KINEMATICS

Speed, distance, time

Average Speed

Average speed is a measure of the distance travelled in a unit of time.
Average speed is calculated by using this formula:

Average speed $\quad \boxed{\bar{v} = \frac{s}{t}} \quad$ distance travelled / time taken

Units of speed

Speed can be measured in many different units.
Usually the unit is metres per second, m/s or m s^{-1}. This means the distance must be measured in metres and the time taken in seconds.

Note: these notes will use the solidus for multiple units, e.g. m/s. However, you can use the negative index, e.g. m s^{-1}, if you prefer.

Measurement of average speed

To measure an average speed, you must:

- measure the **distance** travelled with a measuring tape or metre stick
- measure the **time** taken with a stop clock
- **calculate** the speed by dividing the distance by the time

Calculations involving distance, time and average speed

Note: care must be taken to use the correct units for time and distance.

Example

Calculate the average speed in metres per second of a runner who runs 1500 m in 5 minutes.

$s = 1500$ m
$t = 5$ minutes $= 5 \times 60$ seconds $= 300$ s

$$\bar{v} = \frac{s}{t} = \frac{1500}{300} = 5 \text{ m/s}$$

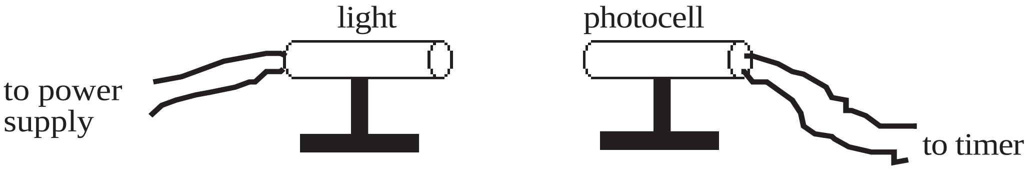
Instantaneous speed

The instantaneous speed of a vehicle at a given point can be measured by finding the average speed during a **very short time** as the vehicle passes that point.

Average speed and instantaneous speed are often very different e.g. the average speed of a runner during a race will be less than the instantaneous speed as the winning line is crossed.

Measuring instantaneous speeds

To measure instantaneous speeds, it is necessary to be able to measure **very** short times. With an ordinary stopclock, human reaction time introduces large errors. These can be avoided by using electronic timers. The most usual is a light gate**.**



A light gate consists of a light source aimed at a photocell. The photocell is connected to an electronic timer or computer.

The timer measures how long an object takes to pass through the light beam.

The distance travelled is the length of the object which passes through the beam.

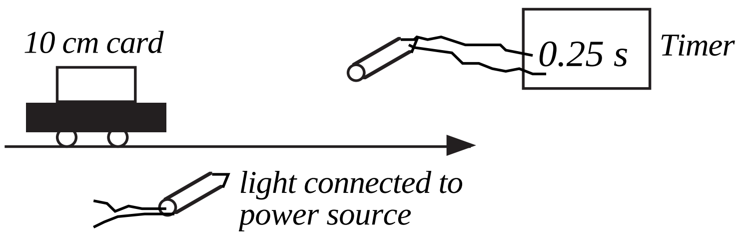
Often a card is attached so that the card passes through the beam. The length of the card is easy to measure.

The instantaneous speed as the vehicle passes through the light gate is then calculated using:

$$\boxed{\text{Speed of vehicle} = \frac{\text{length of card or vehicle}}{\text{time to cut beam}}}$$

Example

A vehicle moves through a light gate as shown in the diagram. Using the data from the diagram, calculate the instantaneous speed of the vehicle as it passes the light gate.



$$speed = \frac{\text{length of card}}{\text{time to cut beam}} = \frac{10}{0.25} = 40 \text{ cm/s} = 0.4 \text{ m/s}$$

Vectors and Scalars

Vector and Scalar quantities

Physical quantities can be divided into two groups:

- a **scalar** quantity is completely described by stating its **magnitude** (size).
- a **vector** quantity is completely described by stating its **magnitude** and **direction**.

Distance and Displacement

Distance is the total distance travelled, no matter in which direction.

Displacement is the length measured from the starting point to the finishing point in a straight line. Its direction must be stated.

Speed and Velocity

Speed and velocity are described by the equations below.

$$\boxed{\text{speed} = \frac{\text{distance}}{\text{time}}} \qquad \boxed{\text{velocity} = \frac{\text{displacement}}{\text{time}}}$$

Velocity is a vector quantity, but speed is scalar.

The direction of the velocity will be the same as the direction of the displacement.

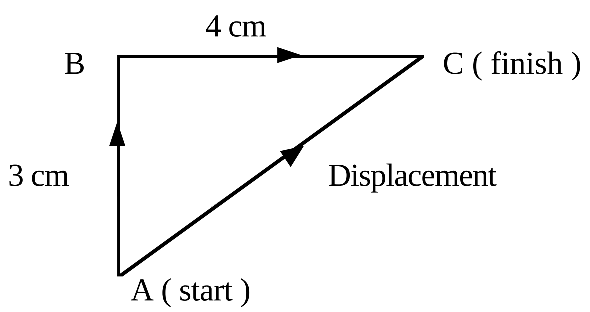
Example

A woman walks 3 km due North and then 4 km due East. She takes two hours.

a) Find the distance she has walked and her displacement.

b) Calculate her average speed and velocity.

We will represent her walk by drawing a diagram to scale. Scale 1cm = 1 km



a) *The distance she has travelled is 3 km + 4 km = 7 km*

Her displacement is from A to C. This can be measured on the diagram as 5 cm, then converted using the scale to 5 km.

The angle BAC is measured to find the direction of her final displacement. It is 53°

Displacement = 5 km at a bearing of (053).

b) $$\textit{average speed} = \frac{\textit{distance travelled}}{\textit{time taken}} = \frac{7}{2} = 3.5 \textit{ km/h}$$

$$\textit{average velocity} = \frac{\textit{displacement}}{\textit{time taken}} = \frac{5}{2} = 2.5 \textit{ km/h at a bearing of (053)}$$

Acceleration
Most vehicles do not travel at the same speed all the time. If they speed up, they are said to accelerate. If they slow down, they decelerate. Acceleration describes **how quickly** velocity changes.
Acceleration is a **vector** quantity. However, only the acceleration of vehicles travelling in straight lines will be considered.

Acceleration is the change in velocity in unit time.

$$\boxed{\textbf{acceleration} = \frac{\textbf{change in velocity}}{\textbf{time taken}}}$$

Units of Acceleration
The units of acceleration are the units of velocity divided by the units of time (seconds).
If the velocity is in m/s, acceleration is in m/s^2 (metres per second squared).
An acceleration of 2 m/s^2 means that every second, the velocity increases by 2 m/s.

Formula for Acceleration

$$\boxed{a = \frac{v - u}{t}}$$

a	=	acceleration	in m/s^2
u	=	initial velocity	in m/s
v	=	final velocity	in m/s
t	=	time taken	in s

Note: If a vehicle is slowing down, the final velocity will be smaller than the initial velocity, and so the acceleration will be negative.
A negative acceleration is a deceleration.

The equation for acceleration can be rearranged to give an alternative version.

$$\boxed{v = u + at}$$

Example
A car is moving at 15 m/s, when it starts to accelerate at 2 m/s^2 . What will be its speed after accelerating at this rate for 4 seconds?

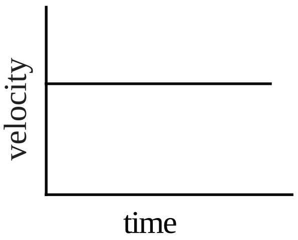
u = 15 m/s $v = u + at$
a = 2 m/s^2 $= 15 + (2 \times 4)$
t = 4 s $= 23$

The car will reach a speed of 23 m/s

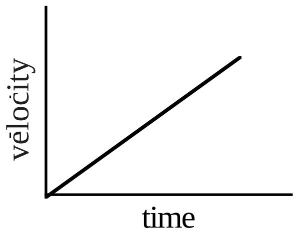
Velocity-time graphs

A velocity-time graph is a useful way to describe the motion of a vehicle.
Time is always plotted along the x-axis, and velocity is plotted along the y-axis.

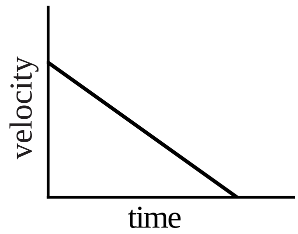
The **shape** of the graph indicates whether the vehicle is accelerating, decelerating or moving at a constant velocity.



constant velocity



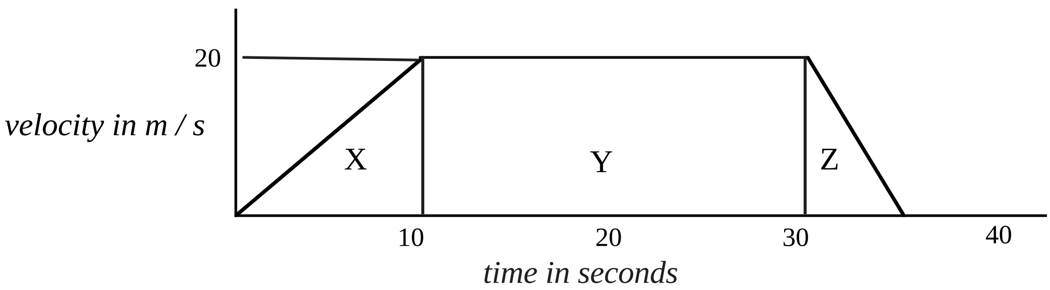
increasing velocity
= acceleration



decreasing speed
= deceleration

The **slope** (or gradient) of the line on a velocity-time graph indicates the acceleration.
While the slope is steady, the acceleration is constant. If the line gets steeper, the acceleration (or deceleration) gets greater.
Acceleration can be calculated using data from the graph and the formula.
The **area** vertically below a section of the graph is equal to the displacement during that time.

Example
The graph describes the motion of a car during 35 seconds.
a) What was the initial acceleration of the car?
b) What was the deceleration?
c) How far did the car travel in the 35 seconds?



a) *initial acceleration lasts from 0 - 10 s:* $u = 0,\ v = 20\ m/s,\ t = 10\ s$

$$a = \frac{v - u}{t} = \frac{20 - 0}{10} = 2\ m/s^2$$

b) *deceleration was from 30 -35 s:* $u = 20\ m/s,\ v = 0,\ t = 5\ s$

$$a = \frac{v - u}{t} = \frac{0 - 20}{5} = -4\ m/s^2$$

c) *distance travelled = area under graph:*
divide into sections of rectangles and triangles: X + Y + Z: use scale for sizes
area X = $^1/_2$ base $\times$ height $= {}^1/_2 \times 10 \times 20 = 100\ m$
area Y = length $\times$ breadth $= 20 \times 20 = 400\ m$
area Z = $^1/_2$ base $\times$ height $= {}^1/_2 \times 5 \times 20 = 50\ m$
Total area = 550 m so: distance travelled = 550 m

DYNAMICS

Forces

Effects of forces

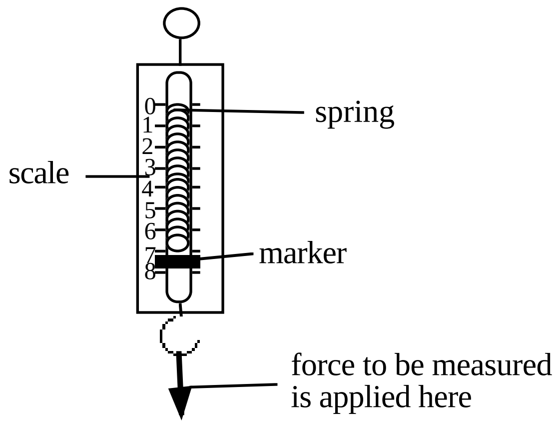
Forces can only be detected by their effects.

They can change:
- the shape of an object (stretch it, squeeze it etc)
- the speed of an object
- the direction of movement of an object

Measurement of Forces

Forces are measured in units called **newtons** (N). (see later for definition)

Forces can be measured with a newton balance. This instrument depends on the effect of a force on the shape (length) of a spring.



A newton balance has a spring inside. The force to be measured is applied to the hook which is attached to the spring. The force causes the spring to stretch. The greater the force, the greater the stretch of the spring and the further the marker moves across the scale.

Mass and Weight

Weight is a force caused by gravity acting on an object's mass. On Earth, it measures the pull of the Earth on the object. It is measured in **newtons**.

Weight always acts vertically downwards. Its size does not just depend on the mass of the object, but on the strength of gravity at that place.

Mass measures the amount of matter in an object. It is measured in **kilograms** (kg).

The value of mass does not change from place to place.

The strength of gravity in a particular place is called **the gravitational field strength.** This tells you the weight of 1 kilogram. Its symbol is **g** and its unit is **N/kg.**

On Earth, g = 10 N/kg.

Mass and weight are connected by the following formula:-

$$\underbrace{W}_{\text{weight in N}} = \underbrace{m}_{\text{mass in kg}}\underbrace{g}_{\text{gravitational field strength in N/kg}}$$

Example

a) What is the weight of a 50 kg girl on Earth?

b) What would she weigh on the moon where the gravitational field strength is 1.6 N/kg?

a) $W = mg = 50 \times 10 = 500\ N$

b) $W = mg = 50 \times 1.6 = 80\ N$

The Force of Friction

Friction is a **resistive** force, which opposes the motion of an object. This means that it acts in the **opposite** direction to motion. Friction acts between any two surfaces in contact. When one surface moves over another, the force of friction acts between the surfaces and the size of the force depends on the surfaces, e.g. a rough surface will give a lot of friction.
Air friction is usually called **air resistance**. It depends mainly on two factors:

- the shape and size of the object
- the speed of the moving object.

Air resistance **increases** as the speed of movement increases.

Increasing and Decreasing Friction

Where friction is making movement difficult, friction should be reduced.
This can be achieved by:

- lubricating the surfaces with oil or grease
- separating the surfaces with air, e.g. a hovercraft
- making the surfaces roll instead of slide, e.g. use ball bearings
- streamlining to reduce air friction.

Where friction is used to slow an object down, it should be increased.
This can be achieved by:

- choosing surfaces which cause high friction e.g. sections of road before traffic lights have higher friction than normal roads
- increasing surface area and choosing shape to increase air friction, e.g. parachute.

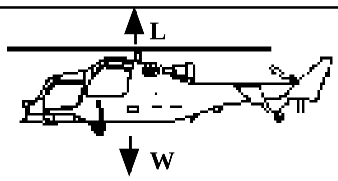
Forces are Vectors

A force is a vector quantity because to describe it properly requires a direction as well as size. Two forces which are equal in size but which act in opposite directions are called **balanced** forces. Balanced forces have the same effect as **no force** at all.

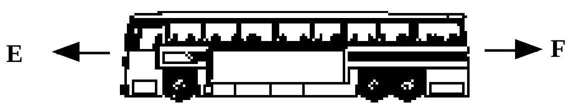
Newton’s First Law

When the forces on an object are balanced (or when there are no forces at all), then neither the speed nor direction of movement will change.
Balanced forces mean **constant velocity** or the object is stationary.

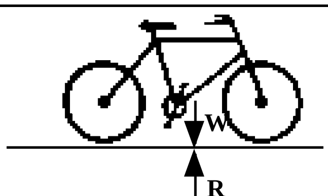
Examples of balanced forces



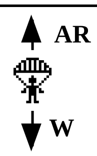
Stationary hovering helicopter
Weight down = **L**ift up



Bus moving at **steady speed**
Engine force forward = **F**riction forces backwards



Stationary bicycle
Weight down = **R**eaction of road up



Parachutist drifting down at **steady speed** (terminal velocity)
Weight down = **A**ir **R**esistance up

Newton's Second Law of Motion

This law deals with the situation when there is an **unbalanced** force acting on an object. The velocity cannot remain constant, and the acceleration produced will depend on the mass of the object and the value of the unbalanced force.
As the unbalanced force acting on an object increases, the acceleration increases also.
As the accelerated mass increases, the acceleration decreases for a given force.

The **newton** is defined as the force which makes a mass of 1 kg accelerate at 1 m/s^2.

These facts can be summarised in an equation:

acceleration in m/s^2

unbalanced force in N $\boxed{\mathbf{F = ma}}$

mass in kg

Example
A car of mass 1000 kg has an unbalnced force of 1600 N acting on it.
What will be its acceleration?

$m = 1000 \text{ kg}$
$F = 600 \text{ kg}$

$$a = \frac{F}{m} = \frac{1600}{1000} = 1.6 \text{ m/s}^2$$

Resultant Forces

When several forces act on one object, they can be replaced by one force which has the same effect. This single force is called the **resultant** or **unbalanced** force.

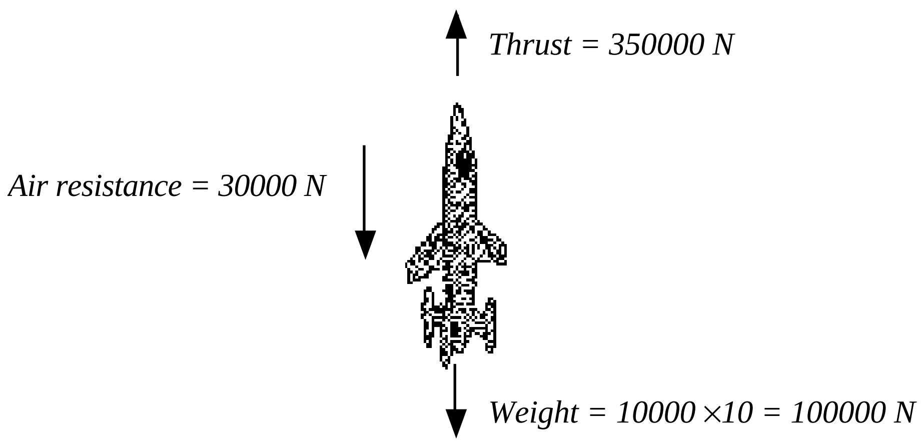
Combining forces in a straight line

Draw a diagram of the object and mark in all the forces acting, using an arrow to represent each force. (Do not forget weight, which is often not specifically mentioned in the question).
Use arithmetic to find the resultant:

- **add** together forces which act in the **same** direction
- **subtract** forces which act in the **opposite** direction.

A diagram like this is called a **free body diagram**.

Example
A short time after take off, a rocket of mass 10000 kg has a thrust of 350000 N and experiences air resistance of 30000 N. Draw a free body diagram and find the resultant force acting on the rocket.



Total upward force = *350000 N*
Total downward force = *100000 N + 30000 N* = *130000 N*
Resultant force upwards = *350000 – 130000* = *220000 N*

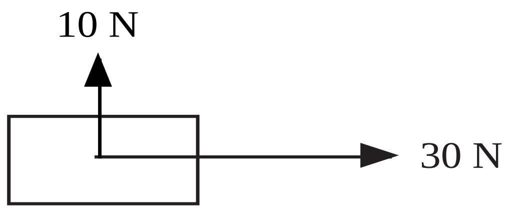
Combining forces at right angles

There are two possible methods for finding the size and direction of the resultant of two forces acting at right angles to each other.

- Draw a scale diagram: (refer to Kinematics, Vectors page 3)
- Use Pythagoras and trig functions.

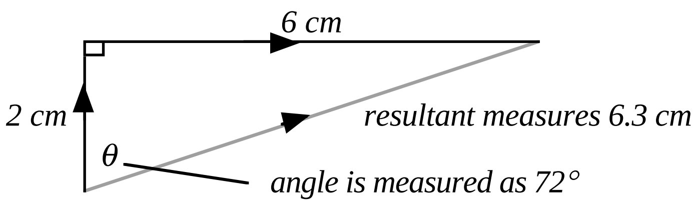
Example

What is the resultant force produced by two forces of 10 N and 30 N which act on an object as shown in the diagram?



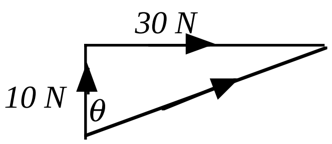
Method 1: Choose Scale: 1 cm = 5 N

Draw vectors head to tail, complete triangle, then measure resultant size and direction.



Resultant = 6.3 × 5 = 31.5 N at an angle of 72° to the 10 N force.

Method 2: Draw sketch of vector diagram, but not to scale.



Resultant $= \sqrt{30^2 + 10^2}$
$= 31.6\ N$

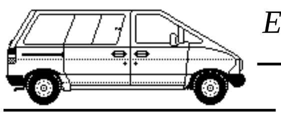
$\tan\theta = 30 \div 10$
$= 3$

$\theta\ \tan^{-1} 3 = 72°$

Calculations using F = ma for more than one force

Draw a free body diagram and mark in all the known forces. Use this to calculate the resultant force (F in the equation) before using the equation.

Example
A car of mass 1000 kg experiences friction equal to 500 N. If the engine force is 1300 N, what will be the car's acceleration?

Friction forces = 500 N ←  → *Engine Force = 1300N*

Resultant force = *1300 – 500* = *800 N*

$$a = \frac{F}{m} = \frac{800}{1000} = 0.8\ m/s^2$$

Acceleration due to gravity and gravitational field strength
Weight is the force which causes an object to accelerate downwards and has the value mg, where g is the gravitational field strength, see page 6.
The value of the acceleration caused by weight can be calculated from Newton's second law, using the equation F = ma where F is now the weight W, and W = mg.

$$\text{acceleration due to gravity} = \quad a = \frac{F}{m} = \frac{mg}{m} = g \quad \text{where g is in m/s}^2$$

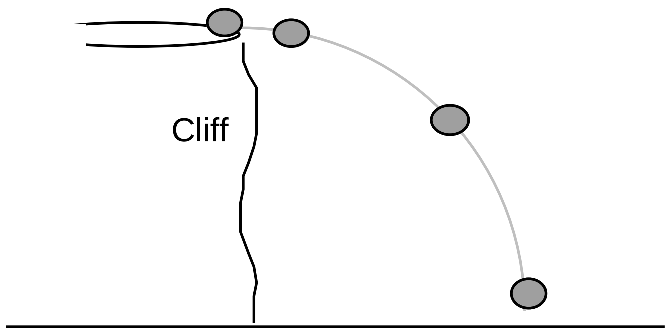
The numerical values of the acceleration due to gravity and gravitatonal field strength are equal.
Their units, N/kg and m/s^2 are also equivalent.

Projectile Motion

A projectile is an object which has been given a forward motion through the air, but which is also pulled downward by the force of gravity. This results in the path of the projectile being curved.
A projectile has two **separate** motions at right angles to each other.
Each motion is **independent** of the other.

The **horizontal** motion is at a **constant velocity** since there are no forces acting horizontally (air resistance can be ignored).
Horizontal distance travelled = horizontal velocity × time in the air. ($s_H = v \times t$)
The **vertical** motion is one of **constant acceleration**, equal to g.
For projectiles which are projected horizontally, the initial vertical velocity is zero.
For vertical calculations, use $v = u + at$, where $u = 0$ and $a = g$

Example
A ball is kicked horizontally at 5 m/s from a cliff top as shown below.
It takes 2 seconds to reach the ground.



a) What horizontal distance did it travel in the 2 seconds?
b) What was its vertical speed just before it hit the ground? *(Take g = 10 m/s²)*

	Horizontal		*Vertical*
a)	$v = 5$ m/s	*b)*	$u = 0$
	$= 2$ s		$a = 10$ m/s^2
			$t = 2$ s
	$s_H = v \times t$		
	$= 5 \times 2$		$v = u + at$
	$= 10$ m		$= 0 + 10 \times 2$
			$= 20$ m/s

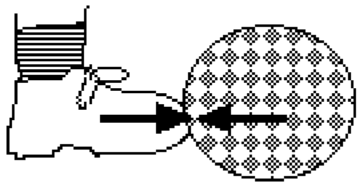
MOMENTUM AND ENERGY

Newton's Third Law

Newton noticed that forces occur in pairs. He called one force the **action** and the other the **reaction**. These two forces are always **equal in size, but opposite in direction**. They do not both act on the same object.
Newton's Third Law can be stated as:
If an object A exerts a force (the action) on object B, then object B will exert an equal, but opposite force (the reaction) on object A.

Newton Pairs

The two forces described above are called a Newton Pair. For example, a Newton pair occurs when footballer kicks a ball.



Object A is the foot. Object B is the ball.
When the player kicks the ball, the foot exerts a force to the right on the ball.
The ball exerts an equal force to the left on the foot.

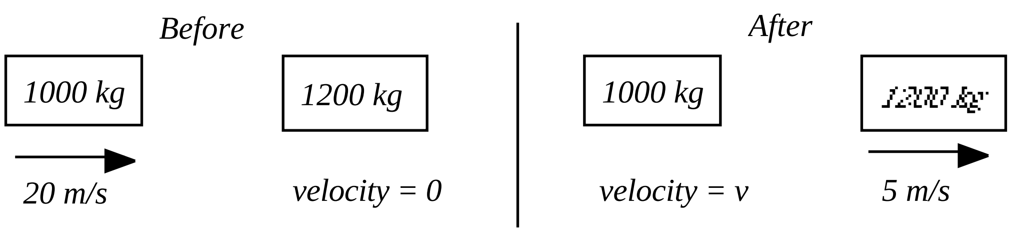
Momentum

Momentum is the product of mass and velocity. Its unit is the kilogram metre/second (kg m/s)
Momentum is a **vector** quantity, but this course will only consider situations where all the objects move in the same direction.

