r/IGCSE Resources

Notes for Cambridge IGCSE™

Physics (0625)

by C.

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Table of Contents

Chapter 1

1.1 Physical quantities and measurement techniques

1.2 Motion

1.3 Mass and weight

1.4 Density

1.5 Forces

1.6 Momentum

1.7 Energy, work and power

1.8 Pressure

Chapter 2

2.1 Kinetic particle model of matter

2.2 Thermal properties and temperature

2.3 Transfer of thermal energy

Chapter 3

3.1 General Waves

3.2 Light

3.3 Electromagnetic spectrum

3.4 Sound

Chapter 4

4.1 Simple phenomena of magnetism

4.2 Electrical Quantities

4.3 Electric circuits

4.4 Electrical safety

4.5 Electromagnetic effects

Chapter 5

5.1 The nuclear model of the atom

5.2 Radioactivity

Chapter 6

6.1 Earth and The Solar System

6.2 Stars and the Universe

Chapter 1

1.1 Physical quantities and measurement techniques

Basics:

- We use rulers to measure lengths
- We use measuring cylinders to measure volume.
- We use micrometer screw gauges to measure very small distances accurately.

Fig. 1: Measuring cylindersPraphai Donphaimueang, CC BY-SA 4.0, via Wikimedia Commons

Scalars and Vectors

Scalars do not have a direction which vectors have a direction.

Scalars only have a magnitude which vectors have both, a magnitude and a direction.

Examples

Scalars: distance, speed, time, mass, energy and temperature

Vectors: force, weight, velocity, acceleration, momentum, electric field strength and gravitational field strength

Resultant of vectors

To calculate the resultant of 2 vectors at a right angle, we use the pythagoras' theorem which is:

$$a^2 = b^2 + c^2$$

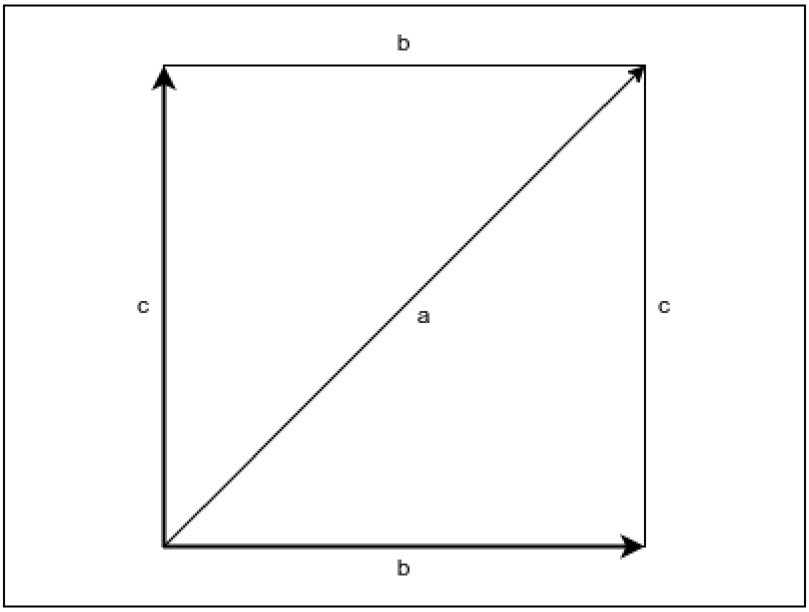


Fig. 2: Resultant of vectors

For example, if b = 3N and c = 3N, then to calculate `a` (the resultant), we would do the following:

$$a^2 = 3^2 + 3^2$$

$$a = \sqrt{3^2 + 3^2}$$

$$a = \sqrt{18}$$

$$a = 4.24$$

1.2 Motion

Speed and Velocity

Speed is the distance travelled per unit time.
In simple words, speed is the distance you travel in a specific amount of time.

We generally use 2 units for speed:

- `m/s` (metres per second)
- `km/h` (kilometer per hour)

As we read earlier, speed is a scalar quantity, therefore does not have a direction.

Velocity is almost the same as speed, except for one major difference, velocity has a direction and therefore is a vector quantity.

In other words, velocity is the distance you travel in a specific amount of time **in a specific direction**.

To calculate velocity, we use the following formula

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

$$\text{velocity} = \frac{\text{distance travelled}}{\text{time taken}}$$

To calculate **average** speed, we use the following formula:

$$\text{average speed} = \frac{\text{total distance travelled}}{\text{total time taken}}$$

Acceleration

Acceleration is the change in velocity per unit time.

In simpler words, acceleration is the increase or decrease of velocity in a given time.

To calculate acceleration, we use the following formula

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

The symbol Δ means change. So Δv means change in velocity (final - initial) or (v-u).
In the formula above, a is acceleration
Δv is change in velocity
Δt is change in time, in simple words, how long it took.

Speed-time graphs

A speed-time graph shows how an object's speed changes over time using a line or curve on a graph.

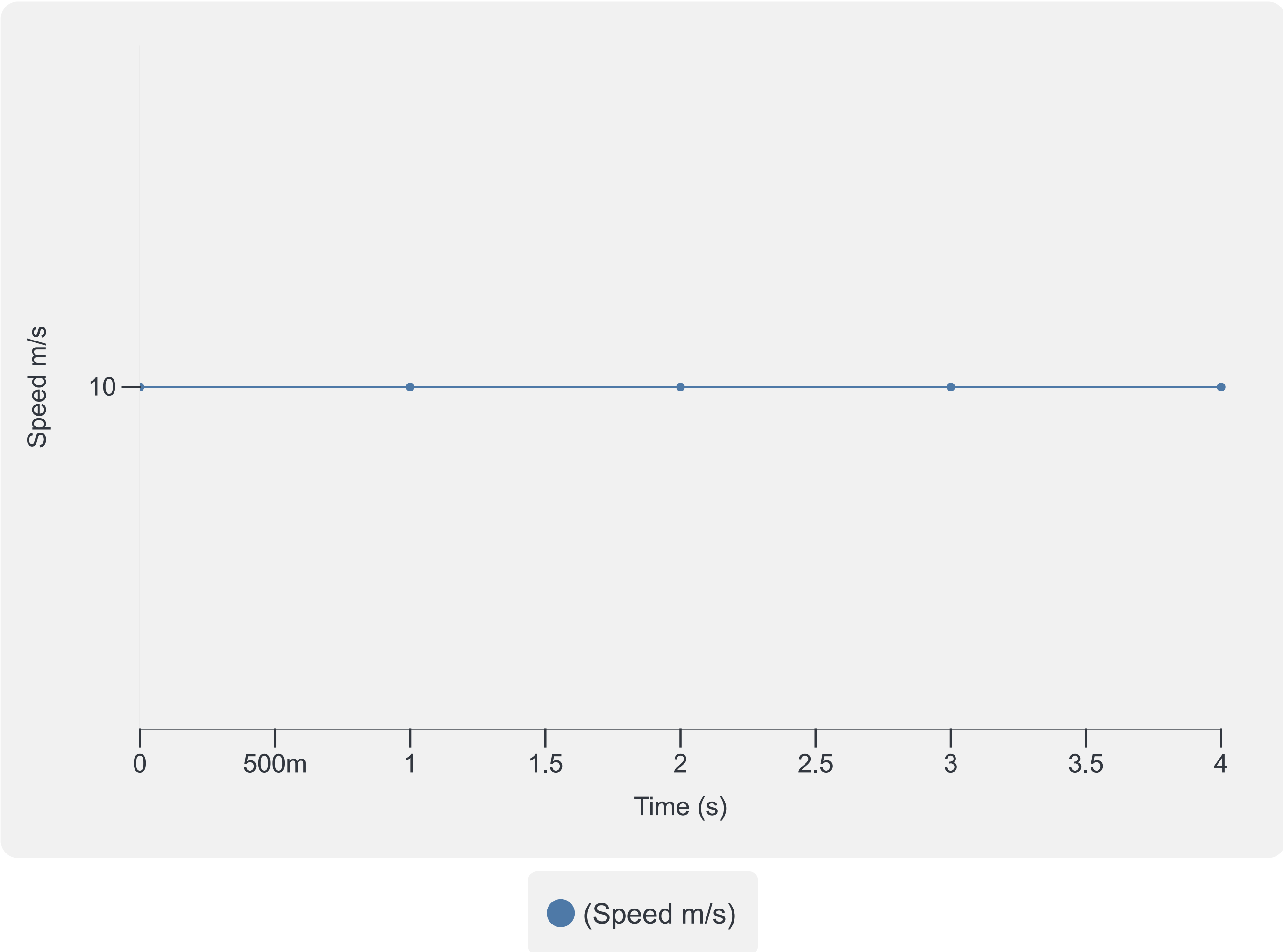
For example, we have this table of the speed of an object at intervals of 1 second.

Time (s)	Speed (m/s)

Time (s)	Speed (m/s)
0	10
1	10
2	10
3	10
4	10

As you can see, the speed of the object does not change at all during the 5 seconds.
We can say that this object has a **constant speed**.

This means that the graph of the object will be a straight line.
A graph for the table has been drawn below.

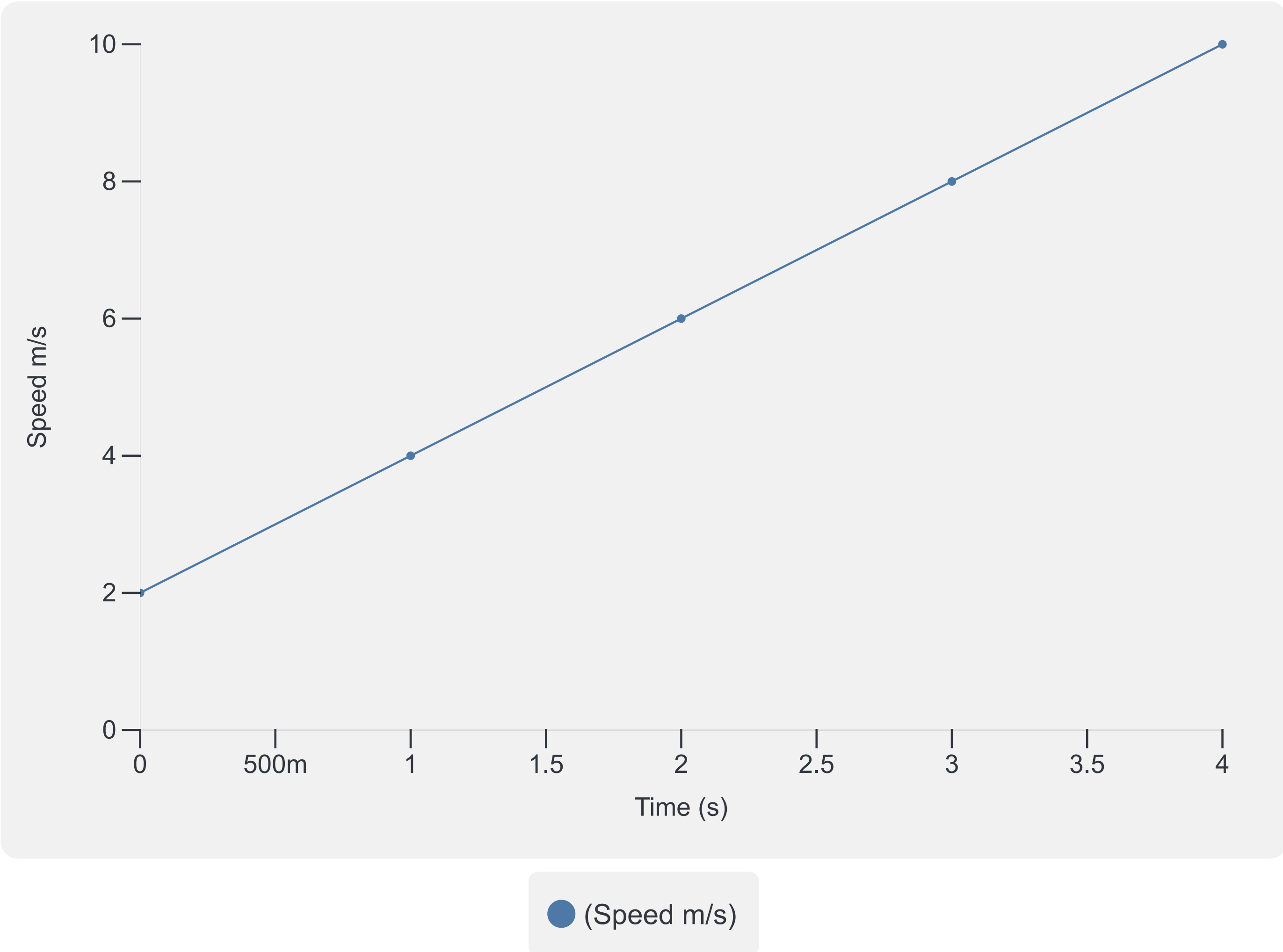


For an object which is accelerating as shown in the table below:

Time (s)	Speed (m/s)
0	2
1	4

Time (s)	Speed (m/s)
2	6
3	8
4	10

The graph for this object would be like this:



We can say that this object is accelerating at a constant acceleration since the graph is not a curve.

However, when the graph is a curve similar to the one below, we can say the acceleration is not constant, therefore changing acceleration.

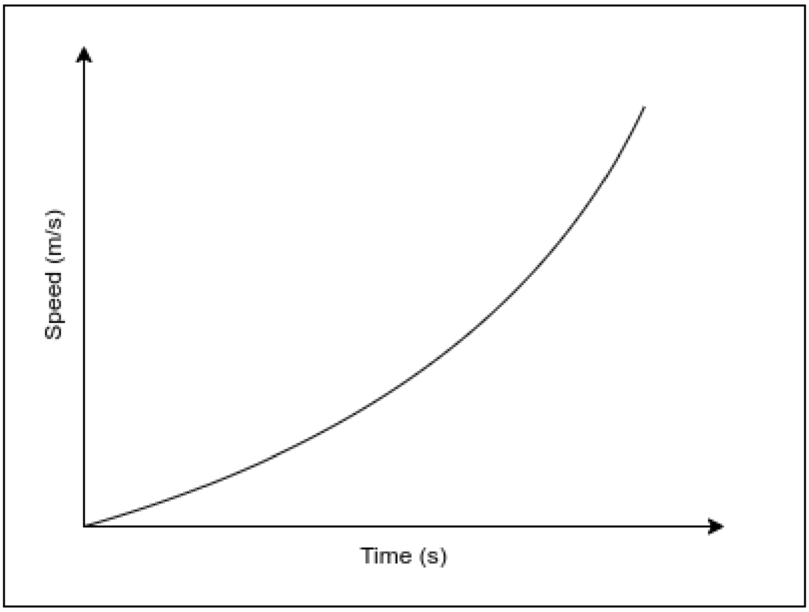


Fig. 3: Changing acceleration

Calculating the acceleration in speed-time graph.

The method is similar to one given below to calculate speed from a distance-time graph.
See Here or scroll down to `Calculating speed from a distance-time graph of an object at constant speed`

Calculating distance from speed-time graph

To calculate distance from a speed-time graph, we calculate the area under it.

For example, in the graph below, you can see that there is a graph of an object which is constantly accelerating first and then has a constant speed.

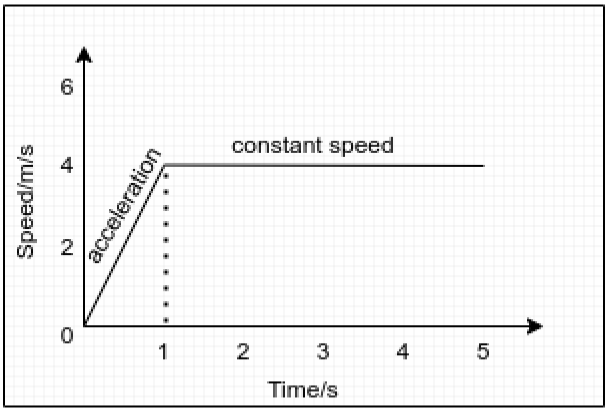


Fig. 4: Graph

To calculate the distance travelled by the object, we need to calculate the total area.
To do that, we first need to divide the shape into two, as indicated by the dotted line on the graph.

Now, we calculate the area of the triangle, which would be $1 \times 4 \times \frac{1}{2}$ which equals to 2.

Next, we calculate the area of the rectangle.

time = 5 - 1 = 4 s
speed = 4 m/s

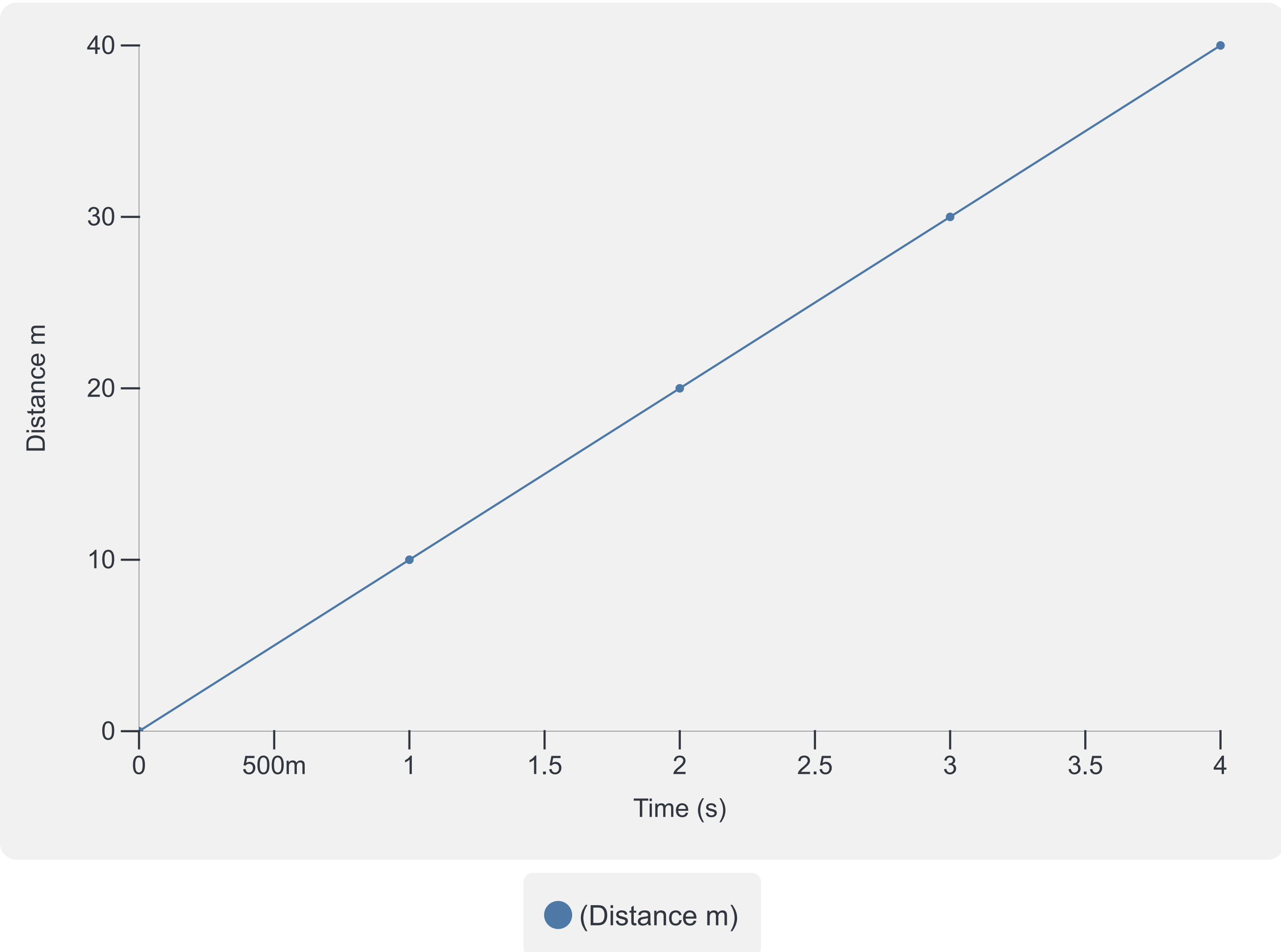
so for the area, 4×4 which is equal to 16.

Therefore the total area would be $2 + 16$ which is 18. The distance travelled by the object would be 18 metres.

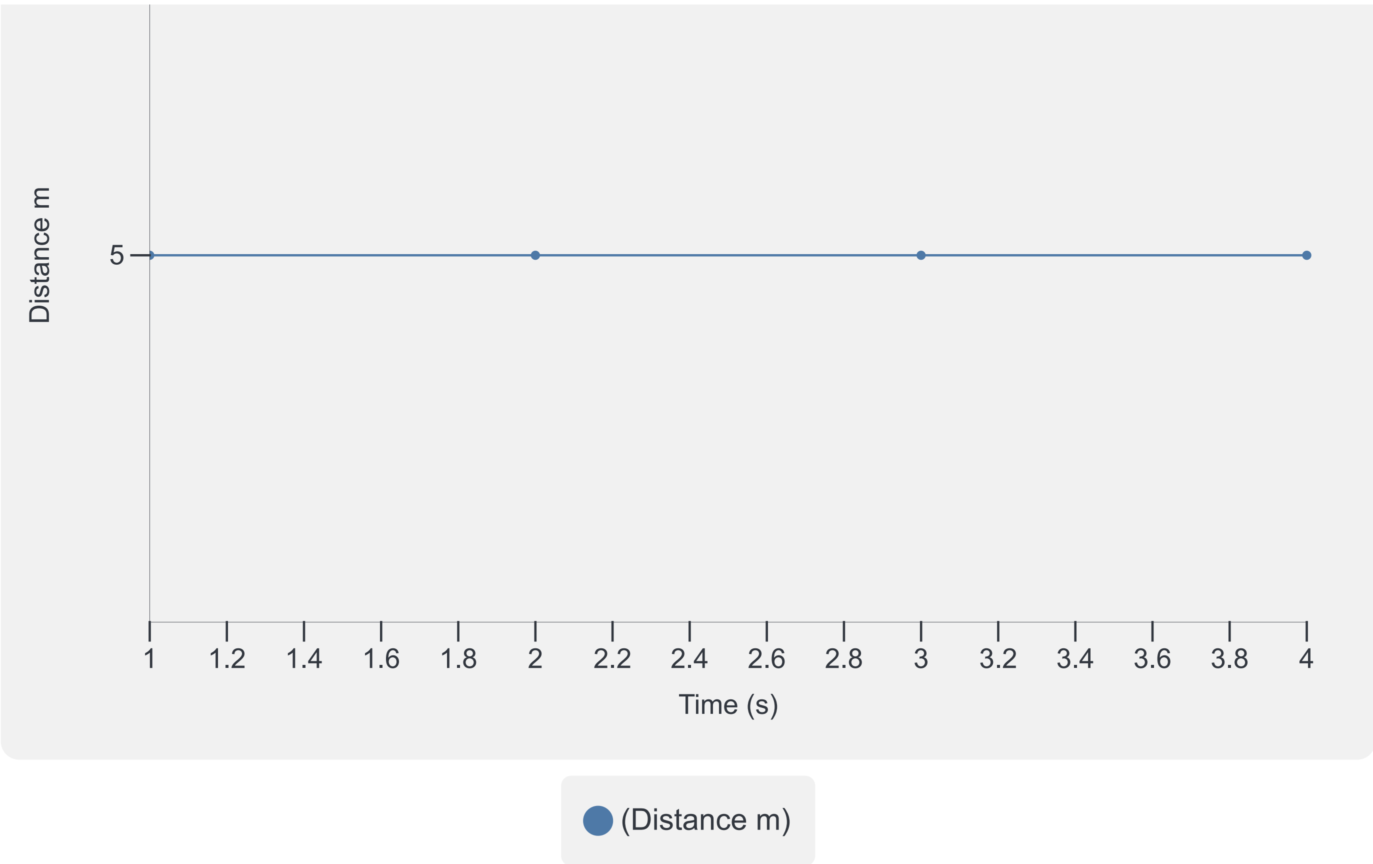
Distance-time graphs

A distance-time graph shows how the distance traveled by an object changes over time using a line or curve on a graph.

