure that the ultrasound gets into the body (any air/tissue boundaries provide very strong reflections so the ultrasound would not enter the body.

Reflections from each boundary take different times to reach the receiver. An image of the foetus is built up.

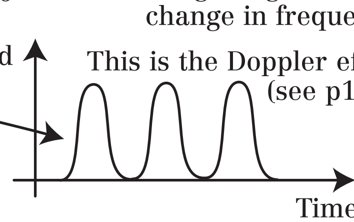
This can be used to monitor the foetus' heart, and to check for growth abnormalities and positioning in the womb before birth.

Monitor the speed of blood flow.



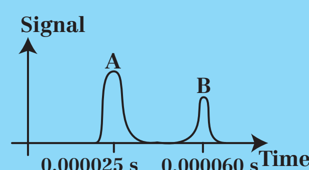
Because the blood is moving, the frequency of the returning echo is slightly different to the frequency of the original sound. The faster the blood is moving the greater the change in frequency.

This is the Doppler effect (see p125).



Questions

1. Is ultrasound a longitudinal or transverse wave? How is ultrasound different to normal sound?
2. The speed of ultrasound in soft tissue is 1540 m/s. The oscilloscope trace shows the returning pulses. How far below the surface of the body was pulse A and pulse B reflected?
3. Suggest two reasons why ultrasound may be preferable to X-rays for medical examinations.
4. Explain how ultrasound could be used to locate the depth below the skin of a cyst (fluid filled pocket) in an organ.
5. Suggest one use of ultrasound in medicine and one in industry other than for making images of hidden objects.



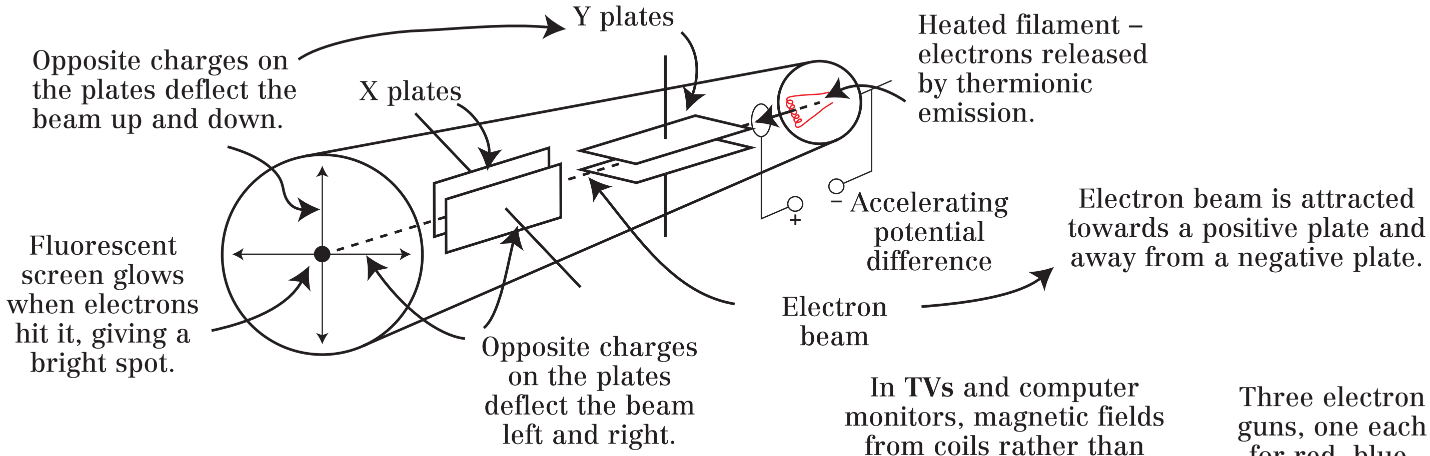
WAVES AND COMMUNICATIONS Uses of Electron Beams

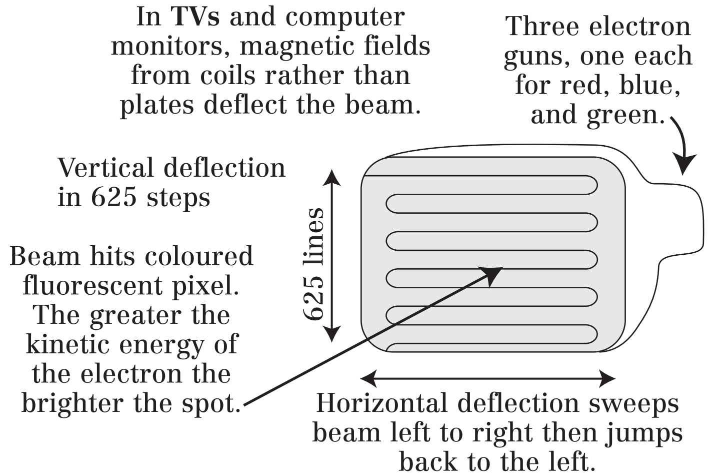
Review p57. Particularly note . . .

1. Electron beams are produced by 'boiling' electrons off a heated filament (thermionic emission). The hotter the filament the more electrons are produced.
2. The electrons are accelerated across a potential difference to increase their kinetic energy.

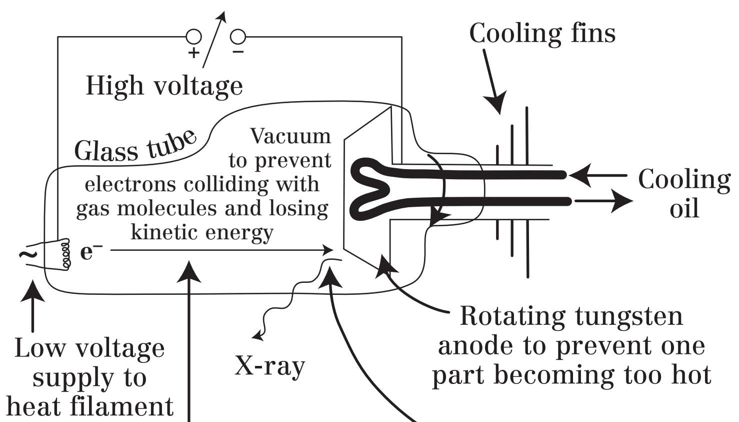
Kinetic energy = electronic charge (1.6×10^{-19} C) × accelerating voltage

Cathode ray tubes – used in computer monitors, TVs, and oscilloscopes.





X-ray tubes:



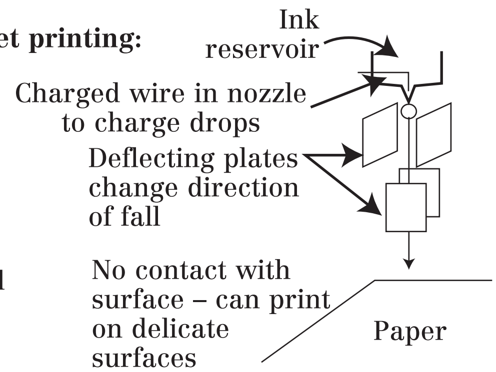
Electrons gain kinetic energy as they accelerate towards the anode. Increasing the potential difference between filament and anode gives electrons more kinetic energy on impact, so higher energy (or 'harder') more penetrating X-rays are produced.

Kinetic energy of electrons on impact

→ 1% X-ray energy

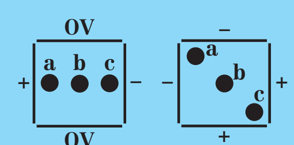
→ 99% thermal energy

Inkjet printing:



Questions

1. The diagram shows the X and Y plates in an oscilloscope viewed end on. In each case which of the dots shown (a, b, or c) correctly shows the position of the beam falling on the screen?

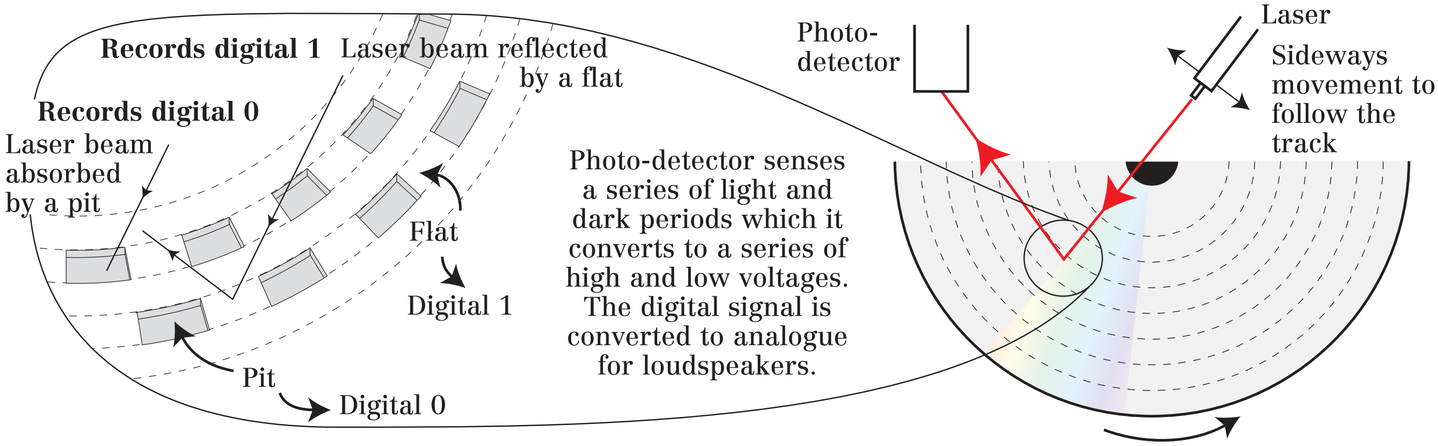


2. How many lines are there on a TV screen? Explain how the electron beam is made to move across the screen.
3. Describe three ways that the tungsten anode in an X-ray tube is kept cool.
4. What adjustment to an X-ray tube produces X-rays that are more penetrating?
5. An X-ray tube accelerates an electron through a potential difference of 40 000 000 V. (Charge on the electron = 1.6×10^{-19}C.)
   a. Show that its kinetic energy when it hits the anode is about 6.4×10^{-12} J.
   b. If 1.6×10^{15} electrons hit the anode, show the total energy they deliver is about 10 kJ.
   c. If this energy is delivered in about 0.2 s what is the power of the tube?
   d. What percentage of the energy above is converted to X-ray energy and hence explain why the tungsten anode needs to be cooled?
   e. Explain what effect increasing the filament temperature would have on the number of X-rays produced in an X-ray tube.

WAVES AND COMMUNICATIONS Beams of Light – CDs and Relativity

Einstein's theory of relativity is one of the most creative and challenging ideas in physics, while reading the information from a CD is a very straightforward application of physics. Yet they both involve ideas about beams of light.

A beam of laser light reads the information stored on a CD (or DVD).



Relativity

This theory makes some weird predictions about how we measure length and time when moving very fast relative to another object.

What would I see if I could ride a beam of light?

Assumptions:
1. The Laws of Physics are the same for all observers regardless of their speed relative to each other.
2. The speed of light is always the same whatever your speed – nothing can travel faster than the speed of light.

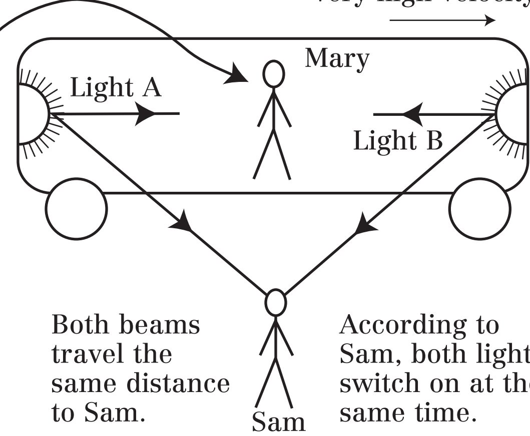
Einstein arrived at his ideas mainly through thought experiments (experiments that are too impractical to do but whose consequences can be tested).

Relativistic effects only show up if you are moving very close to the speed of light. One consequence is that observers can only agree on when events occurred if they are stationary relative to each other.

E.g. In the train, Mary catches up with light from B but moves away from light A.

Therefore, she sees light from B first so thinks B was switched on first.

Very high velocity



Both beams travel the same distance to Sam.

According to Sam, both lights switch on at the same time.

Other results of relativity

- Moving objects appear shortened.
- Moving clocks appear to run slow.
- The mass of an object appears to increase the faster it travels. This leads to the famous equation $\Delta E = \Delta mc^2$.

Some scientists did not like Einstein's ideas because they suggested Newton's Laws were not exactly right.

Other scientists → **Tested the predictions of relativity**

- Atomic clocks flown around the world on a jet aircraft record slightly less time than a stationary clock left on Earth.
- The extraction of energy by nuclear fission and fusion relies on $\Delta E = \Delta mc^2$ being correct.
- Cosmic rays create short-lived particles in the atmosphere. These travel towards the Earth's surface and should decay before reaching it, but do not as the distance appears much shorter to them. Therefore, they can easily cover it in their lifetime.

Questions

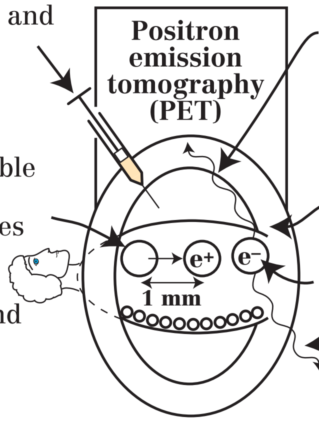
1. Laser beams can be made very narrow and do not spread out much. Why is this necessary for reading a CD as described above?
2. If you shake a CD player while playing a disc the music can be interrupted or skip a section. Using the above description try to explain why.
3. What is a thought experiment?
4. What predictions did Einstein make from his thought experiments?
5. Suggest three ways Einstein's predictions have been tested.

RADIOACTIVITY How is Nuclear Radiation Used in Hospitals?

Stable nuclei are bombarded with protons. These unstable proton-rich nuclei decay by beta-plus emission with short half-lives. They emit positrons.

Positron emitter made into a drug (designed to collect quickly in the organ of interest) and injected into the patient.

Especially if it is a cancerous tumour



1. Unstable nucleus undergoes beta-plus decay and emits a positron (e^+).

2. Positron travels about 1 mm before meeting an electron.

3. The two particles annihilate each other and become two gamma rays.

4. Gamma rays travel off in opposite directions to conserve momentum.

5. Gamma ray pairs are detected by circular detectors, which give a good indication of their origin.

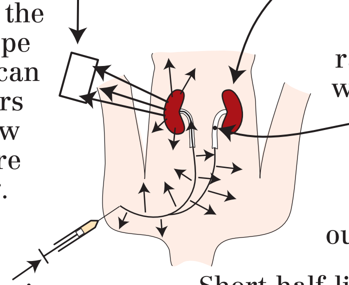
6. The origin of the gamma rays shows where the positron emitting drug has collected.

This can be used to find out how well the drug moves round the body and how well organs of interest are working, or if they contain a tumour.

Progress of the drug can be tracked by a radiation detector outside the body.

Radioisotope attached to a drug that is absorbed by an organ of interest, e.g. a kidney.

Monitoring the flow of the radioisotope over time can tell doctors about how organs are working.