Conservation of momentum

When two objects collide, the momentum of each changes as a result of the forces acting between the objects. However, **providing there are no external forces, the total momentum remains constant before and after the collision.**
This statement is known as the Law of Conservation of Momentum. This law can be used to calculate velocities in collisions.

Example
A car of mass 1000 kg travelling at 20 m/s collides with a stationary van of mass 1200 kg. If the van moves off at 5 m/s, what will be the velocity of the car after the collision?



Total momentum before			=	*Total momentum after*		
(1000 × 20)	+	*0*	=	*(1000 × v)*	+	*(1200 × 5)*
	20000		=	*1000 v*	+	*6000*
	1000 v		=	*14000*		
	velocity of car after		=	*14 m/s forwards.*		

Work and Energy

Energy

Energy cannot be destroyed, but it can be changed from one form into another. All forms of energy are measured in the same unit: the **joule (J).**
When a force causes movement, some energy is changed from one form to another (it is **transformed**) and we say that **work is done**.
For example, the force of friction causes kinetic energy to be transformed into heat.

Work

The work done is a measure of the energy transformed. It is equal to the force multiplied by the distance the force moves. The force and distance must be measured in the **same direction**.
Work is measured in the same units as energy: joules. The symbol for work is E_w.

work done in joules — $\boxed{\mathbf{E_w = F \times s}}$ — distance force moves in metres

force in newtons

Example
A dog pulls a 4 kg sledge for a distance of 15 m using a force of 30 N.
How much work does the dog do?

$F = 30\ N \qquad Ew = F \times d$
$d = 15\ m \qquad\quad = 30 \times 15$
$\qquad\qquad\qquad\quad = 450\ J$

Work done is 450 J. (Note that the mass was not required.)

Power

Power is the rate of doing work. It is measured in watts. 1 watt equals 1 joule per second.

power in watts — $\boxed{\mathbf{P = \frac{E}{t}}}$ — energy or work done in joules

time in seconds

Example
A cyclist uses a force of 60 N and travels 2 km in 8 minutes. What is her average power?

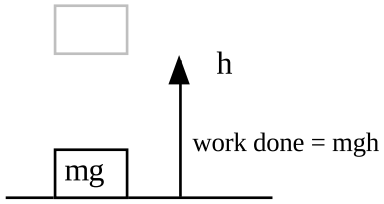
$F = 60\ N \qquad \text{Work done } E_w = 60 \times 2000$
$d = 2\ km = 2000\ m \qquad = 120000\ J$
$t = 8\ min = 480\ s$

$$P = \frac{E_w}{t}$$
$$= \frac{120000}{480} = 250\ W$$

Gravitational potential energy

An object which is raised up to a high position is said to have gravitational potential energy. The work done against gravity to raise it equals the energy transformed into potential energy.

Imagine a mass of m kg lifted through a height of h metres:



Force needed	= weight of m kg = mg newtons
Work done	= force x distance = mg x h
potential energy	**= mgh joules**

$$\boxed{\mathbf{E_p = mgh}}$$

gravitational potential energy gained in joules

h is height gained in metres

mass in kg

gravitational field strength (10 N/kg on Earth)

Example

A chairlift raises a skier of mass 50 kg to a height of 250 m. How much potential energy does the skier gain?

$m = 50\ kg$	$E_p = mgh$
$g = 10\ N/kg$	$= 50 \times 10\ \ 250$
$h = 250\ m$	$= 125000\ J$

Kinetic energy

Kinetic Energy is the energy associated with a moving object. It is measured in joules and has the symbol E_k.

The kinetic energy of a moving object depends on the mass of the object and on the square of its velocity.

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

kinetic energy in joules

speed in m/s

mass in kg

Example

How much kinetic energy does a car of mass 1000 kg have when it is travelling at 20 m/s (approx 50 miles per hour)?

m = 1000 kg $\quad Ek = \frac{1}{2} mv^2 \quad = \frac{1}{2} \times 1000 \times 20^2 = 200000$ J

v = 20 m/s

Kinetic energy and stopping distances
The stopping distance of a vehicle consists of two parts: thinking distance and braking distance. The **thinking** distance increases with speed. Thinking distance = speed × reaction time.

To stop a vehicle, the brakes do work to transform the kinetic energy into heat. This work equals the (braking force × the braking distance). The **braking** distance must therefore increase as the speed and kinetic energy of the vehicle increase.

Efficiency
Machines can be used to transform one kind of energy into another. For example, an electric motor transforms electricity into kinetic energy. This energy might be further transformed into potential energy if the motor is used to drive a lift. However, not **all** the electrical energy which is supplied to the motor will be transformed into the final **useful** form of energy. Some may be transformed into heat, due to friction, and sound. Although no energy has been destroyed, some is 'wasted' because it cannot be used. This makes the machine inefficient. Efficiency is measured by expressing the **useful** energy output as a percentage of the **total** energy input.

Formula for efficiency

$$\boxed{\textbf{\% Efficiency} = \frac{\textbf{useful energy output}}{\textbf{total energy input}} \times \frac{\mathbf{100}}{\mathbf{1}}}$$

The same formula can be applied to power rather than energy.

Example
What is the efficiency of an electric hoist which uses a 400 W motor if it takes 10 s to lift a 60 kg load to a height of 4 m?

$P = 400\ W$
$t = 10\ s$
$m = 60\ kg$
$h = 4\ m$

Useful energy out $= \text{potential energy}$
$= mgh$
$= 60 \times 10 \times 4$
$= 2400\ J$

Total energy in $= Pt$
$= 400 \times 10$
$= 4000\ J$

$$\%\ Efficiency = \frac{\text{useful energy output}}{\text{total energy input}} \times \frac{100}{1}$$

$$= \frac{2400}{4000} \times \frac{100}{1}$$

$$= 60\%$$

HEAT

Specific Heat Capacity

The specific heat capacity of a substance is the amount of heat energy required to change the temperature of 1 kg of a substance by 1 °C.
Specific heat capacity is calculated using the formula:

heat transferred — $\boxed{E_h = cm\Delta t}$ — change in temperature

mass of material

specific heat capacity

Units

The unit for specific heat capacity is the joule per kilogram degree celsius (J/kg °C).

Example
When a kettle containing 2 kg of water (specific heat capacity 4200 J/kg °C) cools from 40 °C to 20 °C, calculate the heat given out by the water.

c = 4200 J/kg °C *m = 2 kg* $T_2 = 40\ ^\circ C$ $T_1 = 20\ ^\circ C$ $E_h = ?$
$E_h = cm\Delta T = 4200 \times 2 \times (40 - 20) = 168000$ *J or 168 kJ*

Changes of State

When ice at its melting point of 0 °C gains heat energy, it changes into water, also at 0 °C. When the process is reversed, water at its freezing point of 0 °C changes into ice at 0 °C. In this case energy is released with no change in temperature.

Specific Latent Heat

The specific latent heat of a substance is the energy involved in changing the state of 1 kg of the substance without any temperature change.
Specific latent heat of a substance is calculated using the formula:

heat transferred — $\boxed{E_h = m\,l}$ — specific latent heat

mass of material

The specific latent heat of **vaporisation** is the heat energy required to change 1 kg of liquid to vapour without temperature change.
The specific latent heat of **fusion** is the heat energy required to change 1 kg of a solid to liquid without change in temperature.

Units

The unit for specific latent heat is the joule per kilogram, J/kg.

Example
A mass of 2.5 kg of ammonia at its boiling point is vaporised when 6500 J of heat is supplied to it. Calculate the specific latent heat of vaporisation of ammonia.

$m = 2.5\ kg \qquad E_h = 6500\ J \qquad l = ?$

$$l = \frac{E_h}{m} = \frac{6500}{2.5} = 2600\ J/kg$$

Principle of Conservation of energy
The total amount of energy remains constant during energy transfers. Energy cannot be created or destroyed but simply transformed to one of its many forms.

Example 1
A piece of brass of mass 2 kg is dropped onto a hard surface without rebounding resulting in a temperature rise of 1 °C. Calculate the speed with which the brass hits the surface.

$m = 2\ kg \qquad \Delta T = 1\ ^\circ C \qquad c = 370\ J/kg\ ^\circ C \qquad v = ?$

Assuming all the kinetic energy of the brass is changed on impact to heat in the brass,

Kinetic energy lost by brass = Heat energy produced in brass

$$\frac{1}{2} mv^2 = c\, m\Delta T$$
$$\frac{1}{2} v^2 = c\Delta T$$
$$v^2 = 2 \times 370 \times 1$$
$$v = 27\ m/s$$

Example 2
Calculate the time taken for a 500 W heater to melt 2 kg of ice at 0 ∞C.

Latent heat of fusion of ice $= 3.34 \times 10^5\ J/kg$

$P = 500\ W \qquad m = 2\ kg \qquad l = 3.34 \times 10^5\ J/kg \qquad t = ?$

Energy required to melt the ice $\quad E = ml = 2 \times 3.34 \times 10^5$
$= 6.68 \times 10^5\ J$

Time taken to melt ice $\quad t = \frac{E}{P} = \frac{6.68 \times 10^5}{500}$

$t = 1336\ s$

KINEMATICS PROBLEMS

Speed, distance and time

1. A runner completes a 200 m race in 25 s. What is his average speed in m/s?

2. A friend asks you to measure his average cycling speed along flat road. Describe which measurements you would take and the measuring instruments you would use.

3. An athlete takes 4 minutes 20 s to complete a 1500 m race. What is the average speed?

4. On a fun run, a competitor runs 10 km in 1 hour. What is her average speed in
   a) km/h b) m/s?

5. Describe how you could measure the average speed of a car as it passes along the road outside your school/college.

6. Concorde can travel at 680 m/s (twice the speed of sound).
   How far will it travel in 25 s at this speed?

7. A girl can walk at an average speed of 2 m/s. How far will she walk in 20 minutes?

8. How long will it take a cyclist to travel 40 km at an average speed of 5 m/s?

9. How long (to the nearest minute) will the Glasgow to London shuttle take if it flies at an average speed of 220 m/s for the 750 km flight?

10. How long, to the nearest minute, will a car take to travel 50 km if its average speed is 20 m/s?

11. Look at this timetable for a train between Edinburgh and Glasgow:

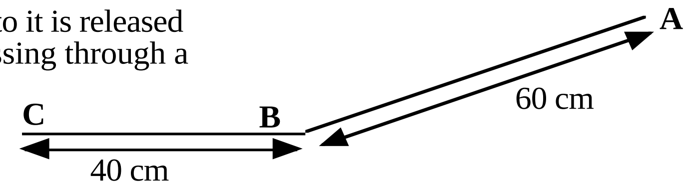
Station	Time	Distance from Glasgow
Glasgow	0800	0 km
Falkirk	0820	34 km
Linlithgow	0828	46 km
Edinburgh	0850	73 km

   a) What was the average speed for the whole journey in m/s?
   b) What was the average speed in m/s between Glasgow and Falkirk?
   c) Explain the difference in average speeds in a) and b).

12. Describe how you would measure the instantaneous speed of a vehicle as it reached the bottom of a slope.

13. In an experiment to measure instantaneous speed, these measurements were obtained:-
    Reading on timer = 0.125 s
    Length of car = 5 cm
    Calculate the instantaneous speed of the vehicle in m/s.

14. A trolley with a 10 cm card attached to it is released from A and runs down the slope, passing through a light gate at B, and stopping at C.
Time from A to B = 0.8 s.
Time on light gate timer = 0.067 s



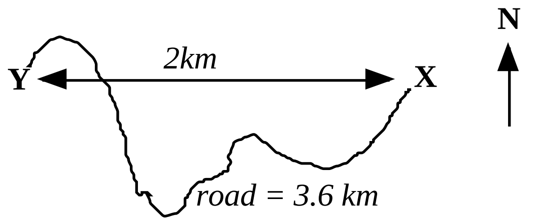
a) What is the average speed between A and B?
b) What is the instantaneous speed at B?

Vectors and Scalars

15. What is the difference between a vector quantity and a scalar quantity?

16. Use your answer to question 15 to explain the difference between distance and displacement.

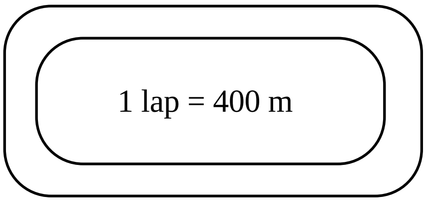
17. A man walks from X to Y along a winding road.



a) What is his displacement at the end of his walk?
b) What distance has he walked?

18. If the walker in question 17 took 40 minutes for his walk, what was
a) his average speed
b) his average velocity?

19. One complete lap of a running track is 400m.

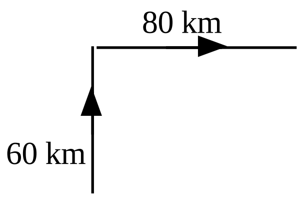


An athlete completes one lap in 48 s in the 400 m race. What is his
a) distance travelled
b) displacement
c) average speed
d) average velocity.

20. Repeat Q 19 for a runner in the 800 m race whose winning time was 1 min 54 s.

21. A car travels 40 km north, then turns back south for 10 km. The journey takes 1 hour. What is
a) the displacement of the car
b) the distance the car has travelled
c) the average velocity of the car }use km h^{-1}
d) the average speed of the car? }

22. A car drives 60 km north, then 80 km east, as shown in the diagram. The journey takes 2 hours.
Calculate the
a) distance travelled
b) displacement
c) average speed
d) average velocity.



Acceleration

23. A Jaguar can reach 27 m/s from rest in 9.0 s. What is its acceleration?

24. The space shuttle reaches 1000 m/s, 45 s after launch. What is its acceleration?

25. A car reach 30 m/s from a speed of 18 m/s in 6 s. What is its acceleration?

26. A train moving at 10 m/s increases its speed to 45 m/s in 10 s. What is its acceleration?

27. A bullet travelling at 240 m/s hits a wall and stops in 0.2 s. What is its acceleration?

28. A car travelling at 20 m/s brakes and slows to a halt in 8 s. What is the deceleration?

29. Describe how you would measure the acceleration of a small vehicle as it runs down a slope in the laboratory.

30. On approaching the speed limit signs, a car slows from 30 m/s to 12 m/s in 5 s. What is its deceleration?

31. A bowling ball is accelerated from rest at 3 m/s^2 for 1.2 s. What final speed will it reach?

32. How long will it take a car to increase its speed from 8 m/s to 20 m/s if it accelerates at 3 m/s^2?

33. A cyclist can accelerate at 0.5 m/s^2 when cycling at 4 m/s. How long will she take to reach 5.5 m/s ?

34. The maximum deceleration a car’s brakes can safely produce is 8 m/s^2. What will be the minimum stopping time if the driver applies the brakes when travelling at 60 mph (27 m/s).

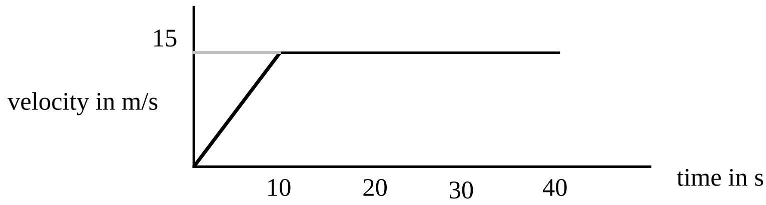
35. The table below gives some performance figures for cars.

Car	**Time for 0 - 60 mph**	**max. speed in mph**
Mondeo 1.8 LX	10.2 s	122
Peugeot 106 XN 1.1	12.5 s	103
Renalt Clio RL	14.3 s	95
Nissan Micra 1.0 S	15.2 s	89
Porsche Boxster	6.5 s	139

a) Which car has the smallest acceleration?
b) Which car has the largest acceleration?
c) Assuming that the acceleration remained constant, how long would it take for the following cars to reach their top speed?
i) Mondeo ii) Porsche

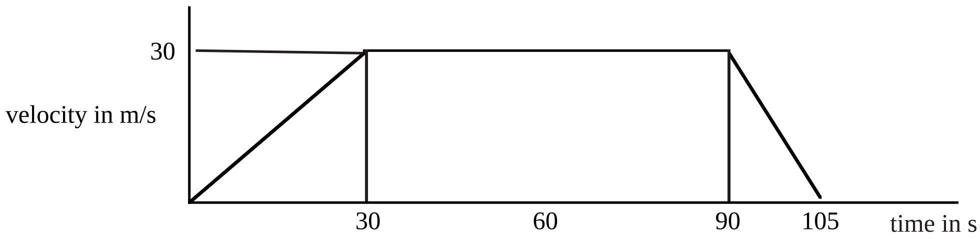
Velocity - time graphs

36. The graph below shows how the velocity of a car varies over a 40 s period.



a) Describe the motion of the car during this 40 s period.
b) Calculate the acceleration of the vehicle.
c) How far does the car travel while accelerating?
d) What is the total distance travelled by the car?

37. Use the graph below to answer the following questions.

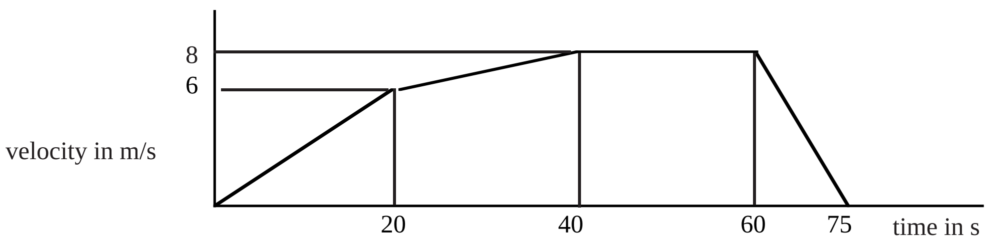


a) During which time is the vehicle travelling at a constant velocity?
b) Calculate the values of i) the initial acceleration ii) the final deceleration
c) What is the braking distance of the car?
d) What is the total distance travelled?
e) What is the average velocity of the car?

38. Draw a velocity-time graph to describe the following motion:-
A car accelerates from rest at 2 m/s for 8 s, then travels at a constant velocity for 12 s, finally slowing steadily to a halt in 4 s.

39. For the vehicle in the previous question, what are the values of
a) the maximum velocity
b) the distance travelled
c) the average velocity?

40. The graph below describes the motion of a cyclist.



a) What is the value of the maximum positive acceleration?
b) Show by calculation whether the cyclist travels farther while accelerating, or while cycling at the maximum velocity.

DYNAMICS PROBLEMS

Gravity, mass and weight

The data table on the right may be required for questions 41-48.
Assume the questions refer to the Earth unless otherwise stated

Planet	g (N/kg)
Mercury	3.7
Venus	8.8
Earth	10
Mars	3.8
Jupiter	26.4
Saturn	11.5
Uranus	11.7
Neptune	11.8
Pluto	4.2

41. What is the weight of a 10 kg bag of potatoes?

42. What is the weight of a 250 g bag of sweets?

43. What is the mass of a 450 N girl?

44. What is the weight of a 10,000 kg spacecraft on
    a) Earth b) Mars c) Venus?

45. What would a 60 kg man weigh on Jupiter?

46. Which planet's gravity is closest to our own?

47. An astronaut who weighs 700 N on Earth goes to a planet where he weighs 266 N. Calculate his mass and state which planet he was on.

48. What would an astronaut weigh on Earth, if his weight on Venus was 528 N?

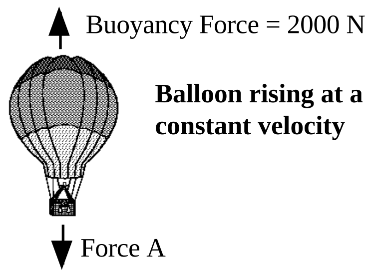
Friction

49. Describe two methods of
    a) increasing friction b) decreasing friction.

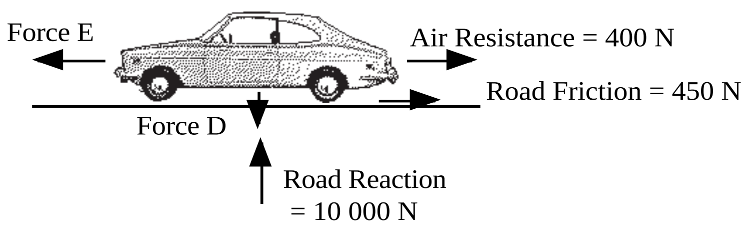
50. Where, in a bicycle, is friction deliberately
    a) increased b) decreased?

Balanced forces and Newton's First Law

51. The diagram shows the forces acting on a balloon as it rises.
    a) What will be the size of force A?
    b) If the balloon was falling at a constant velocity, what would be the size of force A?



52. The diagram below shows the forces acting on a car moving at constant velocity.



a) What can you say about the unbalanced force acting on this car?
b) How big is the engine force E?
c) What is the weight of the car D?

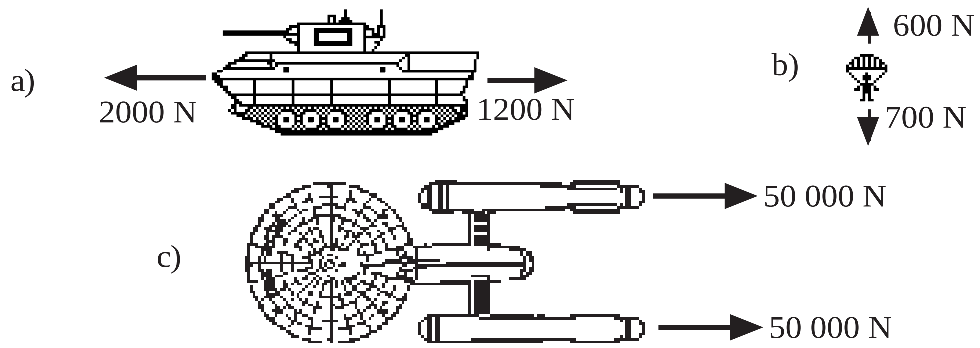
53. Explain, using Newton's First Law, why passengers without seat belts in a stationary car are thrown forwards in the car, when the car stops suddenly.

54. Explain how a parachutist reaches a terminal velocity.

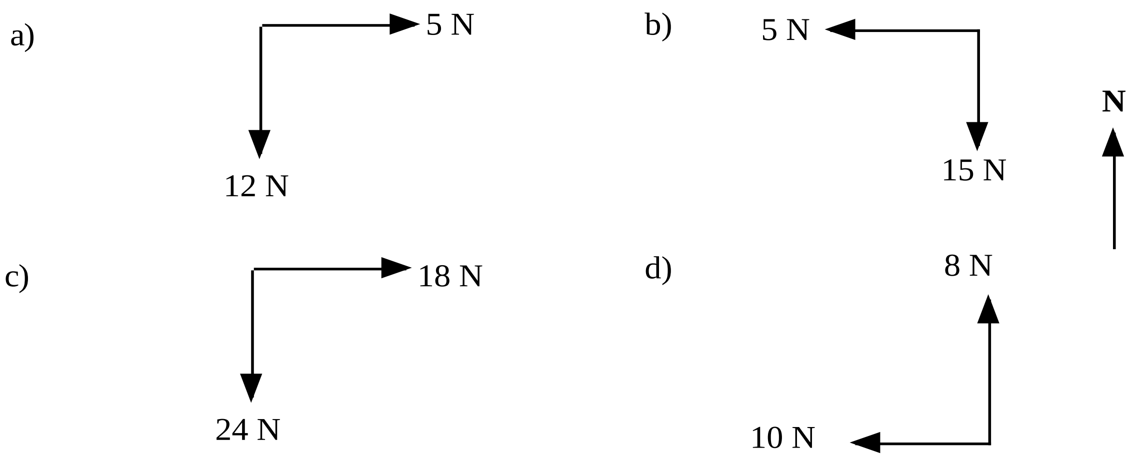
Resultant forces

55. What is meant by the resultant force on an object?

56. What are the resultants of the following forces?



57. By using a scale diagram or otherwise, find the resultant of the following pairs of forces.



Newton's Second Law

58. What force is needed to accelerate a 5 kg mass at 3 m/s^2 ?

59. What will be the acceleration of a 12 kg mass acted on by a force of 30 N?

60. What mass would accelerate at 2 m/s^2 when acted on by a 12 N force?

61. What force will accelerate 250 g at 2 m/s^2?

62. What force would be needed to accelerate a 10 tonne lorry at 1.5 m/s^2? (1 tonne = 1000 kg)

63. Give two reasons why a car will have a smaller acceleration in similar conditions when a roof rack is added.

64. Describe an experiment to investigate the effect of varying the unbalanced force acting on a fixed mass.

65. A car of mass 1200 kg experiences friction equal to 500 N when travelling at a certain speed. If the engine force is 1400 N, what will be the car's acceleration?

66. A car of mass 2000 kg has a total engine force of 4500 N. The frictional drag force acting against the car is 1700 N. What is the acceleration of the car?

67. Two girls push a car of mass 1000 kg. Each pushes with a force of 100 N and the force of friction is 120 N. Calculate the acceleration of the car.

68. A boat engine produces a force of 10000 N and the friction and water resistance total 3500 N. If the mass of the boat is 2000 kg, what will be its acceleration?