The distance-time graph of an object moving at a **constant speed** would be similar to the one below (a slanted **straight** line, not a curve):



And the distance-time graph of an object at rest would be similar to this (a straight line):



The distance-time graph of accelerating and decelerating objects would be similar to this:

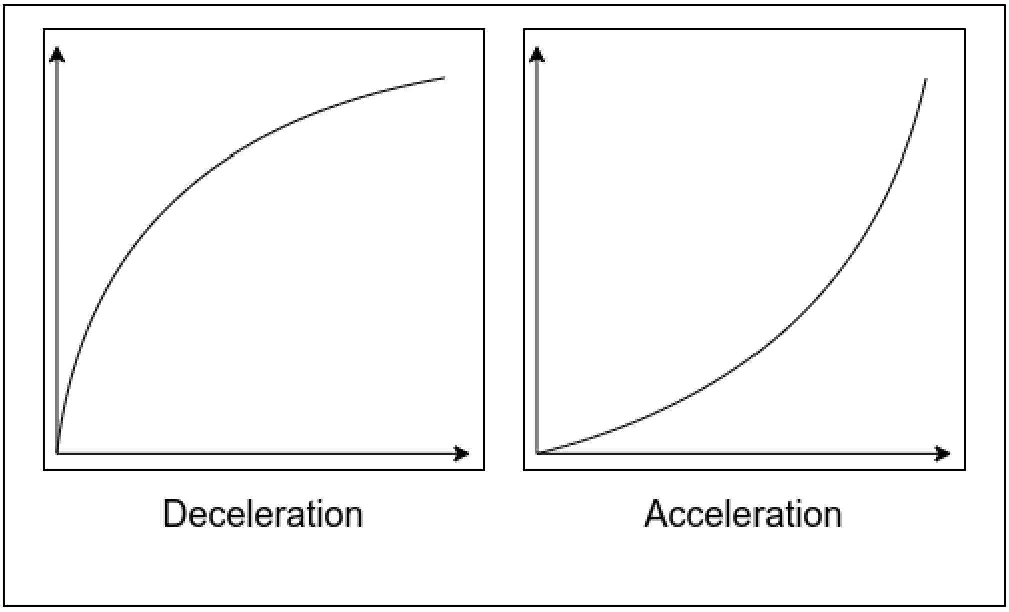


Fig. 5: Acceleration and Deceleration distance-time graph

Note

Deceleration is negative acceleration.

If deceleration = `2 m/s²` then acceleration will be `-2 m/s²`

Calculating speed from a distance-time graph of an object at constant speed

To calculate the speed of an object at constant speed from its distance-time graph, we use the gradient of the line.
To calculate the gradient, we do the following:

- Take any 2 points on the line, for example we can take (1, 2) and (2, 6).
    - Remember, we always write the x coordinate first. (x, y)
- Use the following formula to calculate the gradient:

$$\frac{y_2 - y_1}{x_2 - x_1}$$

So we'll do:

$$\frac{6-2}{2-1}$$

which equals to

$$\frac{4}{1}$$

which is equal to 4.
Therefore the speed of the object is 4 m/s.

The three equations of motion

An easier way to solve sums is using the three equations of motions.
But first you need to know what symbol represents what:
v = final velocity
u = initial velocity
a = acceleration
t = time
s = distance
g = gravity (acceleration of free fall) = 9.8 m/s^2 unless the paper (information on first page of paper)/question specifically mentions to take another value.

First equation

$$v = u + at$$

Second equation

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

Third equation

$$v^2 - u^2 = 2as$$

Free fall

Free fall is when an object falls freely under the influence of gravity alone, without any other forces affecting its motion.

Air resistance is a force that slows down objects falling through the air. It is also known as drag.
The question will usually mention whether to ignore air resistance or not.

When an object is in free fall, it's acceleration will be 9.8 m/s^2 (or 10 m/s^2 depending on the question).

Without air or liquid resistance, falling objects accelerate continuously. However, with resistance, their acceleration decreases and they eventually reach a constant speed known as terminal velocity.

> **Note**
>
> A heavier object and a lighter object when dropped from the same distance, will reach the ground at the exact same time.
> Basically, the mass of the object is not considered in a free fall (as long as air resistance is ignored).
>
> The acceleration of a freely falling body does not depend on the mass of the body.

1.3 Mass and weight

Mass and weight are **DIFFERENT**.

Mass is a measure of the amount of matter in an object when it's not moving.

Weight is a gravitational force on an object that has mass.

Basically, weight is the **effect** of a gravitational field on a mass.

The strength of gravitational field can be described as force per unit mass.

To calculate gravitational field strength (g), we use the following formula:

$$g = \frac{W}{m}$$

$$\text{gravitational field strength} = \frac{\text{weight}}{\text{mass}}$$

> **Note**
>
> g is also equal to the acceleration of free fall.

A balance can be used to determine the relative weight or mass of different objects by comparing their positions.

1.4 Density

Density is basically the mass of an object/substance per unit volume.
So basically the amount of mass in a specific volume of an object is known as density.

We use the symbol ρ (rho) to denote density.

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

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

We usually use three methods to calculate density.

Regularly shaped solids

To calculate the density of a regularly shaped solid, we need the following equipment:

- balance
- ruler

Measure the width, height and length of the object
Calculate the volume of the object by multiplying the three together
Use a balance to measure the mass of the object.
Use the equation below to calculate the density of the object.

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

Liquids

For this, we need the following equipment:

- balance
- measuring cylinder

Use the balance to measure the mass of the **empty** measuring cylinder and note it down.
Now pour the liquid into the measuring cylinder.
Calculate the change in mass on the balance.
Now measure the volume of the liquid using the markings on the measuring cylinder.
Use the equation below to calculate the density of the object.

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

Irregularly shaped solids

For this, we need the following equipment:

- balance
- measuring cylinder

Measure the mass of the object.
Pour x amount of any liquid (water is fine).
Drop the object in the liquid and observe the change in volume, this will be the volume of the object.
Now simply, use the equation below to calculate the density of the object.

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

Note

When an object is in a liquid, if the object's density is lower than that of the liquid, it will float.
Else if the density of the object is higher than that of the liquid, it will sink.
This also applies to 2 liquids which cannot mix together

1.5 Forces

A force is a push or pull that makes things move or change shape.

Extension in springs

Hooke’s Law

The hooke’s law states that the extension of a spring is directly proportional to the stretching force applied.

However, the hooke’s law is only followed upto a point known as the limit of proportionality. If the force goes beyond limit of proportionality, then the spring will no longer follow this law and it’s graph will no longer be linear.

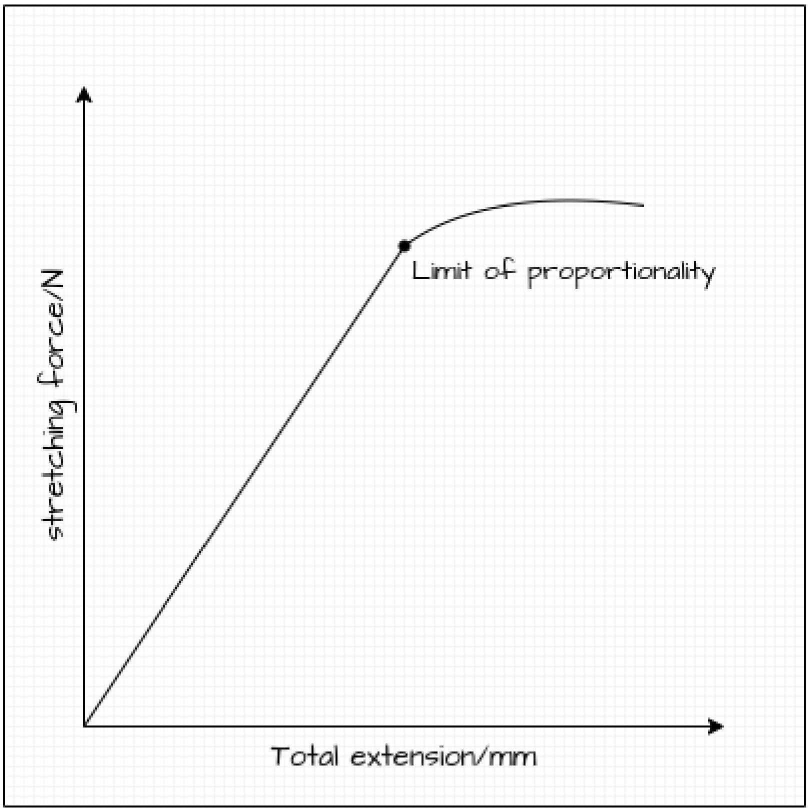


Fig. 6: Hooke's law graph (load–extension)

Note that the graph above is a **load–extension** graph, **load** (N) is on the y axis while **extension** (mm) is on the x axis. Make sure to check the type of graph in the exam.

Spring constant

The hooke's law also has an equation which is:

$$k = \frac{F}{x}$$

$$\text{spring constant} = \frac{\text{Force}}{\text{Extension}}$$

This can be rearranged to

$$F = kx$$

Spring constant can be defined as Force per unit extension. Basically the amount of force required to stretch a spring by one unit (e.g. mm).

Remember that extension is not equal to the total length of the spring, they are different.

Forces and resultants

As you read earlier, forces are vectors, that means that they have both a magnitude and a direction.

For example, a force of 5N is acting on a block towards right (and it is the only force), the block would move towards the right.

However that’s usually not the case, there are other forces always acting on an object such as gravity, and friction/air resistance (if the object is in motion)

For now, we can just assume these forces don’t exist.

Another example:
There are 3 forces acting on a block:

1. A force of 5N towards the right
2. A force of 3N towards the right
3. A force of 10N towards the left

Ignoring air resistance/friction, what would be the resultant force?

Now, the total force towards right is 8N (5N + 3N) while the total force towards left is 10N.
The force towards left is higher by 2N, that is the magnitude of the resultant force and the direction of the same would be left as well. This is shown by the diagram below.

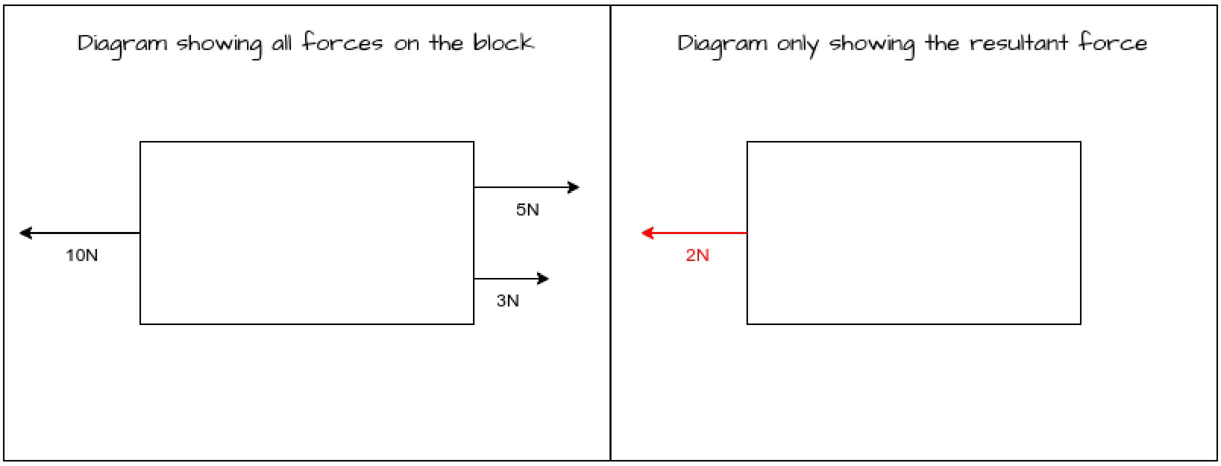


Fig. 7: Resultant force

Force, mass and acceleration

We can use the equation below to calculate resultant force using the object’s mass and the acceleration on the object.

$$F = ma$$

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

However, there are 2 conditions for this.

- The force and acceleration must have the same direction.
- The units of all three
  - Acceleration must be in `m/s`^{2}
  - Mass must be in `kg` (kilograms)

- Force must be in `N` (newtons)

Newton’s first law

Now i know you want to hunt newton down, but this law is fairly simple.

> **Newton's first law**
>
> An object either remains at rest or continues in a straight line at constant speed unless acted on by a resultant force.

In simple words, this law states that an object will keep moving at a constant speed if an external force is not applied to that object (friction, air resistance).

A resultant force may change the velocity of an object by changing its direction of motion or its speed.

Friction

Friction is the force that creates resistance when things slide against each other, making them slow down and producing heat in the process.

For example, imagine that you’re trying a push a heavy box across the floor. The surface of the block and the surface of the floor are in contact and create force in the opposite direction you’re trying to push the block in.

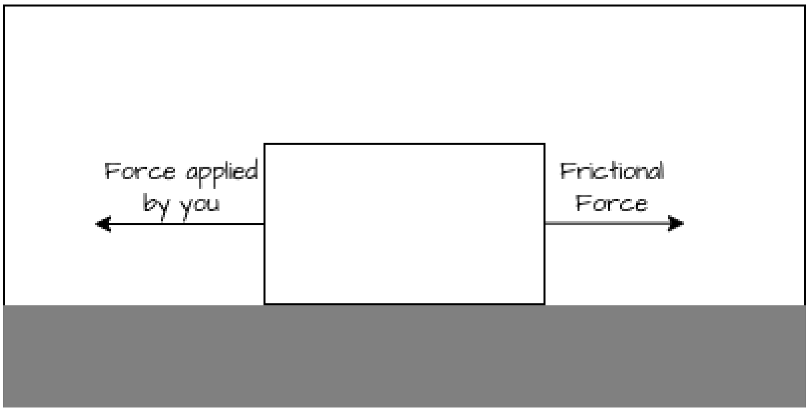


Fig. 8: The direction of frictional force is always in the opposite direction of the force applied on the object

Friction (drag) in liquids and in air

When an object moves through a liquid like water, it experiences friction or drag (basically a term used for air resistance or fluid resistance).

The same applies to objects moving through the air.

For example, an airplane moving across the sky experiences air resistance (drag). This force is also in the opposite direction, making it harder for the plane to move in the air and slowing it down unless another force (force from the engines of the plane) is larger than (if the plane wants to accelerate)/equal to (if the plane wants to maintain a uniform velocity) that of the force of friction.

Circular motion

Circular motion is the movement of an object along a curved path at a constant distance from a central point.

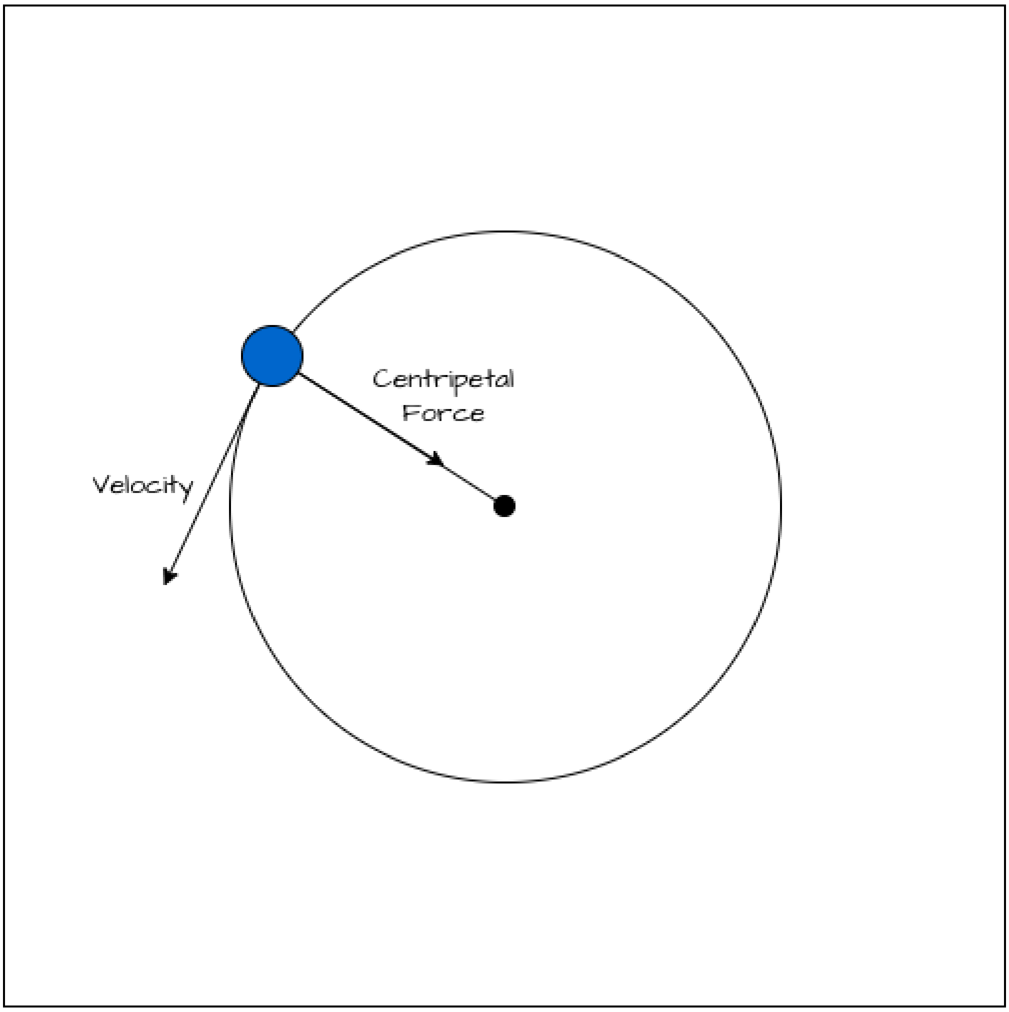


Fig. 9: Diagram showing an object in circular motion

In figure 9 above, you can see that the ball is moving in a circular motion around the circle. Now remember that velocity is a vector and has both a magnitude and a direction.

When the ball moves around the circle, its speed does NOT change unless it is acted upon by an external force. However, the velocity of the ball changes as it's direction has changed.

And change in velocity means acceleration, therefore the ball is accelerating, even though its speed does not change.

Centripetal force

Centripetal force is the force that pulls things towards the center when they're moving in a circle.

When a ball is moving in a circular orbit (like figure 9), there's a force acting on it from the side, right at a 90° angle to its direction towards the center of the orbit/circle.

This force continually changes the ball's direction, causing it to move in a circle instead of a straight line.

This force is known as **centripetal force**.

Important

- More centripetal force leads to faster circular motion when mass and radius of the circle are unchanged.
- With constant speed and mass, increasing force tightens the circle (decrease in radius).
- Heavier objects need more force to maintain the same radius and speed.

Turning effect of forces

Try opening a door with the handle, seems easy, right?
Now try opening the same door again, but this time, try opening it from a side closer to the pivot, it'd be much harder.

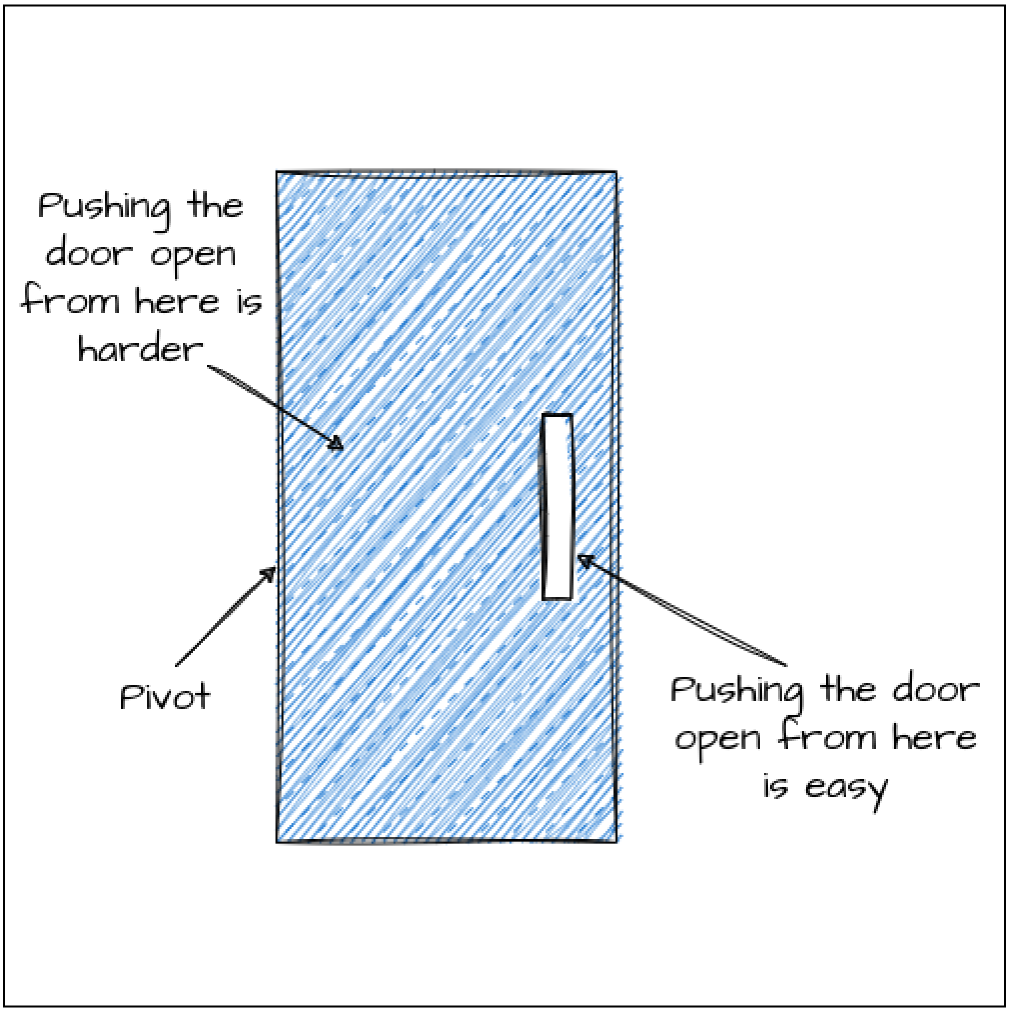


Fig. 10: Diagram showing a door

This happens because of something called the turning effect of force.