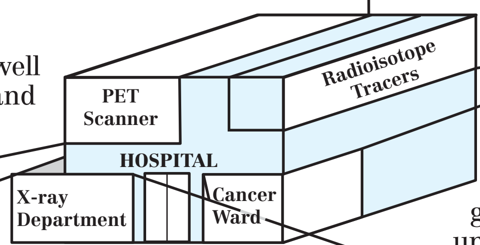


Blockage – radioisotope will not pass and no radiation detected in this area outside body.

Gamma emitter made into a drug and injected.

Short half-life used so radiation does not stay in the body too long.

Alpha emitters cannot be used as they would not pass through the body and are highly ionizing so would cause a lot of cell damage.

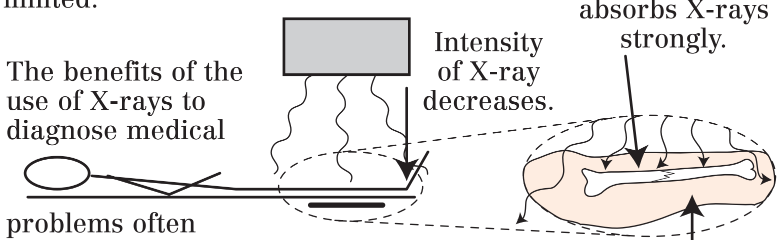


X-rays are high frequency, short wavelength, electromagnetic waves. They are ionizing so can damage cells. Exposure to them needs to be limited.

The benefits of the use of X-rays to diagnose medical problems often outweigh any cell damage caused.

Intensity of X-ray decreases.

Bone contains more heavy atoms, e.g. calcium, which absorbs X-rays strongly.



Flesh contains lighter atoms that do not absorb X-rays strongly.

X-rays expose photographic film and bones show up as a shadow.

Courtesy of Teaching Medical Physics

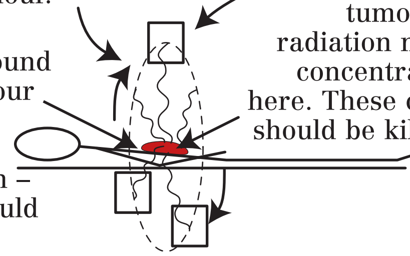
Cancerous cells are those where the DNA has been damaged and grow and divide uncontrollably.

Ionizing radiation can damage the DNA in cells.

If the radiation dose is small, the cells may be able to repair themselves. Large doses of radiation can kill cells. This can be used to kill cancerous cells.

Source of gamma rays

Source rotated around patient centred on the tumour.



Cells around the tumour receive less radiation – they should recover.

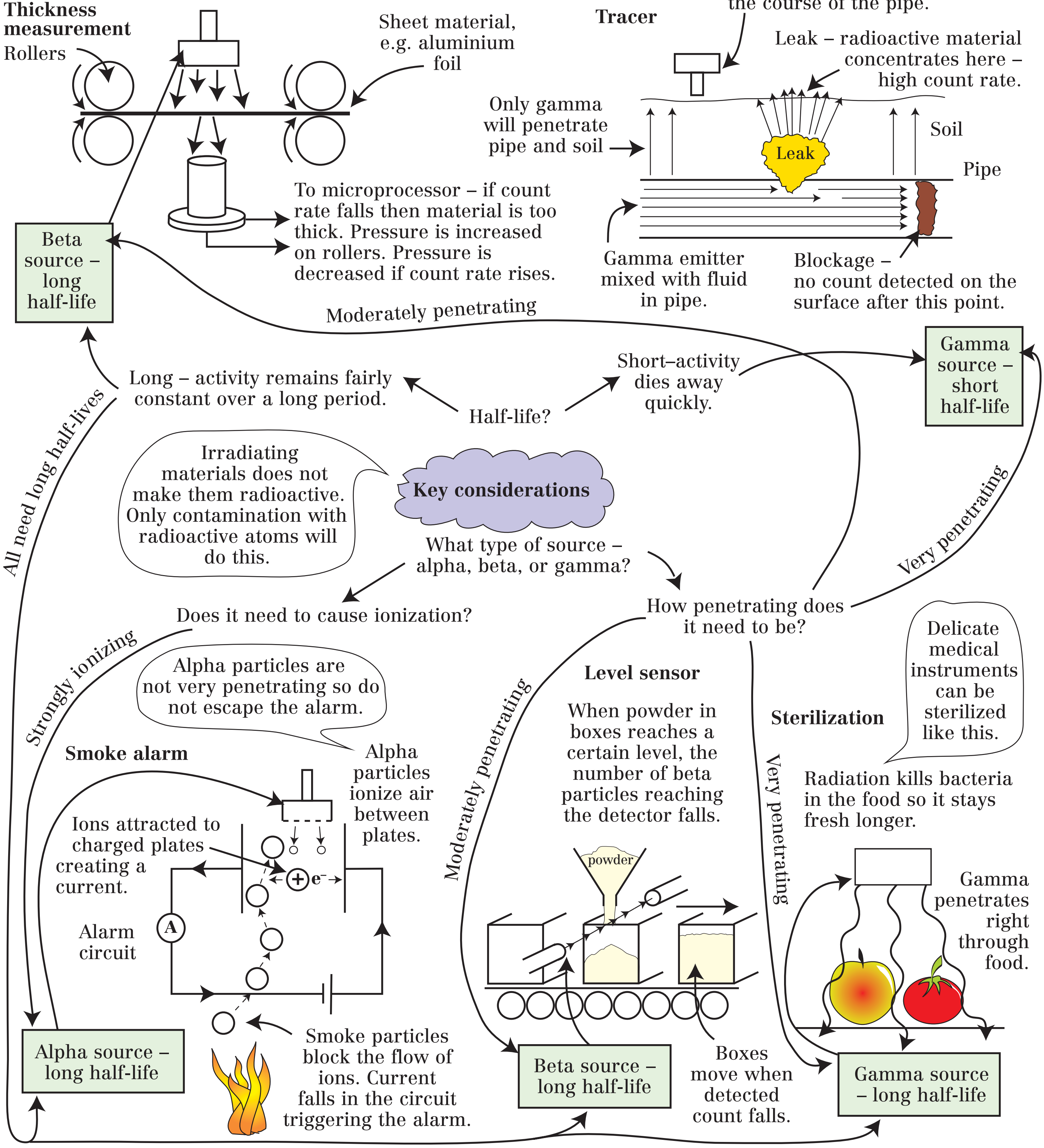
Cancerous tumour – radiation most concentrated here. These cells should be killed.

Radiotherapy may not be successful if the tumour is very large. In this case radiotherapy may be used to reduce suffering. This is called *palliative* care.

Questions

1. Which types of radiation, alpha, beta, or gamma can pass through flesh?
2. Why do the radioisotopes injected into patients always have short half-lives?
3. What absorbs X-rays better, flesh or bone?
4. What does PET stand for? Describe how it works, for example to identify the location of a cancerous tumour.
5. The thyroid gland stores iodine. How could injecting a patient with radioactive iodine-123 allow a doctor to find out how well the thyroid gland is working?
6. Ionizing radiation can cause the DNA in cells to mutate and cause cancer. Therefore, why can we also use ionizing radiation as a treatment for cancer?
7. Why is the source of gamma rays in radiotherapy rotated around the patient?
8. All ionizing radiation causes damage to the body. How do doctors justify exposing patients to it?

RADIOACTIVITY Other Uses of Radioactivity



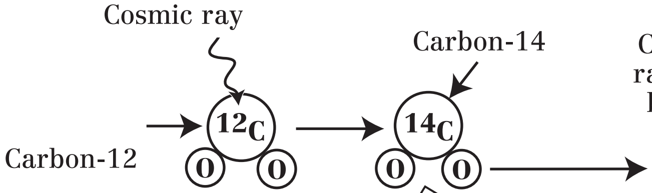
Questions

1. Explain whether an alpha, beta, or gamma source is most useful for the following and why:
   a. Smoke alarms.
   b. Detecting aluminium foil thickness in a factory.
   c. Following the flow of oil along a pipe.
2. Should a radioactive material with a long or short half-life be chosen for the following and why?
   a. Smoke alarm.
   b. Tracer in an oil pipe.
   c. Thickness detection in a factory.
3. Many people are concerned about the effect on their health of radioactive sources. How would you address the following concerns?
   a. 'I don't have a smoke alarm as I do not want a radioactive source in my house.'
   b. 'I am concerned that irradiated food might be radioactive.'

RADIOACTIVITY Radioactive Dating

Cosmic rays from space hit carbon atoms in carbon dioxide in the atmosphere and convert a very small number of them (about four in every three million, million) to carbon-14.

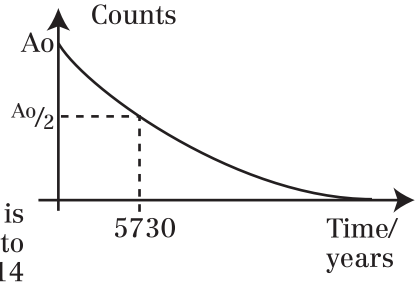
Carbon dating



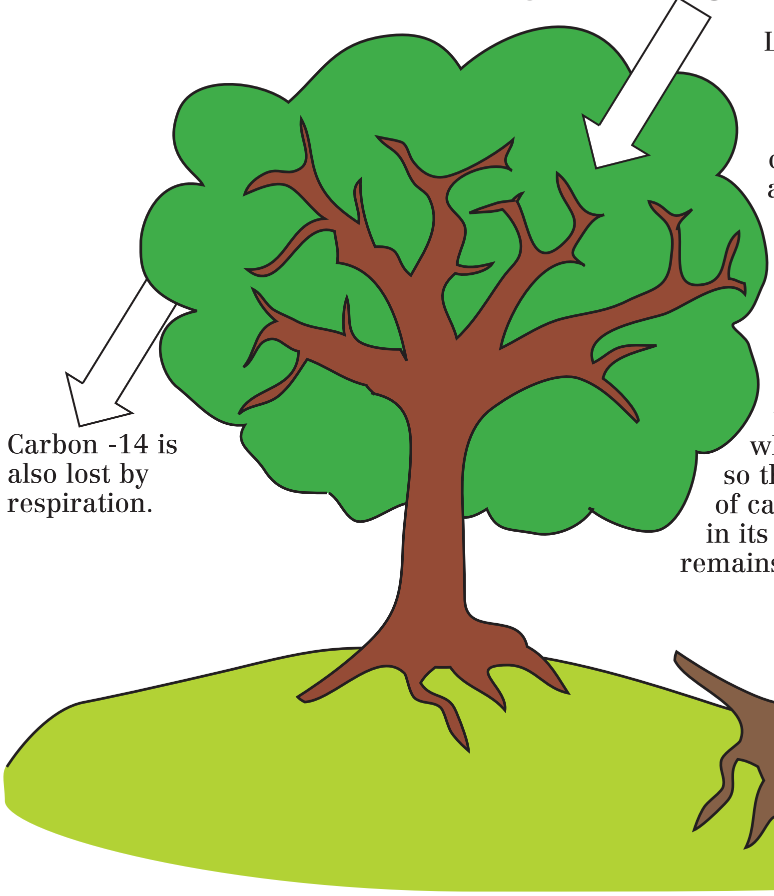
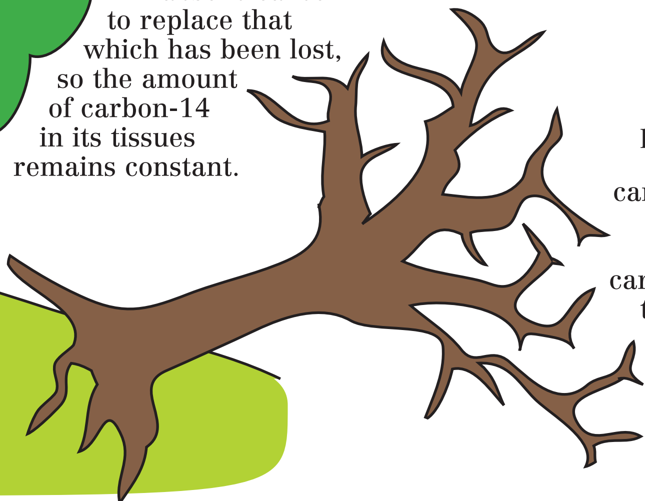
Carbon-14 nuclei are radioactive and decay by giving out a beta particle to form nitrogen nuclei.

$^{14}_{6}C \rightarrow ^{14}_{7}N = ^{0}_{-1}\beta$

Carbon-14 has a half-life of 5730 years.



Living plant material absorbs carbon dioxide (including the radioactive carbon-14) from the air and builds it into its tissues during photosynthesis.

Carbon -14 is also lost by respiration.

While the plant is living, it continues to absorb carbon-14 to replace that which has been lost, so the amount of carbon-14 in its tissues remains constant.

When the plant dies, no more carbon-14 is absorbed and the carbon-14 in the plant's tissues begins to decay away.

Measuring the activity of a sample of ancient materials that were once living and comparing the activity to a living sample can give a fairly accurate indication of when the ancient material was alive.

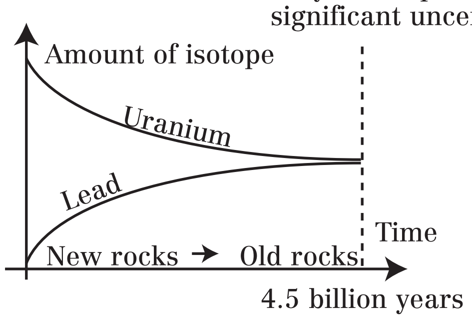
(It works for plant or animal material because animals eat plants and absorb carbon-14 from them.)

Assumption: the concentration of $^{14}CO_2$ in the atmosphere has remained constant.

Very small quantities are involved leading to significant uncertainties.

Dating of rocks

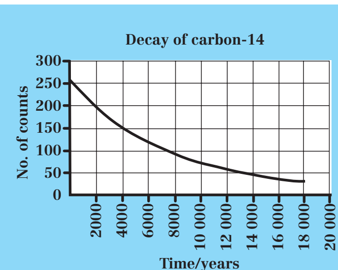
Many rocks contain traces of radioactive uranium. This decays to stable lead with a half-life of 4.5 billion years.



Assuming that there was no lead in the rock when it was formed the ratio of uranium to lead gives an approximate age for the rock.