69. A careless driver tries to start his car with the hand brake still on. The engine exerts a force of 2500 N and the hand brake exerts a force of 1300 N. The car moves off with an acceleration of 1.2 m/s^2. What is the mass of the car?

70. A car of mass 1200 kg can accelerate at 2 m/s^2 with an engine force of 3000 N. What must be the total friction force acting on the car?

71. A helicopter winches an injured climber up from a mountainside.
The climber's mass is 65 kg.
a) What is the weight of the climber?
b) If he is accelerated upwards at 1.0 m/s^2, what unbalanced force is required?
c) What total upwards force must be produced by the helicopter?

72. An 800 kg car is accelerated from 0 to 18 m/s in 12 seconds.
a) What is the resultant force acting on the car?
b) At the end of the 12 s period the brakes are operated and the car comes to rest in a time of 5 s. What is the average braking force acting on the car?

Acceleration due to gravity and gravitational field strength

73. On the moon, where the gravitational field strength is 1.6 N/kg, a stone falls and takes 1.5 s to reach the surface. What is its velocity as it hits the surface of the moon?

Projectiles

74. A stone thrown horizontally from a cliff lands 24 m out from the cliff after 3 s. Find:
a) the horizontal speed of the stone
b) the vertical speed at impact.

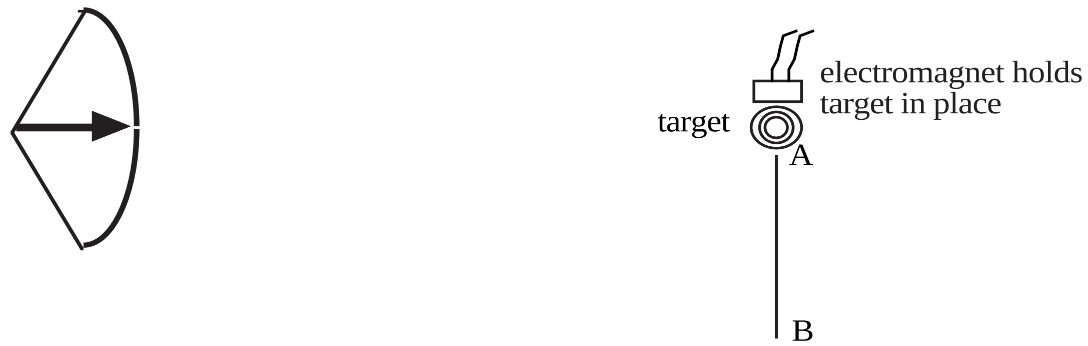
75. A ball is thrown horizontally from a high window at 6 m/s and reaches the ground after 2 s. Calculate:

a) the horizontal distance travelled
b) the vertical speed at impact.

76. An aircraft flying horizontally at 150 m/s, drops a bomb which hits the target after 8 s. Find:
   a) the distance travelled horizontally by the bomb
   b) the vertical speed of the bomb at impact
   c) the distance travelled horizontally by the aircraft as the bomb fell
   d) the position of the aircraft relative to the bomb at impact.

77. A ball is projected horizontally at 15 m/s from the top of a vertical cliff. It reaches the ground 5 s later. For the period between projection until it hits the ground, draw graphs with numerical values on the scales of the ball's
   a) horizontal velocity against time
   b) vertical velocity against time
   c) From the graphs calculate the horizontal and vertical distances travelled.

78. In the experimental set-up shown below, the arrow is lined up towards the target. As it is fired, the arrow breaks the circuit supplying the electromagnet, and the target falls downwards from A to B.



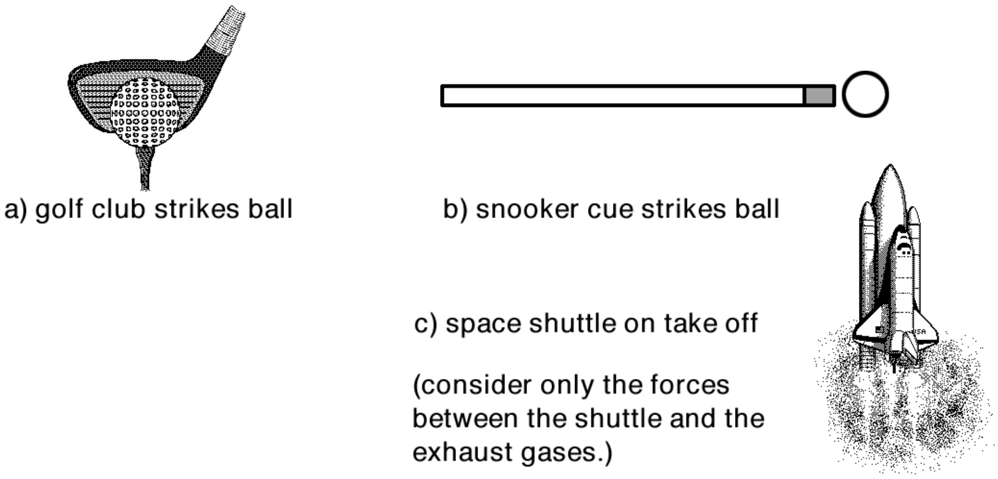
   a) Explain why the arrow will hit the target.
   b) Suggest one set of circumstances when the arrow would fail to hit the target (you must assume it is always lined up correctly).

MOMENTUM AND ENERGY PROBLEMS

Newton's Third Law

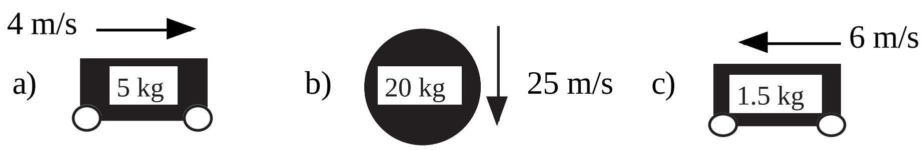
79. State Newton's Third Law.

80. Identify the 'Newton pairs' in the following situations.



Momentum

81. What is the momentum of the body in each of the following situations:



82. State the principle of conservation of energy.

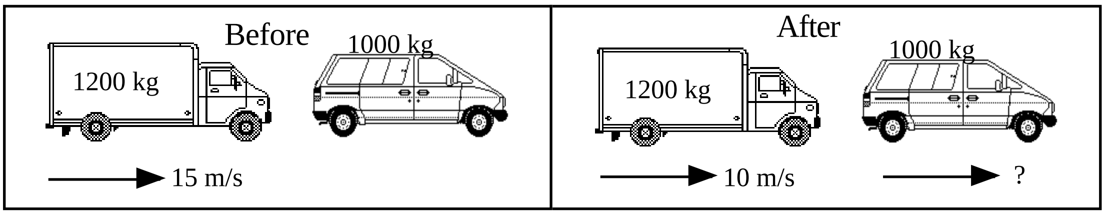
83. A trolley of mass 2 kg and travelling at 1.5 m/s collides and sticks to another stationary trolley of mass 2 kg. Calculate the velocity after the collision.

84. A car of mass 1200 kg and travelling at 20 m/s collides with a stationary car of mass 800 kg. If they move off together after the collision, calculate this new velocity.

85. A skater of mass 70 kg is moving at 4 m/s when he bumps into a skater of mass 50 kg who is not moving. They move off together on the ice. What is their velocity immediately after the collision?

86. A target of mass 4 kg hangs from a tree by a long string. An arrow of mass 100 g is fired with a velocity of 100 m/s and embeds itself in the target. At what velocity does the target begin to move after the impact?

87. The diagram on the next page shows a collision between a moving van and a stationary car. After the collision the van continues to move forward, but with a reduced velocity as shown.
Calculate the velocity with which the car moves forward after the collision.



88. In a game of bowls one particular bowl hits the jack head on causing it to move forward. The jack has a mass of 300 g and was originally stationary. The bowl has a mass of 1 kg and was moving at a speed of 2 m/s before hitting the jack, but continued forwards at 1.5 m/s after the collision. What is the speed of the jack after the collision?

89. A van of mass 1800 kg hits a stationary car of mass 1200 kg. They lock together and move off at 12 m/s. What was the velocity of the van as it collided?

90. Police suspect that a van was breaking the speed limit when it collided with a parked car. Investigations provided them with the following data:-
    mass of parked car = 800 kg
    mass of van = 1000 kg
    velocity of car after collision = 5 m/s
    velocity of van after collision = 11 m/s
    Show whether the van was breaking the 30 mph speed limit (equivalent to 13 m/s).

91. A pellet of mass 0.5 g is fired into plasticine on a stationary vehicle on a linear air track. The mass of the vehicle and plasticine is 100 g. The vehicle moves off as a result of the impact and a card mounted on it cuts through a light gate. The length of card is 10 cm. and the time recorded on the eletronic timer is 0.30 s.
    a) Calculate the velocity of the vehicle in m/s
    b) Calculate the velocity of the pellet before the collision.

Work and Energy

92. Copy and complete these examples of energy transformations.
    a) Car moving at a steady speed along level road
       chemical energy -> ________
    b) Car accelerating along level road
       chemical energy -> ________ + _______
    c) Car braking
       kinetic energy -> ________
    d) Car freewheeling downhill (engine switched off)
       ________ -> ________ + _______

93. A locomotive exerts a pull of 10000 N to pull a train a distance of 400 m.
    How much work is done?

94. A gardener does 1200 J pushing a wheelbarrow with a force of 100 N.
    How far did she push the barrow?

95. A man uses up 1000 J by pulling a heavy load for 20 m. What force did he use?

96. A girl is pushing her bike with a force of 80 N and uses up 4000 J of energy.
How far did she push the bike?

97. A man weighing 600 N climbs stairs in an office block which are 40 m high.
How much work does he do?

98. A worker pushes a 4 kg crate along the ground for 3 m using a force of 20 N, then lifts the crate up to a ledge 1 m high. How much work does he do altogether?

Work, Power and Time

99. A man pushes a wheelbarrow for 60 m using a 50 N force. If he takes 10 s, what is his average power?

100. The man's son pushes the wheelbarrow for 60 m using the same force as his father, but he takes 13 s to do it.
How does a) his work b) his power compare to his father's?

101. A machine lifts a load of 4000 N to a height of 5 m in 20 s. What is its power?

102. A boy who weighs 600 N can run up stairs of vertical height 8 m in 12 s.
a) What is his power?
b) A girl who weighs 500 N takes 10 s to run up the stairs. What is her power?
c) Do they do equal amounts of work?

103. Describe how you could estimate the average power of a student who is running up a flight of stairs. List measurements you would take, how you would obtain these, and indicate how you would calculate the result.

104. A lift can raise a total mass of 800 kg up 10 m in 40 s. What is its power?

105. A weight lifter lifts a mass of 250 kg from the ground to a height of 1.5 m in a time of 2 seconds. What was his average power during the lift?

106. A lift in a building can take a maximum of 10 people of average mass 70 kg.
The mass of the lift is 500 kg.
a) What is the total weight of a full lift?
b) What is the power needed to raise the lift up 30 m in 10 s?

107. A bucket of water of weight 250 N is to be lifted up a 30 m well by a 500 W motor.
How long will it take to raise the bucket?

108. a) What will be the power of the electric motor of a lift which can raise a load of 4000 N at a steady speed of 2 m/s?
b) What is the energy transformation?

Gravitational potential energy

109. A chairlift raises a skier of mass 60 kg to a height of 250 m.
How much potential energy does the skier gain?

110. A brick of mass 3 kg rests on a platform 25 m above the ground on a building site.
   a) How much potential energy is stored in the brick?
   b) If the brick falls 25 m to the ground, how much potential energy will it lose?
   c) What form of energy will the brick gain?

111. Estimate how much gravitational potential energy **you** would gain if you were lifted 30m up to the top of a fun-ride.

112. An apple, mass 100 g, has 300 J of potential energy at the top of the Eiffel Tower.
What is the height of the Eiffel Tower?

113. An astronaut of mass 70 kg climbs to a height of 5 m on the moon and gains 560 J of gravitational potential energy. What must be the gravitational field strength on the moon?

Kinetic energy

114. You are provided with an air track and vehicles, a light gate and timer and some elastic bands. Describe how you could use this apparatus to establish how kinetic energy depends on velocity. Include details of any measurements you would take and any additional measuring equipment needed.

115. Calculate the kinetic energy of the following:
   a) a 5 kg bowling ball moving at 4 m/s
   b) a 50 kg skier moving at 20 m/s
   c) a 0.02 kg bullet moving at 100 m/s.

116. a) How much kinetic energy does a 800 kg car have at a speed of 10 m/s?
   b) If it doubles its speed to 20 m/s, calculate its new kinetic energy?

117. A cyclist who is pedalling down a slope reaches a speed of 15 m/s. The cyclist and her cycle together have a mass of 80 kg.
   a) Calculate the total kinetic energy.
   b) Name two sources of this kinetic energy.

118. Calculate an **approximate** value for the kinetic energy of an Olympic 100 m sprinter as he crosses the line (time for race is about 10 s).

119. What is the speed of a stone of mass 2 kg if it has 36 J of kinetic energy?

120. A motor cyclist and his bike have a total mass of 360 kg and kinetic energy of 87120 J.
What is his speed?

121. The apple in question 112 is dropped from the top of the Eiffel Tower.

a) How much kinetic energy would it have just before hitting the ground?
b) What will be its velocity as it hits the ground?

122. A car of mass 1000 kg is travelling at 20 m/s.
a) How much kinetic energy does it have?
b) If the maximum braking force is 5 kN, what will be the minimum braking distance?
c) If the driver has a reaction time of 0.7 s, how far will the car travel during this 'thinking time'?
d) What will the total stopping distance be?

Efficiency

123. What is the efficiency of a machine which has a power input of 800 W and a power output of 600 W?

124. A machine which is 80% efficient uses 20000 J of energy. What is its energy output?

125. A motor which is 60% efficient has an output power of 480 W. What is its input power?

126. An electric motor rated at 500 W runs for 2 minutes and does 45 kJ of work.
a) What is its input energy?
b) What is its efficiency?

127. What is the efficiency of a motor rated at 750 W which can lift a 25 kg load to a height of 4 m in 2 s?

HEAT PROBLEMS

Specific Heat Capacity

128. 10000 J of energy raises the temperature of 1 kg of liquid by 2 °C. How much energy will be required to raise the temperature of 4 kg of the liquid by 1 °C?

129. The specific heat capacity of concrete is about 800 J/kg°C. How much heat is stored in a storage heater containing 50 kg of concrete when it is heated through 100 °C?

130. 1.344 MJ of heat energy are used to heat from 20 °C to 100 °C. Calculate the mass of water if the specific heat capacity of water is 4200 J/kg°C.

131. 9600 J of heat energy is supplied to 1 kg of methylated spirit in a polystyrene cup. Calculate the rise in temperature produced.
Take the specific heat capacity of methylated spirit to be 2300 J/kg°C.

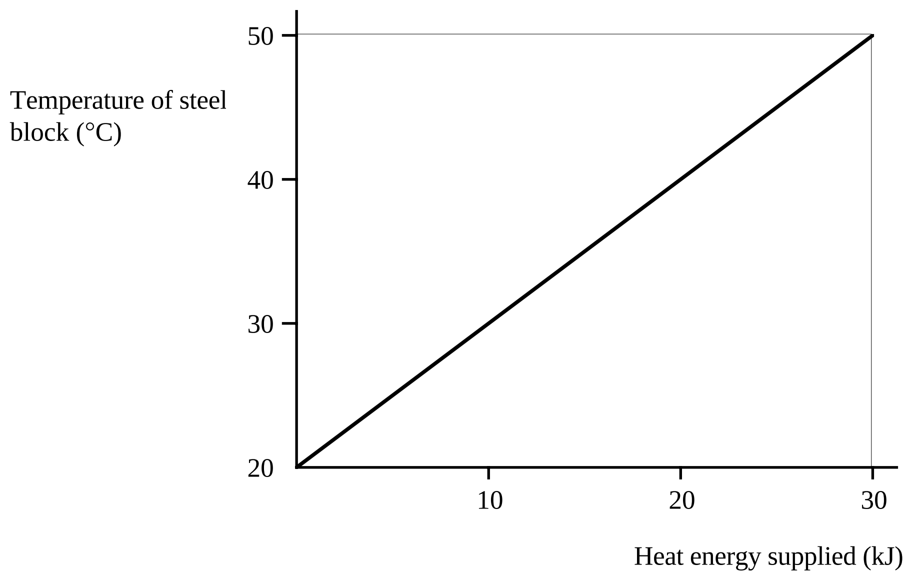
132. When 2.0×10^4 J of heat is supplied to 4 kg of paraffin at 10 °C in a container the temperature increases to 14 °C.
    a) Calculate the specific heat capacity of the paraffin.
    b) Explain why the result in part a) is different from the theoretical value of 2200 J/kg°C.

133. If a kettle containing 2 kg of water cools from 40 °C to 25 °C, calculate the heat given out by the water.

134. The temperature of a 0.8 kg metal block is raised from 27 °C to 77 °C when 4200 J of energy is supplied. Find the specific heat capacity of the metal.

135. The tip of the soldering iron is made of copper with a mass of 30 g. Calculate how much heat energy is required to heat up the tip of a soldering iron by 400 °C.
(specific heat capacity of copper = 380 J/kg°C)

136. The graph below represents how the temperature of a 2 kg steel block changes as heat energy is supplied. From the graph calculate the specific heat capacity of the steel.



Latent Heat

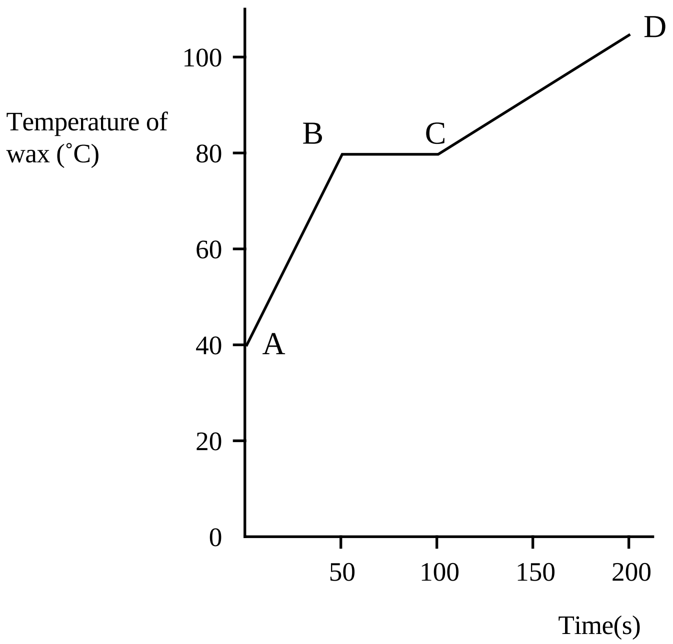
137. Calculate the amount of heat energy required to melt 0.3 kg of ice at 0 °C.
(Specific latent heat of fusion of ice = 3.34×10^5 J/kg)

138. Calculate the specific latent heat of fusion of naphthalene given that 6×10^5 J of heat are given out when 4.0 kg of naphthalene at its melting point changes to a solid.

139. Calculate what mass of water can be changed to steam if 10.6 kJ of heat energy is supplied to the water at 100 °C.
(Specific latent heat of vaporisation of water = 2.26×10^6 J/kg)

140. Ammonia is vaporised in order to freeze an ice rink.
a) Find out how much heat it would take to vaporise 1 g of ammonia.
b) Assuming this heat is taken from water at 0 °C, find the mass of water frozen for every gram of ammonia vaporised.
(Specific latent heat of vaporisation of ammonia = 1.34×10^6 J/kg
Specific latent heat of fusion of ice = 3.34×10^5 J/kg).

141. The graph below shows how the temperature of a 2 kg lump of solid wax varies with time when heated.



a) Explain what is happening to the wax in the regions AB, BC and CD.
b) If a 200 W heater was used to heat the wax, calculate the specific latent heat of fusion of the solid wax.

Principle of Conservation of Energy

142. If 200 g of water at 40 °C are mixed with 100 g of water at 10 °C and no energy is lost, what is the final temperature of the mixture?
(Specific heat capacity of water = 4200 J/kg°C)

143. If an immersion heater heats 300 g of water for 2 minutes and the temperature rises by 30 °C, find the power rating of the heater in watts.

144. A 350 W element is used to boil 300 g of water in a cup. The initial temperature of the water is 20 °C.
   a) How long will it take to reach 100 °C?
   b) State any assumptions made.

145. Meteors are small pieces of matter made mostly of iron. Few meteors hit the surface of the Earth because of the Earth's atmosphere. Assuming all the kinetic energy of the meteor changes to heat energy in the meteor, if a 0.001 kg meteor travelling at 30000 m/s crashes into the Earth's atmosphere resulting in a change in temperature of 20000 °C, calculate the specific heat capacity of the iron.

146. If a copper ball is dropped on a hard surface the ball is deformed, and we can assume all the kinetic energy is transferred to internal energy in the ball. From what height must the ball be dropped to raise its temperature by 2 °C?
(Specific heat capacity of copper = 380 J/kg°C)

147. An electric shower has a 1.5 kW heating element.
   a) How much heat energy can it give out in five minutes?
   b) If the element is used to heat 5 kg of water for 5 minutes, what would be the rise in temperature? (Specific heat capacity of water = 4200 J/kg).

148. A pupil put 2 litres of water at 20 °C into her 1000 W kettle. She switched it on and then forgot it for 15 minutes. Unfortunately, it did not have an automatic cut-out and when she came back the kitchen was full of steam. 1 litre of water has a mass of 1 kg.
   a) How much energy was required to bring the water to boiling point?
   b) How much electrical energy had been used altogether?
   c) How much water had been turned into steam?
   d) Which of your answers are approximate and why?

149. A heating coil carries an electrical current of 2 A for 100 s at a voltage of 20 V. If this is sufficient to boil away 20 g of liquid nitrogen at its boiling point, what is the specific latent heat of vaporisation of nitrogen?

150. A 200 g bun is put in a 600 W microwave oven for one minute. If its temperature rises from 15 °C to 45 °C, what is the specific heat capacity of the bun?

NUMERICAL ANSWERS

Kinematics

1. 8 m/s
3. 5.8 m/s
4. a) 10 km/h
   b) 2.8 m/s
6. 17000 m
7. 2400 m
8. 8000 s (2 h 13 min)
9. 57 min
10. 42 min
11. a) 24.3 m/s
    b) 28.3 m/s
13. 0.4 m/s
14. a) 0.75 m/s
    b) 1.5 m/s
17. a) 2 km west
    b) 3.6 km
18. a) 1.5 m/s
    b) 0.83 m/s west
19. a) 400 m
    b) 0
    c) 8.3 m/s
    d) 0
20. a) 800 m
    b) 0
    c) 7 m/s
    d) 0
21. a) 30 km north
    b) 50 km
    c) 30 km/h north
    d) 50 km/h
22. a) 140 km
    b) 100 km at (053)
    c) 70 km/h
    d) 50 km/h at (053)
23. 3 m/s^2
24. 22.2 m/s^2
25. 2 m/s^2
26. 3.5 m/s^2
27. 1200 m/s^2
28. –2.5 m/s^2
30. –3.6 m/s^2
31. 3.6 m/s
32. 4 s
33. 3 s
34. 3.4 s
35. a) Micra
    b) Porsche
    c) i) 20.7 s ii) 15.1s
36. b) 1.5 m/s^2
    c) 75 m
    d) 525 m
37. a) 30 - 90 s
    b) i) 1m/s^2 ii) –2 m/s^2
    c) 225 m
    d) 2475 m
    e) 23.6 m/s
39. a) 16 m/s
    b) 288 m
    c) 12 m/s
40. a) 0.3 m/s^2
    b) accelerating 200 m
       constant velocity 160 m

Dynamics

41. 100 N
42. 2.5 N
43. 45 kg
44. a) 100000 N
    b) 38000 N
    c) 88000 N
45. 1584 N
47. 70 kg Mars
48. 600 N
51. a) 2000 N
    b) 2000 N
52. b) 850 N
    c) 10000 N
56. a) 800 N to left
    b) 100 N down
    c) 100000 N to right
57. a) 13 N at (067)
    b) 15.8 N at (198)
    c) 30 N at (053)
    d) 12.8 N at (309)
58. 15 N
59. 2.5 m/s^2
60. 6 kg
61. 0.5 N
62. 15000 N
65. 0.75 m/s^2
66. 1.4 m/s^2
67. 0.08 m/s^2
68. 3.25 m/s^2
69. 1000 kg
70. 600 N
71. a) 650 N
    b) 65 N
    c) 715 N
72. a) 1200 N
    b) 2880 N
73. 2.4 m/s
74. a) 8 m/s
    b) 30 m/s
75. a) 12 m
    b) 20 m/s
76. a) 1200 m
    b) 80 m/s
    c) 1200 m
77. b) i) horizontal = 75 m
    ii) vertical = 125 m

NUMERICAL ANSWERS

Momentum and Energy

81. a) 20 kg m/s right
    b) 500 kg m/s down
    c) 9 kg m/s left
83. 0.75 m/s
84. 12 m/s
85. 2.3 m/s
86. 2.44 m/s
87. 6 m/s
88. 1.7 m/s
89. 20 m/s
90. yes - 15 m/s
91. a) 0.33 m/s
    b) 67 m/s
93. 4 MJ
94. 12 m
95. 50 N
96. 50 m
97. 24 kJ
98. 100 J
99. 300 W
101. 1000 W
102. a) 400 W
    b) 400 W
104. 2 kW
105. 1875 W
106. a) 12000 N
    b) 36 kW
107. 15 s
108. a) 8 kW
109. 150 kJ
110. a) 750 J
    b) 750 J
111. 300 × mass
112. 300 m
113. 1.6 N/kg
115. a) 40 J
    b) 10 kJ
    c) 100 J
116. a) 40 kJ
    b) 160 kJ
117. a) 9 kJ
118. approx 3 kJ
119. 6 m/s
120. 22 m/s
121. a) 300 J
    b) 77 m/s
122. a) 200 kJ
    b) 40 m
    c) 14 m
    d) 54 m
123. 75%
124. 16 kJ
125. 800 W
126. a) 60 kJ
    b) 75%
127. 67%

NUMERICAL ANSWERS

Heat

128. 20000 J
129. 4×10^6 J
130. 4 kg
131. 4.17 °C
132. 2 500 J/kg°C
133. 1.26×10^5 J
134. 105 J/kg°C
135. 4560 J
136. 500 J/kg°C
137. 1.002×10^5 J
138. 1.5×10^5 J/kg
139. 0.0047 kg
140. a) 1.34×10^6 J
     b) 5.9×10^{-4} kg
141. b) 5000 J/kg
142. 30 °C
143. 315 W
144. a) 288 s
145. 625 J/kg°C
146. 76 m
147. a) 4.5×10^5 J
     b) 21.4 °C
148. a) 6.72×10^5 J
     b) 9×10^5 J
     c) 0.1 kg
149. 2×10^5 J/kg
150. 6000 J/kg°C

CIRCUITS

Electric Current

Materials can be divided into two main groups, **conductors** and **insulators**. In a conductor, the electrons (sometimes referred to as charges) are free to move through the structure but in an insulator they are not.
Electric current is a measure of the flow of charge around a circuit and depends on the amount of charge passing any point in a circuit every second.
All metals are conductors and, with the occasional exception, all non-metals are insulators.

$$\boxed{I = \frac{Q}{t}} \quad \text{or} \quad \boxed{Q = I\,t}$$

I = electric current
Q = electric charge
t = time taken for charge to pass point

Units

Electric current is measured in ampères, **A**.
Electric charge is measured in coulombs, **C**.
Time is measured in seconds, **s**.