The moment of a force as a measure of its turning effect.

It depends on two factors, the size of the force and the distance between the point where the force is applied to the pivot.

$$\text{moment of a force} = \text{force} \times \text{perpendicular distance from the pivot}$$

The unit of moment is `Nm` (Newton-meter).

Equilibriums

An object is in equilibrium is when:

- there is no resultant force
- there is no resultant moment

This means that for example in the bar below, we can see that the force acting anti-clockwise is 2m from the pivot and is of magnitude 5N while another force is acting clockwise 5m away from the pivot and is of 2N.

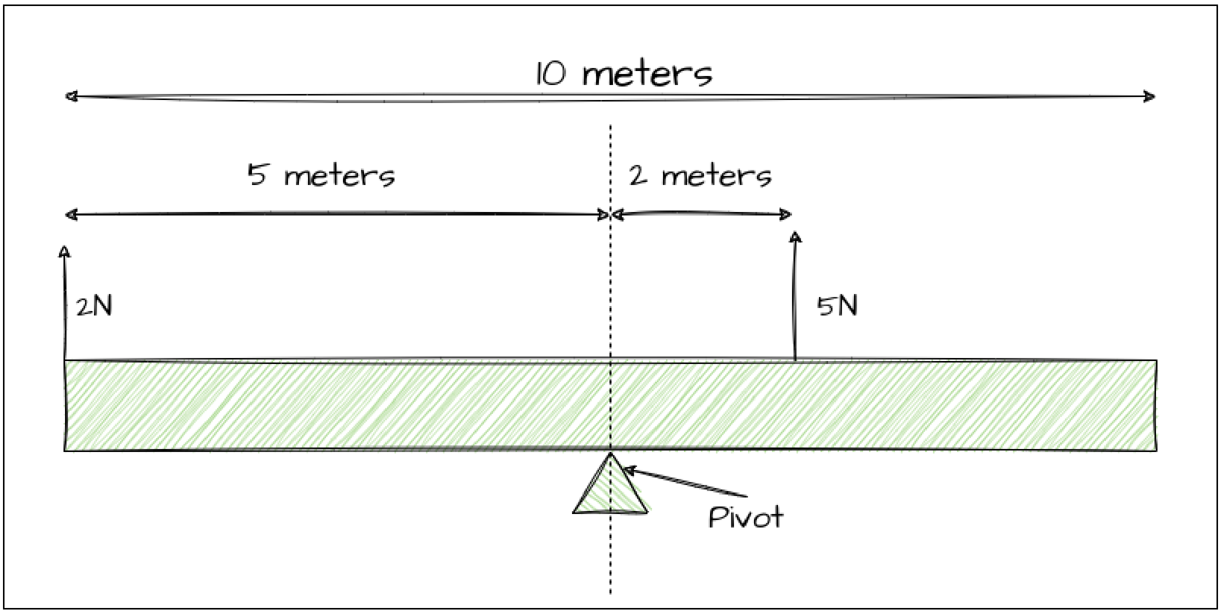


Fig. 11: A bar in equilibrium

Since the moment on the both sides is equal, which means there is no resultant moment, the bar is in equilibrium.

Multiple forces acting on the same side

A bar can also have multiple forces acting on the same side, for example in the figure below:

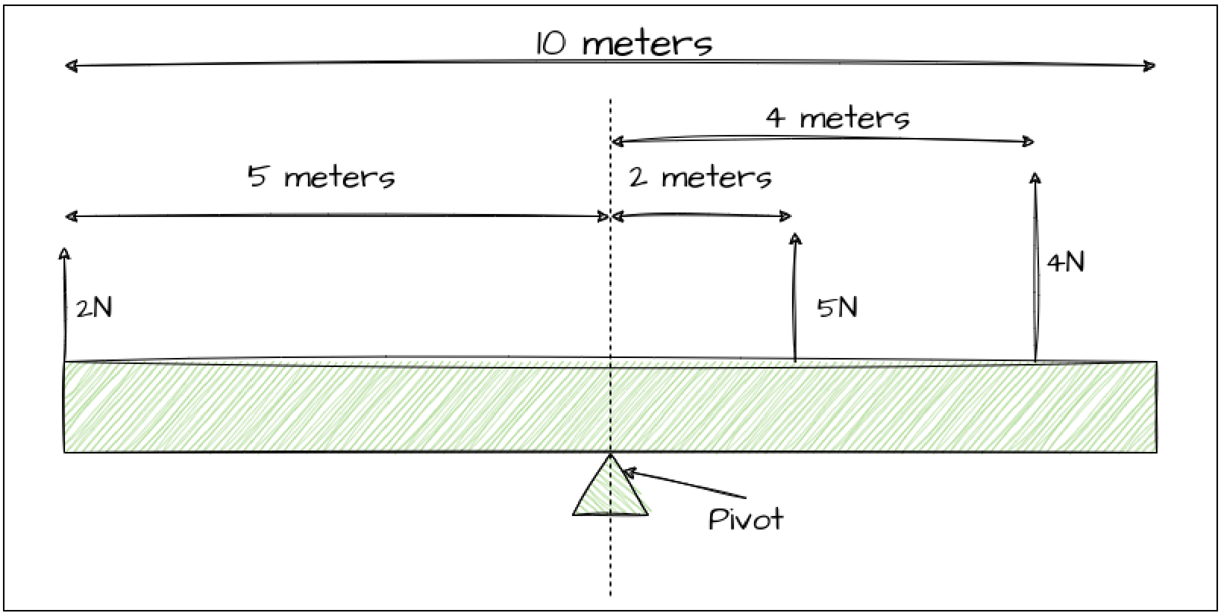


Fig. 12: A bar not in equilibrium

There are two forces acting anti-clockwise, $5 \times 2 = 10 \text{ Nm}$ and $4 \times 4 = 16 \text{ Nm}$, totalling to a total of 26 Nm.

While the total moment on the clockwise side is $2 \times 5 = 10 \text{ Nm}$.

As we can see, the total moments are not equal and the resultant moment will be 16 Nm, anti-clockwise.

We can say that the bar is not in equilibrium.

Centre of gravity

The centre of gravity refers to the point at which all of an object's weight can be considered to be concentrated at.

Centre of gravity and centre of mass can be used interchangeably.

Experiment

To figure out the position of the centre of gravity of an irregularly shaped lamina

Note: A lamina is a thin sheet.

Make 2 holes in the lamina and label it as A and B (as shown in the diagram).
Use a nail/pin to clamp the lamina onto a stand at point A or B (whatever you wish), make sure it can freely swing.
Place the plumb line on the nail and draw a line on the lamina.
Repeat this with the other hole.
The point where these two lines intersect/meet is the centre of gravity.

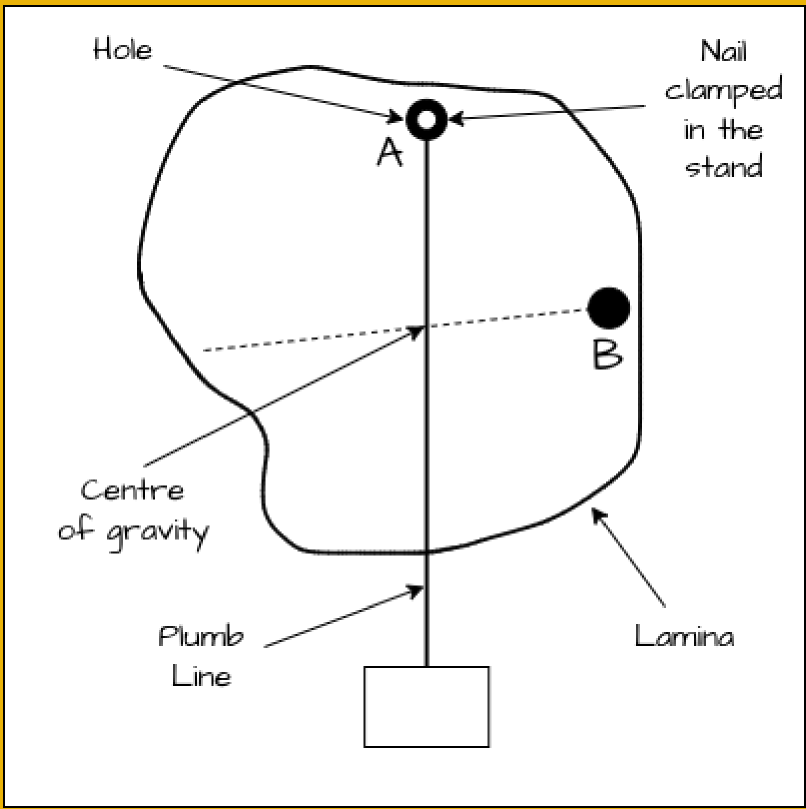


Fig. 13: Diagram showing the method to figure out the centre of mass of a lamina

Stability and Toppling

Toppling is when something tips over because it's not balanced.
The position of the centre of gravity of an object affects whether it topples easily or not.

The position of the center of gravity directly affects the stability of simple objects.

Lower center of gravity enhances stability, making the object less likely to tip over, while a higher center of gravity reduces stability, increasing the risk of toppling.

1.6 Momentum

Momentum is the quantity of motion of an object.
The two units used to measure moment are `kg m/s` (kilogram metre per second) and `N s` (newton second).

$$\text{momentum} = \text{mass} \times velocity$$

$$p = mv$$

Conservation of momentum

When two or more bodies collide with eachother, the total momentum of the bodies remains constant, provided that no external forces act.

Imagine a train is moving at 5 m/s and it collides with a cart at rest, the mass of the train is 10 kg and the mass of the cart is 1 kg.

After the collision, the both start moving together in the same direction, what is the velocity of the combined objects now?

initial momentum = final momentum, momentum will not change.

initial momentum = $(5 \times 10) + (0 \times 1) = 50 \ \text{kg m/s}$
inital mass = 10 kg

final momentum = initial momentum = $50 \ \text{kg m/s}$
final mass = $10 + 1 \ \text{kg}$ = 11 kg

final velocity = $\frac{50}{11} = 4.55 \ \text{m/s}$

Impulse

Impulse = change in momentum

Impulse is also equal to force multiplied by time.

$$\text{Impulse} = \ \text{force} \times \ \text{time}$$

Impulse is the change in momentum of an object and is calculated by multiplying the force applied to the object by the time period over which the force is applied.

Resultant force

Resultant force is the change in momentum per unit time.

$$\text{Resultant force} = \frac{\text{change in momentum}}{\text{time taken}}$$

$$F = \frac{\Delta p}{\Delta t}$$

1.7 Energy, work and power

Energy

Energy can be stored in different ways.
Some of these forms are:

- kinetic (a moving object has kinetic energy)
- gravitational potential (an object which is high up above the surface has g.p.e.)
- chemical (food and fuels, coal, gas, oil, wood etc.)
- elastic/strain (energy in a stretched/compressed object, for example a rubber band or a stretched spring)
- nuclear (energy stored in the nucleus of an atom)
- electrostatic (energy stored in a charged object)
- internal/thermal (total energy contained, fate of all other energy stores)

Important

Principal of conservation of energy

The principal of conservation of energy states that:

Energy can neither be created nor destroyed. It can only change forms/transfer.

Energy transfers

As stated by the principal of conservation of energy mentioned above, energy can only change forms/transfer.

Mechanical work

Mechanical work transfers energy by applying force.
For example, lifting a weight (kinetic energy to potential energy)

Electrical work

Electrical work transfers energy through electric currents
For example, powering a light bulb with electricity (electric energy to light and thermal energy)

Heating

It is the transfer of thermal energy. Causes an increase in the temperature.
For example, heating water on a gas stove (chemical energy to internal/thermal energy)

There are 3 methods to transfer thermal energy:

- Conduction
- Convection

- Radiation

More about this in chapter 2

Sound waves

Sound waves transfer energy from a vibrating source to a microphone or our eardrums.

Kinetic Energy

It is the energy in a moving object. For example, a moving car has kinetic energy.

To calculate kinetic energy, we use the following formula:

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

$$\text{kinetic energy} = \frac{1}{2} \times \ \text{mass} \times \ \text{velocity}^2$$

Where **m (mass)** is in **kg** (kilograms),
v (velocity) is in **m/s**,
and **E_k (kinetic energy)** is in **Joules** (J)

Gravitational Potential Energy

It is the energy in an object above the earth's surface.
Basically the energy in an object because of it's position.
It is also known as g.p.e.

To calculate change in g.p.e, we use the following formula:

$$\Delta E_p = mg\Delta h$$

$$\text{change in g.p.e.} = \ \text{mass} \times \ \text{gravity} \times \ \text{change in height}$$

When **m (mass)** is in **kg** (kilograms),
g (gravity) is in **N/kg** or **m/s^2**,
Δh in **m** (metres),
and ΔE_p is in **Joules** (J).

Work

In an energy transfer, work is done.

Work is the measure of the amount of the energy transferred.

Mechanical or electrical work done is equal to the energy transferred.

For example, lifting a book is work done.

To calculate mechanical work done, we use the following equation:

$$\text{work done} = \text{ force} \times \text{ distance}$$

$$W = Fd = \Delta E$$

where ΔE is the amount of energy transferred,
and distance d is the distance moved by the object **in the direction of the force**.

Tips

Work is measured in Joules (J).
1 J = 1 Nm (newton metre)

For example, imagine you lift up a book at ground which weighs 2 kgs upwards to a height of 5m.

To calculate the work done, we need to calculate the force and the distance in the direction of the force.

Since the book was at ground, the vertical distance is 5m and the force will be $2g$ which is approximately 20N.

$$W = Fd = 20 \times 5 = 100 \text{ Nm}$$

$$100 \text{ Nm} = 100 \text{ J}$$

So the work done was 100 Joules.

Energy Resources

there are 2 types of energy sources:

- renewable
- non-renewable (previously stored energy, finite, will run out eventually)

non-renewable energy cannot be replaced when used up while renewable energy cannot run out.

There are many different energy sources:

- Fossil fuels (chemical energy, non-renewable)
- Biofuels (chemical energy, renewable)
- Waves/Water (hydroelectric, renewable)
- Geothermal energy (renewable)
- Solar energy (renewable)

- Wind energy (renewable)
- Nuclear fuel (nuclear energy, non-renewable)

Chemical energy (Fossil fuels and biofuels)

Fossil fuels (coal, oil, natural gas) are formed from the remains of plants and animals which lived millions of years ago.

Biofuels are fuels derived from organic materials, such as plants, crops, agricultural residues organic waste etc. Examples include ethanol and metanol.

	Biofuels	Fossil Fuels
Advantages	Renewable Less CO2 produced	Produces more energy per litre Established infrastructure (widely available)
Disadvantages	Do not provide a lot of energy Unstable, can explode	Non-renewable Pollute the environment

Fuel undergoes a process known as combustion, this releases heat.
The heat from combustion is used to spin a turbine, which spins a generator producing electricity

Hydroelectric/Tidal energy (from water)

The flow of water from a higher to a lower level (usually in a dam) is used to drive a water turbine which is connected to a generator, this generator produces electricity.

Advantages:

- Renewable
- Low greenhouse gas emissions

Disadvantages:

- Initial high construction cost
- Dams can cause a huge impact on the environment
- Causes harm to aquatic wildlife, as it destroys their habitats

Geothermal energy

Cold water is pumped down into the hot rocks below the Earth's surface, this water heats up and is used to drive a turbine, which is connected to a generator which produces electricity.

Advantages:

- Renewable
- Low greenhouse gas emissions

Disadvantages:

- Initial high drilling cost
- Location-dependent, not all locations can be a geothermal power station

Solar energy

There are 2 uses of this:

- Heating water/other substances
- Producing electricity

Heating

Energy of the electromagnetic waves from the sun is transferred and stored as internal energy in solar panels, this can be used to heat water.

A solar furnace can also be used to produce temperatures upto 3000°C. In a solar furnace, a large curved mirror is used to focus the sun's rays onto a small area.
Solar furnaces can also be used to heat water and produce electricity.

Producing electricity

Solar cells which are made from semiconducting materials are used to convert sunlight into electricity.
This energy is used or is stored a battery for later use.
Multiple solar cells are connected together for larger amounts of energy.

Advantages:

- Renewable
- Environment friendly

Disadvantages

- Expensive to setup
- The sun is not always out and bad weather can affect this as well

Wind energy

Radiation from the sun is also responsible for generating wind energy.
Giant windmils, called wind turbines are used to drive generators, which produce electricity.

Advantages:

- Renewable
- Does not emit greenhouse gases

Disadvantages:

- Noisy

- Expensive
- Take a lot of land space

Nuclear energy

The energy released in a nuclear reactor from the fission of uranium can be used to produce electricity.

Advantages:

- Produces large amounts of power from a small amount of fuel
- Low greenhouse gas emissions

Disadvantages:

- No place for disposal of nuclear waste
- Leaks in the reactor can cause disasters and harm to human life

The sun

The sun is the main source of all energy, except geothermal, nuclear and tidal.
The source of the sun's energy is nuclear fusion.

Currently, it is not possible to reproduce the process of fusion of earth to produce electricity. However, research is being done towards that.

Efficiency of energy transfers

The efficiency of device refers to how much useful energy is obtained from a process compared to the total energy input. It is the percentage of the energy supplied to a device that is usefully transferred.

Efficiency can be calculated using the following equations:

$$\text{efficiency} = (\frac{\text{useful energy output}}{\text{total energy input}}) \times 100$$

$$\text{efficiency} = (\frac{(\text{useful power output}}{\text{total power input}}) \times 100$$

Power

Power is the rate at which energy is transferred or converted.
It can be described as the **work done per unit time** and also as **energy transferred per unit time**.

The unit of Power is Watts (W).

Power can be calculated using the following equations:

$$\text{power} = \frac{\text{work done}}{\text{time taken}} = \frac{\text{energy transferred}}{\text{time taken}}$$

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

where W = work done

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

where ΔE = energy transferred

1 W = 1 J/s

1 kW (kilowatt) = 1000 W = 10^3 W

1 MW (megawatt) = 1 000 000 W = 10^6 W

1.8 Pressure

Pressure can be described as the force exerted per unit area.

To calculate pressure, we use the following formula:

$$\text{pressure} = \frac{\text{force}}{\text{area}}$$

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

Pressure and area are in an **inverse proportion** when force F is constant. If area increases, then pressure decreases.

Pressure and force are in a direct proportion when area A is constant. If force increases, then pressure also increases.

The unit of pressure is pascal (Pa).

1 Pa = 1 N/m^2

Pressure in liquids

As you go deeper beneath the surface of a liquid, the pressure increases.

This increase in pressure with depth is due to the weight of the liquid above pushing down. The more liquid there is above a certain point, the greater the force, and the greater the pressure.

We can calculate the pressure in liquids using the following formula:

$$\text{change in pressure} = \ \text{density} \times \ \text{gravity} \times \ \text{change in depth}$$

$$\Delta p = \rho g \Delta h$$

Chapter 2

2.1 Kinetic particle model of matter

States of matter

Property	Solid	Liquid	Gas
Volume	Fixed volume	Fixed volume	Indefinite volume
Shape	Fixed shape	Indefinite Shape Takes shape of the container stored in	Indefinite Shape Takes shape of the container stored in
Can Compress?	❌	✅ but very little	✅

Solids expand when heated and contract when cooled.

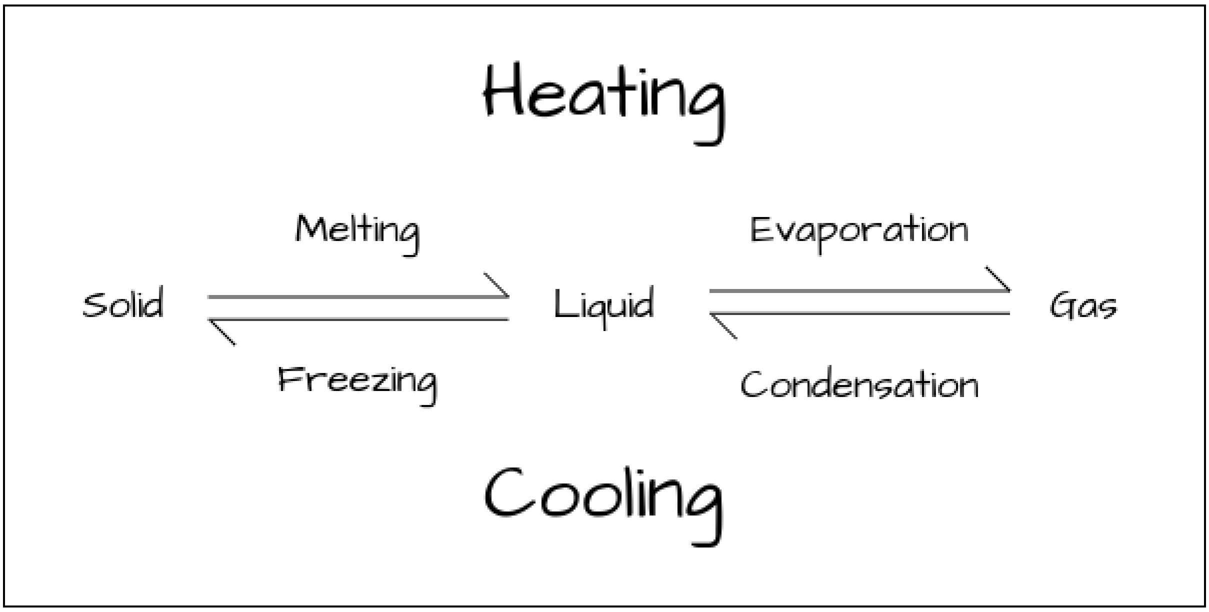


Fig. 1: Changs in state

Particle model

Solids

In solids, particles are packed close together. They cannot move and can only vibrated in a fixed position.
Solids also have strong intermolecular forces due to which along with the particles being packed close together result in a fixed shape and volume.
Solids expand only a little bit when heated.