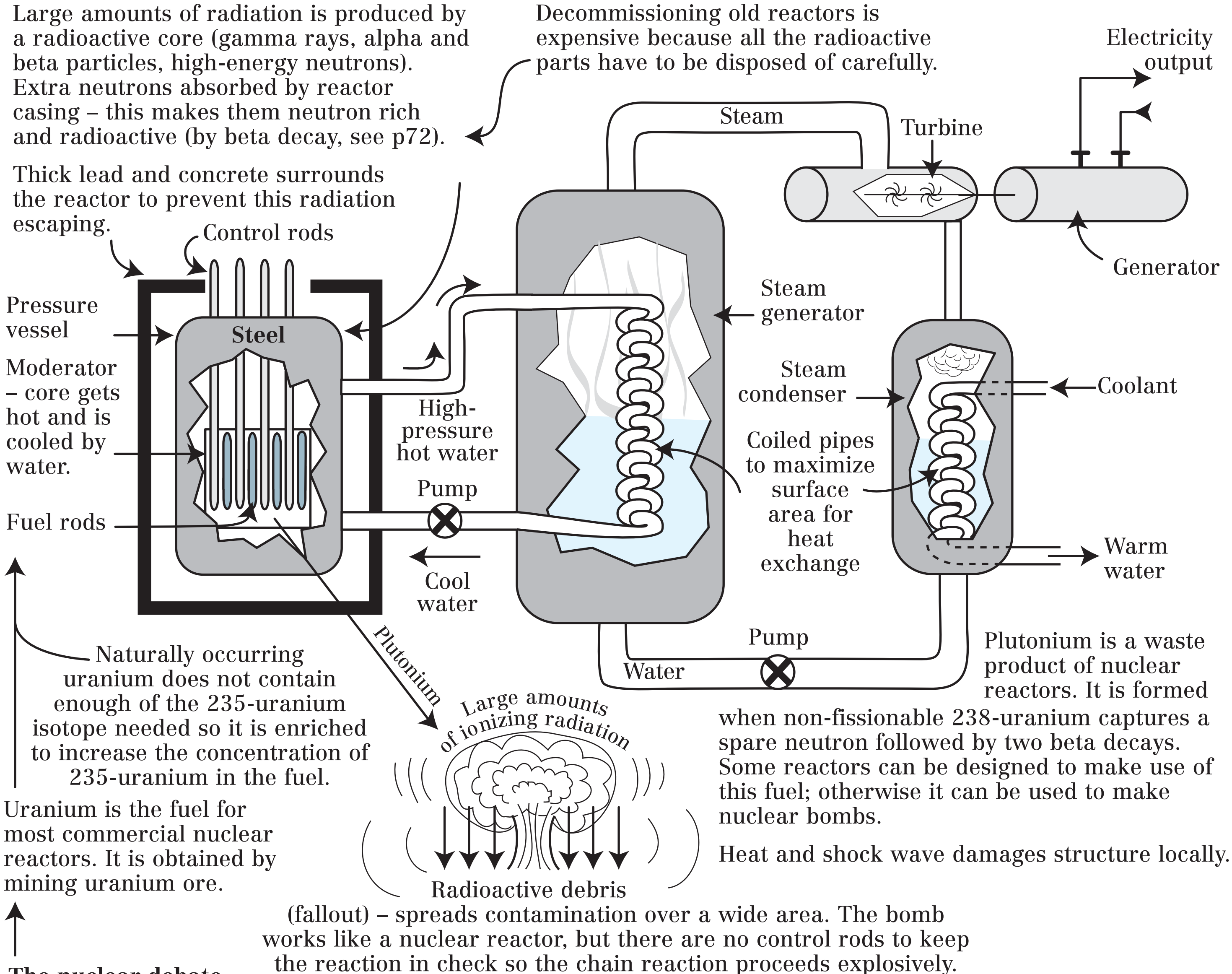
Questions

1. The graph shows the radioactive decay of carbon-14.
   a. Use the graph to calculate the half-life of carbon-14. What does carbon-14 decay into?
   b. A wooden post from an archaeological dig produces 150 counts/min. Wood from an identical species of tree currently alive gives 600 counts/min. How long ago did the wood from the archaeological dig die?
   c. What assumption have you made in the above calculation?

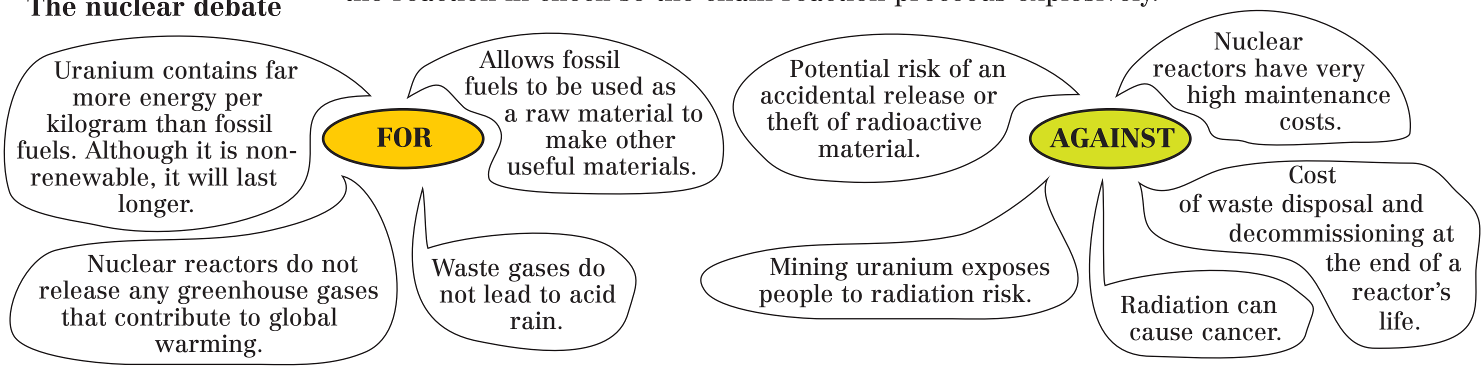


2. Two samples of rock are analysed. The ratio of 238-uranium to 206-lead are as follows:
   Sample A: uranium to lead 5:1 Sample B: uranium to lead 7:1.
   Which rock is older and how do you know? What assumption have you made?
3. The age of the Earth is thought to be about 4.5 billion years. Why can there be no rock in which the number of lead nuclei formed from the decay of uranium outweighs the number of uranium nuclei remaining?

See p77 for a description of the nuclear fission process and the nuclear reactor.



The nuclear debate



Questions

1. Write out a list of energy changes in a nuclear power station starting from nuclear energy stored in uranium fuel and ending with electrical energy in the wires leading from the generator.
2. Where does the fuel for a nuclear power station come from and what has to happen to it before it can be used?
3. The energy released by 1 kg of ^{235}U is about 8×10^{13} J. Show that this could light a 60 W light bulb for about 42 thousand years.
4. Using the diagram of a nuclear power plant above explain:
   a. Why is the reactor surrounded by a thick layer of concrete and lead?
   b. Why is the pressure vessel made of steel?
   c. Why are the pipes in the heat exchangers coiled up?
5. Nuclear weapons cause damage to living things in three ways – what are they?
6. 'Nuclear power damages the environment and should be banned.' Give arguments in favour and against this statement.

RADIOACTIVITY Radioactive Waste

Sources:
- Nuclear fission power stations (p111).
- Industrial users of radioactivity (p109).
- Hospitals and other medical establishments (p108).
- Laboratories.
- Decommissioned nuclear weapons.

These wastes should be disposed of in a way that does not significantly increase the naturally occurring background level of radiation around the disposal site.

Waste is classified into three levels by considering:

- How long the waste will remain at a hazardous level.
- The concentration of radioactive material in the waste.
- Whether it is heat generating.

Low-level

Waste paper, rags, clothing, filters.

Enough radioactive material to require action to protect people but not enough to require special handling or storage. The definition of a 'safe' level might change over time.

Comprises about 90% of the volume but 1% of the radioactivity of all radioactive waste.

Intermediate level

Mainly very small amounts of short half-life isotopes.

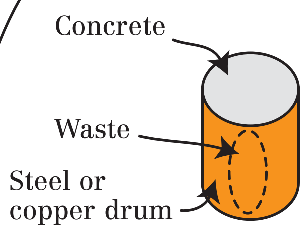
Materials that have been in direct contact with highly radioactive isotopes, e.g. nuclear fuel cladding.

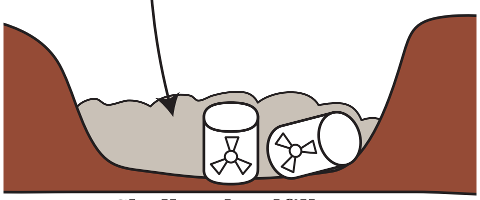
Short half-life / Long half-life

Half-life >30 years or a high proportion of alpha emitters

Requires shielding by encapsulating in concrete (and sometimes lead).

Protects against gamma rays





Shallow landfill

Can be difficult to site as the local population may have concerns about their safety.

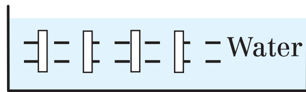
High-level

Radioactive isotopes, e.g. fission products from a reactor. 95% of total radioactivity but a very small volume.

Requires both shielding and cooling.

It is highly radioactive and hot as nuclear decay is still occurring at a high rate.

Allowed to cool under water for about 3 months.



Vitrification

Waste is mixed with glass (which is chemically unreactive and insoluble). Helps to prevent waste leaking out.

Reprocessing

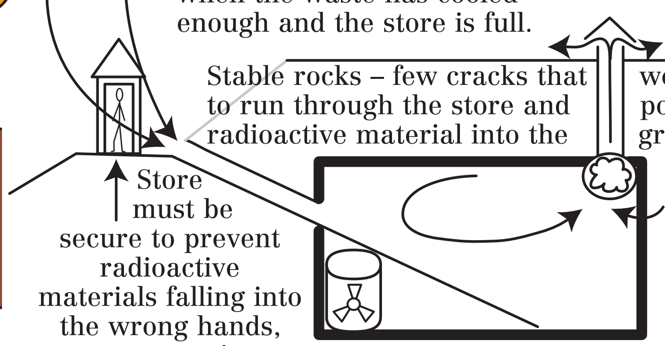
Some spent fuel still contains unreacted isotopes that are in too low a concentration to be useful. They are extracted, concentrated, and added to new reactor fuel.

Eventually the store will be filled with concrete and sealed when the waste has cooled enough and the store is full.

Stable rocks – few cracks that would allow water to run through the store and potentially carry radioactive material into the groundwater.

Store must be secure to prevent radioactive materials falling into the wrong hands, e.g. terrorist organizations.

Air circulated by fans to remove heat produced by the still decaying waste.



Managed underground store

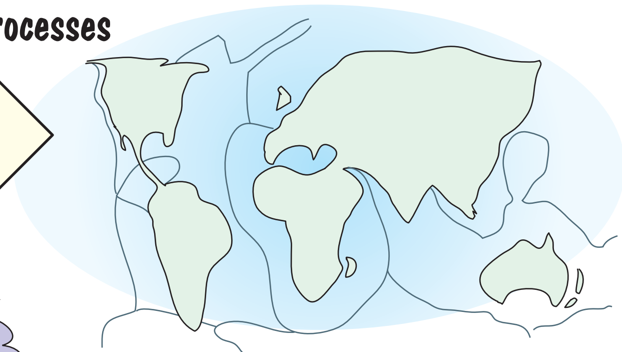
Questions

1. What are the three classifications of nuclear waste?
2. What types of materials make up low-level waste?
3. What is the main constituent of intermediate level waste?
4. What constitutes high-level waste and why is this generally hot?
5. What happens to low-level waste?
6. What happens to intermediate level waste?
7. What happens to high-level waste?
8. Why are spent fuel rods left in cooling ponds for 3 months after use?
9. You are responsible for finding a site for a new managed underground radioactive waste store.
   a. What features would you look for in identifying a suitable site?
   b. What concerns might local residents have?
   c. How might you go about addressing these concerns?

OUR PLACE IN THE UNIVERSE Geological Processes

Theory of plate tectonics

The Earth's crust is made up of a number of independent plates.



Magma rises and pushes plates apart making the ocean grow wider.

Tectonic plates are dragged along by the mantle as it convects under them.

Constructive plate boundary

Plates can move relative to each other.

One slides under another.

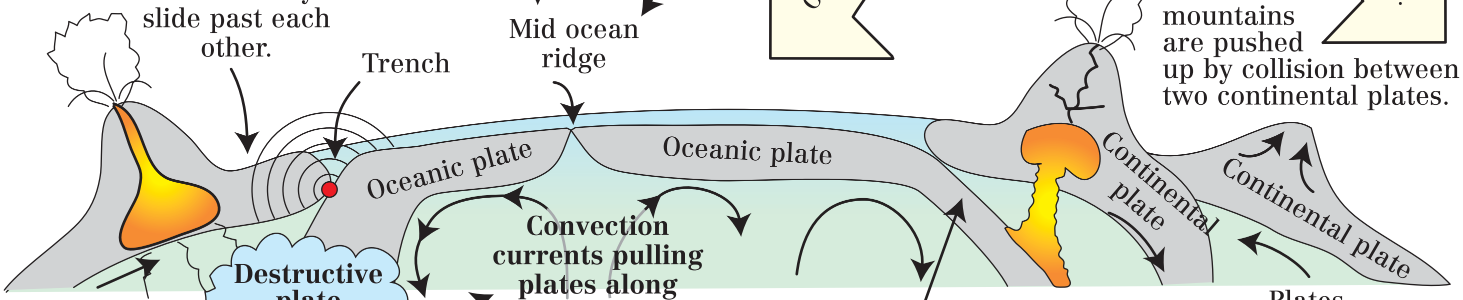
Plates collide.

Earthquakes occur as plates stick as they slide past each other.

Trench

Mid ocean ridge

New mountains are pushed up by collision between two continental plates.



Destructive plate boundary

Convection currents pulling plates along

Radioactive decay of isotopes in the mantle provides the heat.

Subduction zone

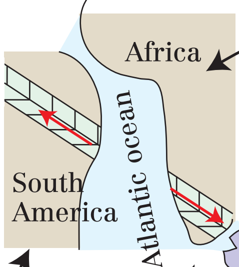
Plates typically move at about 10 cm per year.

Oceanic ridge slides under the continental plate and melts. Some of this molten rock (magma) rises to the surface via cracks in the crust forming volcanoes.

Mantle – very hot and under pressure. Although effectively solid, it can flow very slowly by convection due to the very hot core of the Earth.

Rocks either side of oceans often match, suggesting that they were once joined.

'Fit' of continents, e.g. Africa and South America suggests that they were once joined.



Without mountain building, mountains would eventually be eroded to sea level.

Suggested by Wegener (1912)

Large continent broken apart.

Evidence for plate tectonics

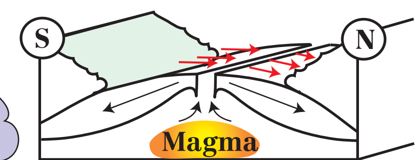
Similar fossils occur in now separated continents, suggesting they were joined when those animals and plants were living.

Wegener's theory was originally not accepted. He did not have any convincing reasons explaining how the plates moved. He overestimated the rate at which plates would move; the rate did not agree with observations.

There were simpler explanations of the same evidence.

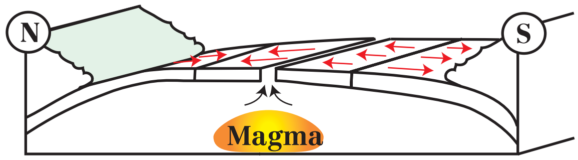
Magnetic striping of rocks is evidence that the oceanic plates are moving apart.

The Earth's magnetic field reverses every few million years; the North Pole becomes the South and *vice versa*.



New rock is magnetized by the Earth's magnetic field as it solidifies.

New rock formed after a reversal of the field will have the opposite magnetization.