Example

Calculate the electric current in a circuit if 3 C of charge pass a point in a circuit in a time of 1 minute.
Ensure that all quantities are stated with the correct units.

$I = ?$ $\quad Q = 3\ C$ $\quad t = 1\ min = 60\ s$

$$I = \frac{Q}{t} = \frac{3}{60} = 0.05\ A$$

Voltage and Potential Difference (p.d.)

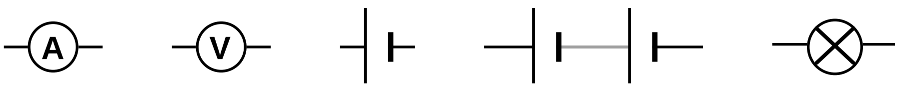
The voltage or potential difference (often referred to as the p.d.) of the supply is a measure of the energy given to the charges in a circuit.

Units

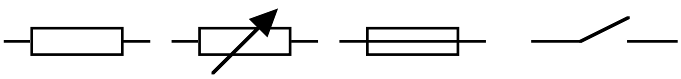
Voltage (p.d.) has the symbol **V** and is measured in **volts**, **V**.

Circuit Symbols

Circuit symbols are used in electrical circuits to represent circuit components or devices to make them easier to draw and understand.
Some of the circuit symbols that you will need to know are shown below.



ammeter voltmeter cell battery (of cells) lamp

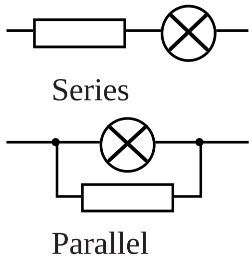


resistor variable resistor fuse switch

Series and Parallel Circuits

Components in a circuit can be connected in series or parallel.
A **series** arrangement of components is where they are **in-line** with each other, that is connected end-to-end.

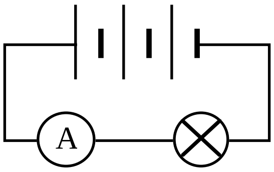
A **parallel** arrangement of components is where they are connected **across** each other where the current has more than one path through that part of the circuit.



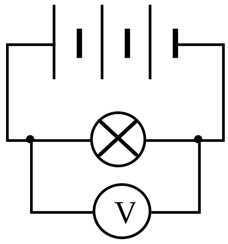
Measuring Current and Potential Difference or Voltage

Electric current is measured using an **ammeter** which is connected **in series** with the component.
Potential difference (p.d.), or voltage, is measured using a **voltmeter** which is connected **in parallel** with the component.

Measuring the **current through** the lamp

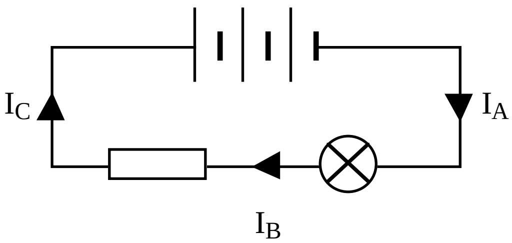


Measuring the **voltage (p.d.) across** the lamp

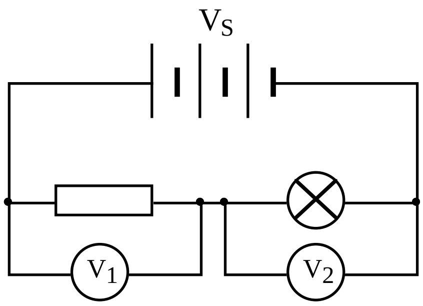


Current and Potential Difference or Voltage in Series Circuits

The current is the same at all points in a series circuit.
The sum of the potential differences across the components in a series circuit is equal to the voltage of the supply.



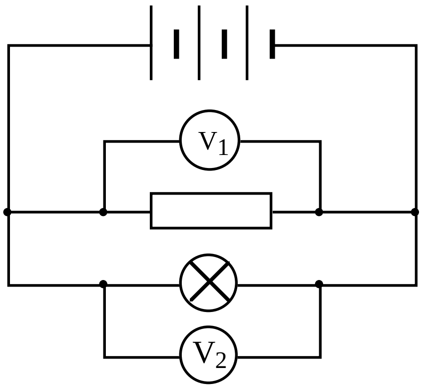
$\boxed{\mathbf{I_A = I_B = I_C}}$

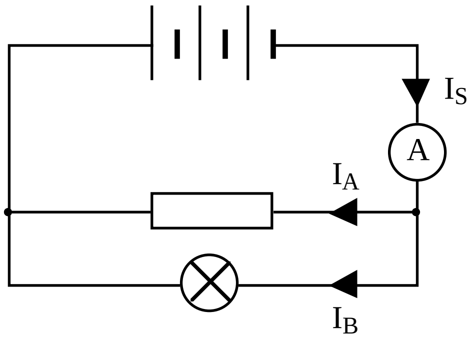


$\boxed{\mathbf{V_S = V_1 + V_2}}$

Current and Potential Difference or Voltage in Parallel Circuits

The potential difference across components in parallel is the same for all components.
The sum of the currents in parallel branches is equal to the current drawn from the supply.





$$\boxed{V_1 = V_2}$$

$$\boxed{I_S = I_A + I_B}$$

Electrical Resistance

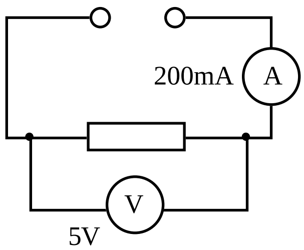
Resistance is a measure of the opposition of a circuit component to the flow of charge or current through that component. The greater the resistance of a component, the less will be the current through that component.
All normal circuit components have resistance and the resistance of a component is measured using the relationship

$$\boxed{R = \frac{V}{I}} \quad \text{or} \quad \boxed{V = I\,R}$$

R = resistance
V = potential difference (voltage)
I = current

Resistance is measured in ohms, Ω.
Potential difference (or voltage) is measured in volts, **V**.
Current is measured in amperes, **A**.
This relationship is known as **Ohm's Law**, named after a German physicist, Georg Ohm.
For components called **resistors**, the resistance remains approximately constant for different values of current therefore the ratio **V/I** (= R) remains constant for different values of current.

Example
Calculate the resistance of the resistor in the diagram opposite.
Ensure that all quantities are stated in the correct units.



R = ?
V = 5 V
I = 200 mA = 0.2 A

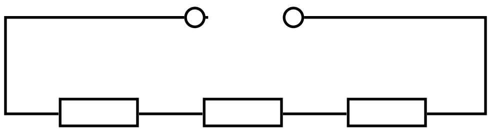
$$R = \frac{V}{I} = \frac{5}{0.2} = 25\ \Omega$$

Resistors in Series

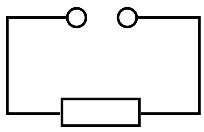
When more than one component is connected in series, the **total resistance** of all the components is equivalent to one single resistor, R_T, calculated using the relationship

$$\boxed{\mathbf{R_T = R_1 + R_2 + R_3}}$$

For the following circuit with three components in series,



is equivalent to



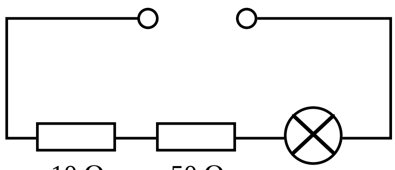
The above relationship is true for two or more components connected in series.

Resistors in Parallel

When more than one component is connected in parallel, the **total resistance** of all the components is equivalent to one single resistor, R_T, calculated using the relationship

$$\boxed{\mathbf{\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}}$$

Example 1 Components in series
Calculate the total resistance of the circuit opposite.



$R_1 = 10\ \Omega$
$R_2 = 50\ \Omega$
$R_3 = 25\ \Omega$

$$R_T = R_1 + R_2 + R_3$$
$$R_T = 10 + 50 + 25 = 85\ \Omega$$

Example 2 Components in parallel
Calculate the total resistance of the components above when connected in parallel.

$R_1 = 10\ \Omega$
$R_2 = 50\ \Omega$
$R_3 = 25\ \Omega$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{10} + \frac{1}{50} + \frac{1}{25}$$
$$= \frac{5}{50} + \frac{1}{50} + \frac{2}{50} = \frac{8}{50}$$

$$\frac{1}{R_T} = \frac{8}{50} \quad \textit{therefore} \quad \frac{R_T}{1} = \frac{50}{8} \qquad R_T = 6.5\ \Omega$$

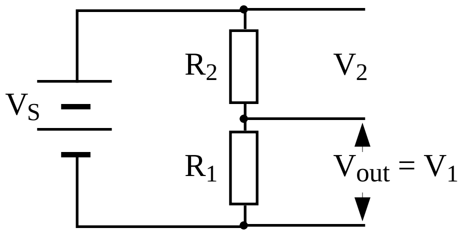
Note:

For components in series, R_T is **always** greater than the largest resistance. For components in parallel, R_T is **always** less than the smallest resistance.

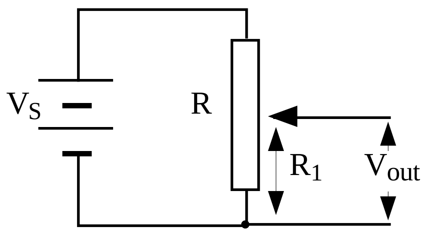
Potential Divider Circuits

A potential divider is a device or a circuit that uses two (or more) resistors or a variable resistor (potentiometer) to provide a fraction of the available voltage (p.d.) from the supply.

Fixed Resistance



Variable Resistance



The p.d. from the supply is divided across the resistors in direct proportion to their individual resistances.

Take the fixed resistance circuit - this is a **series** circuit therefore the current in the same at all points.

$I_{supply} = I_1 = I_2$ where I_1 = current through R_1
and I_2 = current through R_2

Using Ohm's Law:

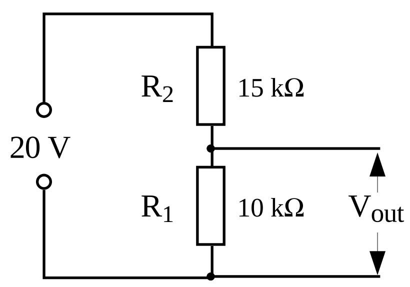
$$I = \frac{V}{R} \quad \text{hence} \quad \frac{V_S}{R_T} = \frac{V_1}{R_1} = \frac{V_2}{R_2}$$

$$\boxed{\mathbf{V_1 = \frac{R_1}{R_T} \times V_S}} \quad \text{or} \quad \boxed{\mathbf{V_1 = \frac{R_1}{R_1 + R_2} \times V_S}} \quad \text{and} \quad \boxed{\mathbf{\frac{V_1}{V_2} = \frac{R_1}{R_2}}}$$

$R_T = R_1 + R_2$

Example

Calculate the output p.d., V_{out}, from the potential divider circuit shown.



$V_{out} = ?$
$R_1 = 10\ k\Omega$
$R_2 = 15\ k\Omega$
$V_S = 20\ V$

$$V_1 = V_{out} = \frac{R_1}{R_1 + R_2} \times V_S$$

$$= \frac{10}{10 + 15} \times 20$$

$$V_{out} = 8\ V$$

Alternatively V_{out} be determined in two stages. First calculate the current in the circuit using $V_S = I(R_1 + R_2)$. Then calculate V_{out} using this current I and $V_{out} = IR_1$.

ELECTRICAL ENERGY

In the earlier section on potential difference, it was stated that the potential difference of the supply is a measure of the energy given to the charges in the circuit.
The energy carried by these charges around the circuit is then converted to other forms of energy by the components in the circuit. Electrical components are devices that change or transform the electrical energy from the supply to the circuit into other forms of energy.
If energy is supplied to the charges in the circuit, then an electric current exists and there is an energy transformation in each of the components in the circuit.

Examples

An electric lamp is designed to emit light energy. This happens because the electric current passing through the filament causes it to get hot; hot enough to glow and emit light. A lamp therefore transforms electrical energy to heat and light energy.
An electric bar fire works in a similar way. The bar of the fire is made from a length of resistance wire similar to the filament of a lamp. The resistance wire is designed to get hot when a current passes through it. It also glows when it is hot, but not as much as the filament of the lamp.

Energy Units

Electrical energy, like all forms of energy, has the symbol **E** and is measured in **joules**, **J**.

Power and Energy

To compare different components, it is often useful to compare the **rate** at which energy is transformed, that is the energy transformed **each second**.
This electrical energy transformed each second is known as the **power**.

$$\boxed{P = \frac{E}{t}} \quad \text{or} \quad \boxed{E = P\,t}$$

P = power
E = energy
t = time

Units

Power is measured in watts, **W**.
Energy is measured in joules, **J**.
Time is measured in seconds, **s**.
1 watt is equivalent to the transfer of 1 joule per second.

Example
If an electric fire uses 1.8 MJ of energy in a time of 10 minutes, calculate the power output of the fire.
Ensure that all quantities are stated with the correct units.

$P = ?$
$E = 1.8\ MJ = 1.8 \times 10^6\ J$
$t = 10\ min = 600\ s$

$$P = \frac{E}{t} = \frac{1.8 \times 10^6}{600} = 3000\ W$$

Power Current and Voltage

Electrical power is also dependent on the potential difference across the component and the current through it. If 1 volt across a component pushes a current of 1 ampére, then the power will be 1 watt.

$$\boxed{\mathbf{P = V\,I}}$$

P = power in watts
V = voltage or potential difference in volts
I = current in ampéres

Example

A 230 V toaster draws a current of 4 A from the mains supply. Calculate the power output of this toaster.

P = ?
V = 230 V $\qquad P = V\,I = 230 \times 4 = 920\ W$
I = 4 A

More Power Equations

Using the equation **P = V I** and Ohm's Law equation **V = I R**, we are able to obtain -

$$P = V\,I$$

but $\quad V = I\,R \quad$ and $\quad I = \dfrac{V}{R}$

therefore $\quad P = (I\,R) \times I \quad$ and $\quad P = V \times \dfrac{V}{R}$

tidying up $\quad \boxed{\mathbf{P = I^2R}} \quad$ and $\quad \boxed{\mathbf{P = \dfrac{V^2}{R}}}$

Example

A component data book states that a 1 kΩ resistor can safely handle a power output of 0.4 W.

a) What is the maximum current it can safely handle?
b) What potential difference would exist across the resistor at this current?

a) *I = ?*
P = 0.4 W
R = 1 kΩ = 1000 Ω

$$I^2 = \frac{P}{R} = \frac{0.4}{1000} = 4x10^{-4}$$

$$I = 0.02\ A$$

b) *V = ?*
P = 0.4 W
R = 1000 Ω
I = 0.02 A

$$V^2 = P\,R = 0.4 \times 1000 = 400 \qquad or \qquad V = I\,R = 0.02 \times 1000, \quad V = 20\ V$$

$$V = 20\ V$$

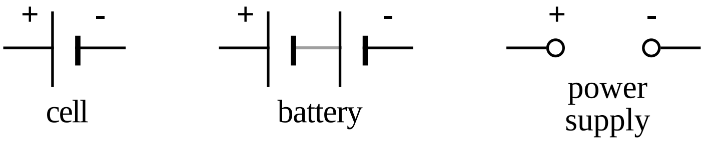
Alternating Current (a.c.) and Direct Current (d.c.)

All power supplies can be grouped into one of two categories depending on the way that they supply energy to the charges in a circuit.

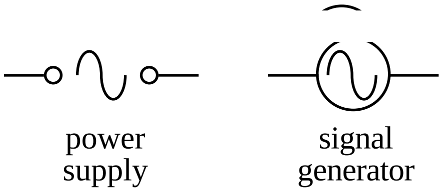
A d.c. supply produces a flow of charge through a circuit in one direction only. An a.c. supply produces a flow of charge that regularly reverses its direction through a circuit.

The direction of the current depends on the direction of the 'push' from the supply, therefore power supplies can provide a direct voltage or an alternating voltage which would result in a direct current (d.c.) or an alternating current (a.c.).

d.c. supplies



a.c. supplies



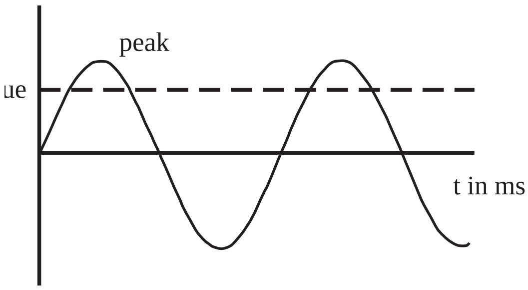
Mains Supply Frequency

The mains electrical supply in the U.K. is an alternating supply with a quoted votage of 230 V and a frequency of 50 Hz, that is it completes one cycle 50 times per second.

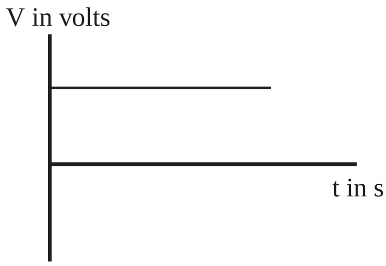
Peak Value and Quoted (Effective) Value of A.C.

A **d.c.** supply provides a constant 'push' to the charges as they move around a circuit whereas the **a.c.** supply does not as the voltage is continually varying.

The voltage for an alternating supply varies from zero to the peak value to zero to the peak value in the reverse direction and so on.



Varying **a.c.** supply



Steady **d.c.** supply

The peak value of voltage for an alternating supply cannot be used as a measure of its effective voltage as the voltage is only at that peak value for a short space of time. The effective voltage of an a.c. supply is **less** than the peak value.

For example, an alternating supply with a peak value of 10 V does not supply the same power to a circuit as a direct supply of 10 V, in fact it is less, approximately 7 V.

The effective value of current and voltage in an a.c. circuit is measured using a.c. meters in the circuit.

The peak value of voltage in an a.c. circuit can be measured using an oscilloscope.

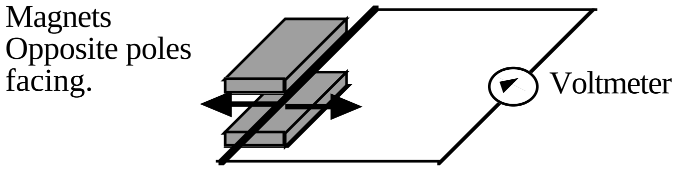
ELECTROMAGNETISM

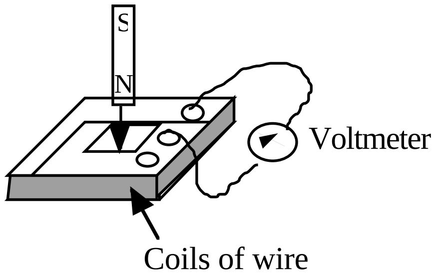
Magnetic field around a current carrying wire.

When an electric current flows through a wire then a circular magnetic field will be set up around the wire.
The direction of the magnetic field will depend on the direction of the electric current.

Induced voltage in a conductor

If a conductor cuts across the lines of a magnetic field, then a voltage will be induced across the ends of a conductor. Note the magnet can move with the conductor stationary or vice versa. An induced voltage will be produced provided the conductor experiences a **changing** magnetic field.



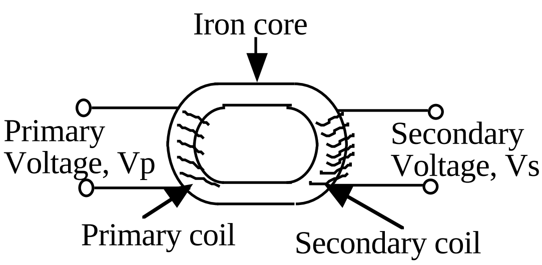


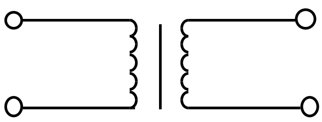
The size of the induced voltage depends on -

- the magnetic field strength
- the number of coils
- the speed of the motion
- the angle at which the conductor cuts the field

Transformers

These are extremely important devices that have numerous uses in everyday life.
(Delivery of electricity to your homes, changing voltages to the required size for televisions, computers, videos, etc.)
Transformers depend on an induced voltage being produced in a coil of wire. This coil is known as the **secondary coil.** For this to happen there must be a changing magnetic field near this coil. The changing magnetic field is produced by an alternating current passing through another coil. This coil is known as the **primary coil.**





Symbol

The input voltage, V_p, is connected to the primary coil.
The output voltage, V_s, is taken from the secondary coil.
A step up transformer is when the secondary voltage is greater than the primary voltage.
A step down transformer is when the secondary voltage is less than the primary voltage.
If N_s = the number of turns in the secondary coil
and N_p = the number of turns in the primary coil then

$$\boxed{\textbf{Turns ratio} = \frac{N_s}{N_p} = \frac{V_s}{V_p}}$$

Example

a) *Calculate the turns ratio for transformer whose primary voltage = 24 V and secondary voltage = 4 V.*

b) *How many turns will be on the primary coil if the secondary coil has 500 turns.*

a)

$$\text{Turns ratio} = \frac{N_S}{N_P} = \frac{V_S}{V_P} \quad \frac{4}{24} \quad \frac{1}{6}$$

$$\text{or } N_S : N_P = 1 : 6$$

b)

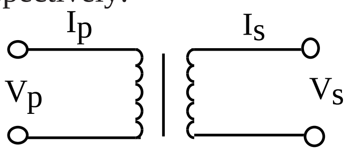
$$\frac{N_S}{N_P} = \frac{1}{6}$$

$$\frac{500}{N_P} = \frac{1}{6}$$

(Cross multiply) $500 \times 6 = N_P \times 1$ *Number turns on primary coil = 3000*

Transformer currents

To consider the energy input and output, the electric current must be taken into account. Consider the following transformer with alternating currents I_p and I_s flowing in the primary and secondary coils respectively:



For an **ideal** transformer (one that has no energy losses) then

$$\text{Input power} = \text{Output power}$$

$$V_P I_P = V_S I_S$$

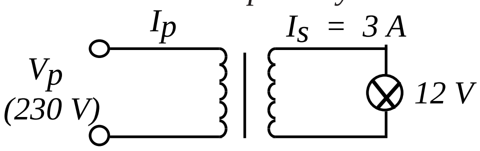
$$\frac{I_P}{I_S} = \frac{V_S}{V_P} \quad \text{(Check this by cross multiplying)}$$

$$\boxed{\frac{\mathbf{N_s}}{\mathbf{N_p}} = \frac{\mathbf{V_s}}{\mathbf{V_p}} = \frac{\mathbf{I_p}}{\mathbf{I_s}}}$$

Note: In a step up transformer, the ‘step up’ only refers to the voltage!
In fact, the current steps down!

Example

A transformer is used to light a 12V bulb from mains voltage. Assuming it to be an ideal transformer find the current in its primary coil.