Liquids

Particles in liquids are slightly further apart. They also have the ability to move past each other.
Liquids have slightly weaker intermolecular forces, allowing them to flow and take the shape of their container.
Liquids expand on heating more than solids, but less than gases.

Gases

Particles in gases are much further apart and usually don't touch each other.
Gases have really weak intermolecular forces and large inter-particle distances, due to which gases can flow easily and can take the shape of the container.
Gases also expand the most when heated.

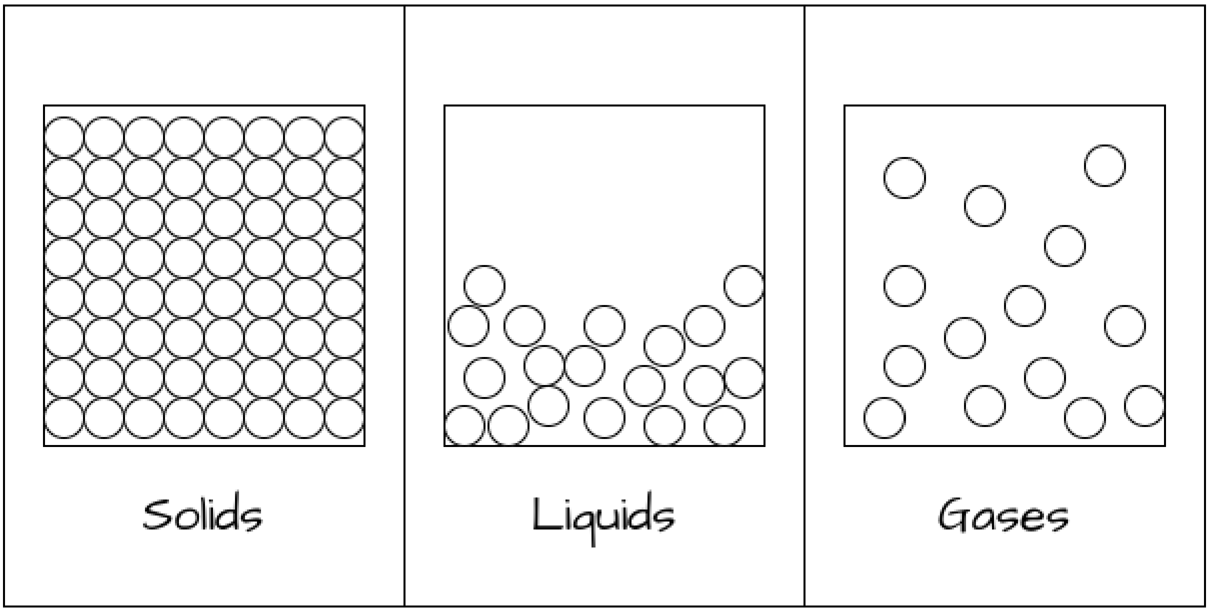


Fig. 2: Arrangement of particles in solids, liquids and gases

Temperature and kinetic energy

As you read above, particles in a solid are always vibrating at their fixed positions. When the solid is heated, it's temperature increases and so does its kinetic energy, causing the particles to vibrate faster, and eventually becoming a liquid.

The higher the temperature, the higher the kinetic energy and vice versa.

−273°C is a temperature which is known as **absolute zero**. At this temperature, the kinetic energy of the particles is 0 and the particles are not moving/vibrating.

Pressure and kinetic energy

The particles in a gas are always moving around, when these particles hit the walls of the container they are in, they cause pressure on the surfaces of the container.
As the kinetic energy in the particles increase, so does their speed, the higher the speed, the more the pressure due to an increase in the number of collisions.

Each collision of the gas particles with the surface of the container causes a change in momentum of the gas particle which in result, produces a force on the surface of the container.

Now imagine that your hand is a gas particle, and a bottle or anything in front of you is the surface of a container, punch that object (carefully) and you'll see that the object has moved because you applied a force on it.

Pressure = force per unit area
therefore, pressure is directly proportional to the force applied.
The more the force applied, the greater the pressure.

If the particles are moving faster/have more kinetic energy, they will apply more force and therefore the pressure will be greater.

Brownian motion

Brownian motion is the random movement of microscopic particles in a liquid or a gas due to collisions with the liquid/gas particles.

This motion is proof that particles in a liquid and gas are always moving.

Remember that microscopic particles may be moved by collisions with light fast-moving molecules

> **Note**
>
> Atoms and molecules are the small pieces that make up stuff, while microscopic particles are a bit bigger and made of these small pieces.

Gases and the absolute scale of temperature

When the temperature of a fixed amount of gas increases and the volume remains a constant, the gas particles gain kinetic energy and move faster.
This results in more frequent and harder collisions with the container walls, causing an increase in pressure.

If the volume of a fixed mass of gas is reduced and the temperature is kept a constant, the space available for gas particles to move within gets smaller.
As the particles continue to collide with the walls, they do so more often due to the reduced space, leading to an increase in pressure.

Boyle's law

This law states that: the pressure of a fixed mass of gas is inversely proportional to its volume if its temperature is kept constant.

The equation for this is:

$$pV = constant$$

$$p_1V_1 = p_2V_2 = constant$$

where p = pressure and V = volume

These equations are only true if the temperature is kept a **constant**.

Celsius and Kelvin temperature scales

To convert temperatures between celsius (°C) and kelvin (K), we use the following formula:

$$T \ (\text{in K}) = \theta \ (\text{in } ^\circ\text{C}) + 273$$

$$\theta \ (\text{in } ^\circ\text{C}) = T \ (\text{in K}) - 273$$

Remember:

$$-273^\circ \ \text{C} = 0 \ \text{K}$$

$$0^\circ \ \text{C} = 273 \ \text{K}$$

2.2 Thermal properties and temperature

Thermal expansion of solids, liquids and gases

Thermal expansion is the tendency of matter to expand when heated and contract when cooled.

In solids, particles are closely packed in fixed positions with strong forces of attraction holding them together, so they vibrate more vigorously with increasing temperature, causing the material to expand.

Liquids expand a little more than solids as their particles can move freely, aren't arranged in a completely fixed pattern and the forces of attraction and weaker compared to solids.

While gases expand the most as their particles are not arranged in any particular pattern and are held together by very weak forces.

Uses of thermal expansion

Thermal expansion has many uses. One of the main ones being bimetallic strips.

Bimetallic strip

A bimetallic strip is a thin strip made by joining two metals that bends when heated because the metals expand at different rates.

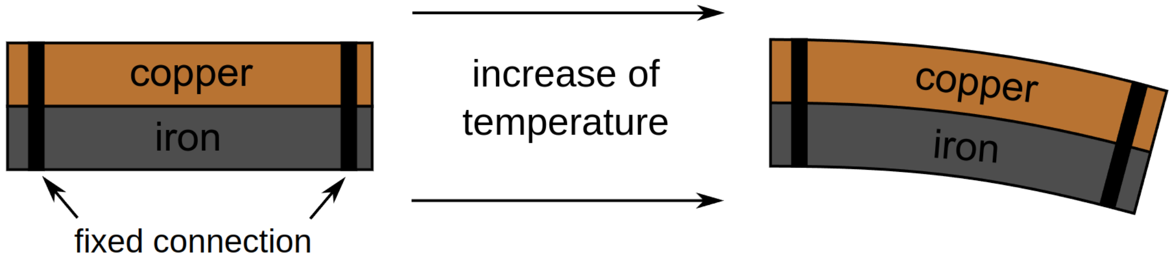


Fig. 3: A bimetallic stripPatrick87, CC BY-SA 3.0, via Wikimedia Commons

Bimetallic strips can be used for fire alarms, thermostats etc.

Fire alarm

Heat from the fire causes the bimetallic strip to bend, triggering/completing an electric circuit which triggers an alarm.

Thermostat

Bimetallic strips and used in thermostats to turn on/off a circuit when a specific temperature is reached.

Liquid-in-glass thermometers

These thermometers contain a liquid inside of a glass tube.
As the temperature increases, the liquid inside the tube expands, causing its level to rise.
We can now use the scale on the glass tube to read the temperature.

Disadvantages of thermal expansion

Railway tracks

Railway tracks constantly go through thermal expansion and contract. These frequent expansions and contractions cause them to become unstable which can be dangerous as it can lead to trains derailing.

To combat this, very tiny gaps are left in between the rails. These gaps are known as **expansion joints**.

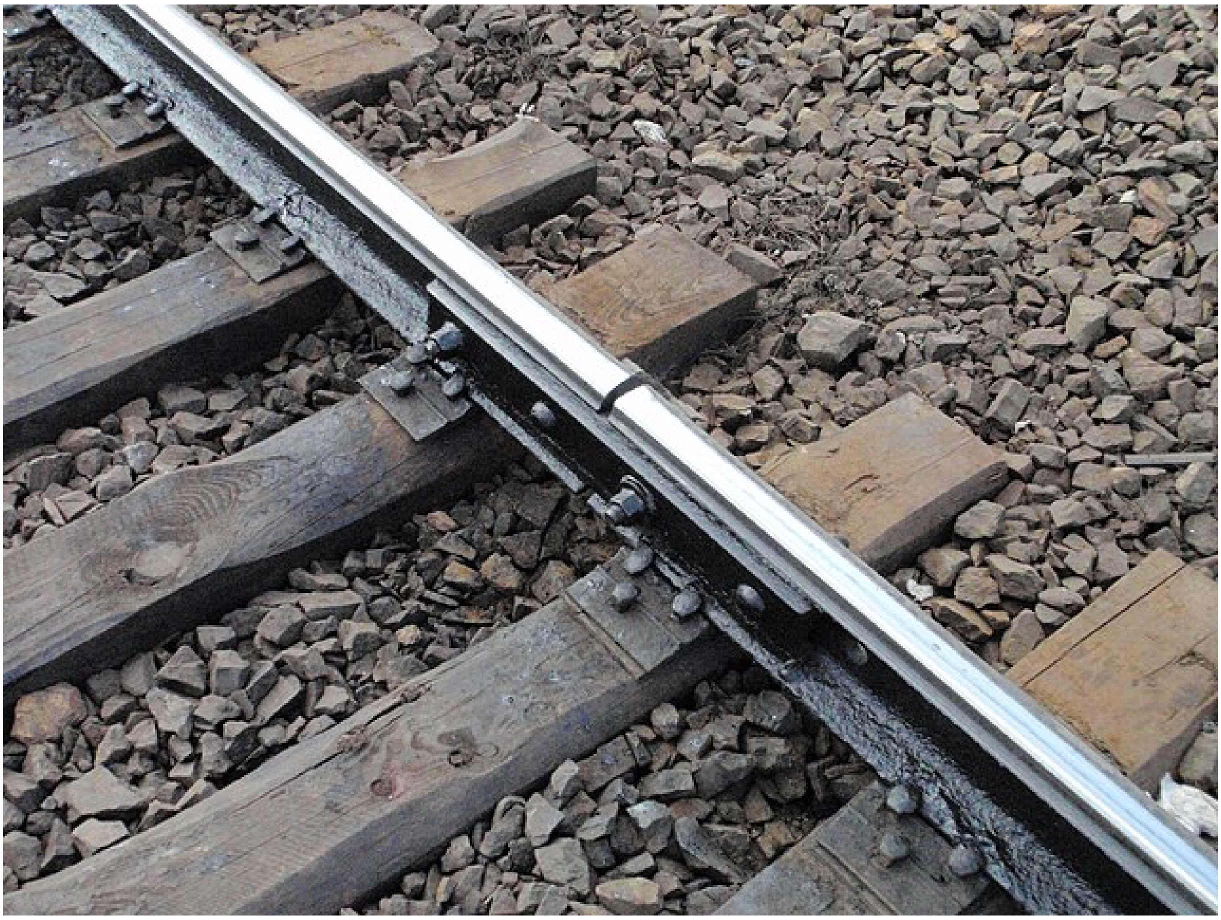


Fig. 4: Expansion joints in a railway trackHelgi, CC BY-SA 3.0, via Wikimedia Commons

Expansion of water

Till about 4°C, water normally contracts as it cools. However, between 4°C and 0°C, water actually expands. Water has a maximum density at 4°C.

This expansion can lead to a lot of problems, for example if the water is in a pipe and it freezes, it can cause the pipe to burst open.

Specific heat capacity

Internal Energy

The internal energy of an object is the energy it has because its particles are moving and interacting.

> **Note**
>
> Temperature is a measure of the average kinetic energy of the particles of an object.

When an object is heated, its temperature increases along with its internal energy. This means that there is also an increase in the average kinetic energies of all of the particles in the object.

Specific heat capacity

Specific heat capacity is the energy required per unit mass per unit temperature increase.

Basically, specific heat capacity is the **amount of energy required** to **raise the temperature** of a **unit mass/kg** of a substance by **one degree Celsius**.

To calculate the specific heat capacity of an object, we use the following formula:

$$c = \frac{\Delta E}{m \Delta \theta}$$

$$\text{specific heat capacity} = \frac{\text{change in internal energy}}{\text{mass} \times \ \text{change in temperature}}$$

The unit of specific heat capacity is $\mathrm{J/(kg^\circ C)}$ while the unit of internal energy is J.

Experiment

Finding specific heat capacities

Water

To find out the specific heat capacity of water, we can do the following:

- Weigh out 1 kg of water in a container
- Note down the current temperature of the water using a thermometer.
- Insert an electric immersion heater with a 12V supply in the water for 5 minutes
- Stir the water and note down the highest temperature you saw on your thermometer.
- Use the formula below to calculate the energy recieved by the water:

$$E = \ \text{power of heater (J/s)} \times 5 \ \text{minutes} \times 60 \ \text{seconds}$$

- Now use the formula to calculate the specific heat capacity of water:

$$c = \frac{E}{1 \ \text{kg} \times \ \text{rise in temperature}}$$

Note that in this experiment we are assuming that no energy is “lost” and all energy is transferred to the water. However, this is not the case in real life.

Solid

It's the same as the experiment for water described above, but in this case, the solid has two holes drilled in it, one for the heater and one for the thermometer.

Melting, boiling and evaporation

As you read earlier, when a substance goes from a solid to a liquid, it is known as melting and when a substance goes from a liquid to a solid, it is known as freezing.

Pure substances have a definite temperature called a melting point (also known as freezing point). This is the temperature at which the substance solidifies or melts at.

At standard atmospheric pressure, the melting point of water is 0°C.

Similarily to melting, pure substances also have a boiling point. The boiling point of water at standard atmospheric pressure is 100°C.

At these points (melting and boiling points), energy is still being supplied to these substances, but there is no change in temperature. This energy is instead used as latent heat to weaken intermolecular forces (latent heat is no longer in syllabus).

Condensation

In condensation, a gas changes into a liquid.
It happens when gas particles lose energy, slow down, and come closer together due to cooling and form intermolecular bonds that hold them together in a liquid state.

Solidification

Solidification is when a liquid changes into a solid.
Liquid particles lose energy, slow down, and arrange themselves into a closely packed, ordered structure with strong intermolecular forces, resulting in a solid state.

Evaporation

Evaporation is the process where high energetic particles near the surface of a liquid gain enough energy to break intermolecular bonds and escape into the surrounding space as gas, leaving behind the less energetic particles in the liquid state.

This causes the rest of the particles in the liquid to cool down because there is a decrease in the overall average kinetic energy in the particles left.

A real life example of this is sweat, when sweat evaporates, it cools your skin down.
This happens because energy from your skin is transferred to the sweat on your skin, which causes the sweat to evaporate, leaving your skin cooler (less average kinetic energy in particles).

There are 3 major factors which affect evaporation:

- Temperature
- Surface area
- Air movement over a surface

Temperature

A higher temperature means that the rate of evaporation is faster as more particles are moving fast enough to escape from the surface.

Surface area

The larger the surface area of a liquid, the higher the rate of evaporation as there will be more particles near the surface of the liquid.

Air movement

Winds blowing over the surface of the liquid can help the particles on the surface of the liquid escape, therefore increasing the rate of evaporation.

Important

Difference between evaporation and boiling

Both boiling and evaporation can be used to change a liquid into a gas.

Boiling	Evaporation
Boiling happens when a pure substance reaches a specific temperature called the boiling point	Evaporation is when the liquid turns into a gas below the boiling point
Particles throughout the liquid escape and turn into a gas	Particles from the surface of the liquid escape when they gain enough energy

2.3 Transfer of thermal energy

There are 3 ways thermal energy is transferred:

- Conduction
- Convection
- Radiation

Conduction

Conduction is the transfer of heat (thermal energy) through matter from places of higher temperature to places of lower temperature without the movement of matter itself.

Some materials are good thermal conductors (metals), while some are bad thermal conductors (a.k.a. insulators; wood, glass, plastic).

To test between conductors and insulators, we can do some experiments such as the ones below:

Experiment

Finding the better conductor

- Take metal rods of different metals (copper, aluminium, iron, brass) but of the same length and cross-sectional area.

- Apply a tiny amount of wax to each rod and stick a matchstick at the end of the rod
- Place the rods on a tripod with the other end (the one without the match) close together.
- Light a candle and place it under the point where the rods meet.
- Now observe as the rods get hot, the match will fall first in the rod which is the most conductive.
- Repeat experiment at least 3 times for accurate results

Experiment

Testing for conductors and insulators

- Take a metal rod and a wooden rod
- Now, take a piece of gummed paper and wrap it around both the rods
- Apply heat (using a candle) to the paper (not to the rod directly).
- You will see that the paper wrapped around the metal rod doesn't burn immidiately but the paper around the wood starts burning. This is because metal is a conductor of thermal energy, and it conducts the heat away from the paper. While the wood is an insulator and while it does conduct heat away, it does it very slowly.

Some solids conduct heat better than insulators but not as well as good conductors, these objects are known as semiconductors.

Conduction and the particle model

In metals, conduction occurs in 2 ways, via motion of electrons and vibration of particles.

Motion of electrons

You might know that metals have a large number of free/delocalized electrons which can move around the metal (delocalized mobile electrons).

As one part of the metal is heated, these electrons gain kinetic energy and start to move faster and further. When these electrons move, they interact with the particles in the cooler parts, heating them up as well.

This process is quicker than the one below.

Vibrating particles

This process occurs in both, metals and non-metals.

When objects heat up, their particles gain kinetic energy and vibrate faster, this causes the cooler particles to vibrate faster as well, increasing their temperature.

This process is not important in metals, but non-metals as this is the only way they can conduct thermal energy as they don't have free electrons.

This process is slow and that is why non-metals are bad conductors.

Conduction in gases and liquids compared to solids

Gases and liquids have widely spaced particles that don't transmit heat as well as the closely packed particles in solids.

Convection

Convection is the flow of thermal energy from places of higher energy to places of lower energy by the movement of the substance itself.

Convection currents are movements in liquids and gases caused by heat, with warmer areas rising and cooler areas sinking.

Basically in convection, warmer substances rise as they become less dense while cooler substances sink as they become more dense.

Convection current can be seen in water by adding potassium permanganate to water and then heating it.

Radiation

Radiation is the transfer of heat energy in the form of electromagnetic waves, without the need for a medium to carry it (it can occur in a vaccum, e.g. space).

Thermal radiation is **infrared radiation**. All objects emit radiation.

When thermal radiation falls on an object, it is partially reflected, transmitted and absorbed.

Effect of surface color on radiation

Black surfaces emit more infrared radiation as they are better at absorbing radiation. They also reflect less radiation as they absorb most of it.

Meanwhile white surfaces on the other hand, emit less radiation and reflect most of it as they are bad absorbers

	Black Surfaces	White Surfaces
Emission	Good emitters	Bad emitters
Absorption	Good absorbers	Bad absorbers
Reflection	Bad reflectors	Good reflectors

Effect of surface texture on radiation

Dull surfaces have more irregularities which allows them to emit more radiation. These irregularities also increase the surface area, causing it to absorb more radiation. They also reflect less radiation as they absorb most of it.

Meanwhilee shiny surfaces are smooth and therefore emit less light. They are also great reflectors which is why they are bad absorbers.

	Dull Surfaces	Shiny Surfaces
Emission	Good emitters	Bad emitters
Absorption	Good absorbers	Bad absorbers
Reflection	Bad reflectors	Good reflectors

Notice both the tables, black and dull surfaces are similar while white and shiny surfaces are similar.

So on a hot sunny day, you should wear white clothes to stay cool (bad absorber, good reflector) and on a cold day, wear black clothes so you stay warm (good absorber, bad reflector).

Temperature and rate of emission of radiation

As you read earlier, radiation is emitted by all objects above absolute zero. This radiation is mostly infrared radiation but can also be light and ultraviolet if the object is very hot (for example, the Sun).

For an object to be at a **constant temperature**, it needs to transfer energy away from the object at the same rate that it receives energy.

If an object is recieving more energy than it is emitting, its temperature will rise.
If an object is emitting more energy than it is recieving, then its temperature will decrease.

The greenhouse effect

Radiation from the sun is either absorbed or reflected back.
The absorbed radiation warms the surface causing it to emit thermal radiation.

The balance between incoming radiation and radiation emitted from the Earth’s surface controls the temperature of the Earth.

Greenhouse gases such as carbon dioxide and methane can cause thermal radiation to get trapped on earth, causing the Earth to heat up.

Experiment

Comparing absorbers of radiation

- Take one shiny surface and one dull black surface

- Take an electric heater and place these surfaces around the heater at the same distance from the heater.
- Now, put a bit of wax on the other side (not the one facing the heater) of both the surfaces and attach a coin to it.
- Turn on the heater and observe which coin falls first.

The coin attached on the dull black surface should fall first as it is a better absorber while the shiny surface will reflect most of the radiation.

The rate of emission of radiation is directly proportional to the surface temperature and surface area of an object.

Consequences of thermal energy transfer

Use of conductors

Good conductors are used for things like pans, radiators and are made up of metals for example aluminium, copper, iron etc. Basically when thermal energy needs to be transferred quickly

Bad conductors can be used to make handles for pans (wood or plastic). Basically used where energy needs to be transferred slowly.

Air is one of the worst conductors and one of the best insulators. Some houses have air gaps in walls (cavity walls, two layers of bricks seperated by air space) to keep warm in winters and cool in summers.

Uses of convection

Convection can be used to heat rooms.
A heater placed on the ground warms the air, which then rises up moving the cooler air down and this process repeats. Convection is also observed when heating water in a pan

Uses of radiation

Radiation can be used in an infrared thermometer to find out the temperature of an object without touching it. This device converts the radiation emitted by an object into an electric signal, which can then be used to find out the temperature.