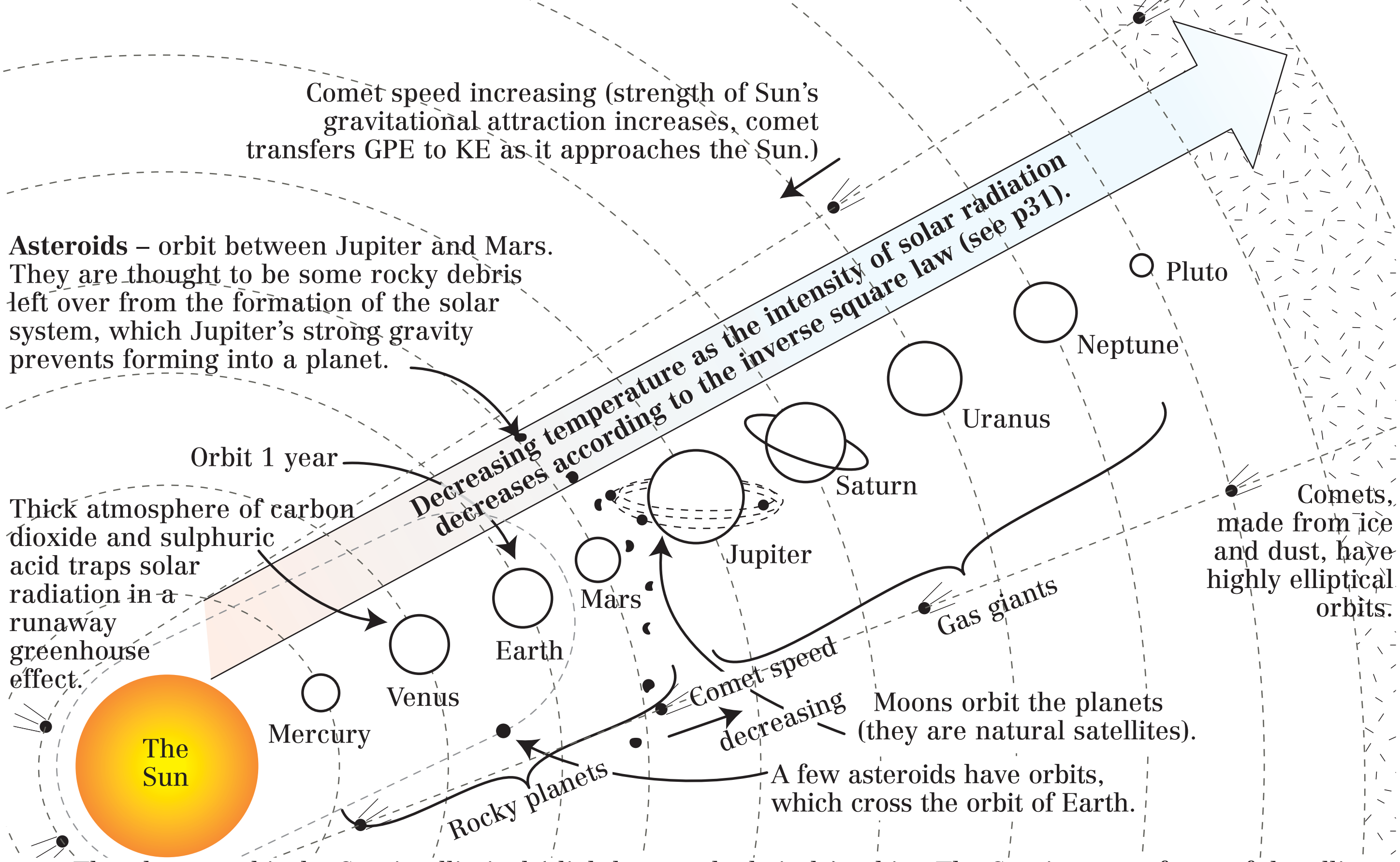


Questions

1. What is the difference between a constructive and destructive plate boundary?
2. Explain why the majority of earthquakes and volcanoes occur near plate boundaries.
3. Give three pieces of evidence mentioned above in support of the idea of plate tectonics.
4. Why did people find it difficult to accept Wegener's ideas?
5. What is the name of the process that causes the material in the mantle to circulate and drag the plates along?
6. Describe how the magnetization of the rocks of the oceanic crust could be used to show that the ocean is growing wider over millions of years.
7. Describe and explain the differences between the collision of two continental plates compared to a continental and an oceanic plate.

OUR PLACE IN THE UNIVERSE The Solar System

Oort cloud – objects made of ice and dust orbiting the Sun far beyond Pluto. Sometimes these fall in towards the Sun and become a comet due to minor gravitational disturbances.



The planets orbit the Sun in elliptical (slightly squashed circle) orbits. The Sun is at one focus of the ellipse.

Quantity	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Mean distance from sun (orbit radius), million km	57.9	108	150	228	778	1430	2870	4500	5900
Time to orbit the Sun, years	0.241	0.615	1.00	1.88	11.9	29.5	84.0	165	248
Orbital speed, km/s	47.9	35.0	29.8	24.1	13.1	9.64	6.81	5.43	4.74
Equatorial diameter, km	4880	12 100	12 800	6790	143 000	120 000	51 800	49 500	?3000
Mass (Earth = 1)	0.0558	0.815	1.000	0.107	318	95.1	14.5	17.2	?0.010
Density g/cm^3	5.600	5.200	5.520	3.950	1.310	0.704	1.210	1.670	?
Moons	0	0	1	2	16	17	15	2	1
Typical surface temperature, °C	167	457	14	–55	–153	–185	–214	–225	–236
Atmosphere	None	Carbon dioxide	Nitrogen, oxygen	Carbon dioxide	Hydrogen, helium	Hydrogen, helium	Hydrogen, helium	Hydrogen, helium	None

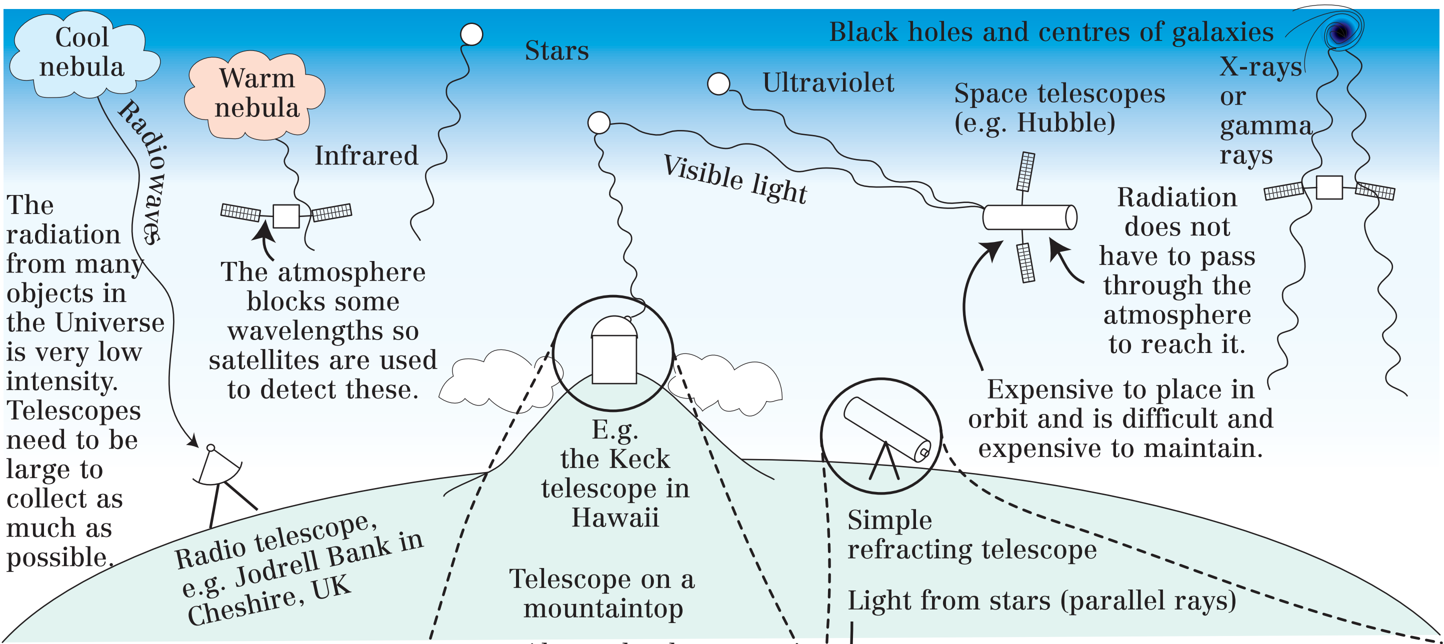
Questions

1. Which of the following orbit the Sun directly and which orbit planets? Comets, moons, asteroids, artificial satellites, planets.
2. Explain why the density of Jupiter, Saturn, Uranus, and Neptune is a lot less than that of Mercury, Venus, Earth, and Mars.
3. Using the data in the table show that: a. The circumference of the Earth's orbit is 942 million km. b. The time the Earth takes to orbit the Sun is 31.6×10^6 s. c. That 31.6×10^6 s = 1 year.
4. Plot a graph of surface temperature vs. distance from the Sun. State and explain any trend you see. One planet is anomalous, which is it and give a scientific explanation for why it does not fit the trend?
5. Explain why the speed of a comet decreases as it moves away from the Sun.

OUR PLACE IN THE UNIVERSE

Telescopes and Types of Radiation Used to Learn About the Universe

Everything we know about space outside the solar system comes from analyzing the electromagnetic radiation collected from space by telescopes.
Different objects in space emit different wavelengths.



Electromagnetic rays are diffracted by an aperture – see p39.

The bigger the aperture the less diffraction and the better the quality of the image.

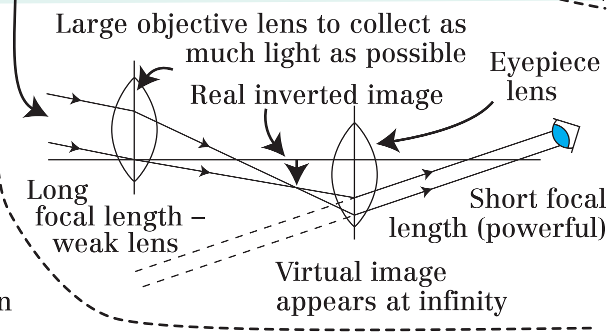
As radiowaves are so long, radio telescopes need to have very big reflecting dishes to avoid too much diffraction.

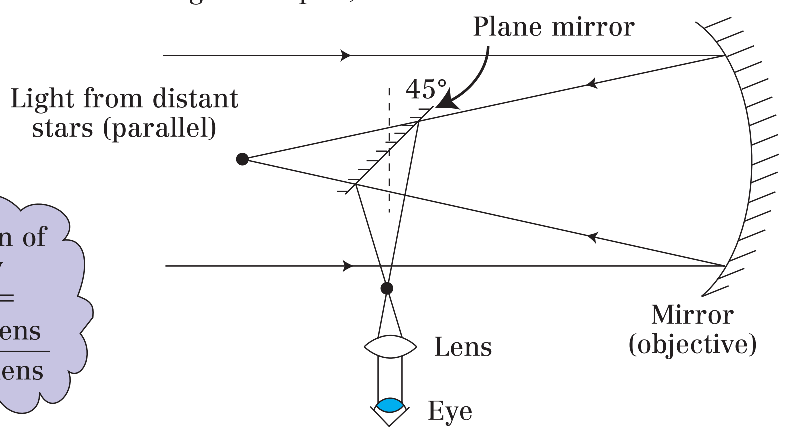
Above clouds

Away from cities which produce light pollution

Less atmosphere to look through (atmosphere contains dust and slightly refracts light reducing the quality of the image).

Large reflecting telescope. (These give better quality images than refracting telescopes.)





All large telescopes use mirrors as they can be supported across their whole diameter (up to about 6 m).

A lens this size would distort under its own weight and ruin the image.

The angular magnification of a telescope is given by

$$\text{Angular magnification} = \frac{\text{focal length of objective lens}}{\text{focal length of eyepiece lens}}$$

Questions

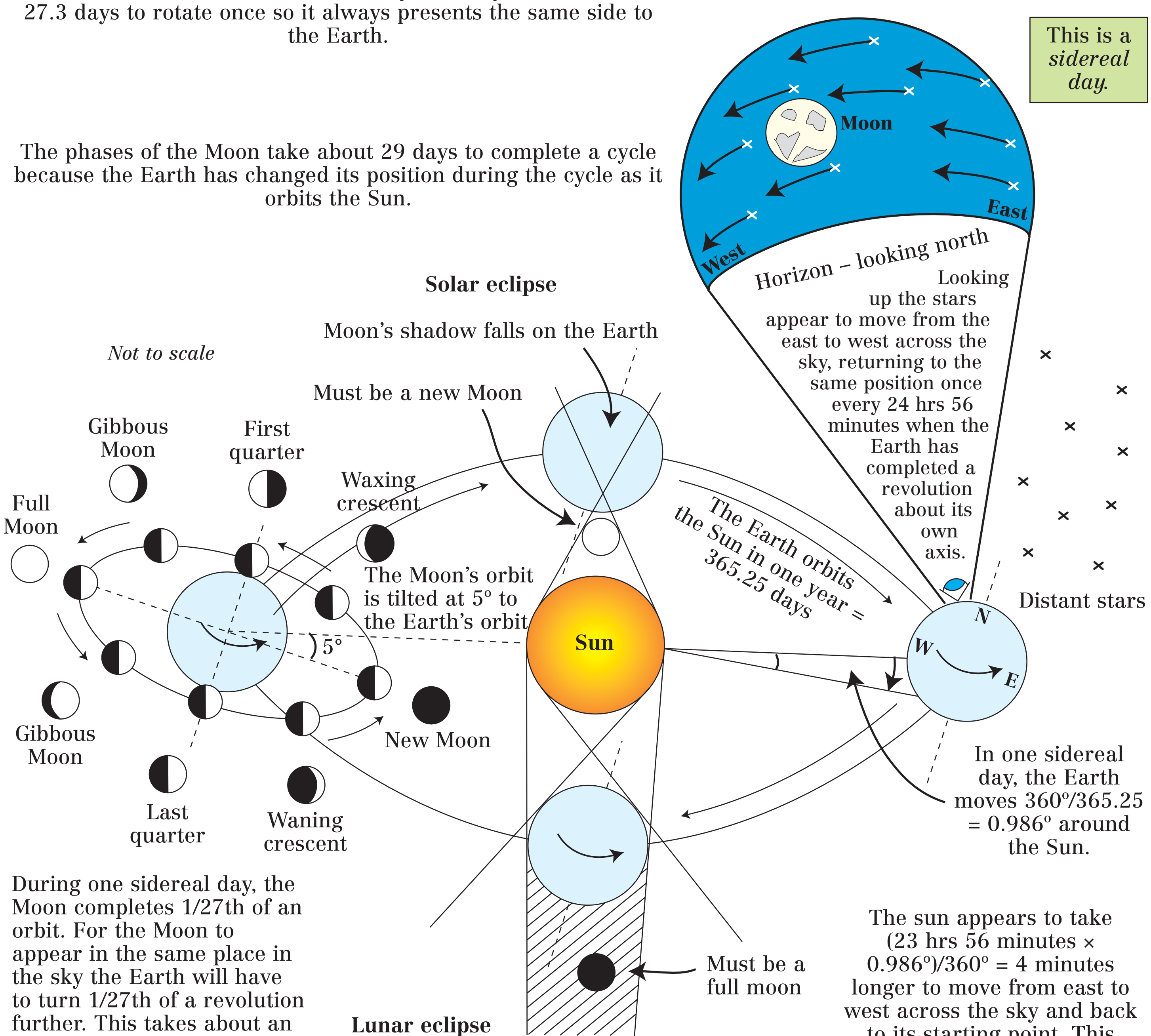
1. Make a list of the advantages and disadvantages of space telescopes compared to ground based telescopes.
2. Why do you think optical telescopes that collect visible light are often placed on mountains whilst radio telescopes can be at sea level?
3. Will the image in a refracting telescope be upright or inverted? Use a ray diagram to illustrate your answer. Suggest two advantages of having a very large objective lens and explain why there is a limit on how big the objective lens can be.
4. The aperture of a reflecting telescope is 0.7 m in diameter and it collects light of wavelength of about 0.00000055 m. Its objective mirror has a focal length of 0.4 m and its eyepiece a focal length of 1.50 cm. The diameter of the Jodrell Bank radio telescope dish is 76.2 m and the wavelengths it collects are around 1 m.
   a. What is the angular magnification of the reflecting telescope?
   b. Which telescope would you expect to suffer the most from diffraction?
5. Suggest at least three reasons why astronomers need to work together in international groups.