An ideal transformer will have no energy losses.

$$\text{Input power} = \text{Output Power}$$

$$V_p I_p = V_s I_s$$

$$230 \times Ip = 12 \times 3$$

$$Ip = \frac{12 \times 3}{230} = 0.16\ A$$

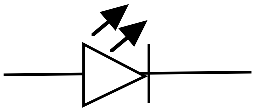
ELECTRONIC COMPONENTS

Output Devices

Examples of these include an LED, a loudspeaker, a buzzer, a seven segment display and a relay switch.

Light Emitting Diodes

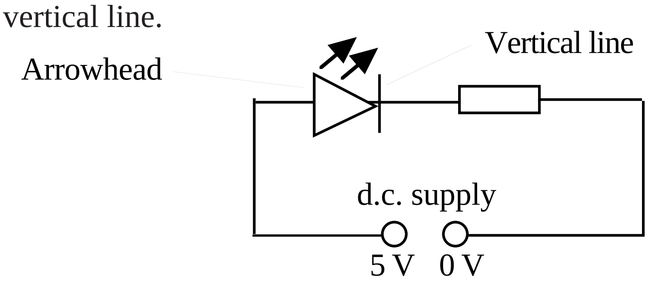
Symbol:



Generally, a resistor is connected in series to limit the size of current that passes through an LED. They operate in the milliamp range.

Current can only flow through an LED in one direction.

The LED will light when the higher voltage is connected to the arrowhead and the lower voltage to the vertical line.



Example

Calculate the series resistor that must be used for the LED above rated at 1.5 V, 100 mA.

$$V_{supply} = 5\ V$$
$$V \text{ across } R = (5 - 1.5)\ V = 3.5\ V$$
$$I \text{ through } R = 100\ mA = 0.1\ A \quad \text{(LED and R are in series)}$$
$$R = \frac{V}{I} = \frac{3.5}{0.1} = 35\ \Omega$$

Input Devices

Examples of these are a microphone, a thermocouple and a solar cell.

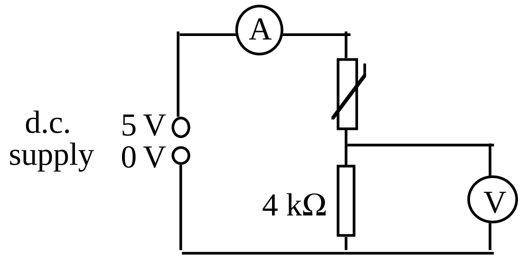
They convert sound, heat and light energy to electrical energy, respectively.

A thermistor is a device which will usually decrease in resistance with increasing temperature.

A light dependent resistor, LDR, will decrease in resistance with increasing light intensity. (**L**ight **D**ecreases its **R**esistance).

Example

Calculate the readings on the meters shown below when the thermistor has a resistance of a) 1 kΩ (warm conditions) and b) 16 kΩ. (cold conditions)



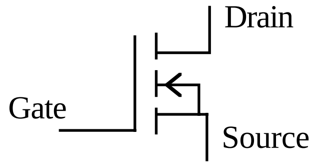
a) $$R_T = (1 + 4)\ k\Omega = 5\ k\Omega$$
$$I = \frac{V}{R_T} = \frac{5}{5000} = 0.001\ A$$
$$V = IR = 0.001 \times 4000 = 4\ V$$

b) $$R_T = (16 + 4)\ k\Omega = 20\ k\Omega$$
$$I = \frac{V}{R_T} = \frac{5}{20000} = 2.5 \times 10^{-4}\ A$$
$$V = IR = 2.5 \times 10^{-4} \times 4000 = 1\ V$$

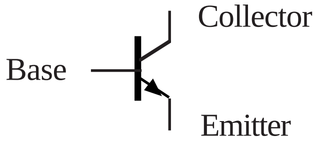
Note similar problems can arise using an LDR instead of a thermistor.

Transistors

N-channel enhancement MOSFET (Metal Oxide Semiconductor Field Effect Transistor).
Symbol:

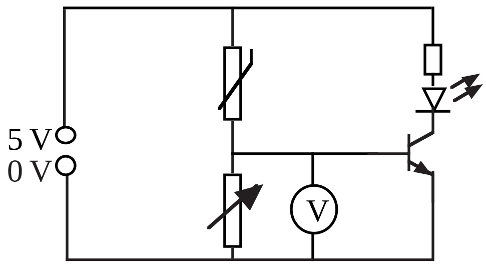


NPN Transistor.
Symbol:



A transistor can be used as a switching device.
When the voltage across the emitter and base (or source and gate) reaches a certain value then the transistor will switch on.

Example
Temperature Warning Light



As the temperature increases then the resistance of the thermistor decreases, so the voltage across it must decrease.
This causes the voltage across the variable resistor to increase. When it reaches about 0.7 V the transistor switches on causing the LED to light. For a MOSFET, the switching voltage is around 1.8 V.

Amplifiers

Amplifiers are used in tape recorders, CD players, satellite communication, repeater stations connecting fibre optic cable, radio and television reception and transmission, mobile phones, hearing aids, heart monitors, tannoy systems, etc.
The output of an audio amplifier will have the same frequency but greater amplitude than the input signal. If not, the sound produced would not be a true representation of the input.

Voltage Gain

$$\boxed{\text{Voltage Gain} = \frac{\text{Output Voltage}}{\text{Input Voltage}}}$$

Note voltage gain is a ratio and has no unit.

Example
Calculate the gain of an amplifier with input voltage = 50 mV and output voltage = 8 V.

$$\textit{Voltage Gain} = \frac{\textit{Output Voltage}}{\textit{Input Voltage}} = \frac{8}{0.05} = 160$$

CIRCUITS PROBLEMS

Electric Current

1. a) Explain what is meant by the term ‘electric current’.
   b) Write down the relationship between charge and electric current.
   c) Give the names of the units used to measure the three quantities.

2. One bar of an electric heater draws a current of 4 A from the mains supply.
   a) How much charge flows through the bar each minute?
   If a second bar is switched on, the charge flowing through the bar each minute increases to 440 C.
   b) Calculate the new current drawn from the mains when both bars are switched on.

3. The manufacturer of the battery in a car states that the battery is rated at 40 ampère-hours. This is one way of telling the user how long the battery will be able to provide electric current to operate appliances.
   eg. this could deliver 40 A for 1 hour or 8 A for 5 hours etc.
   a) Calculate the total charge that this battery can deliver, in coulombs.
   b) The parking lights of the car draw a current of 2 A from the battery. If these lights were left on when the car was parked, calculate the minimum time it would take for the battery to go flat.
   c) State any assumption you are making in your answer to part b).

Conductors and Insulators

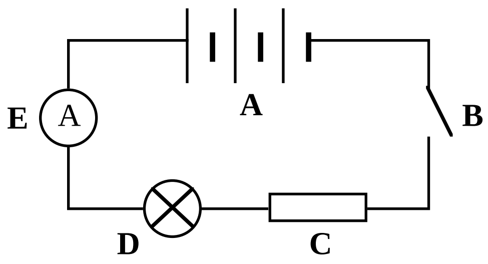
4. The following set of items have to be divided into conductors and insulators.
   paper clip, rubber, pencil refill ‘lead’, wooden ruler, scalpel, glass rod, tongs
   a) Describe a simple experiment which you could carry out to determine whether the items were conductors or insulators.
   b) i) What family of materials, in general, do all conductors fall into?
   ii) What item in the above list is the exception to this ‘rule’?

Voltage and Current

5. a) Describe the difference between the voltage (or potential difference) and the current in a circuit.
   b) Give the name of the unit used to measure voltage or potential difference.

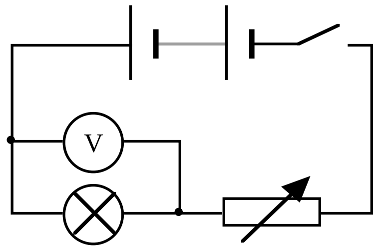
Circuits, Symbols and Meters

6. a) In the circuit below, name the components labelled A, B, C, D and E.



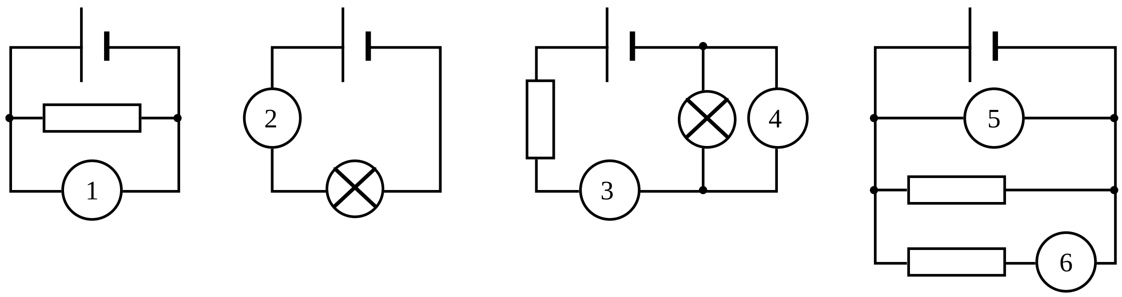
b) State whether this is a series or parallel circuit.

7. Look at the circuit below.



a) Write down the names of the components that are connected in series.
b) Write down the names of the components that are connected in parallel.

8. In the circuits below, identify the meters 1, 2, 3, 4, 5 and 6.



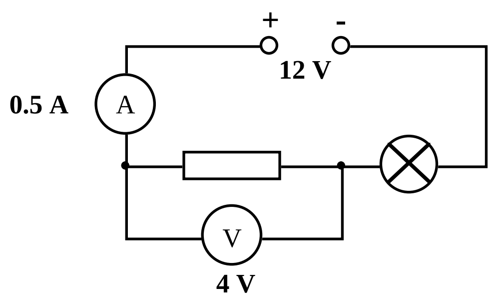
9. a) Write down the rule for the current at all points in a series circuit.
b) Write down the relationship between the supply voltage and the potential differences (voltages) across the individual components in a series circuit.

10. a) Write down the relationship between the supply current and the currents in the branches of a parallel circuit.
b) Write down the potential difference (voltage) rule for all components that are connected in parallel.

11. a) Which of the following statements is/are true for **series** circuits.
    b) Which of the following statements is/are true for **parallel** circuits.

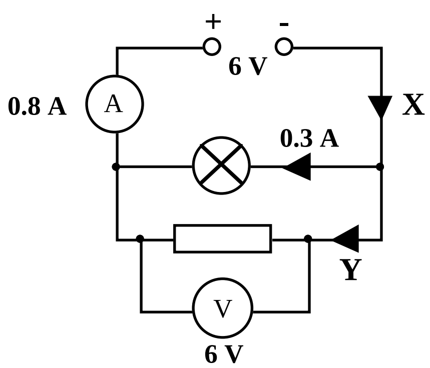
    A There is only one pathway round the circuit.
    B There is more than one pathway around the circuit.
    C The potential differences around the circuit add up to the supply voltage.
    D The potential difference (voltage) is the same across all components.
    E The current is the same at all points in the circuit.
    F The current through each component adds up to the supply current.

12. In the circuit below the ammeter reading is 0.5 A and the voltmeter reading is 4 V.



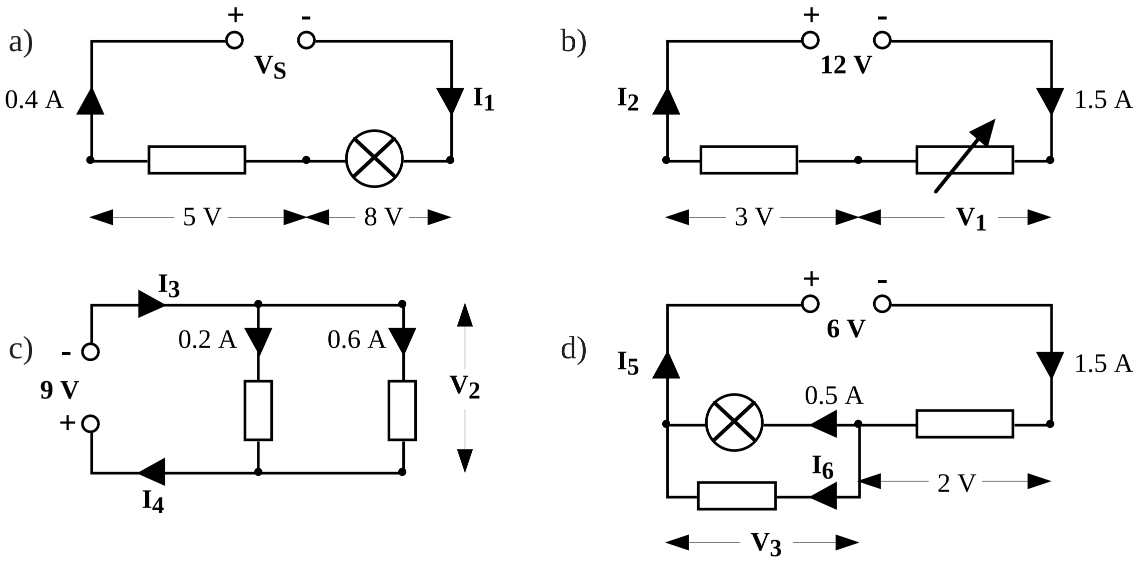
a) State whether this is a series circuit or a parallel circuit.
b) i) What is the current through the lamp?
   ii) What is the potential difference across the lamp?

13. In the circuit below the ammeter reads 0.8 A, the current through the lamp is 0.3 A and the voltmeter reads 6 V.



a) Is this a series or a parallel circuit?
b) i) What are the current values at **X** and at **Y**?
   ii) What is the potential difference across the lamp?

14. Find the missing currents and voltages in the following circuits.



Electrical Resistance

15. Rewrite the following list of potential differences (voltages) in millivolts and arrange in order of increasing value.

    0.65 V, 980 mV, 0.07 V, 3.2 V, 2963 mV

16. Rewrite the following list of currents in amperes and then arrange in order of increasing value.

    5805 mA, 2 mA, 29 mA, 120 A, 8.9 A, 0.03 A

17. In a series circuit, the ammeter reading was noted for different values of resistor in the circuit.
    a) Which electrical quantity does the ammeter measure?
    b) Copy and complete the table below, placing the ammeter readings in the correct order.
    0.6 A, 2.4 mA, 1.2 A, 240 mA.

Resistor (Ω)	**Current ( )**
5	
10	
20	
2.5 k	

18. The current in a lamp bulb was 2 A when connected to a 12 V battery. Calculate the resistance of the lamp bulb.

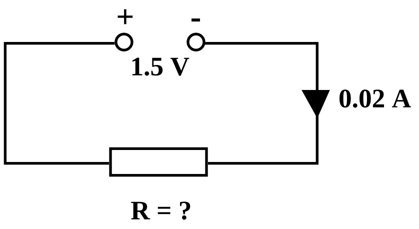
19. When connected across a 3 V supply, the current in a resistor was 60 mA. What is the value of the resistor?

20. A 220 Ω resistor is connected across a 2 V supply. What is the current in the resistor?

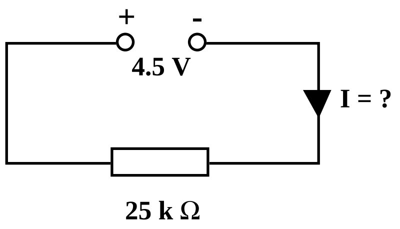
21. A 12 V transformer is connected to a circuit of resistance 1.2 kΩ. What is the current in the circuit?

22. Calculate the missing quantities in the circuits below.

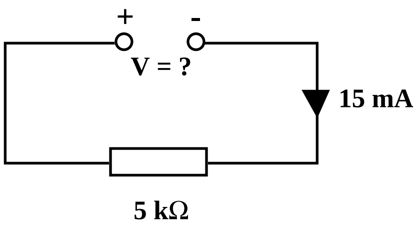
a)



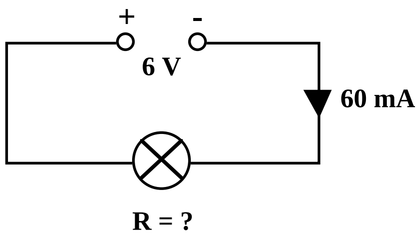
b)



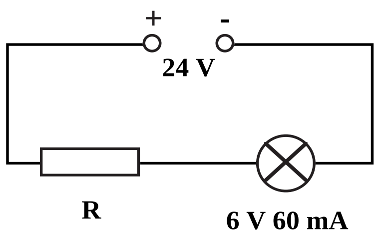
c)



d)

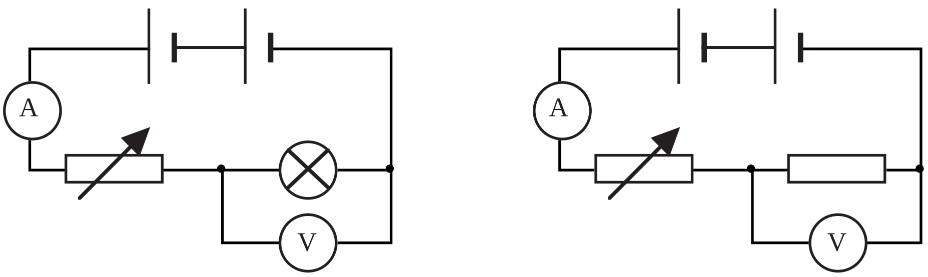


23. The diagram below shows a 6 V 60 mA lamp working off a 24 V supply.



a) What must be the potential difference across the resistor if the lamp is operating correctly?
b) Calculate the value of the resistance of resistor R.

24. Potential difference and current were measured in both circuits below for different values of current



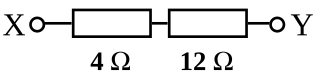
The results for each circuit are shown over the page.

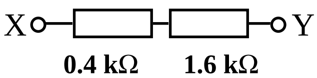
V (V)	I (A)	V/I (ohms)
2.4	0.24	
3.1	0.30	
3.6	0.34	
4.8	0.40	

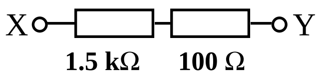
V (V)	I (A)	V/I (ohms)
2.4	0.24	
3.0	0.30	
3.4	0.34	
4.0	0.40	

a) Copy and complete both tables.
b) What is the purpose of the variable resistor in the above circuits?
c) What conclusion can be drawn about the resistance of the lamp bulb as the current increases?
d) What conclusion can be drawn about the resistance of the resistor as the current increases?
e) **Explain** the difference in the behaviour of the lamp bulb and the resistor as the current increases.

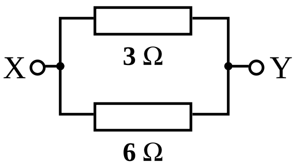
25. Calculate the total resistance between X and Y for the following.

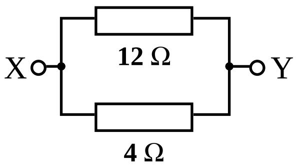
a)


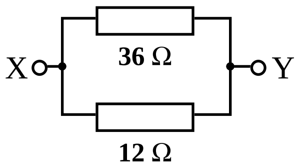
b)


c)


26. Calculate the total resistance between X and Y for the following circuits.

a)


b)


c)


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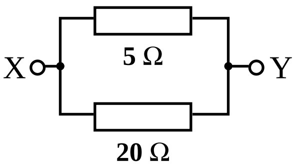

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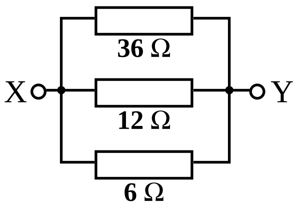

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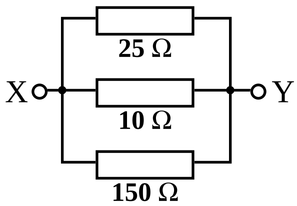


27. a) What will be the resistance of ten 20 Ω resistors when they are connected in **series**?
b) What will be the resistance of ten 20 Ω resistors when they are connected in **parallel**?

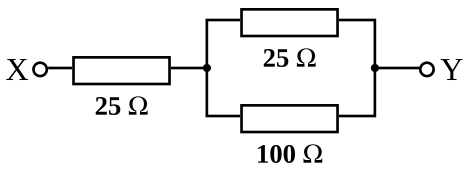
28. You are given the four resistors below.
1 Ω, 10 Ω, 100 Ω, 1000 Ω

a) What is their total resistance when they are connected in series?
A less than 1 Ω
B between 1 Ω and 10 Ω
C between 10 Ω and 100 Ω
D between 100 Ω and 1000 Ω
E greater than 1000 Ω

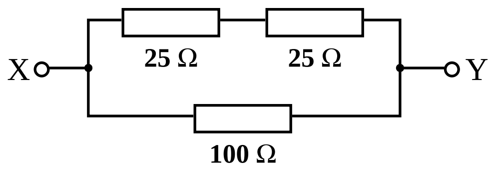
b) What is their total resistance when they are connected in parallel?
   A less than 1 Ω
   B between 1 Ω and 10 Ω
   C between 10 Ω and 100 Ω
   D between 100 Ω and 1000 Ω
   E greater than 1000 Ω

29. Calculate the resistance between X and Y in the following resistor networks.

a)



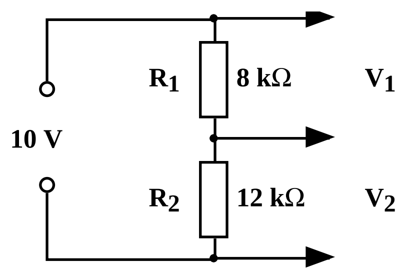
b)



Potential Divider Circuits

30. State what is meant by a potential divider circuit.

31. The following potential divider circuit was set up using the values shown.



a) Calculate the current in the circuit through R_1 and R_2.

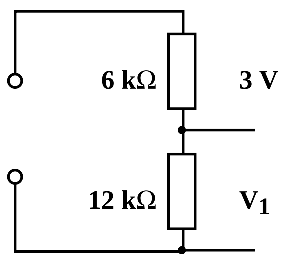
b) Calculate the value of the potential differences (voltages) V_1 and V_2, across each resistor.

c) Use your results to show that the relationship $\frac{V_1}{V_2} = \frac{R_1}{R_2}$ is true.

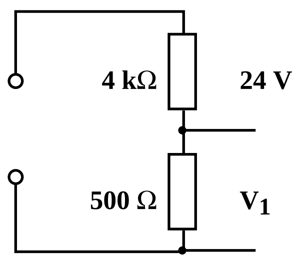
d) Use your results to show that the relationship $V_1 = \frac{R_1}{R_1+R_2} V_S$ is also true.

32. Calculate the value of V_1 in the following circuits.

a)

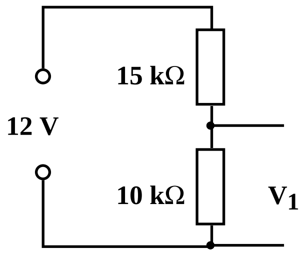


b)

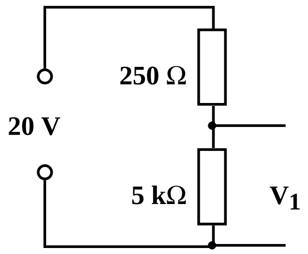


33. Calculate the value of V_1 in the following circuits.

a)

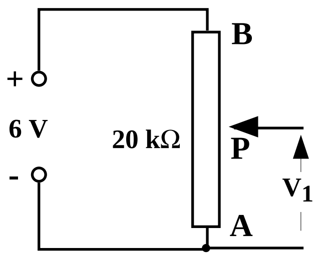


b)



34. A fixed 6 V d.c. power supply has to be reduced to give constant output of 1.5 V using a potential divider.
Design a potential divider circuit that will give a constant output of 1.5 V from the 6 V supply.

35. A 20 kΩ potentiometer AB is connected across a 6V d.c. power supply as shown below.



The sliding contact, P, can be moved to any point along the potentiometer AB.

a) What will be the output voltage, V_1, when the sliding contact, P, is at
   i) position A
   ii) position B
   iii) midway between A and B?
b) What would be the output voltage, V_1, if the sliding contact P was one third of the length along the potentiometer from A?
c) What would be the resistance between points A and P if the potentiometer was adjusted to give an output voltage of 3.5V?

ELECTRICAL ENERGY PROBLEMS

Power and Energy

36. a) If an electric current is passed through a conducting wire, what energy transformation takes place?
    b) Many electrical appliances in the home are designed to make use of this energy transformation. Name four of these appliances.

37. A light bulb has a power rating of 60 W.
    a) How much electrical energy is transformed by the bulb in 1 s?
    b) State the energy changes involved when the lamp is switched on.

38. The electric motor on a ceiling fan uses 207 kJ of electrical energy in 30 minutes.
    a) Calculate the power rating of the motor in the fan.
    b) State the energy changes involved when the ceiling fan is switched on.

39. How much electrical energy is used by the following appliances?
    a) A 400 W drill used for 45 s
    b) A 300 W food processor used for 20 s
    c) An 800 W iron used for 40 minutes
    d) A 2.4 kW kettle that takes 5 minutes to boil the water inside it.

40. What is the power rating of an appliance which transforms -
    a) 500 J in 5 s
    b) 1200 J in 20 s
    c) 1.8 MJ in 10 minutes?