More complex uses of thermal energy transfer

Car radiator

Radiators are installed in cars to dissipate the heat generated by the car’s engine. This process uses both conduction and radiation together to do this. It contains a fluid which circulates between the engine block (a metal block placed on the engine) and the radiator.

When the engine heats up, so does the metal block (conduction), this metal block is constantly touching a fluid and it heats up the fluid.

This fluid is then sent to the radiator which cools it down and sends it back to the block.

Wood/coal fire

Radiation and convection occur when a room is heated by a wood/coal powered fire.

Thermal energy is radiated from the fire which heats up the surrounding air.
Hot air then rises up, pushing the cool air down, and this process repeats.

Chapter 3

3.1 General Waves

Waves are the transfer of energy through oscillations in a medium or through space, characterized by properties like frequency, wavelength, and amplitude.

Waves transfer energy without transferring matter.
Simply, Waves carry energy without moving the stuff they pass through.

This means that they do not require matter to move.

Features of a wave

- Wavefront: An imaginary line connecting points of the same phase.
- Wavelength: The distance between two consecutive wavefronts.
- Frequency: The number of wavefronts passing a point per unit time.
- Crest (peak): The highest point of a wave.
- Trough: The lowest point of a wave.
- Amplitude: The maximum displacement from the equilibrium position.
- Wave Speed: The rate at which the wave travels through a medium.

These will be expanded on later in the topic.

Types of waves

There are two types of waves:

- Transverse waves
- Longitudinal waves

Transverse waves

A wave in which oscillations are at right angles to the direction of motion is called a transverse wave

In other words, the direction of vibration is perpendicular (at right angles) to the direction of wave motion.

Examples

- Ripples on water
- Electromagnetic radiation

Longitudinal waves

A wave where the oscillations are parallel to the direction of motion is called a longitudinal wave.

In other words, the direction of vibration is parallel to the direction of wave motion.

Examples

- Sound waves

Amplitude – the distance from the equilibrium position to the maximum displacement
Wavelength – the distance between a point on one wave and the same point on the next wave
Frequency – the number of waves that pass a single point per second
Speed – the distance travelled by a wave each second

Transverse waveforms have peaks and troughs
Longitudinal waveforms have compressions and rarefactions

Compressions are regions of **high pressure** in a longitudinal wave, while rarefactions are regions of **low pressure**.

Wavelength is the shortest distance between the same point on two consecutive waves (e.g. the distance between two consecutive peaks)

the wave equation:

$$v = \lambda \times f$$

Where

- v = velocity (m/s)
- λ = wavelength (m)
- f = frequency (Hz)

Reflection

- Waves reflect off smooth, plane surfaces rather than getting absorbed
  - Angle of incidence = angle of reflection
- Rough surfaces scatter the light in all directions, so they appear matte and unreflective
- Frequency, wavelength, and speed are all unchanged

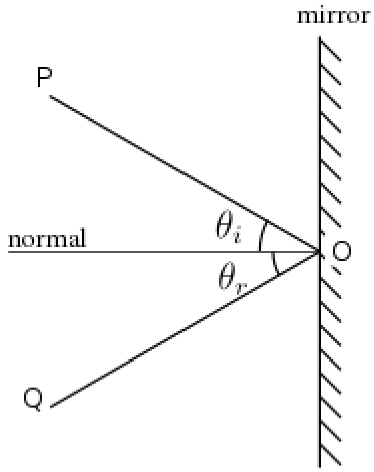


Fig. 1: Reflection DiagramNo machine-readable author provided. Arvelius assumed (based on copyright claims)., CC BY-SA 3.0, via Wikimedia Commons

Refraction

- The speed of a wave changes when it enters a new medium
- If the wave enters a more optically dense medium, its speed decreases and it bends towards the normal
- If the wave enters a less optically dense medium, its speed increases and it bends away from the normal
- In all cases, the frequency stays the same but the wavelength changes.

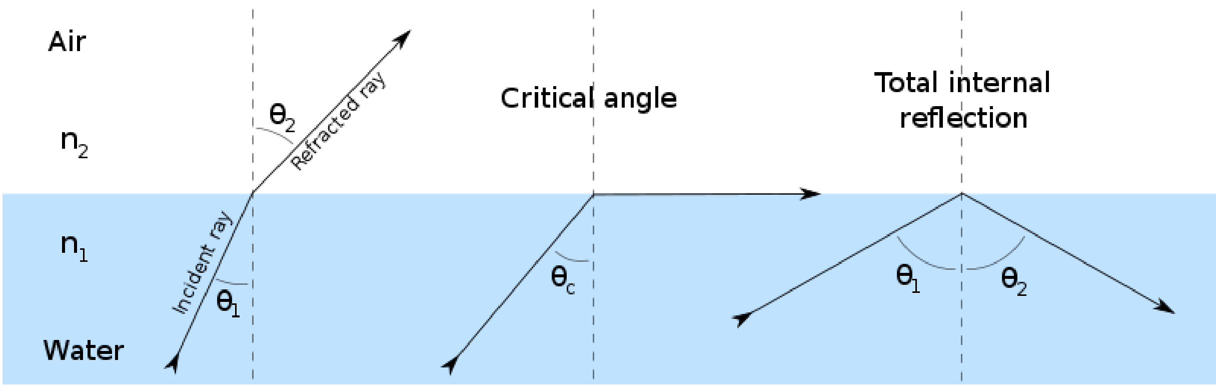


Fig. 2: Refraction diagram Josell7, CC BY-SA 3.0, via Wikimedia Commons

Diffraction

- Waves spread out when they go around the sides of an obstacle or through a gap
- The narrower the gap, the more the diffraction
- The greater the wavelength, the more the diffraction
- Frequency, wavelength, and speed are all unchanged

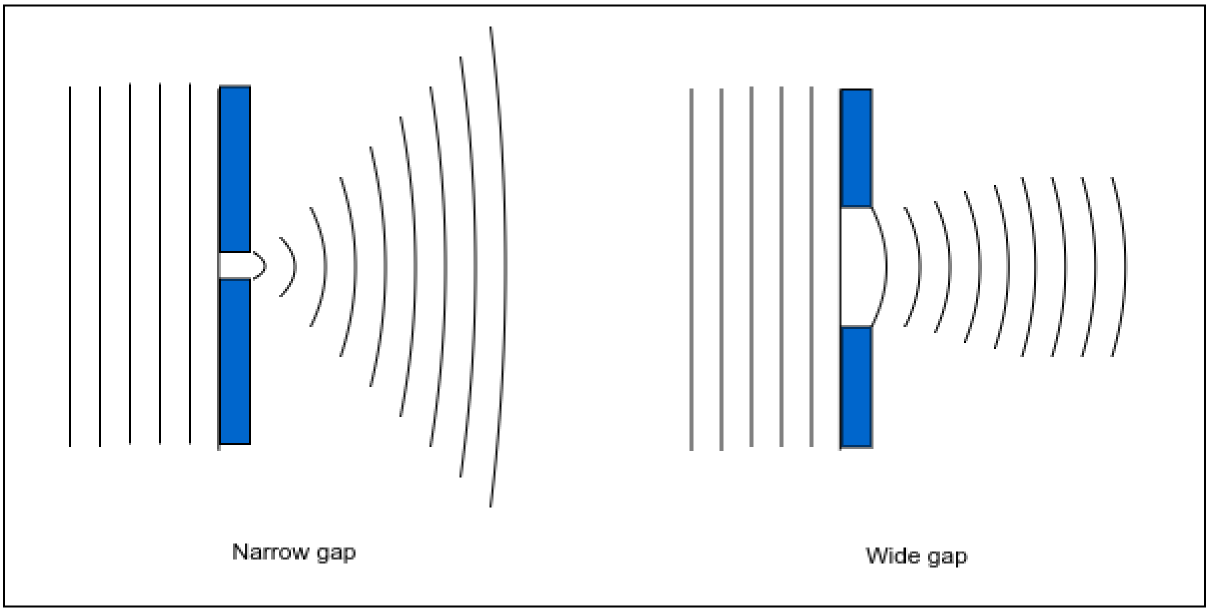


Fig. 3: Diffraction

3.2 Light

Objects which emit their own light are known as luminous sources.

Objects which don't emit their own light and reflect light from a luminous source are known as non-luminous objects.

Law of reflection: angle of incidence = angle of reflection

Periscope

A simple periscope contains 2 **plane** mirrors fixed parallel to and facing each other. Each makes an angle of 45°.

At each mirror, light is turned at 90°.

Regular and diffuse reflection

When light is reflected as a parallel beam, it is known as regular reflection.

When light is reflected irregularly, it is known as diffuse reflection

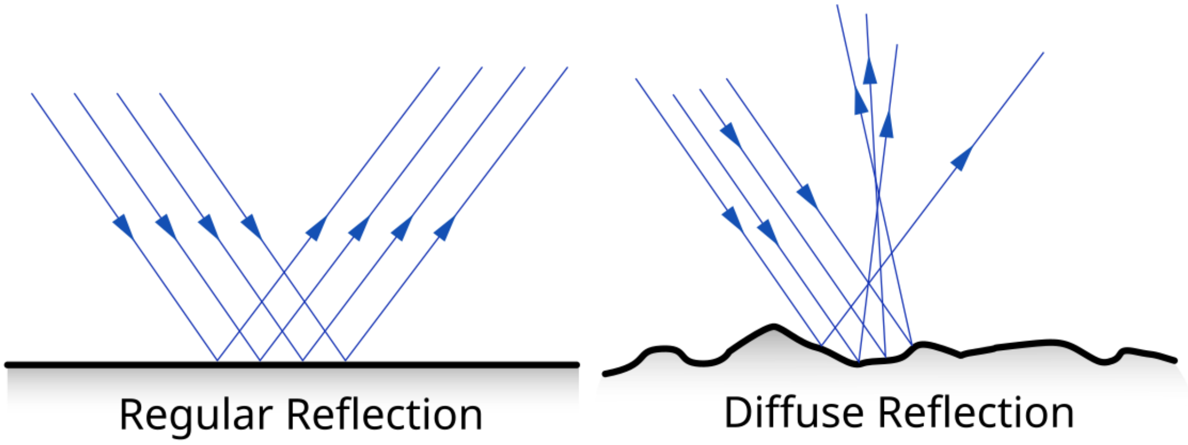


Fig. 4: Regular and diffuse reflectionMikeRun, CC BY-SA 4.0, via Wikimedia Commons

Real and Virtual Images

Real images can be formed on a screen and are inverted while **Virtual** images cannot be formed on a screen and are erect.

Plane mirrors

Images in plane mirrors are:

- virtual
- same size as object
- the same distance as the object is in front

Kaleidoscope

This uses 3 plane mirrors placed in a triangular shape at 60° each. These mirrors are attached to a card with a pinhole in the center and beads are put in front of the mirror and the mirror is closed off with a transparent substance.

Refraction of Light

The bending of light when it passes from one medium to the other is known as refraction.

angle i = angle between incident ray and normal

angle r = angle between refracted ray and normal

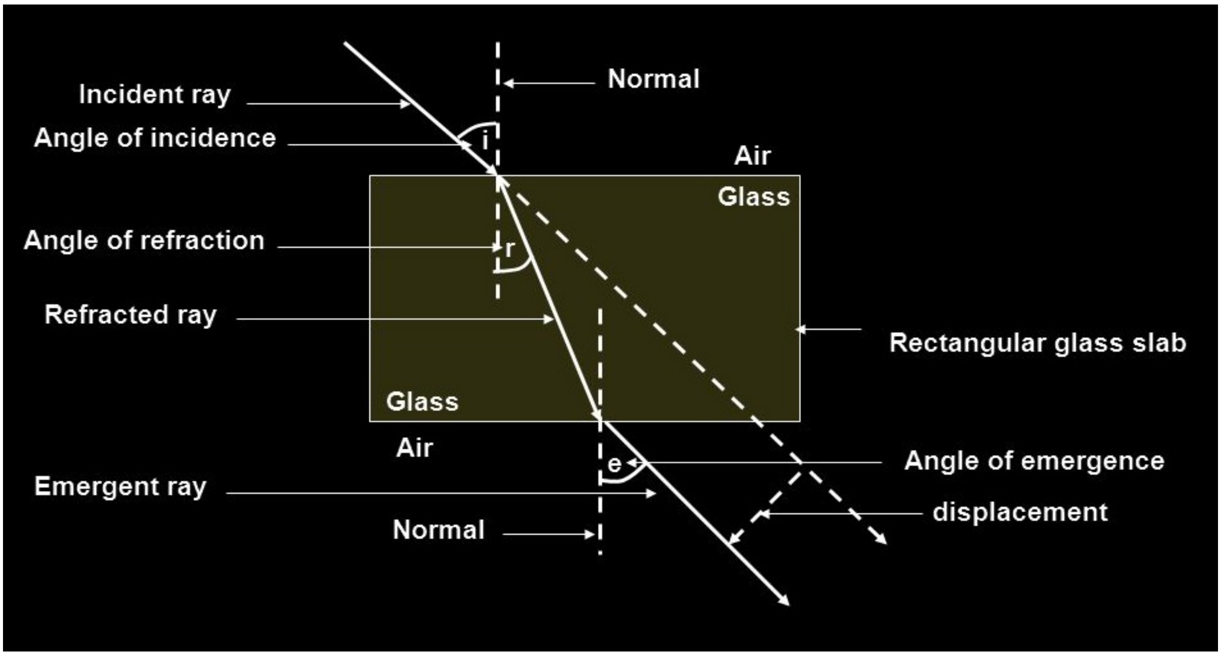


Fig. 5: Labelled refraction

Refractive Index

Light is refracted because its speed changes when it enters another medium.

refractive index = n
n = (speed of light in air or vacuum)/(speed of light in medium)

n = $\frac{sin(i)}{sin(r)}$

Critical Angle

Critical angle: The smallest angle at which light going from one material to another bends so much that it stays inside the first material instead of passing through the boundary.

n = $\frac{1}{sin(c)}$

Optical fibres

They work by trapping light by total internal reflection inside a bent glass rod and piped along a curved path.

Total internal reflection occurs when light traveling through a denser medium encounters a boundary with a less dense medium at an angle of incidence greater than the critical angle, causing all the light to be reflected back into the denser medium.

Several thousand such fibres are taped together from which a flexible light pipe is obtained.

They are becoming popular as they're being used to carry telephone and high speed broadband internet as they're faster than copper cables.

Lenses

Convex Lenses Table:

Case	Object	Image	Size	Nature
1	Between F and C	Same side of lens	Enlarged	Virtual
2	At F	At Infinity	Highly Enlarged	Real
6	At Infinity	At F	Highly Diminished	Real
3	Between F and 2F	Beyond 2F	Enlarged	Real
5	Beyond 2F	Between F and 2F	Diminished	Real
4	At 2F	At 2F	Same size	Real

2 and 6 are pairs
3 and 5 are pairs

Examples

Example 1 (Not in syllabus pretty sure, but it can be used in case you forget how to draw the lens diagram)

Question: A convex lens has a focus point of 10 cm. An object is placed at 5
cm from the lens, find the nature, position and size of the image.
F = 10 cm
U = -5 cm
Object is at 5 cm from C
Case 1 applies.

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\frac{1}{10} = \frac{1}{v} - \frac{1}{-5}$$

$$\frac{1}{10} = \frac{1}{v} + \frac{1}{5}$$

$$\frac{1}{10} - \frac{2}{10} = \frac{1}{v}$$

$$-1 = \frac{10}{v}$$

$$V = -10cm$$

Image will be formed on the same side of lens since V is negative therefore image is virtual and erect.
M = -10/-5 = 2

M = V/U
Magnification is positive therefore image is enlarged.

Example 2

Question: A convex lens has a focus point of 5 cm. An object is placed at 8 cm from the lens. Draw a ray diagram and find the nature, position, size of the image.
Answer:
Image is formed beyond 2F
Image is real
Image is enlarged

Converging = Convex
Diverging = Concave

The principal focus (focal point) is F while the focal length f (cursive small f) is focal length i.e distance CF

A short sighted person will see nearby objects clearly but distant objects blurry

while a far sighted person will see far away objects clearly but nearby objects blurry

Dispersion of Light

Dispersion is when white light is passed through a prism and is dispersed in a spectrum of colours because of different wavelengths and frequencies of different colors which form white light.

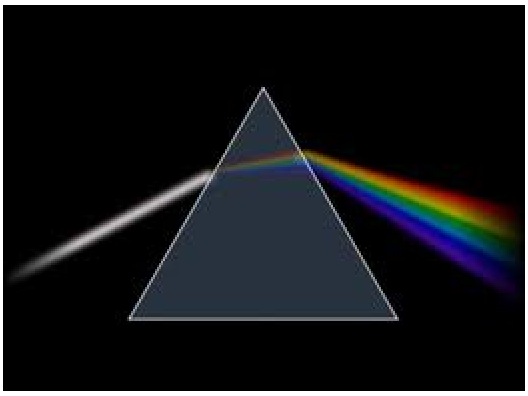


Fig. 6: Dispersion of white lightGagananashree.b1840354, CC BY-SA 4.0, via Wikimedia Commons

Note that if the prism is upside down, the order will reverse, so violet will be at the top and red will be at the bottom.

Light of one single colour and one frequency is known as monochromatic light.

3.3 Electromagnetic spectrum

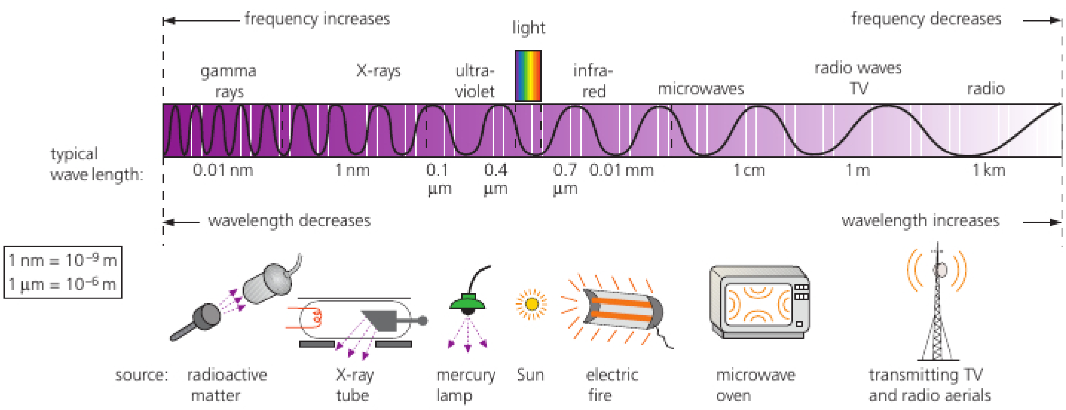


Fig. 7: Diagram showing the electromagnetic spectrum

- The speed of electromagnetic waves is 3×10^8 m/s.

Wavelength of red light = 700 nm
Wavelength of violet light = 400 nm

The higher the amplitude of a light, the higher the intensity of the source, the brighter the light is.

Uses

Radio waves: radio and TV communications; reflected by the ionosphere; long wavelength
Microwaves: satellite communication and microwave oven; pass
through the ionosphere
Infrared radiation: remote controllers and infrared cameras
Ultraviolet light: tanning beds
X-rays: medical imaging and security
Gamma radiation: medical treatment
Fibre optics use visible light.

Hazards

Ultraviolet light: increases the risk of skin cancer (use sun cream)
X-rays and Gamma rays: cause cancer
Microwaves: internal heating of body tissues
Infrared radiation: skin burns

Analogue and digital signals

There are two types of signals:

- Analogue
- Digital

In analogue signals, voltages and currents can have any value within a certain range.

While in digital signals, voltages can have only two values, either high (1) or low (0).

Digital signals are used to transmit information as they are faster and can be sent over long distances.

Sound can be transmitted as a digital or analogue signal. Sound waves (which are analogue) can be converted to signals electronically before transmission.

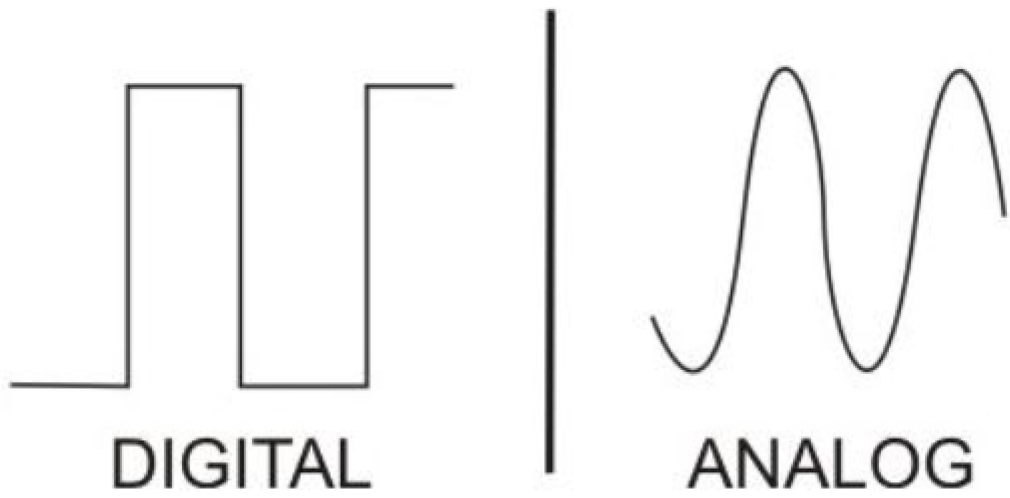


Fig. 8: Digital and analogue signals

3.4 Sound

Humans hear only sounds from about 20 Hz to 20000 Hz

Sounds beyond 20000 Hz are known as ultrasound
Sounds below 20 Hz are known as infrasound

Speed of sound in air is 330 - 350 m/s

Material	Speed/m/s
Air (0°C)	330-350
Water	1400
Concrete	5000
Steel	6000

Methods to measure the speed of sound

Direct Method

Speed of sound in air = distance travelled by sound/time taken = d/t

Chapter 4

4.1 Simple phenomena of magnetism

Magnets have 2 poles: North (N) and South (S).

Some materials which are known as ferromagnets can be magnetised to form magnets. (e.g. Iron, Nickel)

North poles repel eachother
South poles repel eachother
While North poles attract South poles (and vice versa)

Law of magnetic poles: Like poles repel, unlike poles attract.

Magnetic forces result from the interaction between magnetic fields.

Moving charged particles generate magnetic fields, creating the basis for magnetic forces.

The strength and direction of magnetic forces depend on the orientations and strengths of the interacting magnetic fields.

Induced Magnetism

Induced magnetism is when an unmagnetised magnetic material is made magnetic when it touches or is brought near a pole of a permanent magnet.