OUR PLACE IN THE UNIVERSE The Motion of Objects in the Sky

The Moon orbits the Earth once every 27.3 days. It also takes 27.3 days to rotate once so it always presents the same side to the Earth.

The Earth spins on its axis, through 360° once every 23 hrs 56 minutes.

The phases of the Moon take about 29 days to complete a cycle because the Earth has changed its position during the cycle as it orbits the Sun.

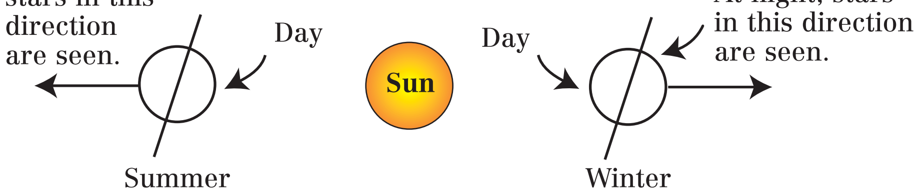


During one sidereal day, the Moon completes 1/27th of an orbit. For the Moon to appear in the same place in the sky the Earth will have to turn 1/27th of a revolution further. This takes about an extra 49 minutes. Therefore, moonrise occurs once every 24 hrs 49 minutes.

Eclipses do not happen once each month because the Moon's orbit is tilted so is usually above or below the direct line between the Earth and Sun.

The sun appears to take (23 hrs 56 minutes × 0.986°)/360° = 4 minutes longer to move from east to west across the sky and back to its starting point. This makes a solar day 4 minutes longer (i.e. 24 hrs exactly) than a sidereal day.

Different stars are seen in different seasons.



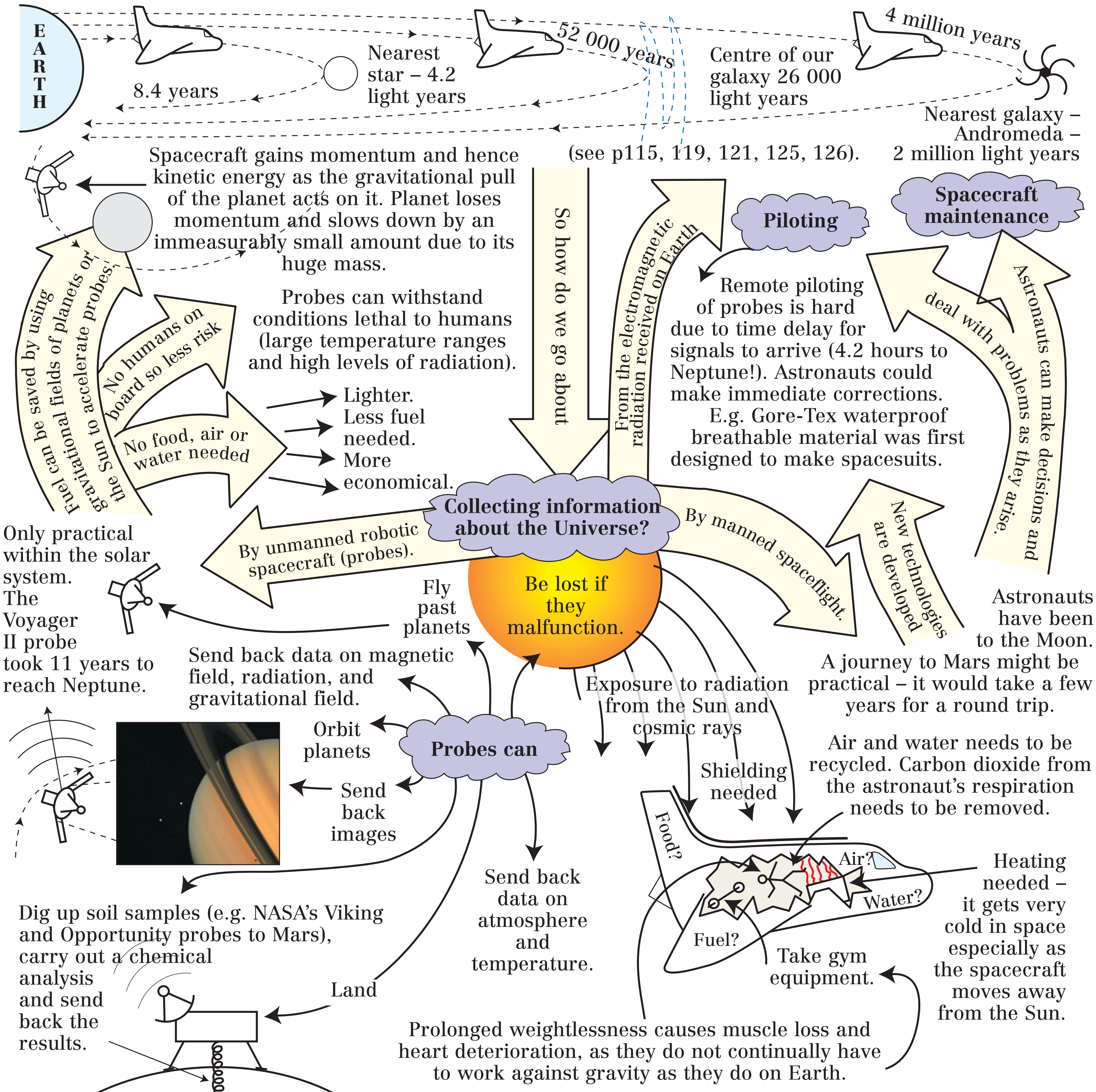
Some planets are visible with the naked eye (Mercury, Venus, Mars, Jupiter, and Saturn). They follow complicated paths in the sky because they too are moving around the Sun, at different speeds relative to the Earth. The term planet means 'wandering star'.

Questions

1. Do most objects in the sky appear to move east to west or west to east? Which objects do not always follow this pattern?
2. What is the difference between a solar day and a sidereal day?
3. What is the difference between a lunar eclipse and a solar eclipse?
4. Why do we not have an eclipse once a month?
5. Why does the Moon appear at slightly different places in the sky each night at the same time?

OUR PLACE IN THE UNIVERSE Exploring Space

The Universe is vast. The light from the nearest star takes 4.2 years to reach Earth. If we could build a spaceship to travel at the speed of light the round trip journey time would be as follows.



Questions

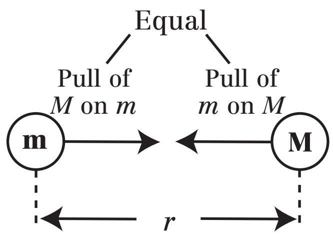
1. What are the three main ways scientists find out about the Universe?
2. Copy and complete the following table to summarize the advantages and disadvantages of two ways of exploring the solar system.

	Manned spaceflight	Unmanned robotic probes
Advantages		
Disadvantages		

3. It is proposed to send astronauts to Mars. Apart from the journey time of a couple of years, what other considerations are necessary when designing a spacecraft to make the journey?
4. 'Exploring Space is a waste of money that would be better spent on giving aid to people who live in poverty.' Do you agree or disagree with this statement? Give some explanation to try to convince somebody to support your view.
5. Explain why manned missions outside the solar system are very unlikely.

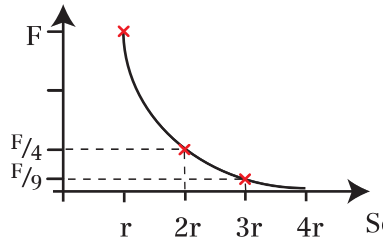
OUR PLACE IN THE UNIVERSE Forces in the Solar System

All masses exert gravitational attractions on all other masses.



This gravitational attraction is:

- Proportional to the product of the two masses ($F \propto M \times m$)
- Inversely proportional to the square of the distance between their centres of mass ($F \propto 1/r^2$).



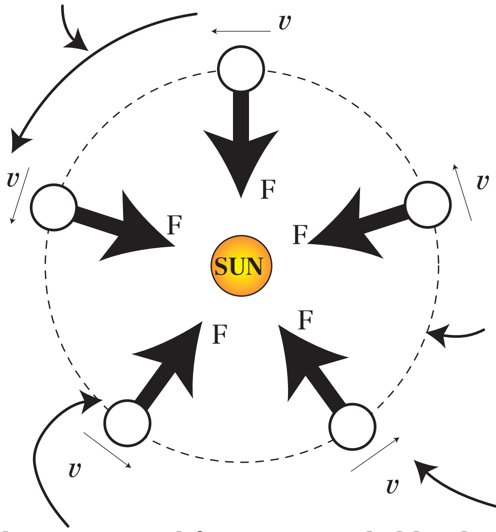
Mathematics

Orbital circumference = $2\pi r$

Orbital period = T

Therefore orbital speed, $v = 2\pi r/T$

Time for one orbit = orbital period.



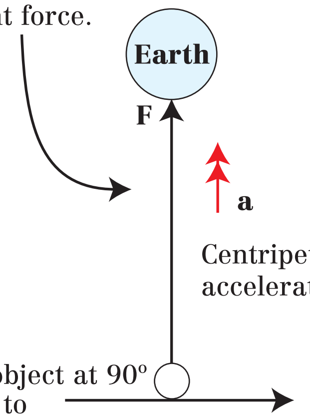
The planets follow nearly circular paths around the Sun (slightly elliptical). To do so they need centripetal force acting towards the centre of their orbit, towards the Sun.

If there were no gravitational forces, the planets and moons would continue to move in a straight line according to Newton's First Law, as there would be no forces acting on them. They would drift off into space.

This centripetal force is provided by the gravitational attraction between the planet and the Sun.

Orbiting body

Centripetal force provided by gravitational attraction is the net resultant force.



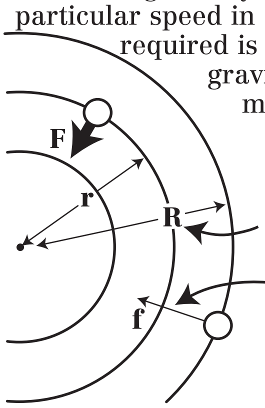
Velocity of object at 90° (tangential) to acceleration.

Satellites and moons orbiting a planet also need centripetal force acting towards the planet at the centre of their orbit. It is provided by the gravitational attraction between the satellite or moon and the planet.

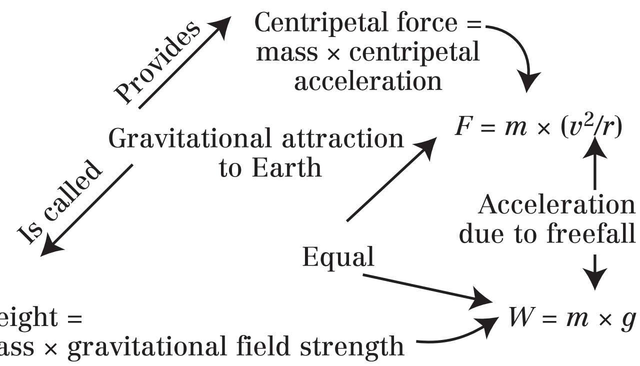
From p19 Centripetal force = mass × velocity^2/radius of orbit.

Therefore, to stay in orbit at a particular distance from a larger body, a smaller body must travel at a particular speed in order that the centripetal force required is exactly provided by the available gravitational attraction between the masses.

As force and distance travelled are always perpendicular, no work is done (N.B. remember work = force × distance in the direction of the force). Therefore, the body does not need any energy to be transferred to stay in orbit.



Advanced maths tells us that the larger the orbit radius the slower the body must move because of the weaker gravitational attraction. In addition, the orbit circumference is bigger so the orbital period rapidly increases.

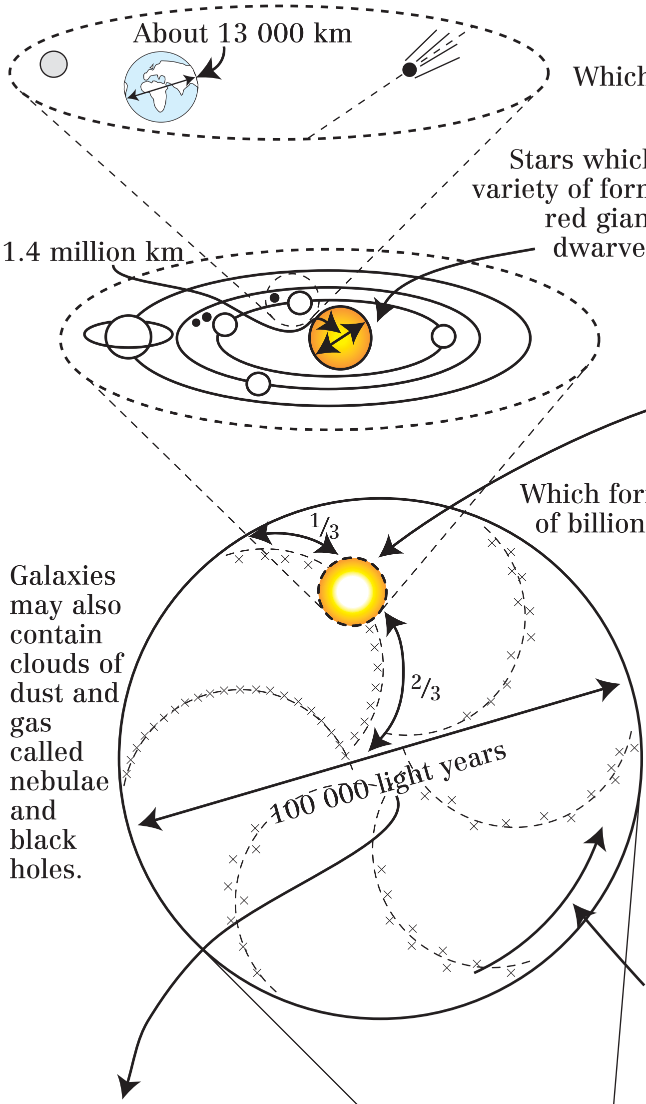


Questions

1. A planet orbits the Sun. What would happen to the size of its gravitational attraction to the Sun if:
   a. It doubled in mass but stayed in the same orbit?
   b. It stayed the same mass but moved to an orbit twice the distance from the Sun?
2. What happens to the orbital period of a planet as you move away from the Sun? Does the table on p114 confirm this? Give two reasons why the orbital period varies in this way.
3. A geostationary satellite has a mass of 5 kg and an orbit radius of 42×10^6 m.
   a. Show that its orbit circumference is about 260×10^6 m.
   b. Given that its orbital period is 86 400 s, show that its orbital speed is about 3000 m/s.
   c. Therefore, show that the centripetal acceleration is about 0.2 m/s^2.
   d. Explain why the satellite's weight in this orbit is about 1 N.