41. How long would a 2 kW electric kettle take to boil the water inside if it uses 100 kJ of electrical energy?

Power, Current, Potential Difference or Voltage and Resistance

42. a) Draw a circuit diagram to show how you would measure the power output of a lamp bulb using a voltmeter and ammeter.
    b) If the meter readings were 6 V and 600 mA, what would be the power of the lamp?
    c) How much energy would this lamp use in 1 hour?

43. A colour television set is rated at 300 W.
    a) Calculate the current drawn by the television when connected to the 230 V mains supply.
    b) How much energy would this television use if it was left on overnight for 8 hours?

44. a) Using the equations $V = IR$ and $P = VI$, show that if a current I flows through a heating element of resistance R, the power of the heater is given by $P = I^2R$.
    b) What is power rating of a 30 Ω heating element when 8 A passes through it?

45. Calculate the power rating of the following devices in a car -
    a) A radio of resistance 6 Ω drawing a current of 2 A.
    b) the rear window heater of resistance 3 Ω drawing a current of 4 A.

46. An electric fire is rated at 2 kW, 230 V.
    a) What is the current in the heating element when it is switched on?
    b) Calculate the resistance of the heating element.

47. A 100 Ω resistor has a maximum safe power rating of 4 W. Calculate the maximum current it can safely handle.

48. Calculate the resistance of a hairdryer element which has a power rating of 960 W when drawing a current of 4 A.

49. By combining the equations V = IR and P = VI, show that the power can also be given by $P = \frac{V^2}{R}$.

50. Calculate the power rating of a heater which has a resistance of 53 Ω working off the mains voltage of 230 V.

51. The fuses used in electrical plugs in the UK come in 2 main sizes - 3 A and 13 A.
    a) What is the purpose if the fuse in the plug connected to an appliance?
    b) What energy change does a fuse depend on to work correctly?
    c) Complete the table below and select which of the above fuses would be most suitable for each of the appliances.

Appliance	Power	Voltage (V)	Current (A)	Most suitable fuse
Food Mixer		230	0.3	
Lamp	100 W	230		
Heater	2.5 kW	230		
Hi-fi unit		230	1.5	

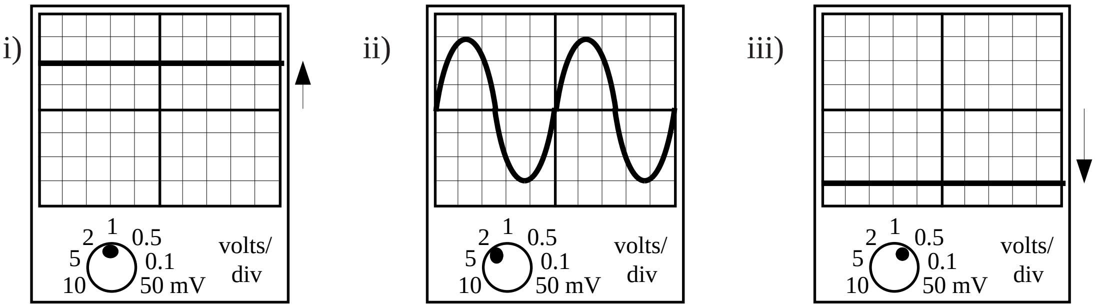
52. A current of 6 A flows along a flex of total resistance 0.2 Ω to an electric heater which has an element of resistance 60 Ω.
    a) Calculate the heat generated each second in
        i) the flex
        ii) the element.
    b) i) What energy change is taking place in both the flex and the element?
        ii) Why does the element become hot and the wire remain cool?
    c) i) What size of fuse, 3 A or 13 A, should be fitted to the plug connected to this heater?
        ii) Explain what would happen if the wrong fuse was fitted to the plug.

A.C. or D.C.

53. Explain the difference between a.c. and d.c. Your answer should state what is represented by the terms a.c. and d.c. and include the words ‘electron’ and ‘direction’.

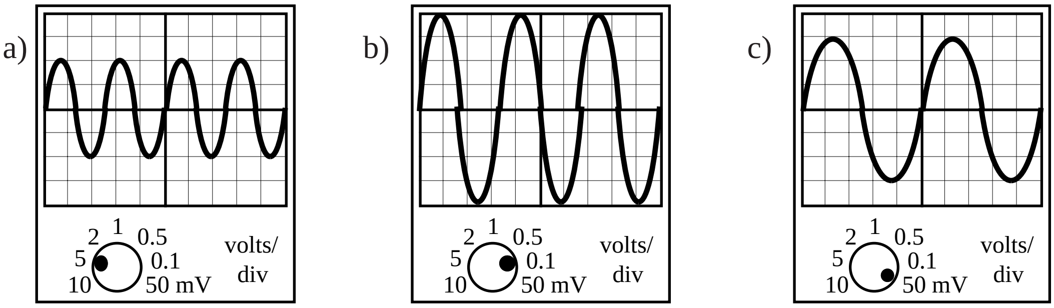
54. Give two examples each of
    a) a.c. power supplies
    b) d.c. power supplies.

55. a) For each of the following traces shown, state whether they are a.c. or d.c..



55. b) Calculate
   i) the applied voltage for trace i) where the Y-gain setting is set at 1 V/division
   ii) the applied voltage for trace iii) where the Y-gain setting is set at 0.5 V/division
   iii) the peak voltage for trace ii) where the Y-gain setting is set at 2 V/division.

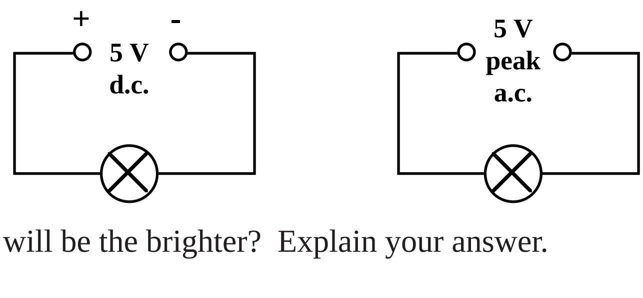
56. Calculate the peak voltages of the traces below using the Y-gain settings shown.



57. a) State whether the mains supply is a.c. or d.c..
   b) What is the frequency of the mains supply?

58. Trace a) in question 21 is produced from the mains supply. If the settings on the oscilloscope are not changed, sketch the trace that would be produced by the following a.c. supplies.
   a) Peak voltage 5 V at a frequency of 25 Hz
   b) Peak voltage 20 V at a frequency of 75 Hz.

59. Two identical bulbs are lit by the supplies shown below.



   a) Which bulb will be the brighter? Explain your answer.

b) The d.c supply is altered so that both bulbs have the same brightness. The a.c. supply remains at the 5 V peak value.
Was the d.c. supply increased or decreased?

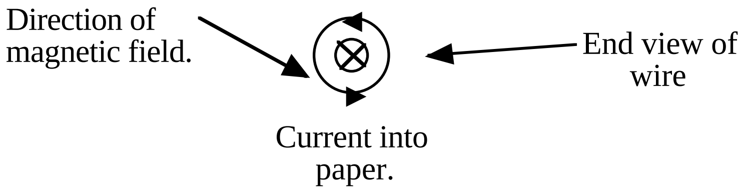
60. An a.c. supply is labelled 12 V. The peak voltage is measured using an oscilloscope.
a) Which of the following is likely to be the measured peak voltage:
17 V, 12 V, 8.5 V, 6 V?
b) Explain your answer.

61. The mains supply is quoted as 230 V.
If connected to the mains supply, which of the following devices would display a value of 230 V:
a) an oscilloscope
b) an a.c. voltmeter?

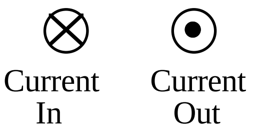
62. Briefly explain the meaning of the term ‘effective voltage’ which is applied to an a.c. supply.

ELECTROMAGNETISM PROBLEMS

63. The diagram below shows the direction of a magnetic field around a current carrying wire.



a) Copy and complete the diagram below showing the direction of the magnetic fields around both current carrying wires.



b) If the wires are free to move, suggest what might happen.
(Remember the arrows point in the direction of North to South)

64. a) Explain how a voltage could be induced in a coil of wire.
b) Give three methods of increasing the size of this induced voltage.

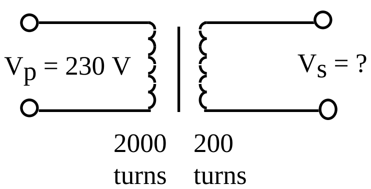
65. Give 4 uses of transformers in every day life.

66. Explain why a transformer will only give a continuous output when used with a.c.

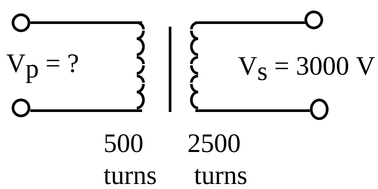
67. Write down the relationship between the voltages and number of turns in the coils of a transformer.

68. Use the above relationship to solve the problems below:

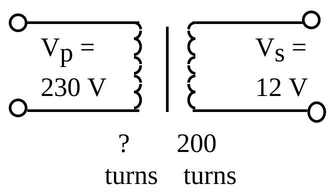
a)



b)



c)



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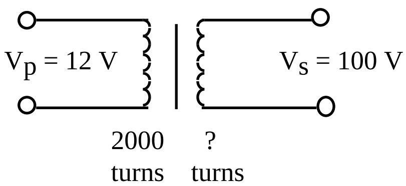

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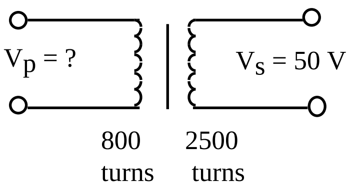

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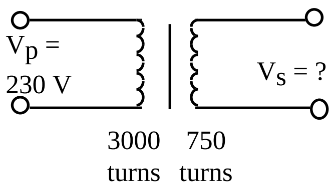
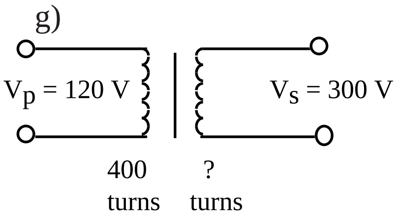


g)



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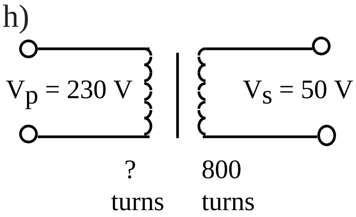
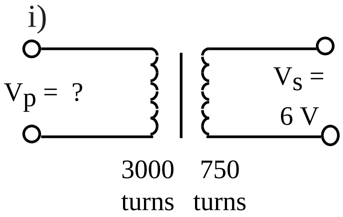
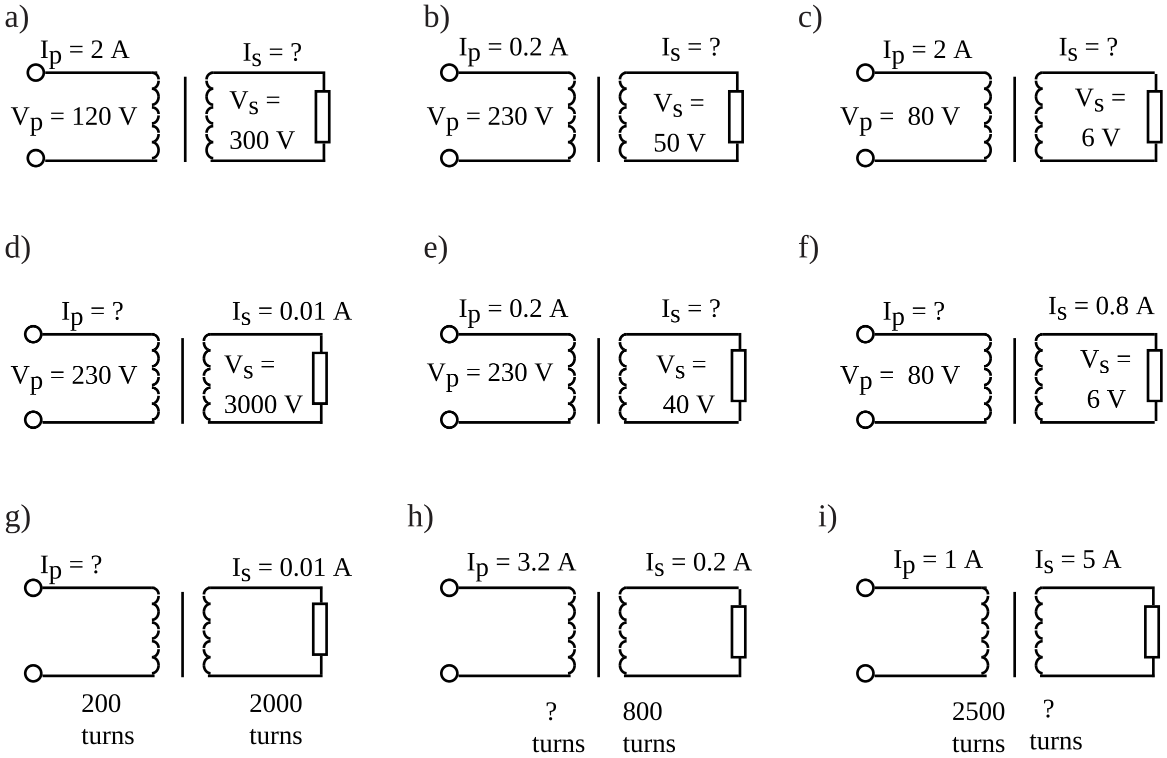


i)



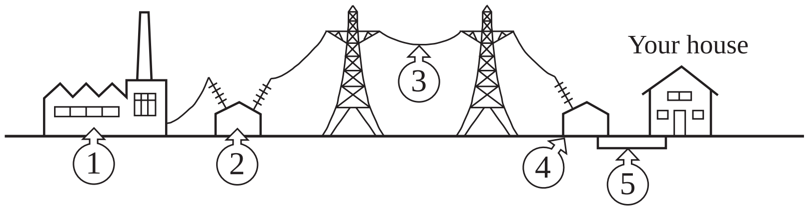
69. Describe what is meant by an ideal transformer.

70. Assuming the transformers below to be ideal, calculate the unknown values in each case.

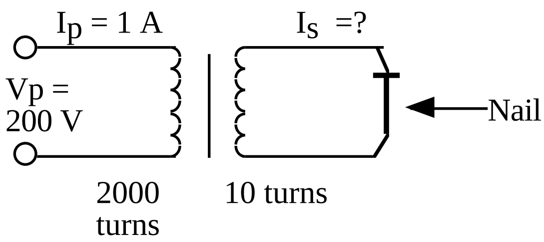


71. An engineer requires a transformer to step down a voltage from 3000 V to 230 V. Calculate the required turns ratio.

72. The diagram below represents thow electricity reaches our homes. Name and state the pupose of numbers 1, 2, 3,4 and 5.



73. The transformer below can be used to generate very high temperatures in the nail attached to the output of the secondary coil. Explain how this can be possible despite it being a step down transformer.

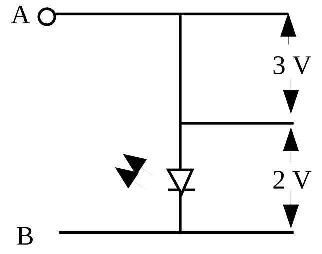


ELECTRONIC COMPONENT PROBLEMS

74. Draw the symbols for
    a) a relay switch
    b) a loudspeaker
    c) an LED.

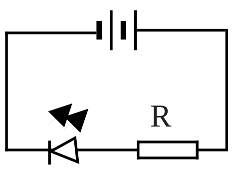
75. Why must a resistor be connected in series with a light emitting diode when using a 5 V supply?

76. An LED and resistor are connected in series to a 5 V supply as shown. The maximum allowed current through the LED is 12 mA. The voltages are given.



    a) +5 V and 0 V are to be connected to the circuit. Which will be connected to A and B if the LED is to light?
    b) Calculate the maximum current through the resistor.
    c) What is the value of the resistor needed to protect the LED?

77. An LED is connected as shown and the following data for the LED is shown.



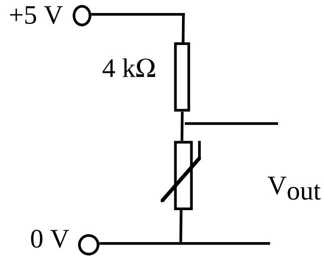
I_{max} = 20 mA
V_{max} = 1 V

Calculate the least value of resistance of the resistor R, placed in series with the LED, which would allow it to work properly.

78. Calculate the following protective resistors from the following data.
    a) V_s = 6 V LED (V_{max} = 1.5 V I_{max} = 50 mA).
    b) V_s = 10 V LED (V_{max} = 2.0 V I_{max} = 100 mA).
    c) V_s = 5 V LED (V_{max} = 1.5 V I_{max} = 50 mA).

79. State what happens to the resistance of:
    a) a thermistor subjected to increasing temperature
    b) an LDR as the light intensity falling on it increases.

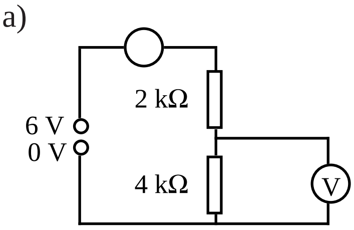
80. a) A thermistor is connected in series to a resistor is connected to a 5 V supply as shown. What will happen to the output voltage as the temperature of the thermistor rises?



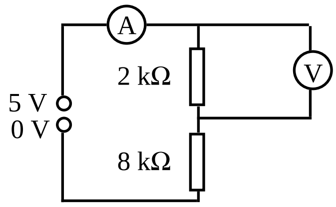
b) What difference would there be to the output voltage if the thermistor and the 4 kΩ resistor were interchanged?

81. Calculate the current and voltage reading in the following circuits.

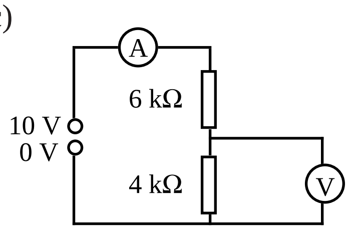
a)



b)



c)



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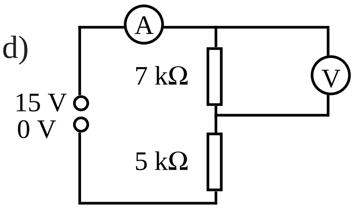

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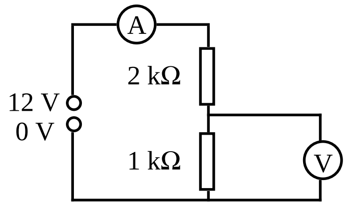

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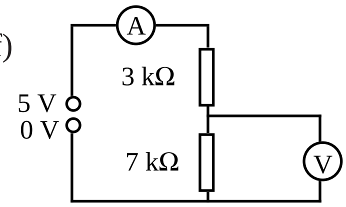
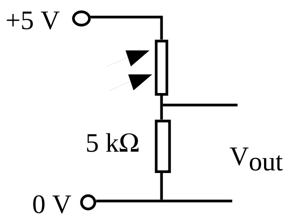


82. An LDR is connected to a 5 kΩ resistor as shown.
The values of its resistance for particular conditions are shown below.

Condition	Resistance
Light	100 Ω
Dark	20 kΩ

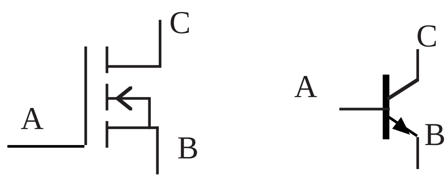


What will be the output voltage when the LDR is
a) in the dark b) in sunlight?

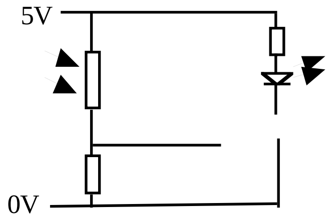
83. a) An LDR of resistance 100 kΩ in darkness is placed in series with a 1 kΩ resistor. The supply voltage is 6 V d.c.
i) Draw the above circuit.
ii) Calculate the voltage across each component.

b) The LDR is placed in the light giving it a resistance of 4 kΩ. Calculate the new voltage cross each component.

84. The diagrams opposite show two different types of transistors.
a) Copy and name each symbol.
b) Label points A, B and C.

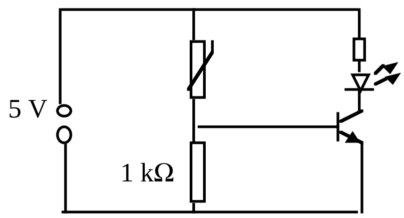


85. A circuit which automatically switches on in light conditions is shown with one important component missing



a) Copy and complete the diagram, adding the missing component.
b) Explain how the circuit works.

86. The circuit below shows a temperature sensing device.



a) Calculate the voltage across the base-emitter of the transistor:
   i) in the cold when the resistance of the thermistor is 9 kΩ.
   ii) at 100 °C when its resistance is 1 kΩ.
b) Hence explain how the circuit works.
c) How could you alter the sensitivity of the device?

87. Design a circuit which would allow an LED to light when it gets too dark.

88. State the energy changes for the following input devices.
a) a microphone b) a thermocouple c) a solar cell.

89. State the purpose of an amplifier.

90. Give four examples of electronic systems that use amplifiers.

91. Explain why a good audio amplifier should only increase the amplitude of the input signal and not the frequency.

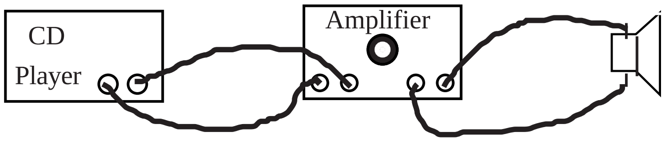
92. State the expression for the voltage gain of an amplifier.

93. An amplifier has a gain of 20. Calculate the output voltage if the input voltage is 200 mV.

94. Find the unknown values using the expression for the gain of an amplifier.

a)	Gain = 200	V_{in} = 5 mV	V_{out} = ?
b)	Gain = ?	V_{in} = 10 mV	V_{out} = 5 V ?
c)	Gain = 200	V_{in} = ?	V_{out} = 1.5 V

95. Describe how the voltage gain of the amplifier shown below could be measured experimentally.



Your description should include

i) a diagram showing any extra apparatus required
ii) the measurements taken
iii) how you would use these measurements to calculate the gain. (Note the input and output will be a.c.).

NUMERICAL ANSWERS

Circuits

2. a) 240 C b) 7.3 A
3. a) 144 000 C b) 72 000 s or 20 hours c) constant current
4. b) i) metals ii) pencil ‘lead’ is carbon
11. a) A, C, E b) B, D, F
12. a) series b) 0.5 A c) 8 V
13. a) parallel b) i) X: 0.8 A, Y: 0.5 A c) 6 V
14. a) I_1 = 0.4 A b) V_1 = 9 V, I_2 = 1.5 A
    c) I_3 = 0.8 A, I_4 = 0.8 A, V_2 = 9 V d) I_5 = 1.5 A, I_6 = 1 A, V_3 = 4 V
15. 70 mV, 650 mV, 980 mV, 2963 mV, 3200 mV
16. 0.002 A, 0.029 A, 0.03 A, 5.805 A, 8.9 A, 120 A
17. a) current b) 1.2 A, 0.6 A, 240 mA, 2.4 mA down the table
18. 6 Ω
19. 50 Ω
20. 0.009 A
21. 0.01 A
22. a) R = 75 Ω b) I = 1.8×10^{-4} A c) V = 75 V d) R = 100 Ω
23. a) 18 V b) 300 Ω
24. a) Table 1: 10, 10.3, 10.6, 12 down the table
    Table 2: 10 for all entries down the table
25. a) 16 Ω b) 2 kΩ c) 1.6 kΩ
26. a) 2 Ω b) 3 Ω c) 9 Ω d) 4 Ω e) 3.6 Ω f) 6.8 Ω
27. a) 200 Ω b) 2 Ω
28. a) E b) A
29. a) 45 Ω b) 33 Ω
31. a) $5\text{x}10^{-4}$ A or 0.5 mA b) V_1 = 4 V, V_2 = 6 V
32. a) V_1 = 6 V b) V_1 = 3 V
33. a) V_1 = 4.8 V b) V_1 = 19 V
35. a) i) V_1 = 0 V ii) V_1 = 6V iii) V_1 = 3 V b) V_1 = 2 V c) R_{AP} = 11.7 kΩ

Electrical Energy

37. a) 6 J
38. a) 100 W b) 60 W c) 3000 W
39. a) 115 W
40. a) 18000 J b) 6000 J c) 1.92×10^{6} J d) 7.2×10^{8} J
41. 50 s
42. b) 0.36 W c) 1296 J
43. a) 1.3 A b) 8.64×10^{6} J
44. b) 1920 W
45. a) 24 W b) 48 W
46. a) 8.7 A b) 26 Ω
47. 0.2 A
48. 60 Ω
50. 998 W
51.