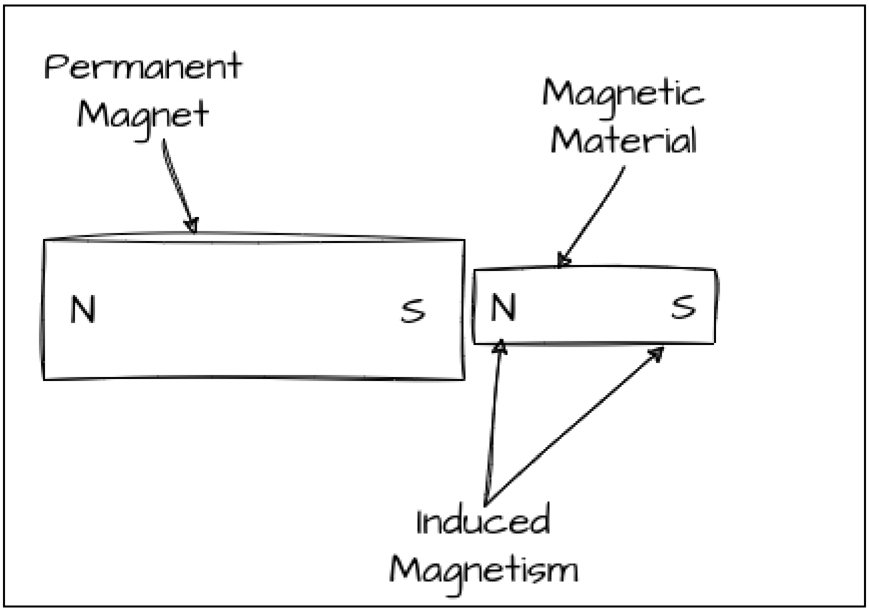


Fig. 1: Induced Magnetism

Induced magnetism can be permanent or temporary.

Temporary Magnetism

When magnetism is induced onto soft iron, it does not induce magnetism permanently and will lose magnetism when the source is removed. For example, joining a bunch of soft iron blocks together with a magnet like the figure below.

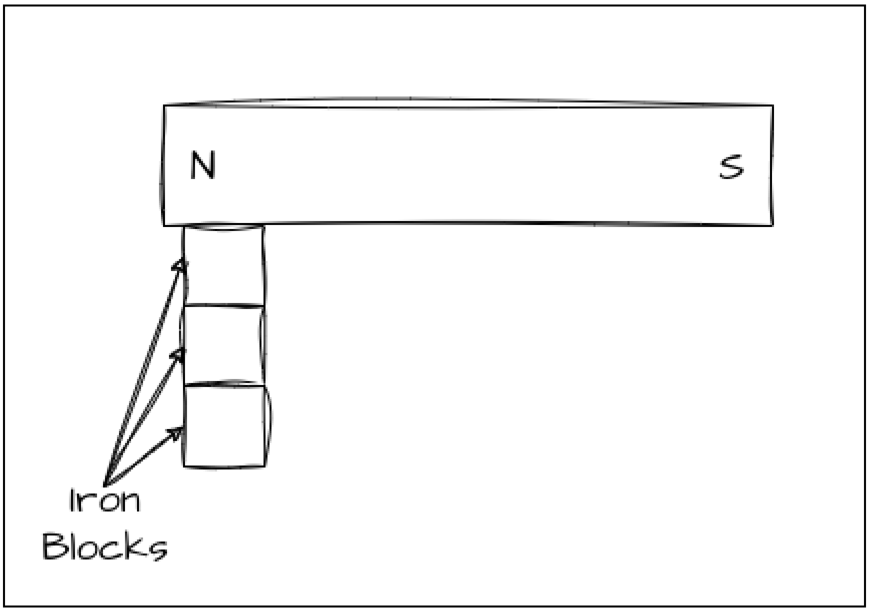


Fig. 2: Soft iron blocks joined to a magnet inducing temporary magnetism

When you will remove the source magnet, all the blocks will also lose their magnetism.
This is known as temporary magnetism.

Permanent Magnetism

If we do the same experiment we did above using steel instead of iron, the steel would retain it's magnetism.
This is known as permanent magnetism.

Remember

Magnetic materials that magnetise easily but are ready to lose their magnetism are known as soft.
While others such as steel which are harder to magnetise but do not lose their magnetism are known as hard.

Magnetic and non-magnetic materials

Magnetic materials such as iron, steel and nickel are attracted by magnets and can induce magnetism.

While non-magnetic materials such as aluminium and wood are not attracted by magnets.

Magnetic fields

A magnetic field is a region in which a magnetic pole experiences a force.

Magnetic fields always go from north pole to south pole.

Magnetic fields around a bar magnet can be seen in the diagram below.

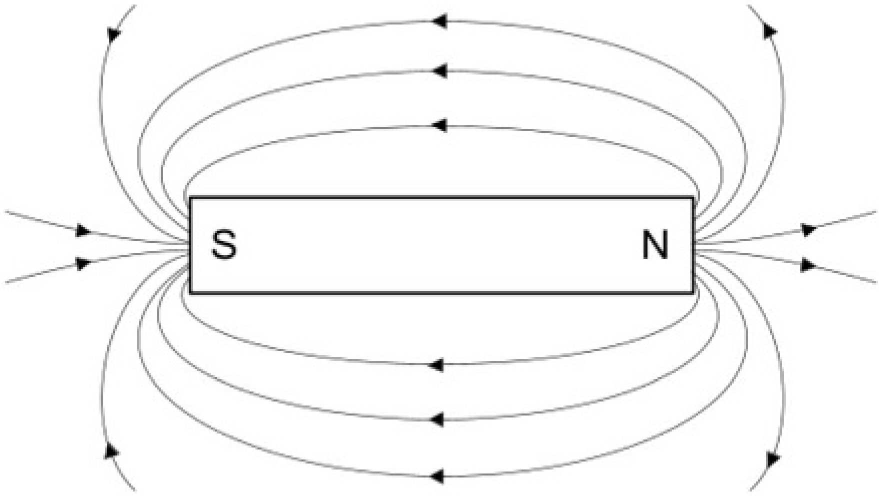


Fig. 3: Magnetic fields around a bar magnet

The spacing of magnetic field lines represents the relative strength of a magnetic field, with closer spacing indicating a stronger field and wider spacing indicating a weaker field.

Definition

The direction of a magnetic field at a point is the direction of the force on the N pole of a magnet at that point

Experiment to plot magnetic fields

There are 2 methods to do this:

- Magnetic Compass
- Iron Fillings

Magnetic compass

1. Place a bar magnet on a flat surface.
2. Take a compass and bring it near the magnet without touching it.
3. Observe the needle of the compass.
4. The needle will align itself with the magnetic field lines produced by the magnet.
5. Mark the direction of the needle with a pencil.
6. Repeat this process at different locations around the magnet.
7. Connect the marked points to obtain a series of lines representing the magnetic field. These lines are known as magnetic field lines.

A magnetic compass can also be used to determine the direction of the magnetic fields.

Iron Filings

1. Place a bar magnet on a flat surface.
2. Sprinkle iron filings evenly around the magnet.
3. Gently tap the surface to allow the iron filings to align with the magnetic field.
4. As the filings respond to the magnetic force, they will arrange themselves along the magnetic field lines.
5. While keeping the magnet in place, you can use a transparent cover or a piece of paper to gently press down on the iron filings, securing them in position.
6. Now, you can lift the magnet and observe the pattern formed by the iron filings, representing the magnetic field lines.

Electromagnets

An electromagnet is a type of magnet that is created by passing an electric current through a coil of wire. (see diagram below)

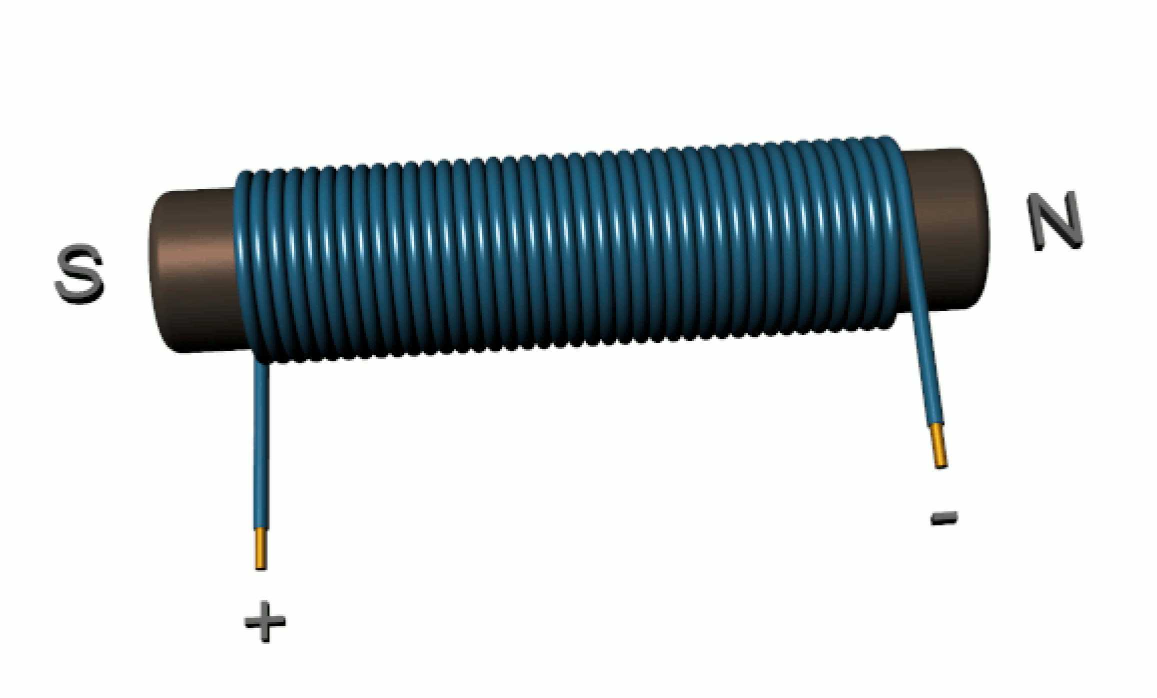


Fig. 4: Electromagnet with a soft iron core

This type of magnet only works when current is actively being passed.

The strength of an electromagnet increases if
a. the current in the coil increases

b. the number of turns on the coil increases
c. the poles are moved closer together.

Uses of permanent and electromagnets

Permanent magnets, made from materials like steel, retain their magnetism and are used in applications where a constant magnetic field is required. These include compasses, computer hard disks, electric motors, generators, microphones, loudspeakers, and everyday devices like credit cards. They do not require a current to maintain their magnetism.

Electromagnets, on the other hand, are temporary magnets that allow for variable magnetic fields by controlling the electric current. They are used in cranes, electric bells, magnetic locks, relays, and practical motors and generators, providing the ability to switch the magnetic field on and off and vary its strength.

4.2 Electrical Quantities

There are two types of charges: positive (+) and negative (-).

Positive charges repel eachother
Negative charges repel eachother
While positive charges attract negative charges (and vice versa)

As you may know, protons have a positive charge while electrons have a negative charge.

Charges can be produced by rubbing because friction causes electrons to be transferred from one material to the other.

A simple example is rubbing a balloon against your hair and it'll stick to the wall. In this example, your hair has negatively charged electrons and when you rub the balloon against your hair, friction causes these electrons to move over to the balloon.

Remember

Protons (positive charges) are never transferred from one object to another. Therefore, only electrons are transferred.

Experiment to check if a substance is a conductor or insulator

A simple and short experiment is to make a simple circuit, with a bulb, a 1.5V d.c. battery/cell, a pair of alligator clips and obviously the materials to test.

Now clip both of the alligator clips to the material on opposite sides, if the bulb lights up, it is a

Now clip both of the alligator clips to the material on opposite sides, if the bulb lights up, it is a conductor, else it's an insulator.

The brightness of the bulb indicates how good/bad of a conductor the substance is.

Insulators and Conductors

Conductors have a pool of delocalized free electrons which can move around to transfer charges. These electrons can move around different atoms.

Insulators do not have any free electrons to transfer charges therefore they cannot conduct electricity.

Examples of conductors: Copper, gold, etc.
Examples of insulators: Rubber, plastic, etc.

Remember

Charge is measured in Coulombs (Unit: C). The charge on an electron is $1.6 * 10^{-19}$ C.

An electric field is a region in which an electric charge experiences a force.

Definition

The direction of an electric field at a point is the direction of the force on a positive charge at that point.

Patterns of electric fields

(i) Around a point charge
An electric field around a point charge is radial and points in all directions, with strength decreasing with distance (also, it is a vector quantity).

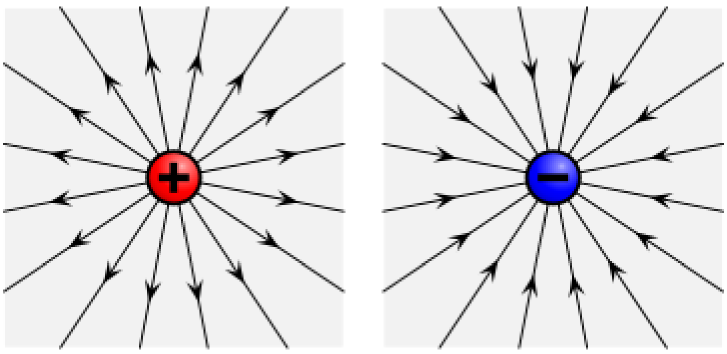


Fig. 5: Pattern of electric fields around a point chargeMikeRun, CC BY-SA 4.0, via Wikimedia Commons

(ii) Around a charged conducting sphere

The electric field around a charged conducting sphere is uniform and radially symmetric. The strength of the electric field decreases as the distance from the sphere increases.

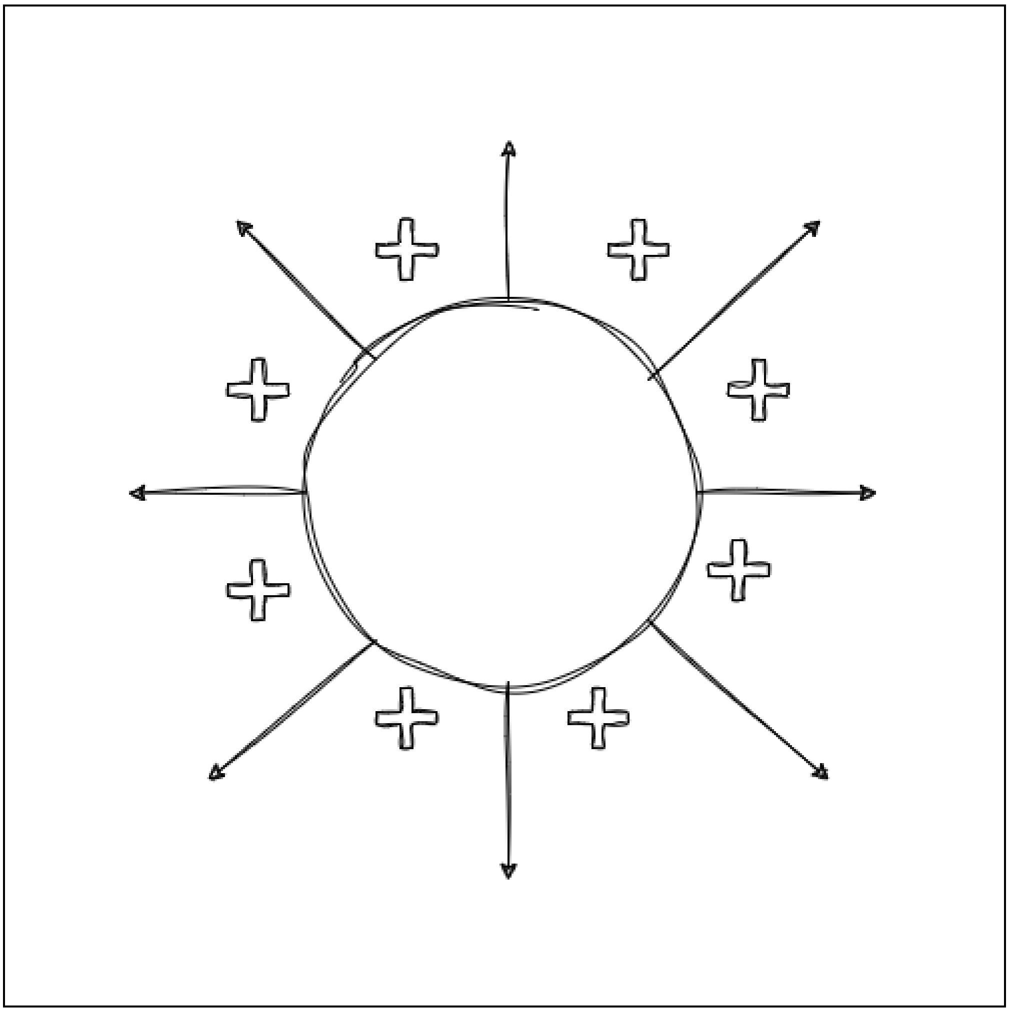


Fig. 6: Electric fields around a charged conducting sphere

(iii) Between two oppositely charged parallel conducting plates

Oppositely charged parallel conducting plates create an electric field between them, which exerts a force on charged particles. The strength and direction of the electric field depend on the distance between the plates and the magnitude of the charges.

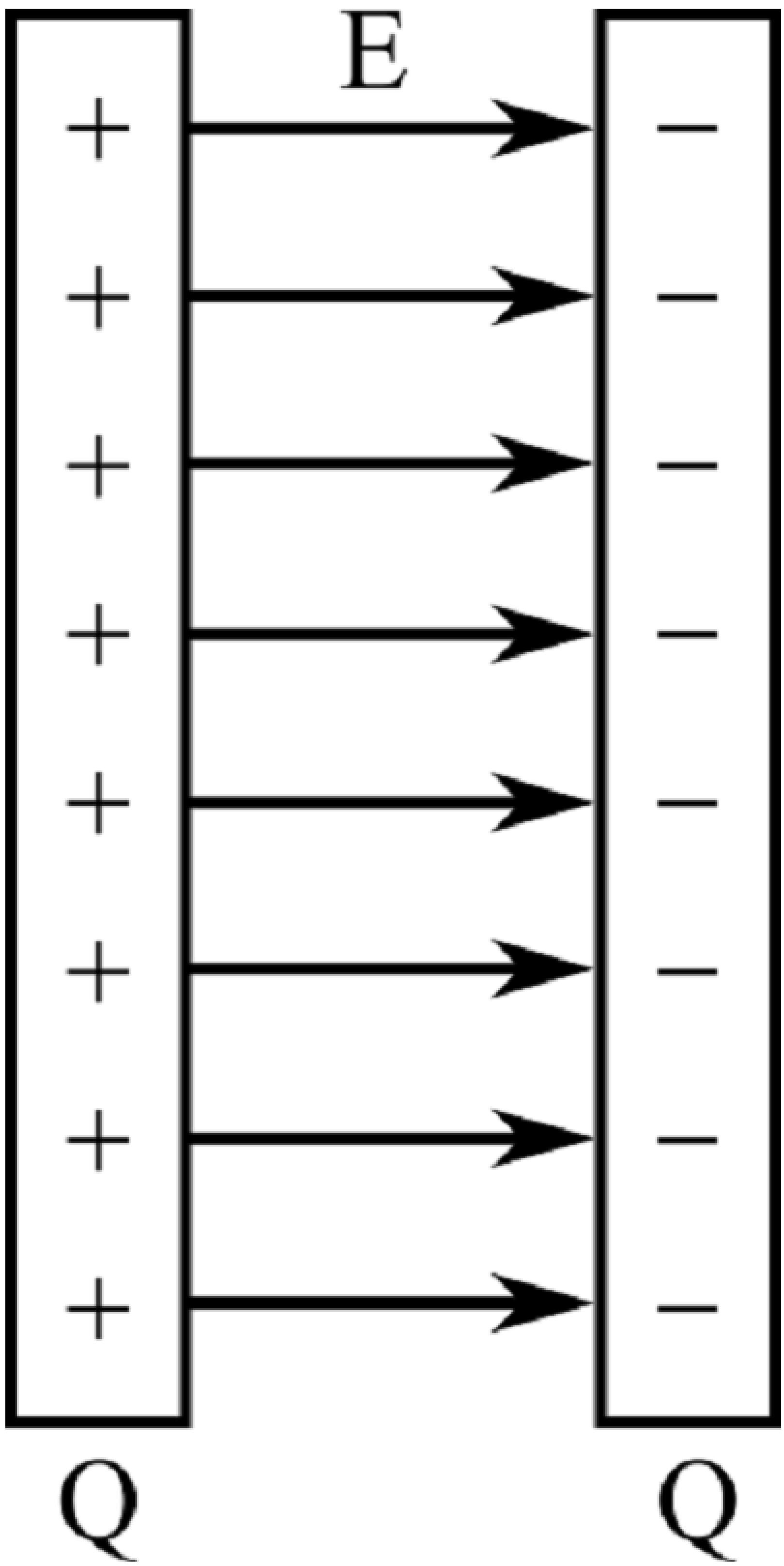


Fig. 7: Electric fields between two oppositely charged parallel conducting plates

4.2.2 Electric current

Current is related to the flow of charge. The unit of current is Ampere (also known as Amps and also just A).

Remember

1 Amp = 1 Coulomb per second

1 A = 1 C/s

Current is basically the rate at which charge flows at.

Current can be calculated using the following formula:

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

Where I = Current (A or C/s), Q = Charge (Coulombs) and t = time (seconds).

To measure current in a circuit, we use something called an ammeter, this device is used in **series** with the component(s). There are two types of ammeters: analogue and digital.

A suitable range (senstivity) must be chosen when measuring current using an ammeter, for example if you know the current is low, use a range from 10 mA (milli amps) to 100 mA. If you know the current is going to be high, use a higher range like 1 A to 10 A.

Direct and alternating current

Direct current

In direct current, electrons flow in one direction only.

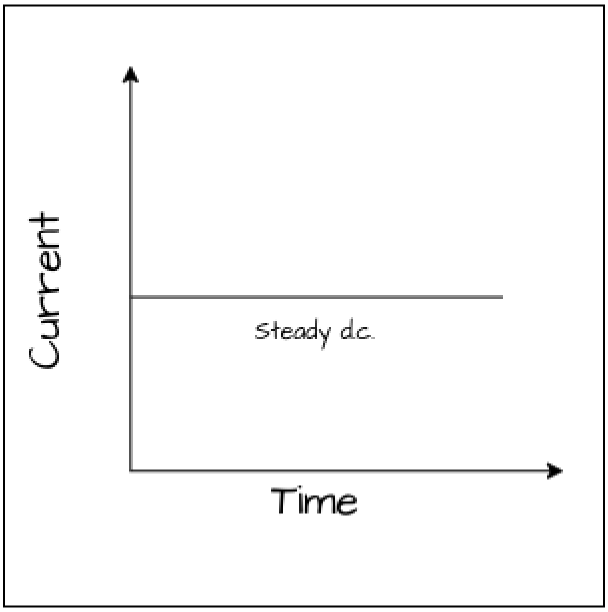


Fig. 8: Steady d.c. graph

Alternating current

The direction of the flow of current reverses regularly.
a.c. also has a frequency. The number of cycles in one second is the frequency of the current.