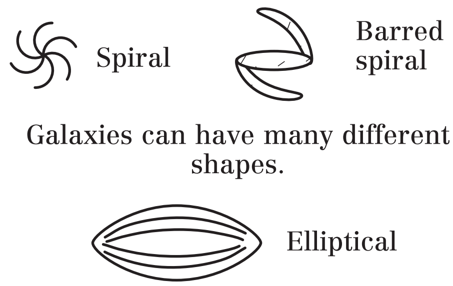
OUR PLACE IN THE UNIVERSE The Structure of the Universe

The Universe consists of:
Planets, moons, asteroids, and comets.



Which orbit . . .

Stars which also come in a variety of forms (main sequence, red giants, and white dwarves, see p122).

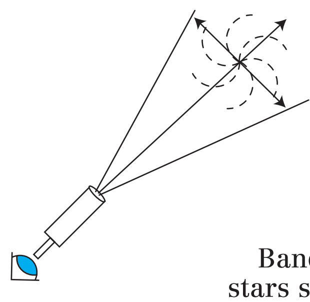


Galaxies can have many different shapes.

Our Sun is in an arm of a spiral galaxy we call the Milky Way. We see this as a band of stars across the night sky as we look through the plane of our galaxy.

Which form themselves into clusters of billions of stars called *galaxies*.

Galaxies may also contain clouds of dust and gas called nebulae and black holes.



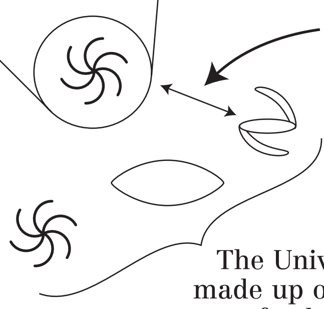
Band of stars seen

Rotates very slowly, once every 240 million years.

The *nearest* star to Earth is about 4.2 light years away. Since the light has taken 4.2 years to reach Earth we see the star as it was 4.2 years ago.

A light year is the distance light will travel (at 3×10^8 m/s) in a year. It is about 9.5×10^{15} m or 9.5 million, million kilometres.

Each galaxy is separated from its neighbours by many times it own diameter so, as the Universe contains billions of galaxies, it is unimaginably vast.



The Universe is made up of billions of galaxies.

Astronomers have detected planets around some nearby stars. If even a small proportion of the stars in the rest of the Universe have planets, some astronomers think it is very likely that there is life elsewhere in the Universe.

The further we look into space the longer the light has been travelling so the further back in time we are seeing.

Like the solar system, galaxies are held together by gravity.

Some astronomers are looking for signals sent by intelligent life from elsewhere in the Universe. This is called the 'search for extraterrestrial intelligence' or SETI.

Questions

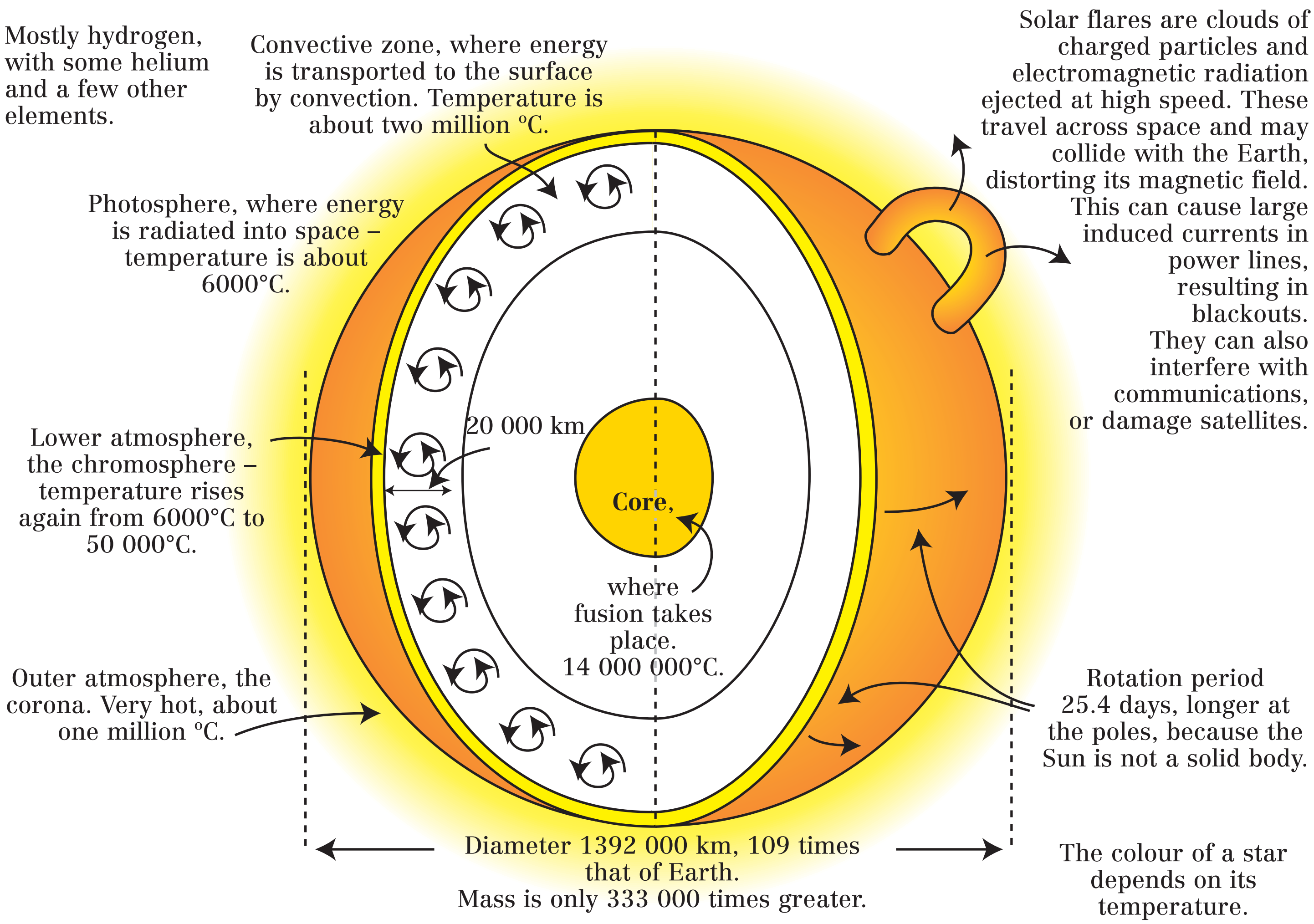
1. List the following objects in order of size: galaxy, planet, star, and comet.
2. What force is responsible for holding galaxies together?
3. A galaxy is 100 000 light years from Earth. When we look at the galaxy through a telescope, we are seeing it as it was 100 000 years ago. Explain why.
4. If the nearest star is 4 light years away, show it would take a rocket travelling at 11 km/s (the speed needed to just escape the Earth) about 109 000 years to get there. (Speed of light = 3×10^8 m/s.)
5. Suggest why astronomers find it so difficult to detect planets around stars other than the Sun.

OUR PLACE IN THE UNIVERSE The Sun

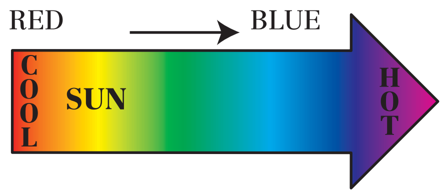
For many years, scientists could not work out the source of energy for the Sun. Some thought the energy was released as the Sun shrank in size releasing gravitational potential energy. Others thought it was a chemical reaction like coal burning in a fire. However, geologists knew that the age of the Earth was about 5000 million years old and none of these ideas would provide enough energy to keep the Sun's energy output at the observed rate for anything like that long.

We now know that the Sun is about 4600 million years old and its energy comes from nuclear fusion (see p78 for more details). In the core, under extreme pressure and temperature, hydrogen nuclei are forced together to form helium nuclei releasing vast amounts of energy. There is enough fuel for another 5000 million years.

Einstein's famous relation $\Delta E = \Delta mc^2$, shows this enormous energy release, ΔE, comes at the expense of a small overall loss in the mass of the particles, Δm, linked by the speed of light $c = 3 \times 10^8$ m/s. Inside the Sun, 600 million tonnes of hydrogen are converted in nuclear fusion reactions every second, and 4 million tonnes of this is converted into energy.



The colour of a star depends on its temperature.



Light can exert a force on particles of matter. We do not usually notice this because the force is extremely small. However, with the amount of light in the Sun the pressure is significant and stops the outer layers collapsing under gravity.

Questions

1. What provides the energy for the Sun?
2. How can you guess the temperature of a star simply by looking at it? (N.B. Never look directly at the Sun.)
3. What problems can solar flares cause on Earth?
4. If the Sun looses 4 million tonnes (4×10^9 kg) every second, use $\Delta E = \Delta m \times (3 \times 10^8 \text{ m/s})^2$ to calculate the energy output of the Sun per second, i.e. its power.
5. Show that if the Sun has a diameter 109× that of the Earth, its volume is over 1 million times greater.

Stars and Their Spectra

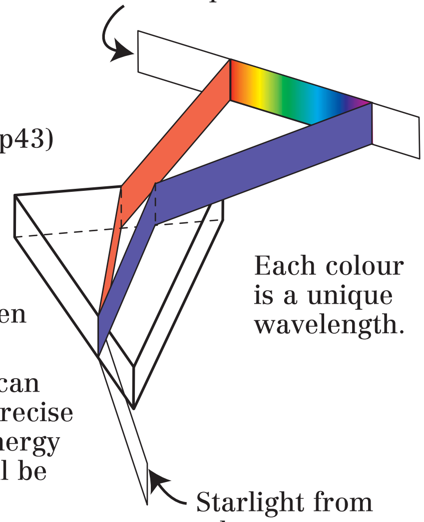
Analyzing the light from stars can tell us . . .

- How bright they are (and therefore how far away they are).
- What elements they contain.
- How fast they are moving.

By splitting the starlight up into its spectrum.

(See p43)

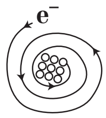
Continuous spectrum



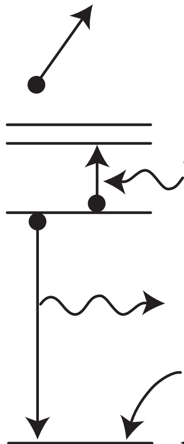
Each colour is a unique wavelength.

Starlight from telescope

1. More advanced physics tells us the electrons in Rutherford's model of the atom should lose energy and spiral into the nucleus.



2. Clearly, this does not happen, atoms are stable. Neils Bohr suggested that the electrons could only have certain energy levels, like the rungs on a ladder.

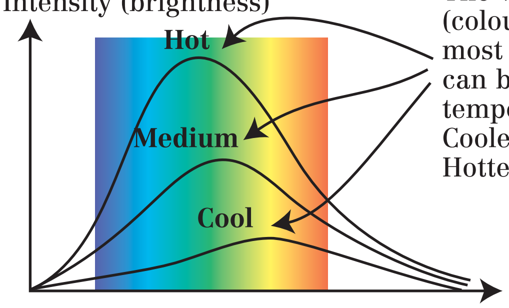


3. If an electron is given enough energy, it escapes completely. The atom has been ionized.
4. To move up levels electrons can absorb light energy. Only a precise wavelength, related to the energy difference between levels will be absorbed.
5. Moving down levels releases light of a specific wavelength that depends on the energy difference between levels. Minimum energy; electrons cannot go lower and so cannot crash into the nucleus.

Energy level; electrons can only have certain energies in the atom, not any energy in between levels, like a person standing on a ladder can only stand on the rungs, not in between.

Every element has a unique set of energy levels and absorbs a unique set of wavelengths.

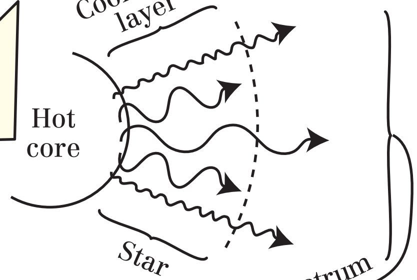
All hot bodies, like stars, produce a continuous spectrum of wavelengths.



The wavelength (colour) of the most intense light can be related to temperature.
Cooler stars → redder
Hotter stars → bluer

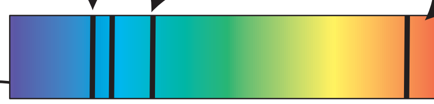
Temperature is also related to *brightness*.

Brightness can be used to find the distance to the star (by the inverse square law [see p31]).



Atoms in the outer layer of the star absorb light of certain wavelengths according to the energy levels in the atoms present.

Specific wavelengths not present = black.



The missing colours are unique to the atoms that absorbed them. Each element produces its own unique *line spectrum*.

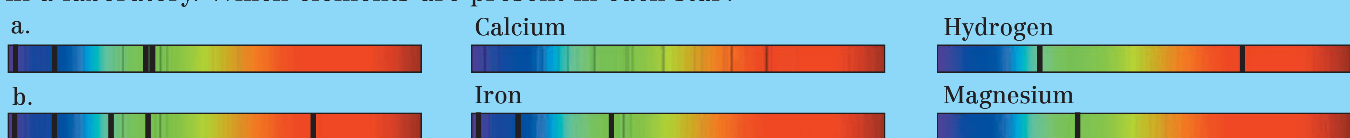
This is an absorption line spectrum as certain wavelengths have been absorbed by the outer layers of the star.

Absorption spectra can be thought of as like a fingerprint, or barcode, uniquely identifying the element responsible.

The line spectrum identifies what elements are present in the outer layers of the star.

Questions

1. What piece of apparatus could be used to split starlight into its spectrum?
2. Explain how scientists can estimate the temperature of a star by analyzing the light received on Earth from it.
3. Why are there black lines present in the spectra of stars? What information does the position of the lines give us?
4. Here are the line spectra of two stars together with the line spectra of some common elements measured in a laboratory. Which elements are present in each star?

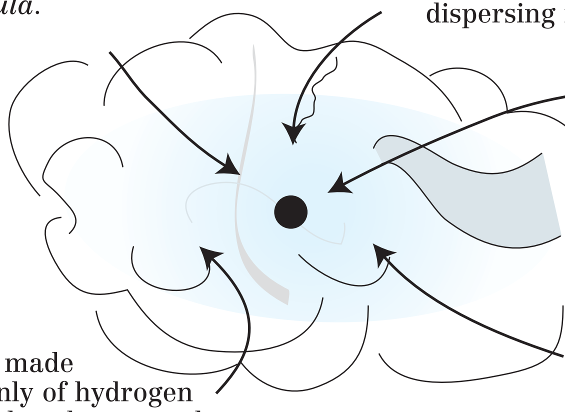


OUR PLACE IN THE UNIVERSE The Life Story of a Star

A cloud of gas in space is called a *nebula*.