69 W	230	0.3	**3 A**
100 W	230	**0.43**	**3 A**

	2.5 kW	230	**10.9**	**13 A**
	345 kW	230	1.5	**3 A**
52.	a) i) 7.2 J	ii) 2160 J	c) i) 13 A	
55.	a) i) d.c.	ii) a.c.	iii) d.c.	
	b) i) 2 V	ii) 1.5 V	iii) 6 V	
56.	a) 10 V	b) 0.4 V	c) 150 mV	
57.	a) a.c.	b) 50 Hz		
60.	a) 17 V			
61.	a) a.c. voltmeter			

Electromagnetism

68. a 23 V
 b) 600 V
 c) 3833 turns
 d) 16,667 turns
 e) 16 V
 f) 58 turns
 g) 1000 turns
 h) 3680 turns
 i) 24 V

70. a) 0.8 A
 b) 0.92 A
 c) 26.7 A
 d) 0.13 A
 e) 1.15 A
 f) 0.06 A
 g) 0.1 A
 h) 50 turns
 i) 500 turns

71. $N_s/N_p = 13/1$

73. $I_S = 200$ A

Electronic Components

76. a) A - +5 V B - 0 V
 b) 12 mA
 c) 250 Ω
77. 100 Ω
78. a) 90 Ω
 b) 80 Ω
 c) 70 Ω
81. a) 0.001 A, 4 V
 b) 0.0005 A, 1 V
 c) 0.001 A, 4 V
 d) 0.00125 A, 8.75 V
 e) 0.004 A, 4 V
 f) 0.0005 A, 3.5 V
82. a) 1 V
 b) 4.9 V
83. a) LDR - 5.9 V R - 0.1 V
 b) LDR - 4.8 V R - 0.2 V
86. a) i) 0.5 V
 ii) 2.5 V
93. 4 V
94. a) 1 V
 b) 500
 c) 0.0075 V

WAVES

Waves can transfer **energy**, e.g. water waves can transfer energy across the water.
Radio and television signals are waves that travel through the air at 300 million m/s.
(3×10^8 m/s). This is the same speed as the speed of light.
The light from a thunder storm is seen before the sound of the thunder since the speed of light is much greater than the speed of sound.

The **distance** travelled by a wave travelling at a **constant speed** can be calculated using:

distance travelled (m) — $\boxed{\mathbf{s = vt}}$ — time taken (s)

speed (m/s)

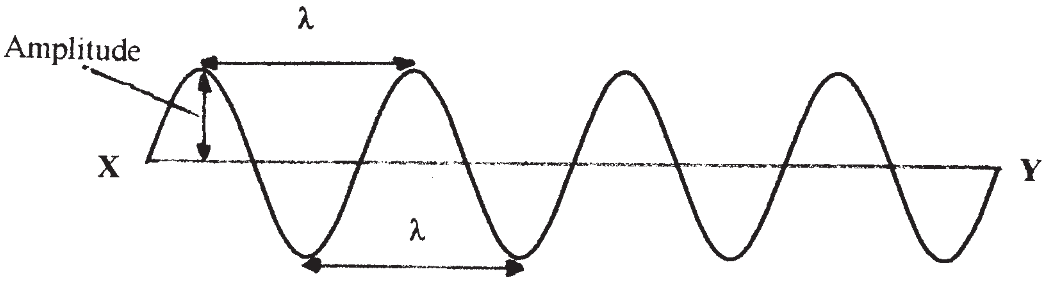
Note: these notes will have metres per second written as m/s. However you can use the negative index, e.g. m s^{-1}, if you prefer.

The **frequency, f,** of a wave is the number of waves that pass a point in 1 s.
Frequency is measured in hertz (Hz).

The **wavelength, λ,** of a wave is the horizontal distance between two adjacent troughs or crests or any two corresponding points on the wave.
Wavelength is measured in metres (m).

The **amplitude** of a wave is half the vertical distance between a trough and a crest.
Amplitude is measured in metres (m).

The **period, T,** of a wave is the time it takes one wave to pass a point.
Period is measured in seconds (s).

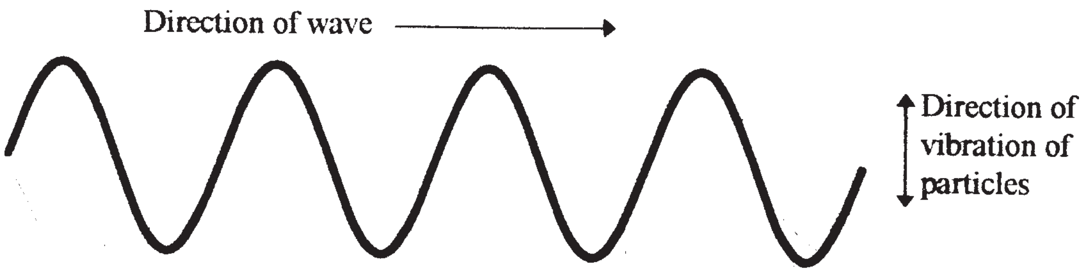


Example
In the diagram above the distance between X and Y is 10 m. If 20 waves pass B in 5 s, find a) the wavelength b) the frequency and c) the period of the wave.

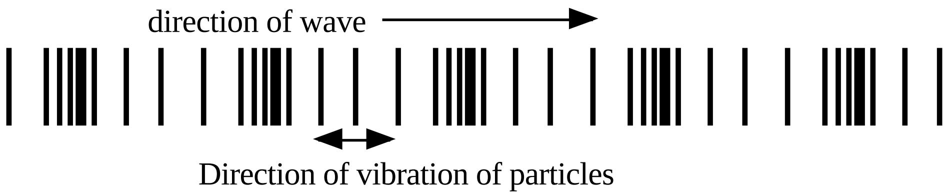
a) *XY = 4 complete wavelengths = 10 m.* $\lambda = {}^{10}/_{4} = 2.5$*m*
b) *In 5 s the number of waves that pass Y = 20*
In 1 s the number of waves that pass Y = ${}^{20}/_{5} = 4$ *Frequency, f = 4 Hz*

c) *20 waves pass B in 5 s*
Time for 1 wave = ${}^{5}/_{20} = 0.25$ *s* *Period of wave = 0.25 s*

Transverse and longitudinal waves
A transverse wave is one in which the particles making up the wave vibrate at 90° to the direction of the wave.
Examples of transverse waves are water waves, light, gamma rays, X-rays and all members of the electromagnetic spectrum.



A longitudinal wave's particles vibrate along the same line as the direction of the wave. Sound travels as a longitudinal wave.



Speed, frequency and wavelength.
The relationship between these is

$$\boxed{v = f\lambda}$$

This is known as the wave equation.

The Electromagnetic Spectrum
Listed below are the members of the electromagnetic spectrum.

Gamma rays, X-rays, ultraviolet, visible light, infrared, microwaves, TV and radio.

Low λ ——— **increasing λ** ———→ Long λ
High f ←——— **increasing f** ——— Low f

Each member travels at the speed of light = 3×10^8 m/s

Example
Microwaves have a frequency of 9.4 GHz. Calculate their wavelength.

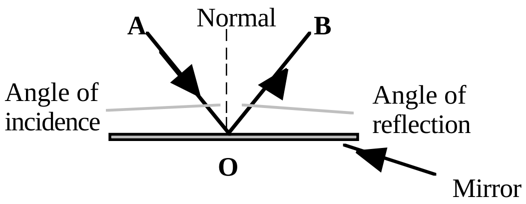
$$v = f\lambda$$

$$\lambda = \frac{v}{f} = \frac{3 \times 10^8}{9.4 \times 10^9} = 3.2 \times 10^{-2} \quad (= 3.2\ cm)$$

REFLECTION

Light

The diagram below shows the path of a ray of light when reflected off a mirror.
The normal is a line drawn at 90^0 to the mirror.

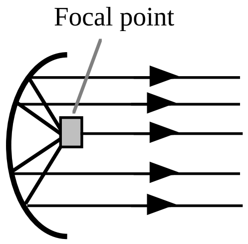


Angle of incidence = Angle of relection

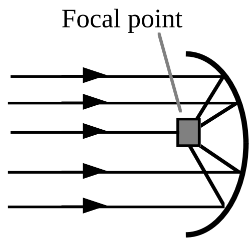
The **principle of reversibility of light** states that a ray of light which travels along any particular path from some point A to another point B travels by the same path when going from B to A, e.g. in the above diagram the ray travels from A to O to B. If the direction was reversed then the ray would follow B to O to A.

Curved Reflectors

These can be used in transmitters and receivers of waves, e.g. sound, infrared, microwaves, TV signals and satellite communication.



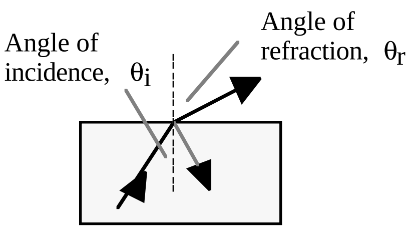
Transmitter placed at focal point.



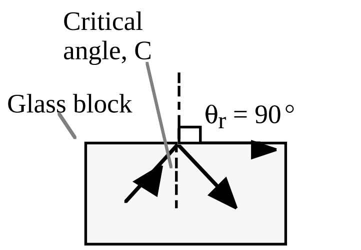
Receiver placed at focal point

Total Internal Reflection and Critical Angle

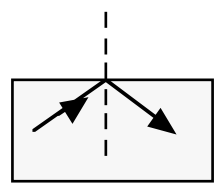
When light travels from glass to air, if the angle of incidence in glass gives an angle of refraction of 90° in air, then the angle in glass is known as the **critical angle, C.**
Beyond this angle there will be total internal reflection.



Angle of incidence less than critical angle
(θ_i < C)



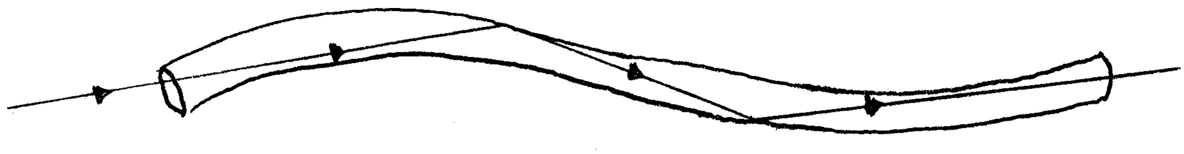
Angle of incidence = critical angle
Angle of refraction = 90 °
(θ_i = C)



Angle of incidence greater than critical angle. Ray undergoes total internal reflection
(θ_i > C)

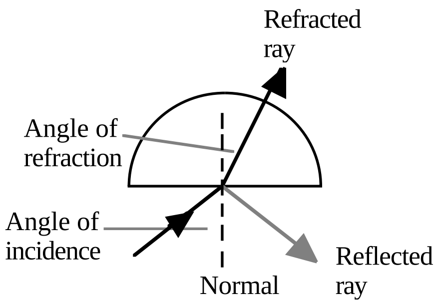
Optical Fibres

Light can travel through these by being totally internally reflected.

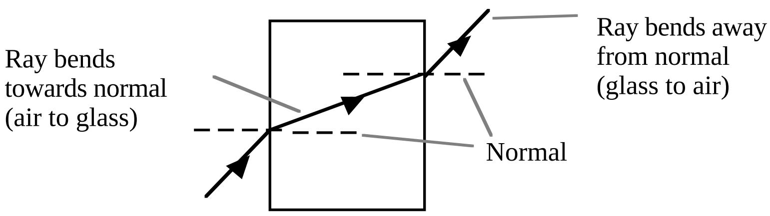


REFRACTION

When light passes from one medium to another, e.g. air to glass, part is reflected back into air and the rest passes through the medium with a change in direction.

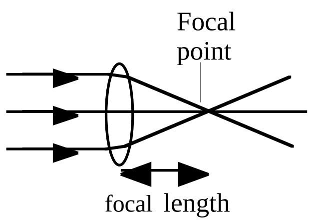


The light is said to be bent or **refracted** as it passes through the glass. This is due to the speed of light being less in glass than air. The ray will bend **towards** the normal.
The speed of a light ray increases as it leaves the medium. When a ray of light's speed increases then it will bend **away** from the normal.

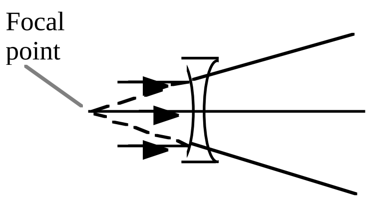


Lenses

The ray diagrams below show the effect of converging and diverging lenses on parallel rays of light.



Converging lens



Diverging lens

Image formation by a converging lens

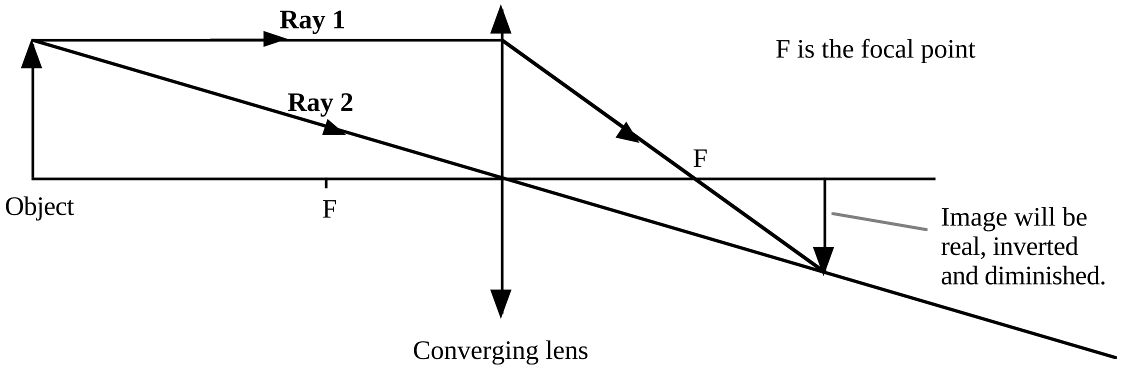
Images can be described as:

- **real or virtual**
- **inverted or upright**
- **magnified, same size or diminished.**

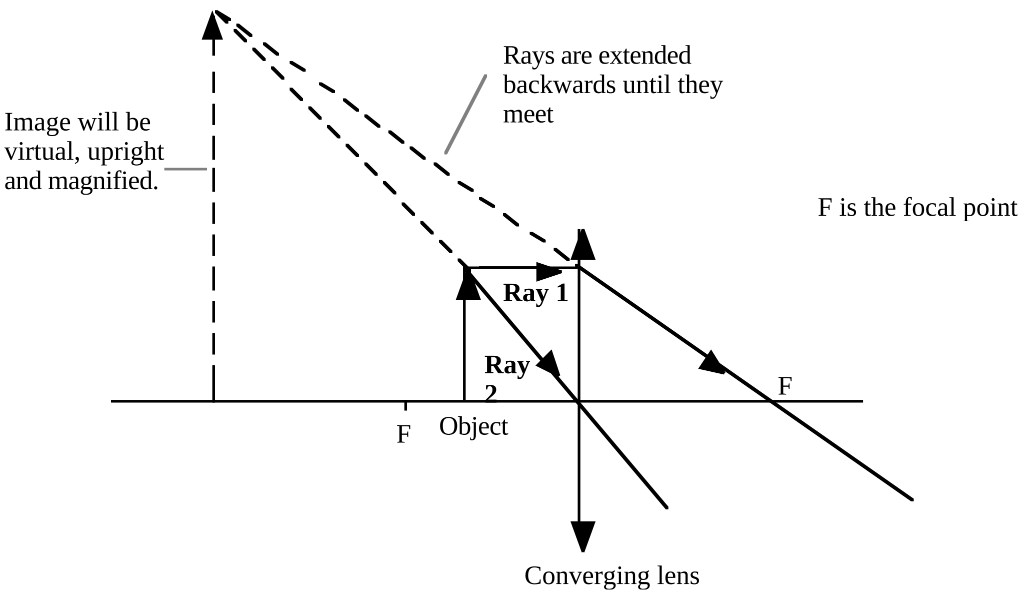
Ray Diagrams

- Choose an appropriate scale (better done on graph paper).
- Draw ray 1 from the tip of the object parallel to the axis, passing through the focal point of the lens.
- Draw ray 2 from the tip of the object, passing through the centre of the lens.
- Where the two rays meet will be the image of the tip of the object.

Object distance greater than twice the focal length



Object distance less than the focal length



The type of image formed is dependent on the object distance from the lens.

OBJECT POSITION FROM LENS	TYPE OF IMAGE
More than two focal lengths	Real, inverted and diminished
Between one and two focal lengths	Real, inverted and magnified
Less than one focal length	Virtual, upright and magnified

Power of a Lens

This is given by

$$\boxed{P = \frac{1}{f}}$$

focal length measured in metres

The power is measured in **dioptres (D)**.
A converging lens has a positive power.
A diverging lens has a negative power.

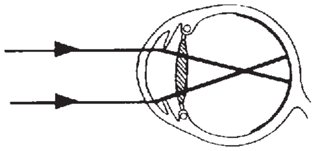
Example

Calculate the power of a converging lens with a focal length of 20 cm.

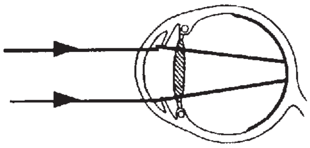
$f = 0.2\ m \qquad P = \frac{1}{f} = \frac{1}{0.2} = 5D$

Short and Long Sight

People who are short sighted have difficulty seeing distant objects. The image is formed short of the retina of the eye.

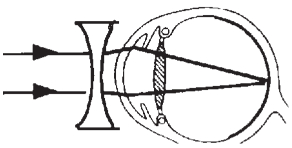


Long sighted people can see distant objects but have difficulty seeing near objects. The image would be formed behind the retina of the eye.

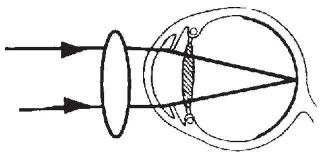


To rectify these:

- a diverging lens is used for short sight.



- a converging lens is used for long sight.



WAVES AND OPTICS PROBLEMS

Speed of waves

1. Thunder is heard 20 seconds after a lightning flash. If the speed of sound is 340 m/s, how far away is the storm?

2. Explain why, during a thunder storm, you see the lightning before you hear the thunder.

3. On a day when the speed of sound in air is 330 m/s, how long would sound take to travel a distance of 1.6 km?

4. During a thunder storm it is noticed that the time interval between the flash of lightning and the clap of thunder gets less. What does this tell you about the storm?

5. Describe a method of measuring the speed of sound in air giving:
   a) the apparatus used
   b) the measurements taken
   c) any equations used in the calculation.

6. Ten pupils are standing on Calton Hill, looking at Edinburgh Castle. They measure the time difference between seeing the smoke from the one o'clock gun and hearing the bang. The measured times are 3.8 s, 4.2 s, 4.0 s, 3.8 s, 4.4 s, 3.8 s, 4.0 s, 4.2 s, 3.6 s, and 4.2 s.
   a) Calculate the average time for the group.
   b) Calculate the distance from the Castle to Calton Hill if the speed of sound is 330 m/s.

7. An explosion in Grangemouth could be heard in South Queensferry one minute later . Given they are 20 km apart, calculate the speed of sound in air.

8. On a day when the speed of sound is 330 m/s, how long would the sound take to travel a distance of 19.8 km?

9. In a race the runners are at different distances away from the starter. They will hear the starting horn at different times. Using the speed of sound as 340 m/s, calculate the time difference in hearing the horn for two runners who are 5 m and 15 m from the starter.

10. Calculate how long it would take light to travel from the sun to the earth, a distance of 1.49×10^8 km.

11. How long will it take a radio signal to travel from Britain to Australia, a distance of 1.8×10^4 km.

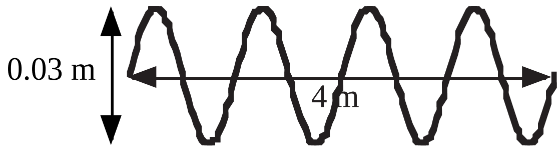
12. a) Explain, using a diagram, the difference between a transverse and longitudinal wave.
    b) What type of waves are the following:
       i) sound waves
       ii) water waves
       iii) light waves.

13. Explain, using the particle model, why sound travels quicker in metals than gases.

14. Explain why sound cannot travel through a vacuum.

Speed, frequency, wavelength and period

15. The diagram below represents a wave 0.2 s after it has started.



Calculate the following quantities for this wave:
- a) wavelength
- b) amplitude
- c) frequency
- d) speed.

16. A swimming pool is to have a wave-making machine installed. The time taken for a wave to travel the length of the 50 m pool has to be 20 s and the wavelength has to be 4 m.
    - a) Calculate the speed of the waves.
    - b) Calculate the required frequency of the waves.

17. Wave A has a wavelength of 6 cm and a frequency of 50 Hz. Wave B travels 250 m in 1 minute 40 s. Which wave travels faster - and by how much?

18. 40 waves are found to pass a point in 20 s. If the waves have a wavelength of 0.015 m, calculate their speed.

19. Calculate the wavelength of a wave of frequency 0.1 Hz and speed 5 m/s.

20. State what is meant by the period of a wave.

21. If the speed of a water wave is 0.6 m/s and the wavelength of each wave is 6 cm, calculate
    - a) the frequency
    - b) the period of the wave.

22. Waves of wavelength 5 cm travel 120 cm in one minute.
    Find their
    - a) speed
    - b) frequency
    - c) period.

23. A sound generator produces 25 waves every 0.1 s. If the speed of sound is 330 m/s, find:
    - a) the wavelength of the sound
    - b) the period of the waves.

24. a) List the members of the electromagnetic spectrum in order with the largest wavelength first.
b) What do all the members have in common?

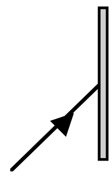
25. How far will radio waves travel in a) 2 m s b) 0.25 m s c) 1 m s.

26. Calculate the wavelength of waves of frequency a) 5 GHz b) 4 MHz c) 200 GHz.

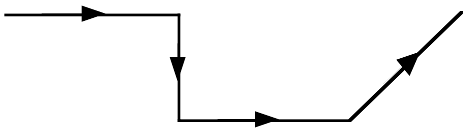
27. Calculate the transmission frequency of Radio Scotland broadcasting on 370 m on the Medium waveband. Give your answer in MHz.

Reflection

28. Copy and complete the diagram below labelling clearly
a) the angle of incidence
b) the angle of reflection
c) the normal.



29. The diagram shows the path of a ray of light . The ray was made to change direction using mirrors, but these have been left out.

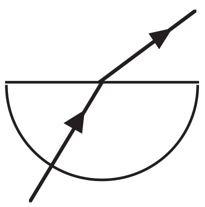


Copy the ray of light and complete the diagram by placing the mirrors in exactly the correct position.

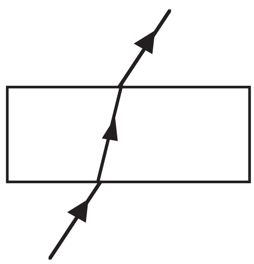
30. If you were given a semicircular glass block, a ray box and single slit, describe how you would demonstrate total internal reflection. Include a diagram in your explanation.

31. Copy the following diagrams, showing the path of the rays when their direction is reversed.

a)



b)



32. Explain, using a diagram, how a curved reflector is used in a torch to produce a beam of light.

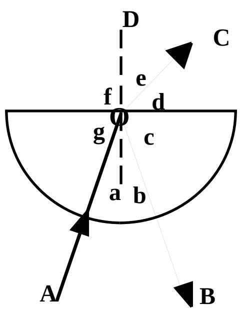
3. An outside broadcast unit at a football game beams television signals by means of a satellite dish to a receiver unit. Show by means of a diagram how
   a) the beam is sent
   b) the beam is received.

34. How can a curved reflector be used to ensure heat is directed more efficiently from an electric fire.

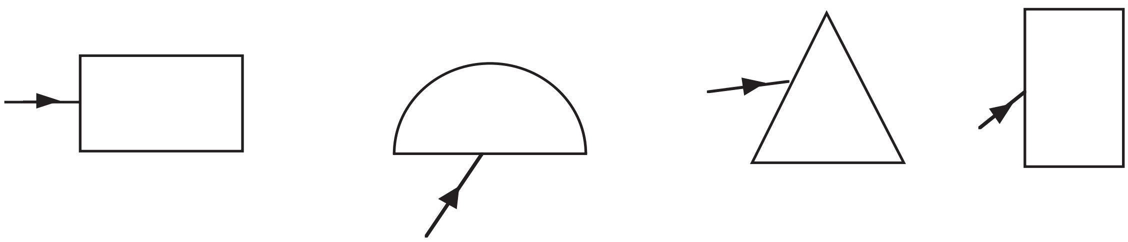
35. a) Optical fibre systems use repeater stations. What is the purpose of repeater stations?
    b) Light signals travel through glass at a speed of 2×10^8 m/s. How long would it take to travel between two repeater stations which were 100 km apart?

Refraction

36. Identify the following from the diagram shown below.
   i) the incident ray ii) the reflected ray iii) the refracted ray
   iv) the normal v) the angle of incidence vi) the angle of refraction
   vii) the angle of reflection.



37. Copy and complete the following diagrams.
   a) b) c) d)



38. By constructing accurate ray diagrams, describe the images produced using a converging lens of focal length 5 cm for the following object distances,
   a) 15 cm b) 8 cm c) 2 cm.

39. A projector can be used to produce a magnified image on a screen.
   a) Describe where the slide would have to be positioned, relative to the converging lens, to form this image.
   b) To ensure seeing the image the right way up what would have to be done to the slide?

40. A slide viewer produces a virtual, magnified image. Where would the object (the slide) have to be placed, relative to the lens, to produce this type of image?