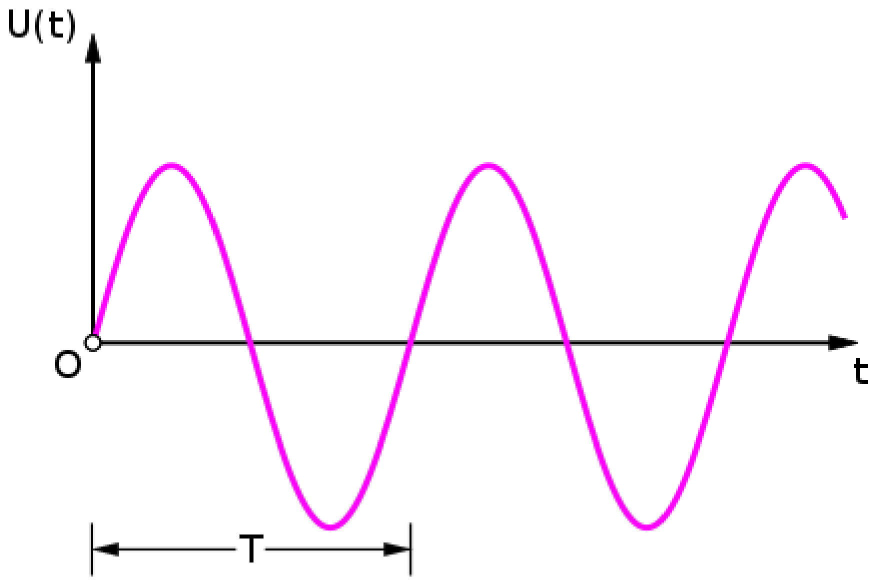


Fig. 9: a.c. graph MikeRun, CC BY-SA 4.0, via Wikimedia Commons

The symbol for a.c.:

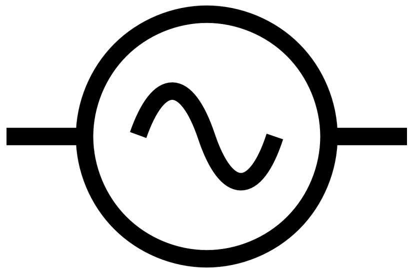


Fig. 10: a.c. symbol

In circuits, the flow of current is from positive to negative. However, the flow of electrons is from negative to positive.

Easy way to remember this

Electrons are negative, and as we know negative charges repel other negative charges therefore electrons are repelled by the negative terminal towards the positive terminal.

4.2.3 Electromotive force and potiential difference

Electromotive force

Electromotive force (e.m.f) is the work done (in Joules) by a source (a cell) in moving a unit charge (Coulomb) around a **complete circuit**.

The unit of e.m.f is volts (denoted by V).
1 Volt = 1 Joules per Coulomb
1 V = 1 J/C

Basically, the work done to move 1 coulomb around a **circuit** is known as e.m.f.

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

Where E = e.m.f (Volts), W = work done (Joules) and Q = Charge (Coulombs)

Potential Difference

Potential difference (p.d.) is really similar to e.m.f., they both have the same unit and almost are the same thing, except for one difference.

P.d. is the work done (in Joules) by a source (a cell) in moving a unit charge (Coulomb) through a **component**.

Basically, the work done to move 1 coulomb through a **component** is known as p.d.

Voltmeters are similar to ammeters, but measure p.d. instead of current and are always connected in parallel to the component(s) you're measuring the p.d. across.

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

Where V = p.d. (Volts), W = work done (Joules) and Q = Charge (Coulombs)

4.2.4 Resistance

Resistance is the opposition posed by a device to the flow of current.
It's unit is ohms (Ω)

$$V = I \times R$$

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

Where V = p.d., I = Current and R = Resistance

Experiment to determine resistance using a voltmeter and an ammeter

1: Make a circuit similar to the one below

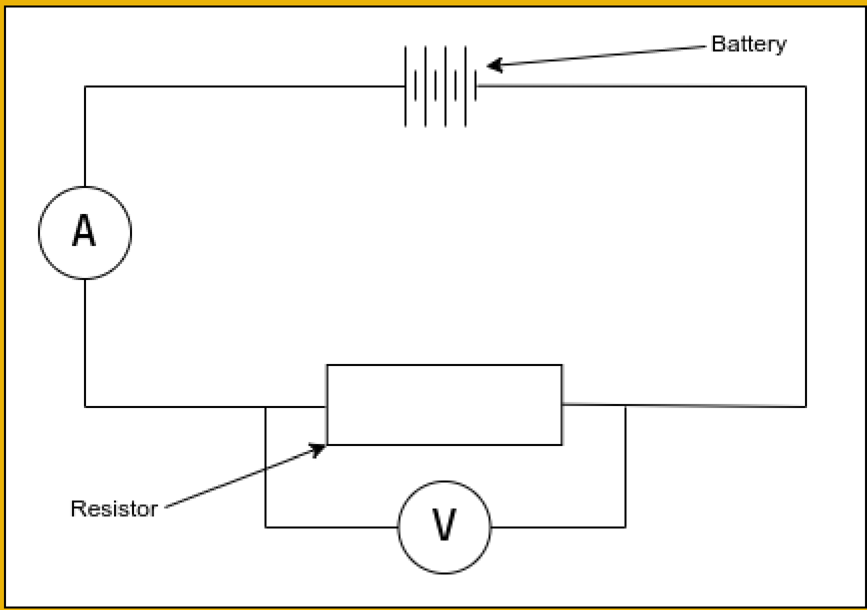


Fig. 11: Circuit with resistor, battery, voltmeter and ammeter

2: Measure the voltage and the current on V and A respectively.

3: Use the equation $R = \frac{V}{I}$ to calculate the resistance of the resistor.

Remember

Resistance of a metallic wire is directly propotional to the length of the wire while it is **inversely** propotional to the cross-sectional area of the wire.

In simple terms:
The more the length, the more the resistance.
The more the cross-sectional area, the less the resistance.

Resistivity

Resistance R of a wire is:
a. directly proportional to it's length
b. inversely proportional to the cross sectional area of the wire.

We use the formula

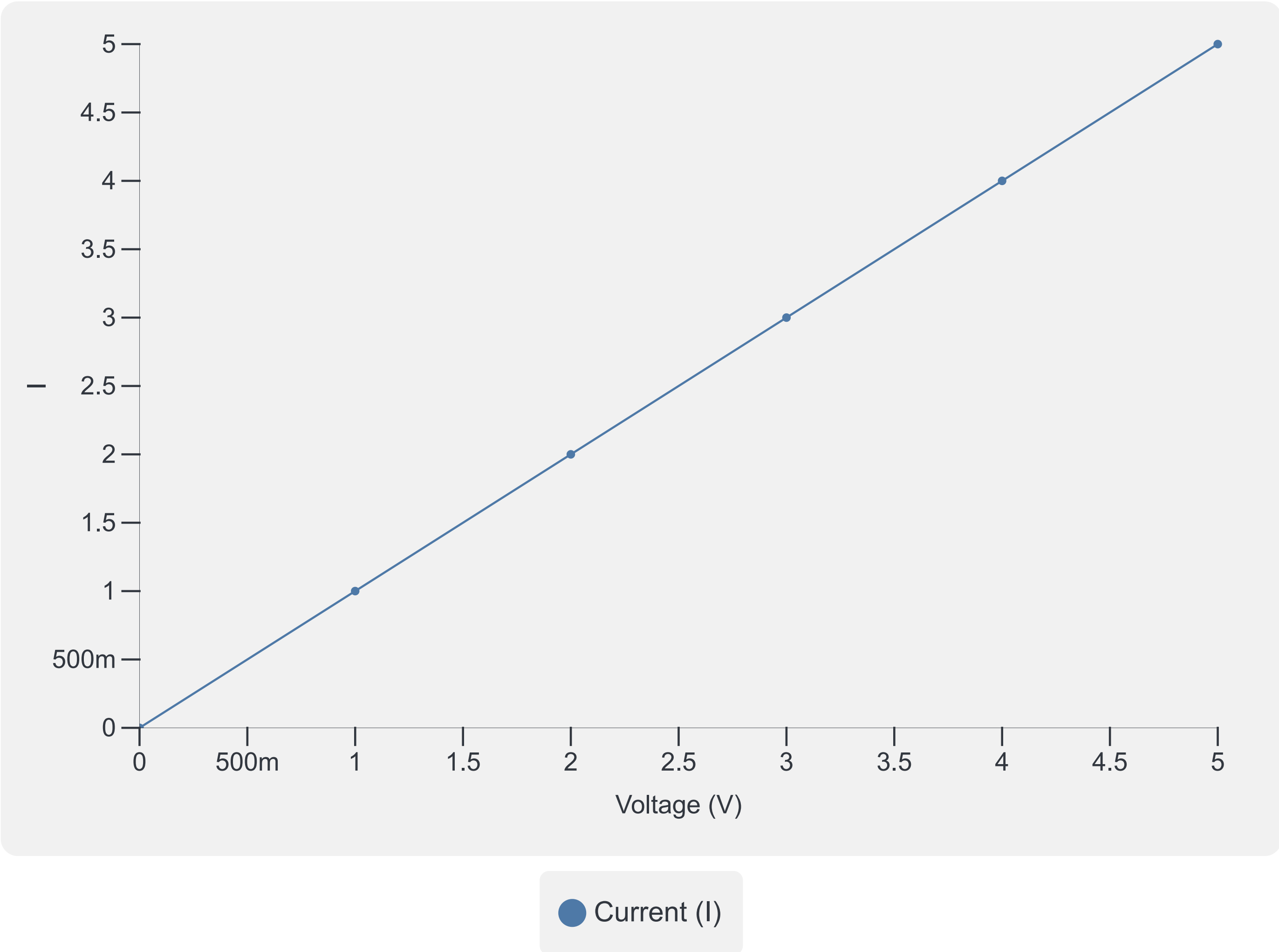
$$R = \frac{\rho \times L}{A}$$

Where R = Resistance
ρ (rho) = Resistivity (constant)

L = Length
A = Cross sectional area

Current voltage graphs: Ohm's Law

Resistor (constant resistance)



A resistor with constant resistance and metallic conductors follow the Ohm's Law so they have straight line I-V graphs.

Ohm's law: The current in a metallic conductor is directly proportional to the p.d. across its ends if the temperature and other conditions are constant.

Filament lamp

The I-V graph for a filament lamp, such as a bulb represents an "S" shape.

At low voltages, the current is relatively small because the filament has high resistance when it is cold.

As the voltage increases, the lamp heats up, reducing its resistance, and the current rises more steeply.

However, at higher voltages, the lamp's resistance decreases less, resulting in a gentler slope of the graph.

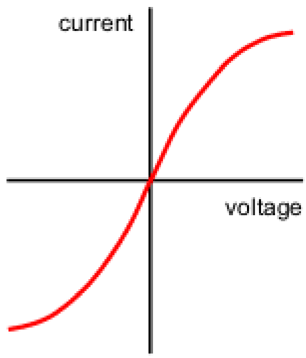


Fig. 12: I-V graph of filament lamp

Diode

A diode's typical I-V graph shows that it allows current to pass in one direction but almost blocks it in the opposite direction. It has low resistance when connected forward, allowing current flow, but high resistance when reversed. This characteristic makes it a non-ohmic conductor, conducting in one direction only.

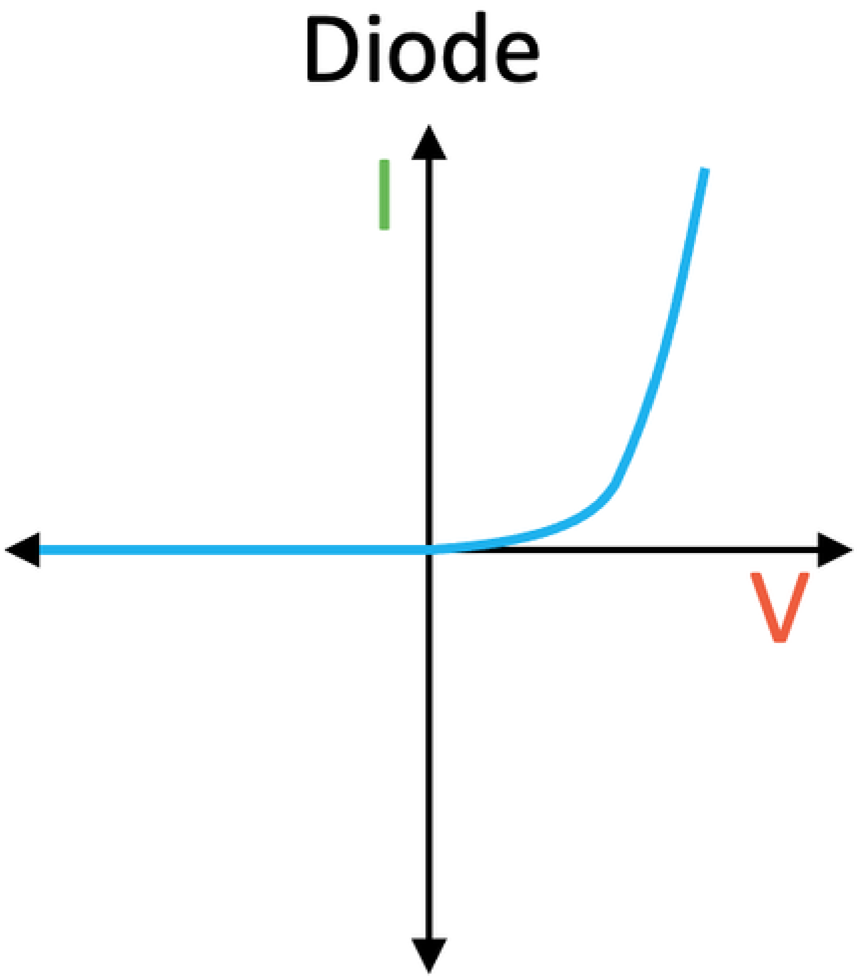


Fig. 13: I-V Graph of Diode

4.2.5 Electrical energy and electrical power

Electric circuits transfer energy from a power source (e.g., battery) to circuit components and eventually dissipate it into the surroundings. The source provides electrical energy, which powers the components. The components utilize or convert this energy into various forms (e.g., heat, light) before it is released into the surroundings.

Power

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

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

Where W = Work done in Joules
P = Power
and t = time taken in seconds

The unit of Power is Watts (W), also known as Joules per second (J/s)

Another formula for power is:

$$\text{Power} = \ \text{Voltage} \times \ \text{Current}$$

$$P = V \times I$$

To calculate energy used, we use the following formula

$$\text{Energy} = \ \text{Power} \times \ \text{Time} = \ \text{Voltage} \times \ \text{Current} \times \ \text{Time}$$

$$E = P \times t = V \times I \times t$$

Paying for electricity

Kilowatt-hour (kWh) is the electrical energy used by a 1 kW appliance in 1 hour.
1 kWh = 1000 W $\times$ 60m $\times$ 60s
which is equal to 3.6 $\times$ 10^6 joules.

To calculate kWh, we divide the energy used in joules by 3.6 $\times$ 10^6.

If we have the power of the appliance, we can just convert it to kW (1 kW = 1000 W) and then multiply the number of hours

Sample question 1

An electric heater uses 3000 W for 3 hours, how much electricity is used and how much will it cost if one kWh = 30 cents?

3000 W = 3 kW
3 kW $\times$ 3 hours = 9 kWh

9 kWh $\times$ 30 cents = 270 cents = $2.7

Sample question 2

A lamp uses 100 W for 15 minutes, how much electricity is used and how much will it cost if one kWh = 25 cents?

First convert minutes to seconds so t = 60 $\times$ 15 = 900 seconds

Energy = 100 W $\times$ 900 seconds
Energy = 90000 Joules

Now divide this energy by 1 kWh in joules which is 3.6 $\times$ 10^6 joules,

$$\frac{90000}{3.6 \times 10^6}$$

Which is equal to 0.025 kWh

Cost = 0.025 $\times$ 25 cents = 0.625 cents = $0.00625

4.3 Electric circuits

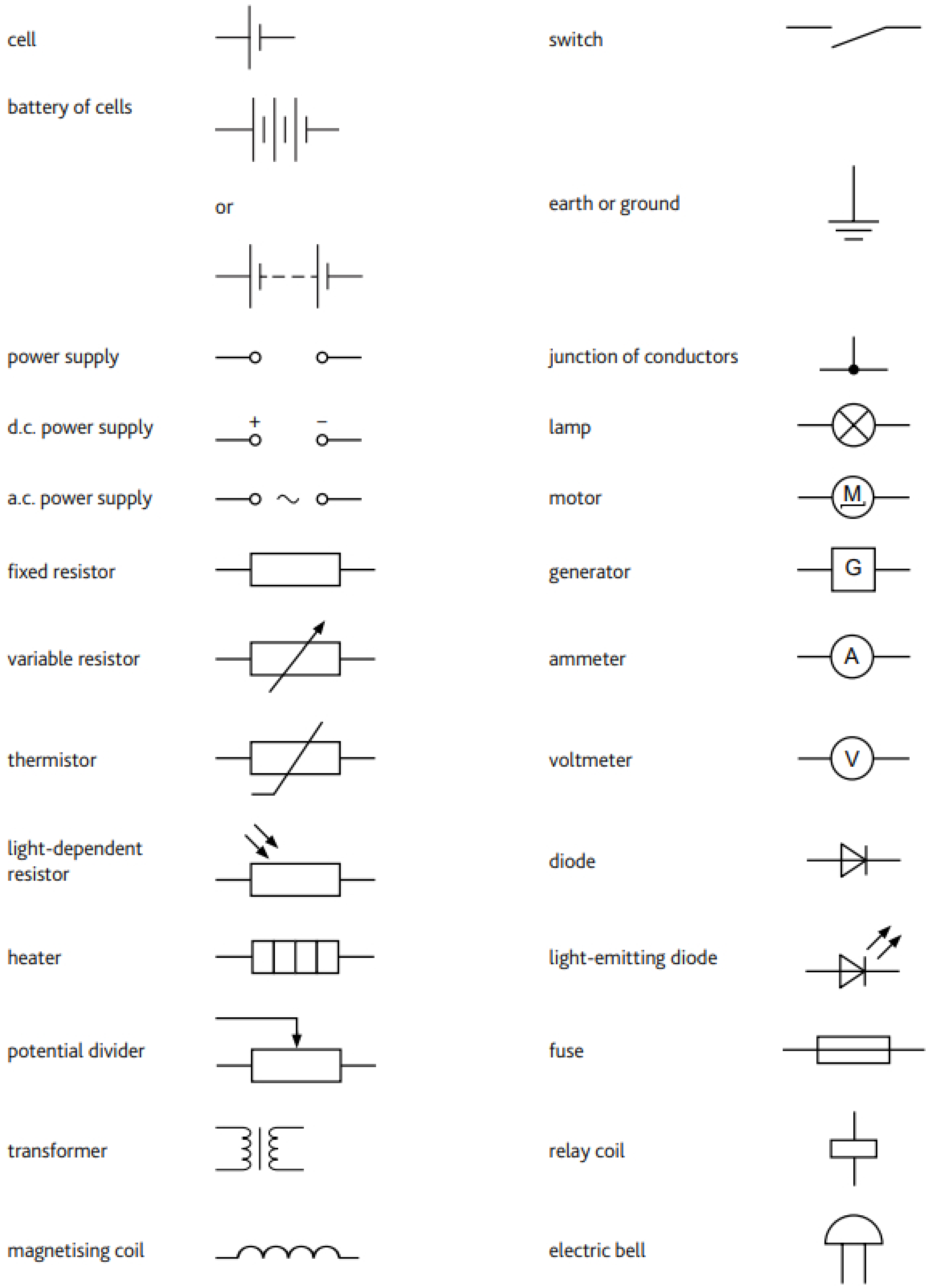


Fig. 14: Circuit symbols

Use of all components in 1-2 lines (extra)

- Cells: Provide a source of direct current (DC) by chemical reaction.
- Batteries: Consist of multiple cells connected together to provide a higher voltage.
- Power Supplies: Electrical devices that convert input voltage into a regulated output voltage for powering electronic systems.

> - Generators: Convert mechanical energy into electrical energy through electromagnetic induction.
> - Potential Dividers: Divide a voltage into smaller fractions using resistors, allowing for voltage control and signal attenuation.
> - Switches: Control the flow of current in a circuit, either by opening or closing the circuit path.
> - Resistors (Fixed and Variable): Fixed resistors provide a constant resistance, while variable resistors (potentiometers or rheostats) allow for adjustable resistance.
> - Heaters: Convert electrical energy into heat energy, often used in applications such as heating elements.
> - Thermistors (NTC): Temperature-sensitive resistors that decrease in resistance as temperature increases.
> - Light-Dependent Resistors (LDRs): Resistors whose resistance decreases with increasing light intensity.
> - Lamps: Convert electrical energy into light energy, commonly used for illumination.
> - Motors: Electrical devices that convert electrical energy into mechanical energy, producing rotational motion.
> - Ammeters: Measure the flow of electric current in a circuit, connected in series.
> - Voltmeters: Measure the voltage across a component or circuit, connected in parallel.
> - Magnetising Coils: Coils of wire that generate a magnetic field when an electric current passes through them.
> - Transformers: Devices that transfer electrical energy between two or more coils through electromagnetic induction, used for voltage transformation.
> - Fuses: Safety devices that interrupt the flow of current in a circuit when an excessive current is detected, protecting against overloads.
> - Relays: Electromechanical switches controlled by an electric current, often used for switching high-power circuits with low-power control signals.