1. The gas tends to be quite cool, preventing it dispersing into space.

2. Sometimes the density in parts of the nebula increases.



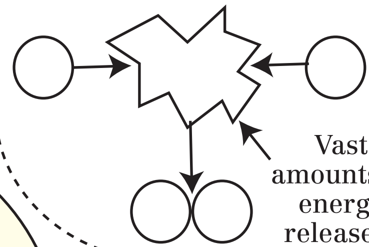
It is made mainly of hydrogen gas, but there may be small amounts of other elements and dust.

3. Other molecules are gravitationally attracted to this denser region.

Billions of years

Fusion

Nuclei are moving so fast that when they collide their electrostatic repulsion cannot keep them apart and they join.

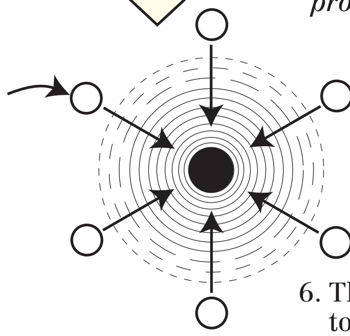


Vast amounts of energy released.

4. The molecules moving towards this region gain kinetic energy (like a ball falling to Earth). Therefore, as the nebula contracts the gas molecules gain kinetic energy. Kinetic energy of a collection of gas molecules is usually referred to as heat energy.

Another way of thinking about this is to consider that the gravitational attraction is compressing the gas, and from the gas laws (p66) the temperature rises proportionally to the pressure.

5. The nebula becomes a *protostar*.



6. The nebula begins to heat up.

Temperature rise to 10

Eventually can be implodes

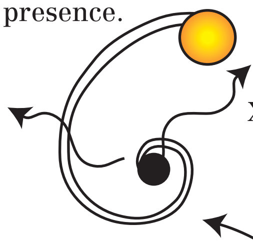
This massive explosion releases so much energy that the outer layers are blown off and their nuclei are ripped apart and reformed in every possible way, making the whole range of elements in the periodic table.

Supernova

Briefly as bright as a whole galaxy.

The debris can form a nebula, from which new stars, like our Sun, may form.

Black holes sometimes attract matter from a neighbouring star. This spirals into the black hole, like water down a plughole. This releases X-rays that astronomers can use to detect their presence.

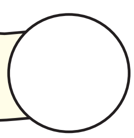


Blackhole

This is a region of space where, because a very large mass has been compressed into a tiny (possibly zero) volume, gravity is so strong not even light can travel fast enough to escape from it.

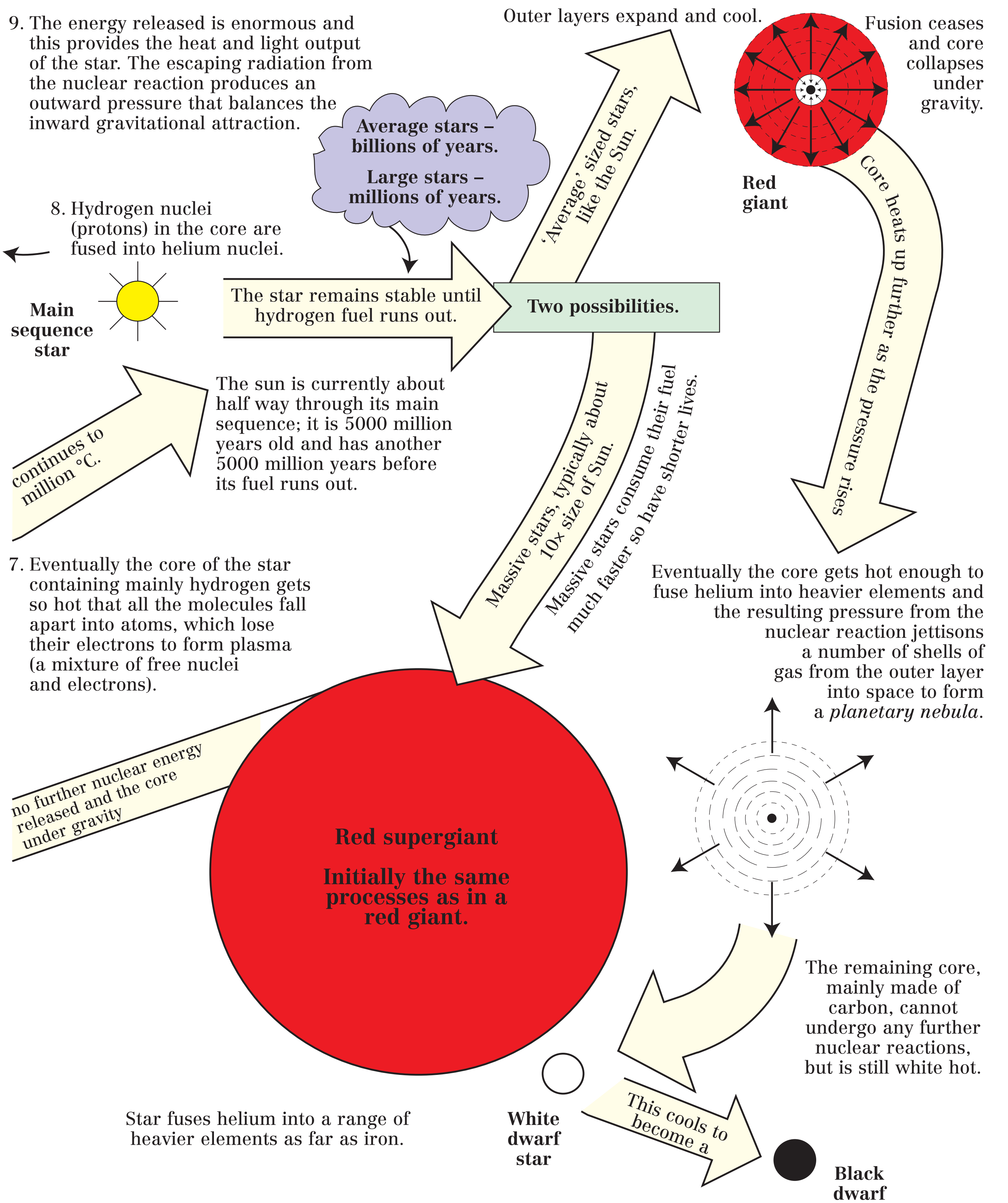
The remaining core is formed entirely of neutrons. It is a *neutron star*.

The matter here is incredibly dense; 1 cm^3 has a mass of about 10 000 000 tonnes.



Neutron star

If the mass of the neutron star is large enough even it will collapse under gravity to form a *black hole*.



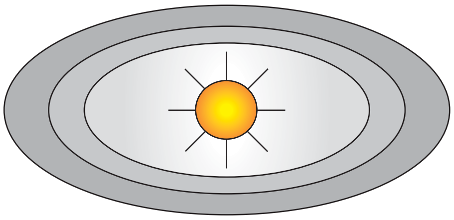
Questions

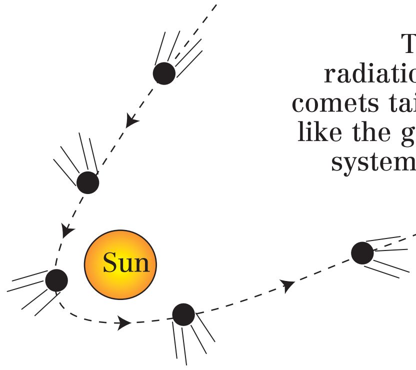
1. What is an interstellar gas cloud called?
2. Outline the history of the Sun from its formation to its current state.
3. What process provides the energy to make stars shine and stop them collapsing under gravity?
4. Outline what will happen to the Sun when it runs out of hydrogen fuel in its core.
5. What type of star will end in supernova and what might happen to the debris from this explosion?
6. What is a black hole? Can we see them?
7. The early universe only contained hydrogen. Where did all the other elements we see around us come from?

OUR PLACE IN THE UNIVERSE How Did the Solar System Form?

We saw on p122 that the Sun began to form when a nebula (of gas and dust) collapsed under gravity. The centre of the nebula began to heat up until about 4500 million years ago, when the temperature was high enough, fusion started, and the Sun became a star.

1. Orbiting around the newly formed Sun was the remains of the gas and dust from the nebula.

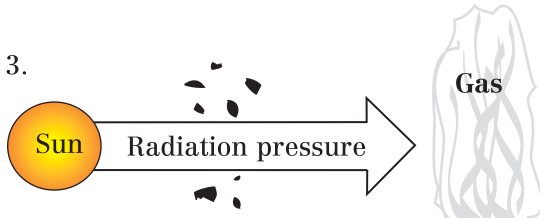




There is evidence for radiation pressure because comets tails, formed from gas like the gas in the early solar system, always point away from the Sun as the gas is blown away by the radiation from the Sun.

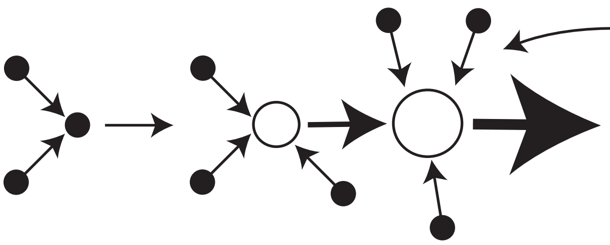
2. The debris' gravitational attraction to the Sun kept it in orbit, but the pressure from the radiation escaping from the Sun pushed the lighter gases into a larger orbit, leaving more massive dust particles orbiting closer to the Sun.

3.



Massive dust particles

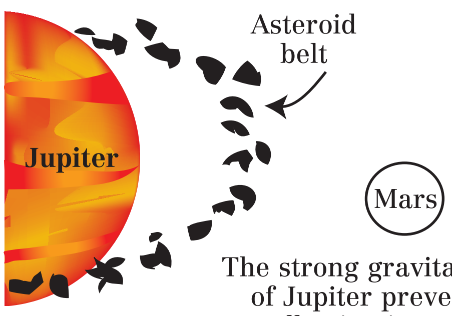
Light gas particles



The heat generated by these collisions melted the rocks allowing the young planets to form into spheres before they cooled down.

4. The dust particles collided with each other and began to collect into larger clumps. These grew as they collected more dust into rocks, which eventually joined to form planets.

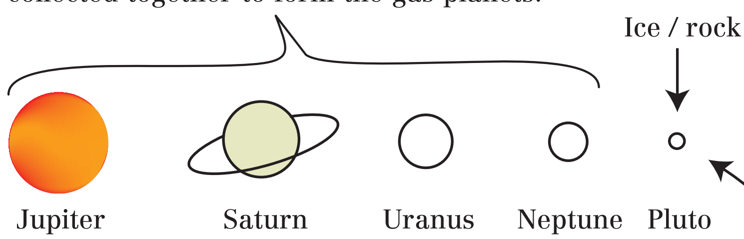
Craters on other planets are evidence for these collisions, which still continue. We call the small rocks asteroids. Plate tectonics covers up craters on Earth, but there are still some impact craters to be seen. Scientists think these may explain some extinction processes such as that of the dinosaurs.



The strong gravitational field of Jupiter prevents them collecting into a planet.

Some astronomers think the asteroid belt, between Mars and Jupiter, might be the remains of planets that collided, perhaps due to the influence of Jupiter's very strong gravitational field.

The gases further out in the solar system also collected together to form the gas planets.



Pluto does not fit this pattern. It is suggested that it has been captured by the Sun's gravity and did not form in the solar system.

Questions

1. What force is responsible for keeping the planets in orbit around the Sun?
2. Explain why the rocky planets are found close to the Sun, whilst the gas planets are found further away.
3. What evidence is there that the planets formed by collisions between lumps of dust and rock?
4. The explanation of how the solar system formed is just a theory. Suggest why scientists have found it difficult to get evidence to support the theory.

OUR PLACE IN THE UNIVERSE The Expanding Universe

Consider a moving source of waves.

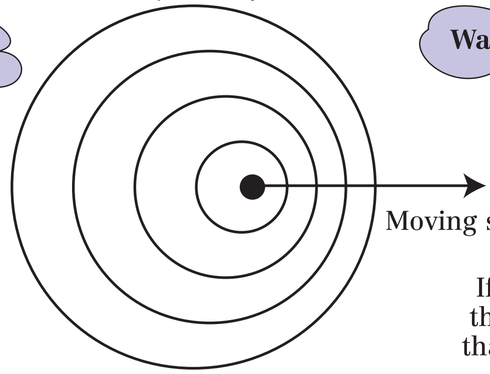
This is the *Doppler effect*.

The change in pitch as an ambulance siren passes is an example of this.

Waves behind are stretched out.

If sound waves, the pitch is lower than the source.

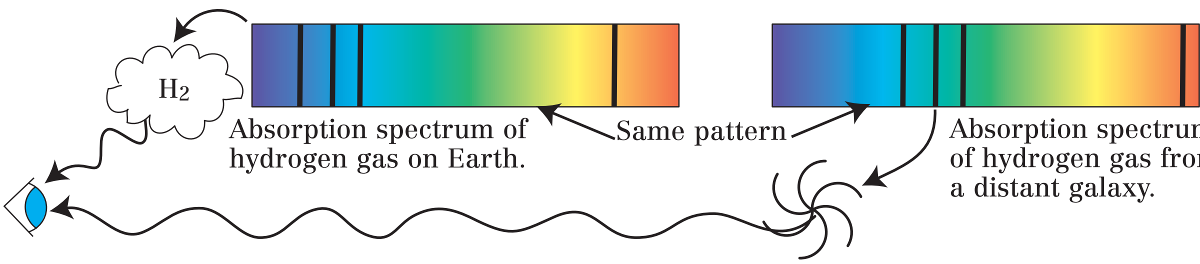
If light waves, they look redder than the source.



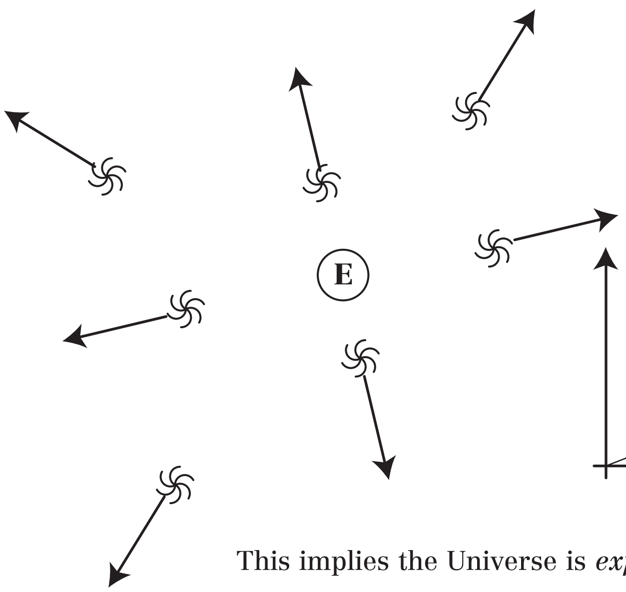
Waves ahead are compressed.

If sound waves, the pitch is higher than the source.

If light waves, they look bluer than the source.