41. Describe how the power of a lens could be found experimentally. This should include :
    a) a list of apparatus used
    b) a description of the procedure
    c) how the measurement(s) was used to find the power of the lens.

42. Find the power of the following lenses :
    a) f = 25 cm b) f = 10 cm c) f = 20 cm

43. Calculate the focal length of the following lenses :
    a) P = +2 D b) P = +2.5 D c) P = -8 D d) P = -5 D

44. a) Explain how being
        i) short sighted
        ii) long sighted would affect a person.
    b) Show how rays would pass through an eye resulting in
        i) short sight ii) long sight
    c) Explain which type of lens would be used to correct the above conditions.

NUMERICAL ANSWERS

1. 6800 m

3. 4.85 s

6. a) 4 s
   b) 1320 m

7. 333 m/s

8. 60 s

9. 0.029 s

10. 497 s

11. 0.06 s

15. a) 1 m
    b) 0.015 m
    c) 20 Hz
    d) 20 m/s

16. a) 2.5 m/s
    b) 0.625 Hz

17. A by 0.5 m/s

18. 0.03 m/s

19. 50 m

IONISING RADIATIONS

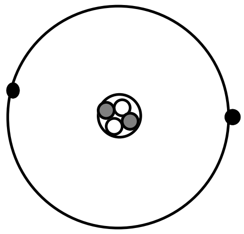
Atoms

Every substance is made up of atoms. Each element is made up of the one kind of atom, sometimes these atoms are combined together to form molecules.
Inside each atom there is a central part called the **nucleus.** The nucleus contains two particles:

protons: these have a positive charge
neutrons: these have no charge.

Surrounding the nucleus are negatively charged **electrons**.
An uncharged atom will have the same number of protons and electrons.
Consider the element helium, which has two neutrons and two protons in the nucleus, and two electrons surrounding the nucleus. This can be represented as:

Neutron
Electron
Proton



atom of helium

Ionisation

Atoms are normally electrically neutral but it is possible to add electrons to an atom or take them away. When an electron is added to an atom a negative ion is formed; when an electron is removed a positive ion is formed. **The addition or removal of an electron or electrons is called ionisation.** It is important to remember that the nucleus remains unchanged during this time.

Ionising Radiations

There are some atoms which have unstable nuclei which throw out particles to make the nucleus more stable. These atoms are called **radioactive**. The particles thrown out cause ionisation and are called ionising radiations.
There are three types of ionising radiation:

Alpha particles are the nuclei of helium atoms. They have 2 neutrons and 2 protons in the nucleus and are therefore positively charged.

Symbol: ${}^{4}_{2}\alpha$

Beta particles are fast moving electrons. They are special electrons because they come from within the nucleus of an atom. They are caused by the break up of a neutron into a positively charged proton and a negatively charged electron.

Symbol: ${}^{0}_{-1}\beta$

Gamma rays are caused by energy changes in the nuclei. Often the gamma rays are sent out at the same time as alpha or beta particles. Gamma rays have no mass or charge and carry energy from the nucleus leaving the nucleus in a more stable state.

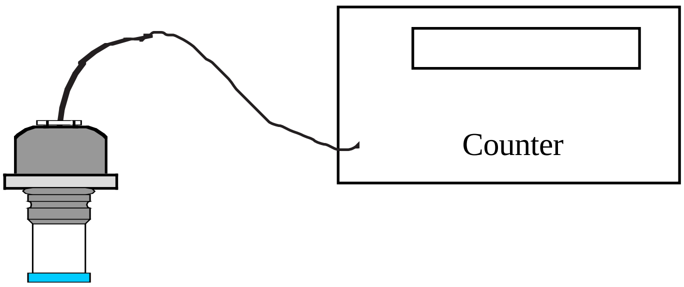
Symbol: γ

Properties of radiation
Alpha particles will travel about 5 cm through the air before they are fully absorbed. They will be stopped by a sheet of paper. Alpha particles produce much greater ionisation density than beta particles or gamma rays. They move much more slowly than beta or gamma radiation.

Beta particles can travel several metres through air and will be stopped by a sheet of aluminium a few millimetres thick. They have a lower ionisation density than alpha particles.

Gamma rays can only be stopped by a very thick piece of lead. They travel at the speed of light and have a very low ionisation density.

Detection of Radiation
A Geiger-Müller (GM) tube is used to detect α, β and γ radiation. If any of these enter the tube, ions are produced resulting in a small current flow. The current is amplified and a counter counts the number of events giving an indication of the level of radioactivity.



Geiger - Müller tube

Effects of radiation on living things
All living things are made of cells. Ionising radiation can kill or change the nature of healthy cells. This can lead to different types of cancer.

Uses of the properties of radiation
Radiation can be used in the treatment of cancer. The radioactive source, cobalt-60 kills malignant cancer cells. The source is rotated around the body centred on the cancerous tissue so the cancerous cells receive radiation all the time. However, as the source is moving the healthy tissue only receives the radiation for a short time and is therefore not damaged.

Radioactive tracers help doctors to examine the insides of our bodies. Iodine-131 is used to see if our thyroid glands are working properly. The thyroid gland controls the rate at which our body functions. The thyroid gland absorbs iodine, so a dose of radioactive iodine (the tracer) is given to the patient. Doctors can then detect the radioactivity of the patient's throat, to see how well the patient's thyroid is working.

DOSIMETRY

Activity

The activity, A, of a radioactive source is the number of decays, N, per second. It is measured in bequerels where 1 Bq = 1 decay per second.

Absorbed dose

The greater the transfer of radiation energy to the body the greater the chance of damage to the body. The absorbed dose, D, is the energy absorbed per unit mass of the absorbing material and is measured in grays, Gy.

$$1 \text{ Gy} = 1 \text{ J/kg}$$

The biological effects of radiation

All ionising radiation can cause damage to the body. There is no minimum amount of radiation which is safe. The risk of biological harm from an exposure to radiation depends on:

- the absorbed dose
- the kind of radiation
- the body organs or tissue exposed.

The body tissue or organs may receive the same absorbed dose from alpha or gamma radiation, but the biological effects will be different. To solve this problem a quality factor Q is used which is simply a number given to each kind of radiation as a measure of its biological effect. Some examples are given below.

Q	Type of radiation
1	beta particles / gamma rays
10	protons and fast neutrons
20	alpha particles

Dose equivalent

When scientists try to work out the effect on our bodies of a dose of radiation they prefer to talk in terms of dose equivalent. The dose equivalent H is the product of D and Q.

$$\text{Dose equivalent} = \text{absorbed dose} \times \text{quality factor}$$

$$\boxed{\mathbf{H = DQ}}$$

The dose equivalent is measured in sieverts, Sv.

Example
A worker in the nuclear industry receives the following absorbed doses in a year.
30 mGy from gamma radiation, Q = 1
300 mGy from fast neutrons, Q = 10
Calculate the dose equivalent for the year.

$$H = DQ$$

for gamma $H = 30 \times 10^{-3} \times 1 = 30 \times 10^{-3}$ Sv

for neutrons $H = 300 \times 10^{-6} \times 10 = 3.0 \times 10^{-3}$ Sv

total $H = 30 \times 10^{-3} + 3.0 \times 10^{-3} = 33 \times 10^{-3}$ Sv

Background radiation
Everyone is exposed to background radiation from natural and from man-made radioactive material. Background radiation is always present. Some of the factors affecting background radiation levels are:

- Rocks which contain radioactive material, expose us to ionising particles
- Cosmic rays from the sun and outer space emit lots of protons which cause ionisation in our atmosphere
- Building material contain radioactive particles and radioactive radon gas seeps up from the soil and collects in buildings, mainly due to lack of ventilation.
- The human body contains radioactive potassium and carbon
- In some jobs people are at greater risk. Radiographers exposed to X-rays used in hospitals and nuclear workers from the reactor.

Natural radiation is by far the greatest influence on our exposure to background radiation.

Examples

Natural source	Annual dose (mSv)	Man made	Annual dose (mSv)
From Earth	0.4	Medical	0.25
Cosmic	0.3	Weapons (fall out)	0.01
Food	0.37	Occupational	0.01
Buildings (radon)	0.8	Nuclear discharges	0.002
Total	1.87	Total	0.272

The individual values above do not need to be memorised but notice that the annual dose equivalent per year is about 2 mSv.

HALF-LIFE AND SAFETY

Half-life

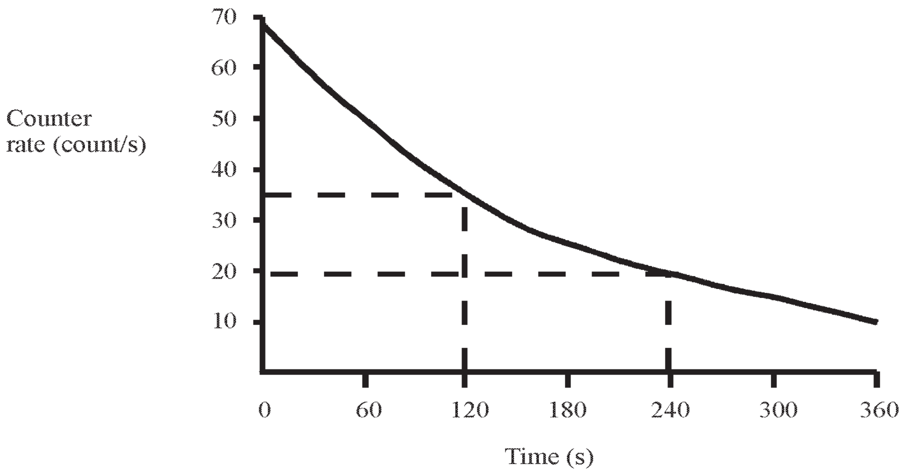
Radioactive decay is a random process. This means that for a radioactive source, it can never be predicted when an atom is about to decay. In any radioactive source, the activity decreases with time because the number of unstable atoms gradually decreases leaving fewer atoms to decay.

The **half-life** of a radioactive source is the time for the activity to fall to half its original value.

Examples

1. *A Geiger-Muller tube and ratemeter were used to measure the half-life of radioactive caesium-140. The activity of the source was noted every 60 s. The results are shown in the table. By plotting a suitable graph, find the half-life of caesium-140.*

Time (s)	*0*	*60*	*120*	*180*	*240*	*300*	*360*
Count Rate (counts/s) (corrected for background)	*70*	*50*	*35*	*25*	*20*	*15*	*10*



From the graph the time taken to fall from 70 counts/s to 35 counts/s = 120 s
35 counts/s to 17.5 counts/s = 120 s

Average half life of caesium-140 = 120 s.

2. *A source falls from 80 MBq to 5 MBq in 8 days. Calculate its half-life.*

80 → *40* → *20* → *10* → *5*

This takes 4 half-lifes (count the arrows) = 8 days
One half life = 2 days

Safety with radioactivity

- Always use forceps or a lifting tool to remove a source. Never use bare hands.
- Arrange a source so that its radiation window points away from the body.
- Never bring a source close to your eyes for examination. It should be identified by a colour or number.
- When in use, a source must be attended by an authorised person and it must be returned to a locked and labelled store in its special shielded box immediately after use.
- After any experiment with radioactive materials, wash your hands thoroughly before you eat. (This applies particularly to the handling of radioactive rock samples and all open sources.)
- In the U.K. students under 16 may not handle radioactive sources.

Reducing the dose equivalent

- Use shielding, by keeping all radioactive materials in sealed containers made of thick lead. Wear protective lead aprons to protect the trunk of the body. Any window used for viewing radioactive material should be made of lead glass.
- Keep as far away from the radioactive materials as possible.
- Keep the times for which you are exposed to the material as short and as few as possible (dentists often ask you to hold the X-ray film in place while they keep well behind the screen. This may seem unfair - but the dentist takes lots of X-rays over the year and so is at greater risk.)

Radioactive hazard warning sign

- The sign should be displayed on all doors/corridors leading to where radioactive materials are stored.
- The sign should be displayed on all containers of radioactive materials.

NUCLEAR REACTORS

Advantages of using nuclear power to produce electricity

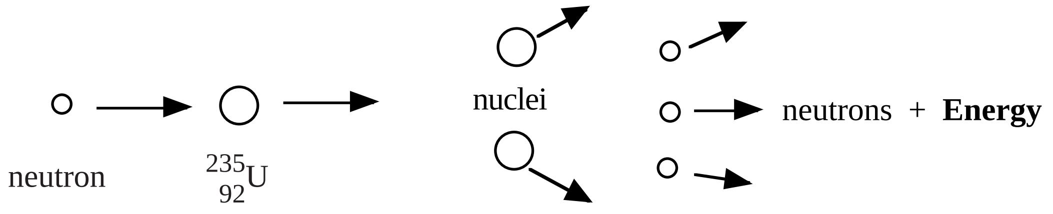
- Fossil fuels are running out, so nuclear power provides a convenient way of producing electricity.
- A nuclear power station needs very little fuel compared with a coal or oil-fired power station. A tonne of uranium gives as much energy as 25000 tonnes of coal.
- Unlike fossil fuels, nuclear fuel does not release large quantities of carbon dioxide and sulphur dioxide into the atmosphere,which are a cause of acid rain.

Disadvantages of using nuclear power to produce electricity

- A serious accident in a nuclear power station is a major disaster. British nuclear reactors cannot blow up like a nuclear bomb but even a conventional explosion can possibly release tonnes of radioactive materials into the atmosphere. (The Chernobyl disaster was an example of a serious accident.)
- Nuclear power stations produce radioactive waste, some of which is very difficult to deal with.
- After a few decades nuclear power stations themselves will have to be disposed of.

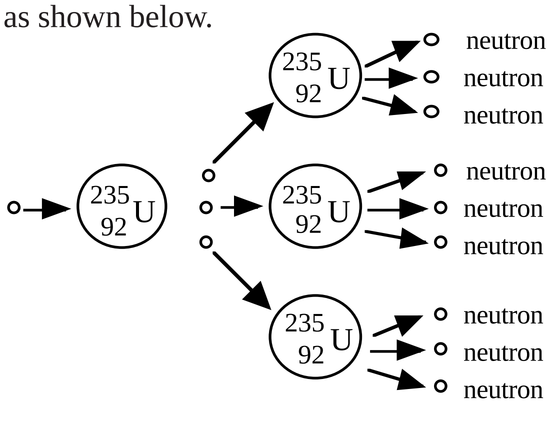
Nuclear fission

An atom of uranium can be split by a neutron. This can produce two new nuclei plus the emission of neutrons and the release of energy.



Chain reaction

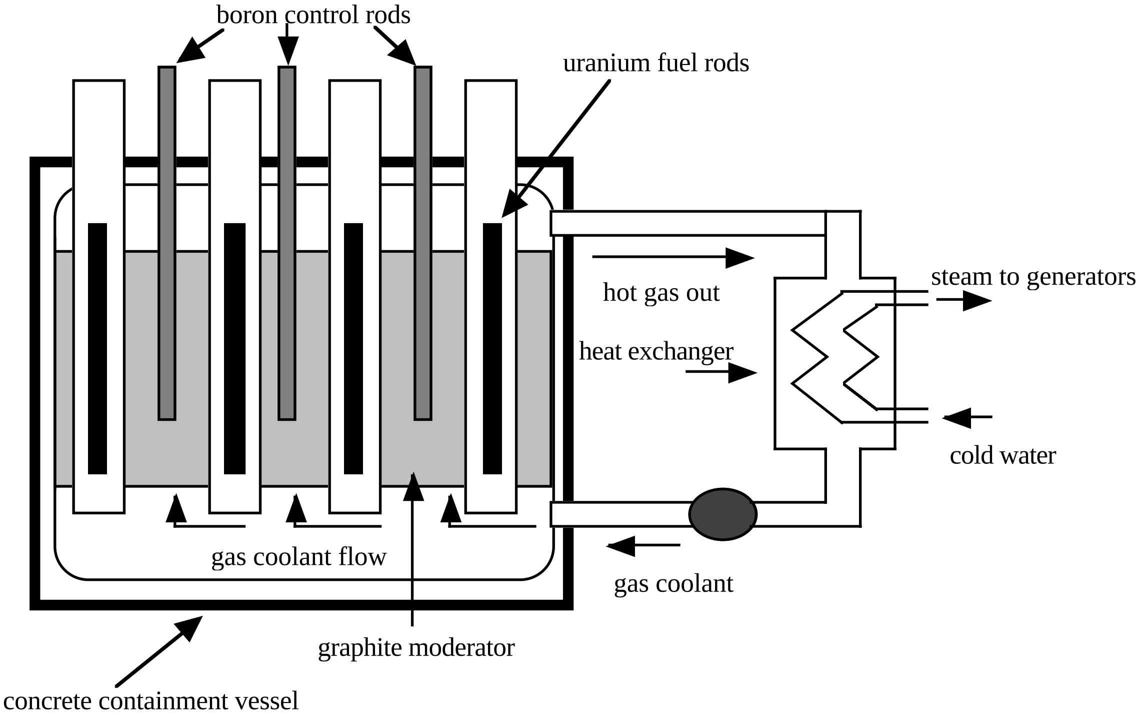
Once a nucleus has divided by fission, the neutrons that are emitted can strike other neighbouring nuclei and cause them to split releasing energy each time. This results in what is called a chain reaction as shown below.



In a controlled chain reaction, on average only one neutron from each fission will strike another nucleus and cause it to divide. This is what happens in a nuclear power station. In an uncontrolled chain reaction all the neutrons from each fission strike other nuclei producing a large surge of energy. This occurs in atomic bombs.

The nuclear reactor

There are five main parts of a reactor as shown in the diagram below:



- The fuel rods are made of uranium-238 enriched with uranium-235 which produce energy by fission.
- The moderator, normally made of graphite, has the fuel rods embedded in it. The purpose of the moderator is to slow down neutrons that are produced in fission, since a nucleus is split more easily by slow moving neutrons.
- The control rods are normally made of boron, and they control the rate of production of energy. The boron rods absorb neutrons so by lowering them into the reactor, the reaction can be slowed down. In the event of an emergency they are pushed right into the core of the reactor and the chain reaction stops completely.
- A cooling system is needed to cool the reactor and to transfer heat to the boilers in order to generate electricity. British gas-cooled reactors use carbon dioxide gas as a coolant.
- The containment vessel is made of thick concrete which acts as a shield to absorb neutrons and other radiations.

Radioactive waste

Nuclear power stations produce radioactive waste materials, some of which have half-lives of hundreds of years. These waste products are first set in concrete and steel containers then buried deep under ground or dropped to the bottom of the sea. These types of disposals are very controversial. Some scientists believe the containers will keep the radioactive material safe for along time, other scientists are worried that the containers will not remain intact for such a long time. Most recently the British government has decided to dig up radioactive waste buried in the 1960’s near Dounreay in Scotland for fear of radioactive leakage.

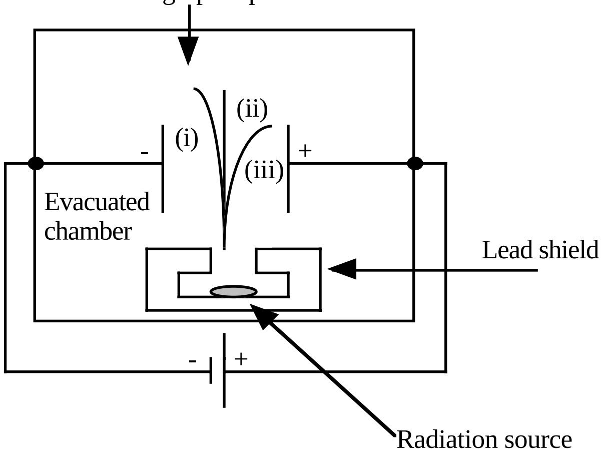
RADIOACTIVITY PROBLEMS

Ionising radiations

1. Using a diagram, describe the simple model of an atom.

2. Describe what is meant by the term ionisation.

3. In an experiment, radiation from a sample of radium is passed through an electric field. It is split into three different components (as shown in the diagram below).



(a) Name the radiations labelled (i), (ii) and (iii).
(b) Which radiation is deflected most by the electrostatic field?
(c) What is the function of the lead shield?
(d) Why is the experiment carried out in an evacuated chamber?
(e) What is the purpose of the photographic film?

3. The brain can suffer from cancer called glioblastoma. This form of cancer is treated by injecting the patient with boron-10 and then irradiating the patient with neutrons. This produces two particles lithium and an alpha particle.
(a) Explain how the alpha particle could help with the glioblastoma.
(b) Why could this process be dangerous for healthy tissue?

4. The table below represents data obtained from an absorption experiment using three separate radioactive sources (background count = 20 counts per minute).

	Count rate (per minute)		
Absorber	Source A	Source B	Source C
air	3125	900	420
paper	3130	880	38
1 mm aluminium	3000	380	20
10 mm lead	1900	20	21

(a) What effect did paper have on each of the three sources?
(b) Use the data in the table to try to identify the type of radiation from each source.

Dosimetry

5. What do we mean by the activity of radioactive material?

6. What does the risk of biological harm from radiation depend on?

7. A worker spends some time in an area where she is exposed to the following radiations:

   thermal neutrons = 8 mGy   Quality factor = 3
   fast neutrons = 40 μGy   Quality factor = 10

   (a) Calculate the dose equivalent for each type of neutron.
   (b) What is the total dose equivalent for the exposure?

8. What does the quality factor for each radiation give us an indication of?

9. In the course of his work an industrial worker receives a dose equivalent of 200 μSv. Determine the absorbed dose if he is exposed to alpha particles, with a quality factor of 20.

10. An unknown radioactive material has an absorbed dose of 500 μGy and gives a dose equivalent of 1 mSv. Calculate the quality factor of the material.

11. A patient receives a chest X-ray with a dose equivalent of 2.0 mSv. If the quality factor of the X-ray is 1, calculate the absorbed dose of the patient.

12. A lady has a dental X-ray which produces an absorbed dose of 0.3 mGy. Calculate the dose equivalent of this X-ray.

13. A nuclear worker is exposed to a radioactive material producing an absorbed dose of 10 mGy. She finds that the material emits particles with a quality factor of 3. Calculate the dose equivalent for this exposure.

14. A physics teacher uses a gamma source in an experimental demonstration on absorption The teacher receives an absorbed equivalent of 0.5 μSv. Calculate her absorbed dose if the quality factor for gamma radiation is 1.

15. (a) Alpha particles produce a dose equivalent of 50 mSv from an absorbed dose of 2.5 mGy. Calculate the quality factor of the alpha particles.
    (b) Why does exposure to alpha radiation increase the risk of cancer more than X-rays or gamma rays?

16. The unit for absorbed dose is the gray, Gy. Explain this term and give another unit for absorbed dose.

17. What is background radiation and from where does it originate?

Half life and safety

18. Explain what is meant by 'half-life'.

19. The following data was obtained from an experiment to determine the half life of a radioactive source:

Time (minutes)	0	20	40	60	80
Count rate (number of counts per minute)	100	60	45	30	20

(a) Describe how you could carry out this experiment.
(b) Determine the half-life of the radioactive source.

20. A radioactive material has a half life of 5 days. If the original activity is 120 Bq, what will be the activity after 20 days?

21. If a radioactive material has a half life of 600 years, how long will it take for the activity to fall to 10 Bq if the original activity was 80 Bq?

22. A radioactive substance has a half-life of 4 hours. What fraction of the original activity is left after one day?

23. The activity of a source starts at 100 MBq. After 20 days it has fallen to 6.25 MBq. Calculate the half life of the source.

24. What is the half-life of a radioactive source if the activity falls from 4000 kBq to 125 kBq in 40 days?

25. The half life of Cobalt-60 is 5 years. If the source, 25 years ago, had an activity of 500kBq, what would be the activity now?

26. What are the main sources of background radiation.

27. The table of results below show how the count rate for a radioactive source varies with time. The background count was 60 counts per minute.

Time (minutes)	0	5	10	15	20
Count rate (counts/minute)	1660	1100	750	510	350

(a) Plot a graph of corrected count against time.
(b) Determine the half-life of the source.

28. Describe the safety procedures when handling radioactive materials.

29. How can the dose equivalent be reduced for a radioactive source?

30. Write a note on the storage of radioactive material including warning signs and where they should be displayed.

Nuclear reactors

31. Explain what is meant by fission?

32. (a) What is a chain reaction?
    (b) Explain how a chain reaction works in a nuclear reactor and a nuclear bomb.

33. In a nuclear reactor what is the purpose of the following:
    (a) the concrete shield surrounding the reactor
    (b) the carbon dioxide pumped through the reactor
    (c) the graphite moderator?

34. How is the temperature of a nuclear reactor controlled?

35. Write down some advantages and disadvantages of using nuclear fuel to generate electricity.

36. (a) Why does radioactive waste worry many people?
    (b) Describe the problems with the storage and disposal of radioactive waste?

NUMERICAL ANSWERS

7. a) H = 24 mSv for thermal neutrons.
   H = 400 μSv for fast neutrons.
   b) 24.4 mSv

9. 10 mGy

10. 2

11. 2 mGy

12. 0.3 mSv

13. 30 mSv

14. 0.5 mGy

15. 20

20 7.5 Bq.

21. 1800 years
22. 1/64

23. 5 days.

24. 8 days.

25. 15.625 kBq.

27. b) 8 minutes