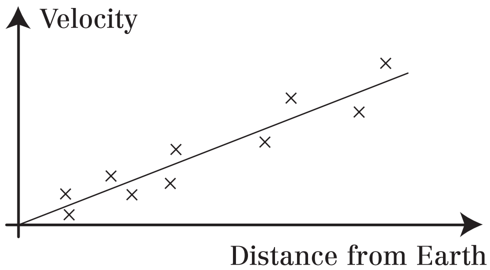


The light from hydrogen in the galaxy looks redder than the same light from stationary hydrogen on Earth. This *red shift* tells us the galaxy is moving away. The *bigger* the red shift the *faster* the galaxy is *moving away*.



Edwin Hubble measured the distance to many galaxies together with their speed and direction of motion from the Doppler shift of their light. He found:

- All galaxies were moving away (all red shifted).
- The further away the galaxy, the faster it was moving.

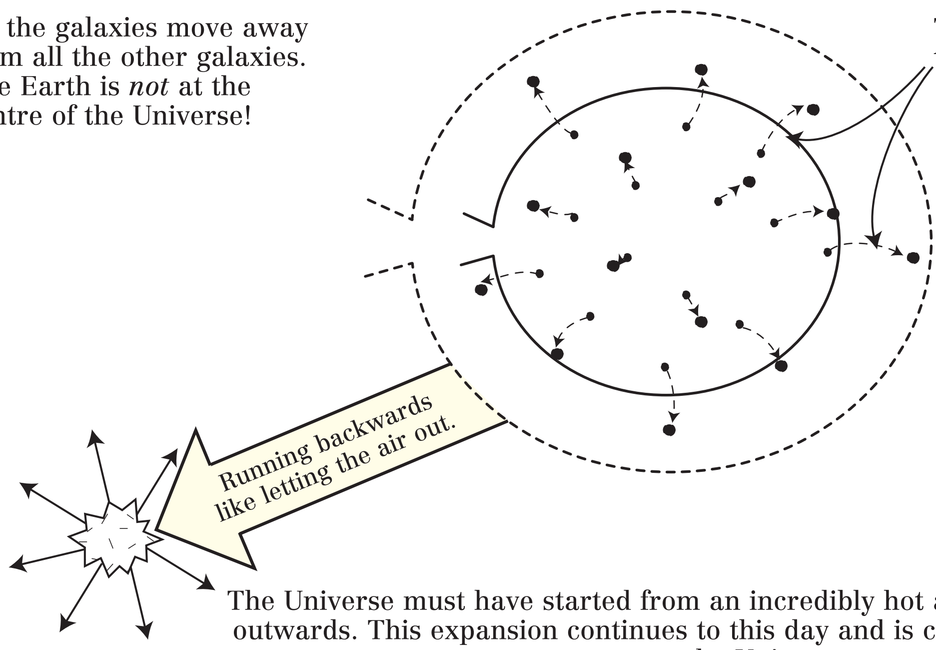


Conclusion: the speed a galaxy is moving away is directly proportional to its distance from Earth.

This implies the Universe is *expanding*. Consider the galaxies like dots on an inflating balloon.

All the galaxies move away from all the other galaxies. The Earth is *not* at the centre of the Universe!

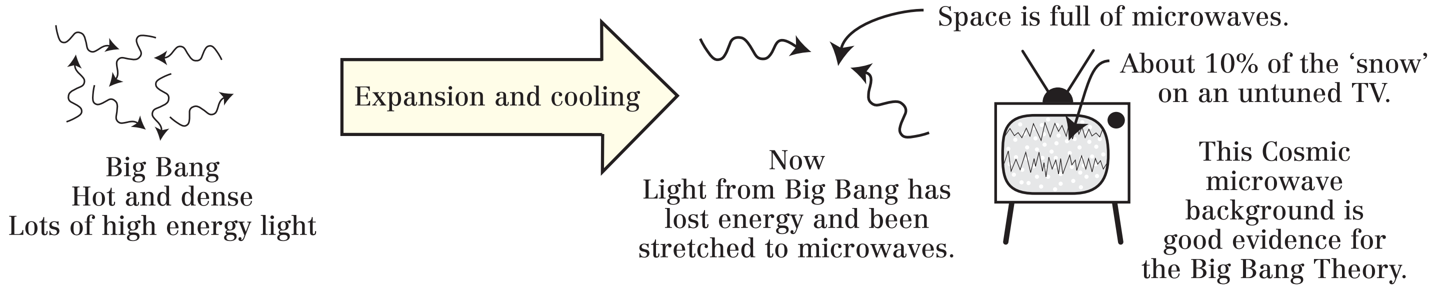
The further apart the galaxies are, the faster they move apart.



Be careful – the Universe is not expanding into empty space like this balloon. It is the space *between* the galaxies that is growing, like the rubber of the balloon stretching *between* the dots.

The Universe must have started from an incredibly hot and dense point and exploded outwards. This expansion continues to this day and is called the 'Big Bang Theory of the Universe.

OUR PLACE IN THE UNIVERSE The Expanding Universe – Further Evidence



The age of the Universe can be calculated by measuring how far galaxies have moved and their speed.

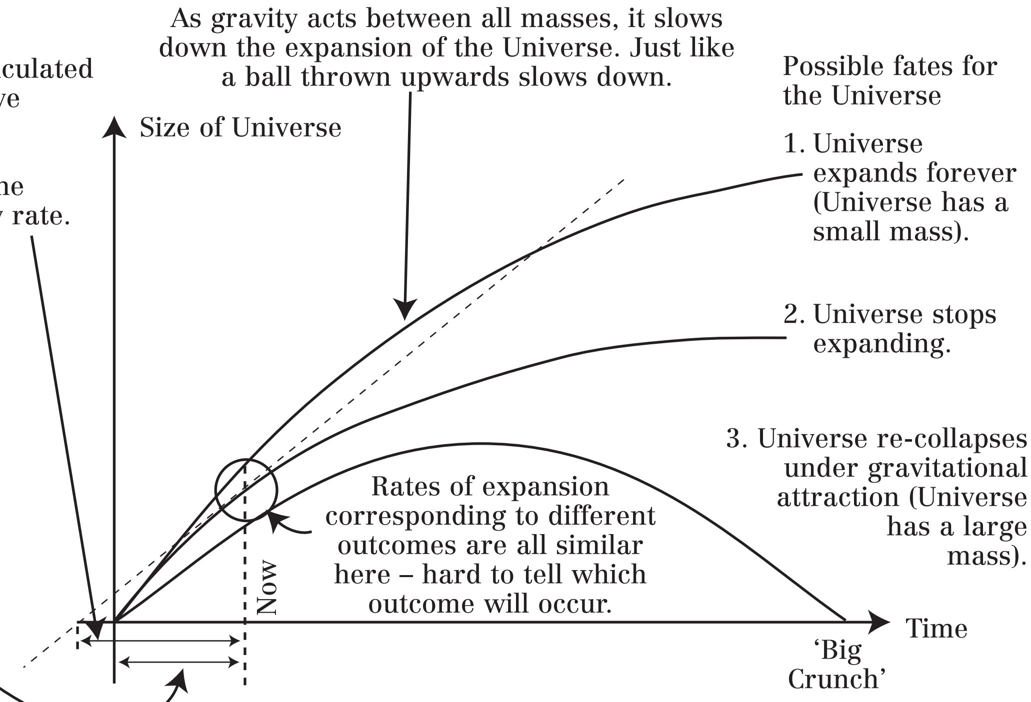
The calculated age assumes that the Universe has expanded at a steady rate.

If the expansion is slowing due to gravity, the actual age is less than this.

Our best estimate of the age of the Universe is

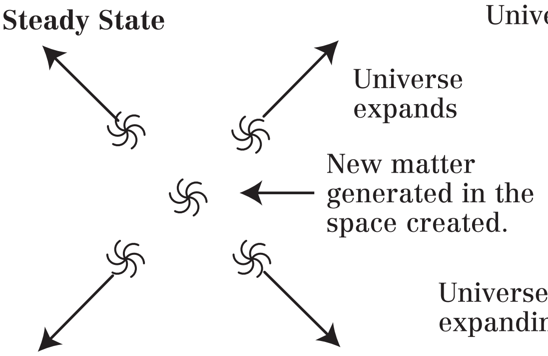
14 thousand million years

Some scientists disagree because they think some galaxies are older than this.

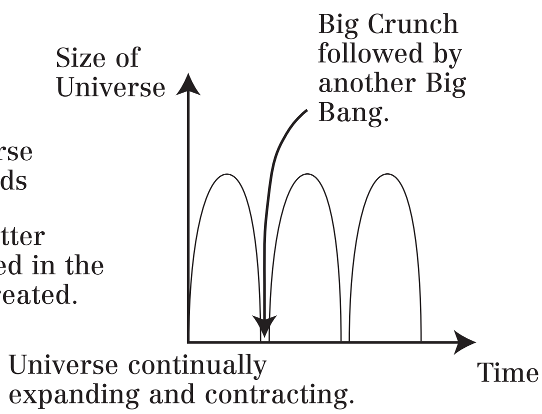


Other theories

Steady State



Oscillating Universe



Which of fates 1, 2, or 3 will occur depends on the total mass of the Universe and the rate of expansion.

We need to calculate the mass of the Universe.

But we think the majority of the mass of the Universe is 'dark matter', which we cannot see.

Measuring this and the exact rate of expansion is very hard so the age and fate of the Universe remain very controversial.

Questions

1. What is the Doppler effect? Suggest where you might be able to observe the Doppler effect in everyday life.
2. If a galaxy was moving towards the Earth, how would the light received from it be affected? What if it was moving away?
3. Explain what led Hubble to propose that the Universe is expanding.
4. What was the Big Bang? Suggest two pieces of evidence for this theory of the Universe.
5. Outline three possible fates for the Universe. What two factors will dictate which outcome actually occurs?
6. Suggest some reasons why scientists are uncertain about the age and fate of the Universe.
7. Make a list of three controversial facts in this topic. Explain why they are controversial. If possible, suggest some data scientists could collect to try to settle the dispute.

FORMULAE

The lists below bring together all the formulae in the book.

FORCES AND MOTION

Speed (m/s) = distance (m) / time (s) $s = d/t$

Average speed (m/s) = total distance travelled (m) / total time taken (s) $s = d/t$

Acceleration (m/s^2) = change in velocity (m/s) / time taken (s) $a = \Delta v/\Delta t$

Equations of motion for uniformly accelerated motion

$$v = u + at$$

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

$$v^2 = u^2 + 2ax$$

v = final velocity (m/s)
u = initial velocity (m/s)
a = acceleration (m/s^2)
t = time taken (s)
x = distance travelled (m)

Force (N) = mass (kg) × acceleration (m/s^2). $F = ma$

Weight (N) = mass (kg) × acceleration due to gravity (m/s^2). $W = mg$

Weight (N) = mass (kg) × gravitational field strength (N/kg). $W = mg$

Density (kg/m^3) = mass (kg) / volume (m^3) $D = m/V$

Pressure (N/m^2 or Pa) = force (N) / area (m^2) $P = F/A$

Momentum (kgm/s) = mass (kg) × velocity (m/s)

Impulse (Ns) = Force (N) × time force acts for (s) = change in momentum (kgm/s) $F\Delta t = mv - mu$

Centripetal acceleration (m/s^2) = [velocity (m/s)]^2 / radius (m). $a = v^2/r$

Centripetal force = mass (kg) × acceleration (m/s^2) = mass (kg) × [velocity (m/s)]^2 / radius (m) $F = mv^2/r$

Orbital speed (m/s) = orbit circumference (m) / orbital period (s) $v = 2\pi r/T$

Moment (Nm) = Force (N) × perpendicular distance from line of action of the force to the axis of rotation (m).

Principle of moments

Sum of anticlockwise moments = sum of clockwise moments when in equilibrium.

Energy

Work done = force (N) × distance moved in the direction of the force (m). $w.d. = F \times d$

Power (W) = energy transferred (J) / time taken (s). $P = E/t$

Energy transferred = work done

Gravitational potential energy transferred (J) = mass (kg) × gravitational field strength (N/kg) × change in height (m) $GPE = mg\Delta h$

Kinetic energy (J) = $1/2$ mass of object (kg) × [speed (m/s)]^2. $KE = \times mv^2$

Efficiency (%) = useful energy output (J) / total energy input (J) × 100%.

Nuclear energy

Energy released (J) = change in mass (kg) × [speed of light (m/s)^2] $\Delta E = \Delta mc^2$

Waves

Wave speed (m/s) = frequency (Hz) × wavelength (m). $v = f\lambda$

Intensity (W/m^2) = power (W) / area (m^2). $I = P/A$

Refractive index, n = speed of light in vacuum (m/s) / speed of light in medium (m/s) $n = c/v$

Snell's Law

Refractive index n, = sin (angle of incidence) / sin (angle of refraction) $n = \sin i / \sin r$

sin (critical angle) = refractive index of second material / refractive index of first material $\sin c = n_r / n_i$

Magnification = image height / object height

Power of lens (dioptre) = 1/focal length (metres)

Angular magnification = focal length of objective lens / focal length of eyepiece lens

Electricity

Current (A) = charge passing (C) / time taken (s). $I = Q/t$

Potential difference (V) = energy transferred (J) / charge passing (C). $V = E/Q$

Resistance (Ω) = potential difference (V) / current (A) $R = V/I$

Power (W) = [current (A)]^2 × resistance (Ω) $P = I^2R$

Power (W) = current (A) × voltage (V) $P = IV$

Power (W) = [voltage (V)]^2 / resistance (Ω) $P = V^2/R$

Electrical energy (kWh) = power (kW) × time (h)

Kinetic energy of an electron (J) = charge on the electron (C) × potential difference (V) $KE = e \times V$

Transformer formula

Primary voltage (V) / secondary voltage (V) = No. of turns on primary / No. of turns on secondary. $V_p/V_s = N_p/N_s$

Thermal physics

Kelvin → °C = (temperature / K) – 273

°C → Kelvin = (temperature / °C) + 273

Energy supplied (J) = mass (kg) × specific heat capacity (J/kg K) × temperature change (K) $\Delta E = m \times s.h.c. \times \Delta T$

Energy (J) = mass (kg) × specific latent heat (J/kg) $E = mL$

Pressure (Pa) / temperature (Kelvin) = constant. P/T = constant.

Pressure (Pa) × volume (m^3) = constant. PV = constant

Units

Length – metres, m
Time – seconds, s
Mass – kilogram, kg
Speed or velocity – metres per second, m/s
Acceleration – metres per second^2, m/s^2
Force – Newton, N
Momentum – kilogram metre per second, kgm/s
Impulse – Newton second, Ns
Moment – Newton metre, Nm
Density – kilograms per metre^3, kg/m^3
Pressure – Newton per metre^2, N/m^2 (equivalent to 1 Pascal, Pa)
Work done – Newton metre, Nm
Power – Watt, W
Energy – Joule, J (equivalent to one Newton metre, Nm)
Frequency – Hertz, Hz
Wavelength – metre, m
Intensity – Watts per metre^2, W/m^2
Power of lens – dioptre
Current – Amps, A
Charge – Coulombs, C
Potential difference – Volts, V
Resistance - Ohms, Ω
Electrical energy - Joules, J (or kiloWatt-hours, kWh. 1 kWh = 3.6 × 10^6 J)
Temperature – Kelvin, K or Celsius, °C.
Specific heat capacity – Joules per kilogram per Kelvin, J/kg K
Specific latent heat – Joules per kilogram, J/kg

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