4.3.2 Series and Parallel circuits

There are 2 types of circuits:

Series circuits

In series circuit, the current remains the same and voltage differs across each component

for example, in this circuit:

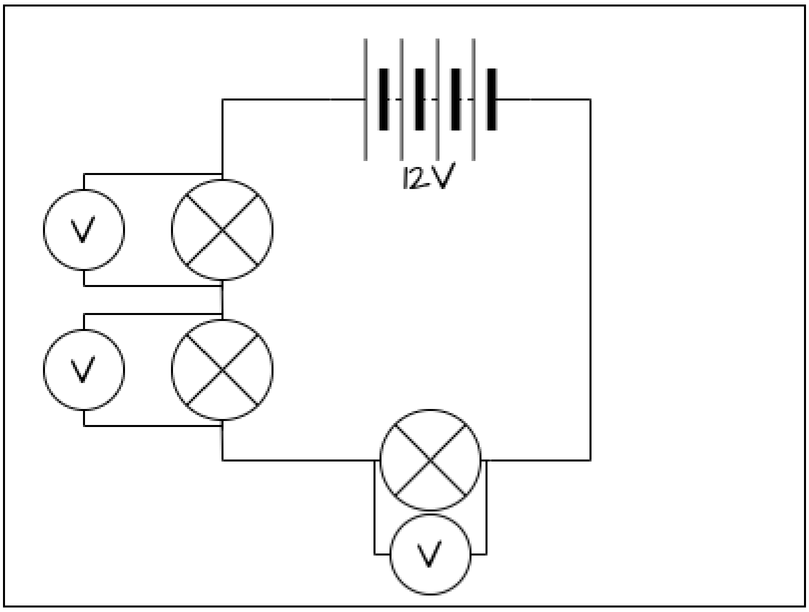


Fig. 15: Series Circuit

The sum of potential difference across all components should be equal to 12V
the total p.d. across the components in a series circuit is equal to the sum of the individual p.d.s across each component.

Parallel circuits

Meanwhile in a parallel circuit voltage (P.d.) stays the same and current is divided between components.

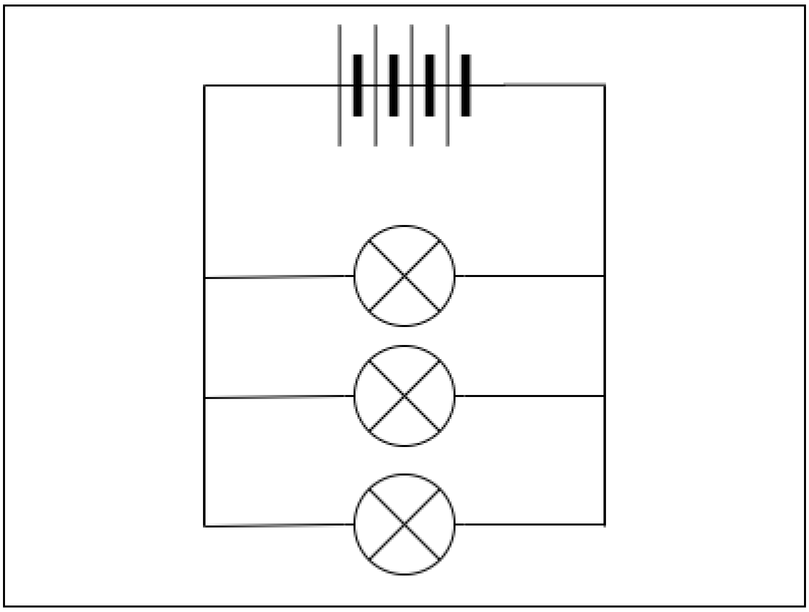


Fig. 16: Parallel circuit

Constructing Series and Parallel circuits

In a series circuit, we connect all the components on same path, while in parallel, all components have a different path.

Calculating p.d and current in circuits

To calculate p.d., and current in both series and parallel circuits, we use the resistance along with the formula $V = I \times R$

Before we calculate p.d. and current, we need to know how to calculate total resistance in both types of circuits.

For series circuits, we simply add the resistance of each component.

But in parallel circuits, we use the following formula

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

In the case there are only two resistances in parallel, we can also use this simpler formula:

$$\frac{R_1 \times R_2}{R_1 + R_2}$$

Remember

In parallel circuits, the current from the source (for e.g., battery) is greater than the current in each branch. Also, effective resistance of two resistors is less than that of either one alone

Usually, we prefer connecting components such as light bulbs in parallel instead of series.
That is because of one very simple reason which is that if one light bulb fails, the others will work.
But if one light bulb fails in series, all stop working.
Additionally, all bulbs will get the same amount of voltage in a parallel circuit and current will be divided.

Junctions

This is one topic which seems to be neglected for some reason (obviously because they're the middle child) but is actually really simple.
A junction is something which divides the current and then joins it back, see the diagram below.

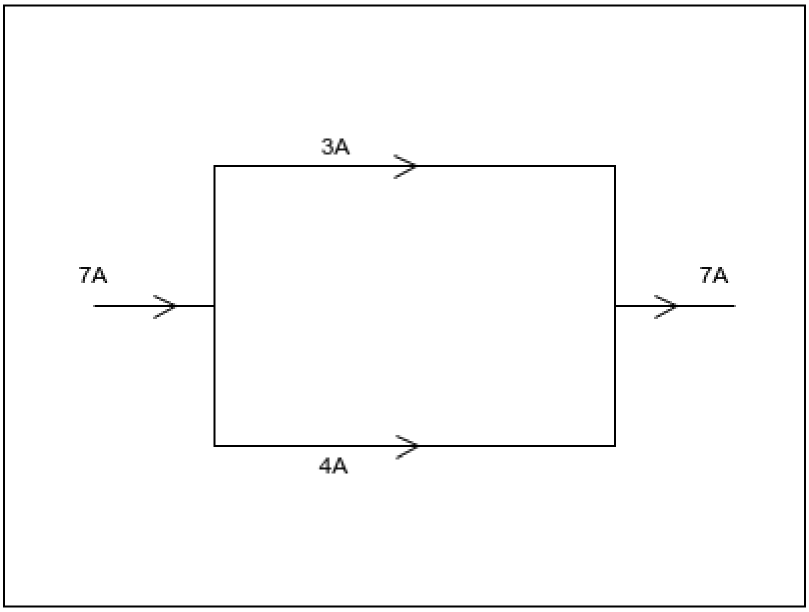


Fig. 17: Junction

Basically current splits when entering a junction and then joins back when leaving the junction.

Total current going inside junction must be equal to the current leaving the junction.

4.3.3 Action and use of circuit components

Remember

As the resistance of an electrical conductor increases, the voltage across it also increases for a constant current. R is directly proportional to V when I (current) is constant.

A variable potential divider adjusts the output voltage by changing the position of an adjustable resistor or potentiometer within the circuit.

Basically a resistor whose resistance you can change (a.k.a. a variable resistor).

Equation for a potential divider:

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

The equation for a potential divider states that the ratio of the resistances is equal to the ratio of the voltages across them.

LDR (Light Dependent Resistor):

- Use: LDRs are used to detect and measure light levels in various applications like automatic lighting systems and light meters.
- How it works: LDRs have a resistance that decreases as the intensity of light falling on them increases. This property allows them to sense and respond to changes in light levels by adjusting

the electrical current passing through them.

Thermistor (NTC):

- Use: NTC thermistors are employed for temperature measurement, control, and compensation in devices like thermostats and temperature sensors.
- How it works: NTC thermistors contain semiconducting metallic oxides that exhibit a significant decrease in resistance as temperature rises. This characteristic enables them to generate electrical signals corresponding to temperature variations, allowing for accurate temperature monitoring and control.

Relays:

- Use: Relays are electrically operated switches that control high-power circuits with low-power control signals. They are essential components in automation systems and industrial control applications.
- How it works: Relays consist of an electromagnetic coil that, when energized, creates a magnetic field, causing the relay's contacts to open or close. This mechanism allows them to control the flow of current in circuits, enabling the switching of high-power loads with the help of low-power control signals.

LED (Light-Emitting Diode):

- Use: LEDs are used for illumination, indicators, and displays in a wide range of electronic devices and lighting applications.
- How it works: LEDs are semiconductor diodes that emit light when forward biased. When a forward voltage is applied, electrons and holes recombine within the LED's semiconductor material, releasing energy in the form of light. The emitted light's color depends on the specific semiconductor materials used in the LED.

Semiconductor Diode (Forward Bias, Reverse Bias, and Rectifier):

- Use: Semiconductor diodes are used for rectification, signal detection, and switching in electronic circuits.
- How it works:
  - Forward Bias: Applying a positive voltage to the anode and negative voltage to the cathode of a diode allows current flow through the diode, making it conductive.
  - Reverse Bias: Applying a positive voltage to the cathode and negative voltage to the anode of a diode blocks current flow, acting as an insulator.
  - Rectifier: Diodes are commonly used as rectifiers to convert alternating current (AC) to direct current (DC). When connected in the forward bias configuration, diodes allow current flow during positive half-cycles of the AC signal while blocking it during negative half-cycles. This process rectifies the AC signal, resulting in a pulsating DC waveform. Additional filtering components can be used to smooth the pulsations and obtain a steady DC output.

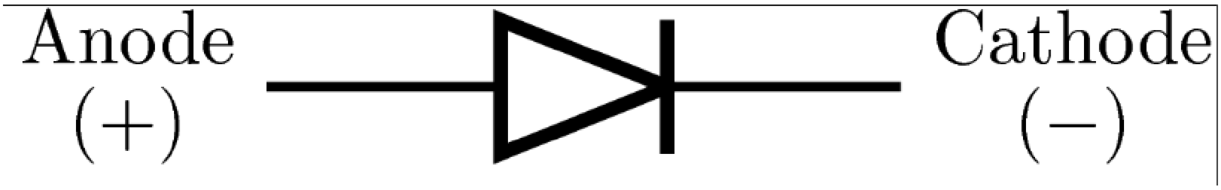


Fig. 18: Cathode and Anode of a diode

4.4 Electrical Safety

Hazards of electricity when using mains supply

Hazard	Description
Damaged Insulation	Damaged insulation in wires or cables can result in exposed live conductors. This increases the risk of electric shock and short circuits, posing a potential threat of fires and damage to equipment or property.
Overheating Cables	Overheating cables occur when the current exceeds their capacity or due to poor connections. This hazard raises the risk of fire and damage to the cables and surrounding materials, including the potential melting or burning of cables, equipment damage, and the risk of injury.
Damp Conditions	Damp conditions, characterized by the presence of moisture or water near electrical equipment, outlets, or wiring, elevate the risk of electric shock and short circuits. This can lead to electric shocks, equipment damage, fires, and potential harm to individuals.
Excess Current from Overloading	Overloading happens when the current drawn by electrical devices surpasses the capacity of plugs, extension leads, or sockets. This hazard increases the likelihood of overheating, fire, and damage to electrical devices. Overloaded plugs, extension leads, or sockets can overheat, melt, or cause fires, potentially leading to equipment damage and injury.

Mains circuit

A mains supply refers to the electricity which comes from the utility company to your house or an industry.

A mains circuit uses alternating current (a.c.).

A mains circuit consists of three wires: the live, netural and earth.
Wire colors are different through out the world.
In India, the live wire is red, neutral is black and earth is green.

Current flows from the live wire to the neutral wire.
The earth wire is used for safety purposes and is connected to the earth or ground.

The purpose of the earth wire is to direct any current from a fault or electrical leakage to the ground/earth.

The outer casing of an electrical appliance must either be non-conductive or connected to the ground for safety.

Non-conductive Casing: Some appliances have a casing that does not let electricity pass through (for example plastic).

Grounded Casing: Other appliances are connected to the ground using a wire. This ensures that any electricity that leaks out of the appliance goes safely into the ground.

These safety measures prevent electric shocks and protect people from harm.

It is important to connect the switch to the live wire (and not the neutral) because the live wire carries the current, therefore when the switch is off, the flow of current is interrupted.

Trip switches and fuses

Trip Switches

Use and Operation: Trip switches, also called RCDs, detect imbalances in current. If they sense a fault, they quickly cut off the power to the circuit.

Importance: Trip switches protect against electric shocks by stopping the current when there's a problem.

Setting: Trip switches have different sensitivity levels. Common settings are 30mA and 100mA, depending on the required safety level.

Fig. 19: A trip switchABB ltd, CC BY-SA 3.0, via Wikimedia Commons

Fuses

Use and Operation: Fuses have a metal wire that melts if the current is too high. When it melts, it breaks the circuit and stops the flow of electricity.

Importance: Fuses protect against too much current, short circuits, and equipment damage. They help prevent fires.

Fuse Ratings: Choosing the right fuse rating is important. It should be equal to or slightly higher than the maximum expected current, while still following safety guidelines.

Fig. 20: FusesMedvedev, CC BY-SA 3.0, via Wikimedia Commons

A fuse without an earth wire protects the circuit and wiring of a double-insulated appliance by stopping too much electrical current from flowing, which prevents damage.

4.5 Electromagnetic effects

4.5.1 Electromagnetic induction

Electromagnetic induction is when you create electricity in a wire by moving a magnet nearby.

When a wire moves near a magnet or experiences a changing magnetic field, it can produce a special kind of electricity called electromotive force (e.m.f.). This happens because of electromagnetic induction.

The special kind of electricity it produces (induces) is known as induced e.m.f.

The induced e.m.f. always works against the change that caused it.

Example

A very simple example of this induced e.m.f. would be a hand-crank flashlight (a flashlight where you need to rotate a handle with your hand).

In these flashlights, when you rotate the handle, the handle moves a magnet near a coil of wire, this causes a change in magnetic field. This induces e.m.f. (electromotive force) into the coil, generating electricity to power the flashlight.

Fleming's right-hand rule

Fleming's right-hand rule is a simple trick with your right hand to figure out the **direction of force** on a wire carrying current when it's in a magnetic field.

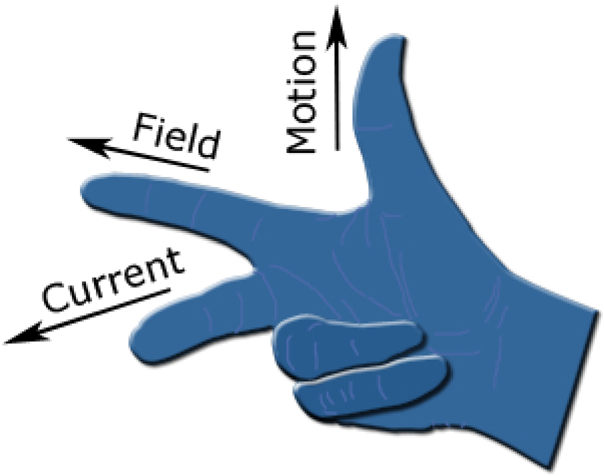


Fig. 21: Fleming's right hand ruleDouglas Morrison DougM, CC BY-SA 3.0, via Wikimedia Commons

- Force (Motion): The force on a wire is in a direction perpendicular (at right angles) to both the magnetic field and the induced current.
- Magnetic Field: The magnetic field around a wire points along the direction you wrap your fingers around the wire with your thumb pointing in the direction of the current.
- Induced Current: When a wire moves across a magnetic field, the induced current direction is determined using the right-hand rule, where your thumb shows the motion direction, and your fingers indicate the direction of the induced current.

Factors affecting the magnitude of an induced e.m.f.

Speed

Moving the magnet or coil faster creates a stronger induced electric force because the changes in the magnetic field are quicker.

Coil Turns

More loops in the coil make the induced electric force stronger as more magnetic field lines pass through it.

Magnet Strength

A stronger magnet produces a bigger induced electric force when a conductor moves through its magnetic field, resulting in a stronger electrical effect.

Important

The size of an induced e.m.f. is directly proportional to the rate at which the conductor cuts magnetic field lines.

4.5.2 The A.C. Generator

A simple form of an a.c. generator has a coil of wire that spins around inside a fixed magnet. When the coil rotates, it creates electricity that changes direction periodically, producing alternating current (a.c.).

To transfer this electricity from the spinning coil to an external circuit, we use slip rings and brushes.

Slip rings are like metal rings connected to the coil (they rotate with the coil), and brushes are small pieces of conductive material that touch the slip rings.

When the coil spins, the brushes maintain contact with the slip rings, allowing the generated electricity to flow through the brushes and into the external circuit.

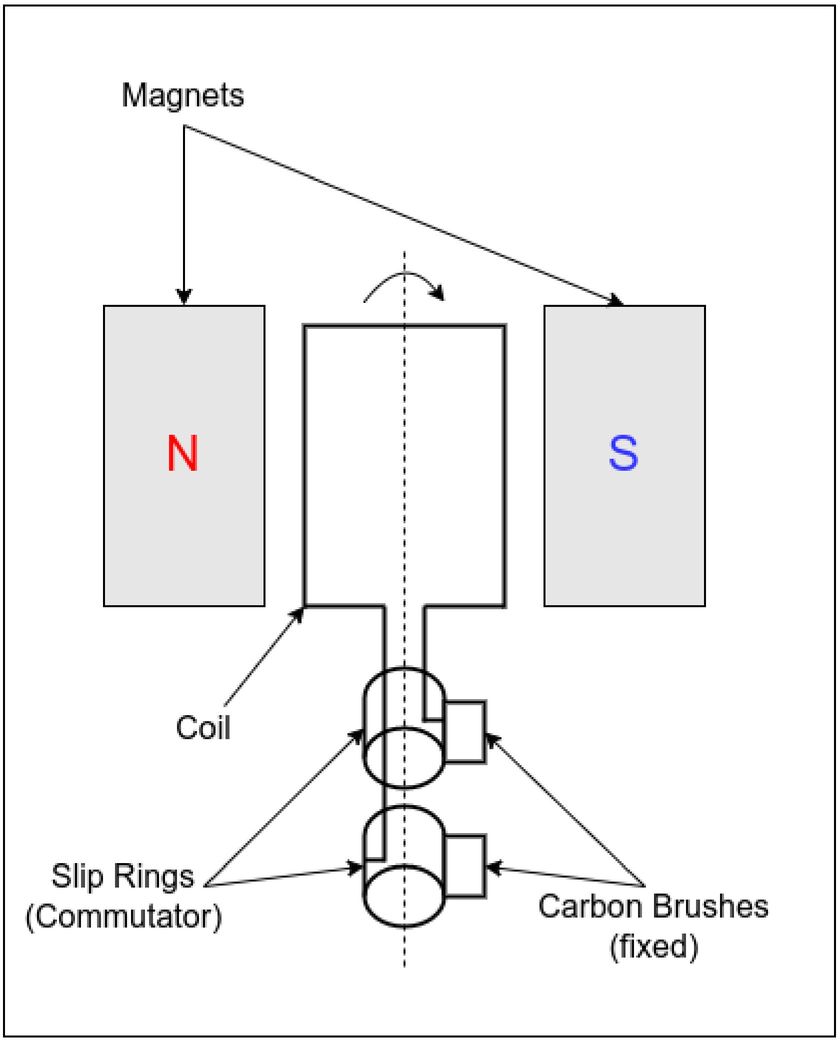


Fig. 22: A.C. Generator diagram

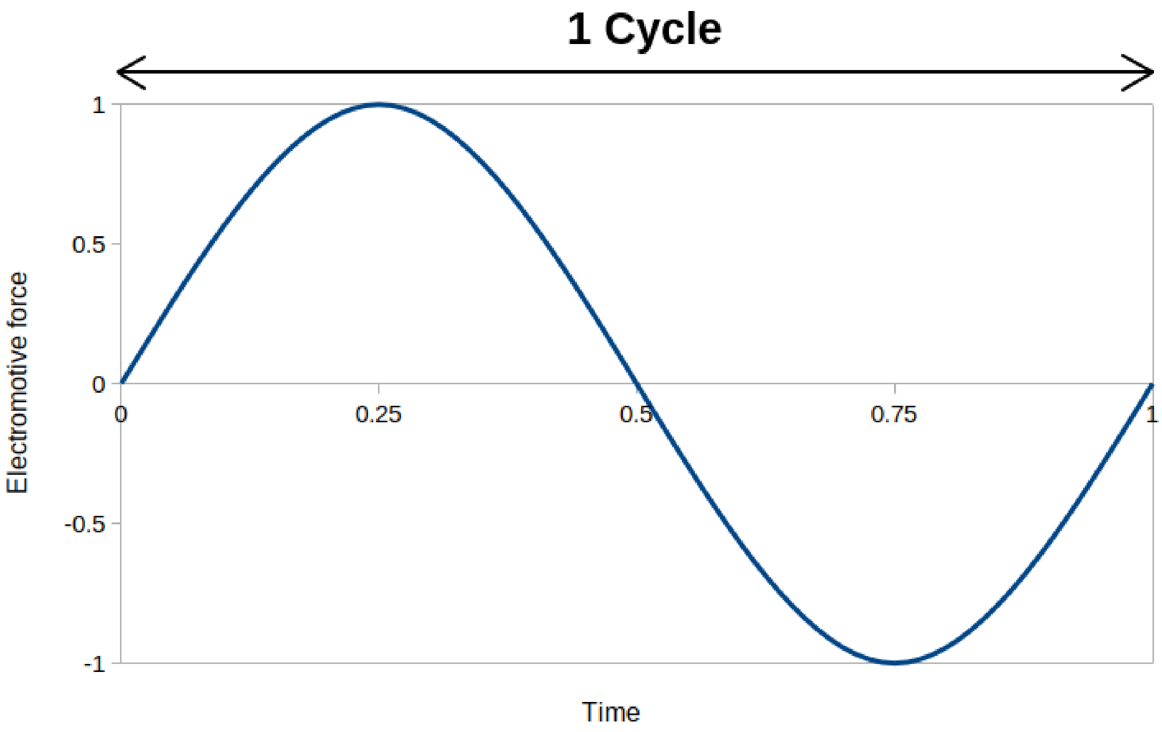


Fig. 23: Graph of a.c. generator

At the starting point (t = 0), the graph shows zero e.m.f. At this point, the coil is vertical

As the generator coil spins, the graph rises to its highest point (peak) when the coil is turned halfway (t = 0.25). The coil is horizontal at this point

Then goes back down to zero again when the coil completes half a spin (t = 0.5), the coil is vertical again

The graph then goes down to the negative peak (trough) when the coil is turned three-quarters (t = 0.75). The coil is horizontal again in this position.

Finally, as the coil completes one complete spin (t = 1), the e.m.f. goes back to 0. The coil is vertical again.

The fleming's right-hand rule mentioned earlier is used for this.

Generators are used in real life to generate electricity.

In thermal power stations, the coil is rotated by steam with extremely high pressure, this steam is obtained by heating water using coal/oil/nuclear reactor

When the coil is horizontal, the e.m.f. is at its peak.
When the coil is vertical, the e.m.f. is zero.

4.5.3 Magnetic effect of a current

Right-hand grip rule

The Right-hand grip rule helps find the direction of magnetic field lines around a current-carrying conductor.

To use the Right-hand grip rule, point your right thumb in the direction of the current flow, and the curl of your fingers (make a fist) will show the direction of the magnetic field lines around the conductor.

In the diagram below,
I = current
B = direction of field

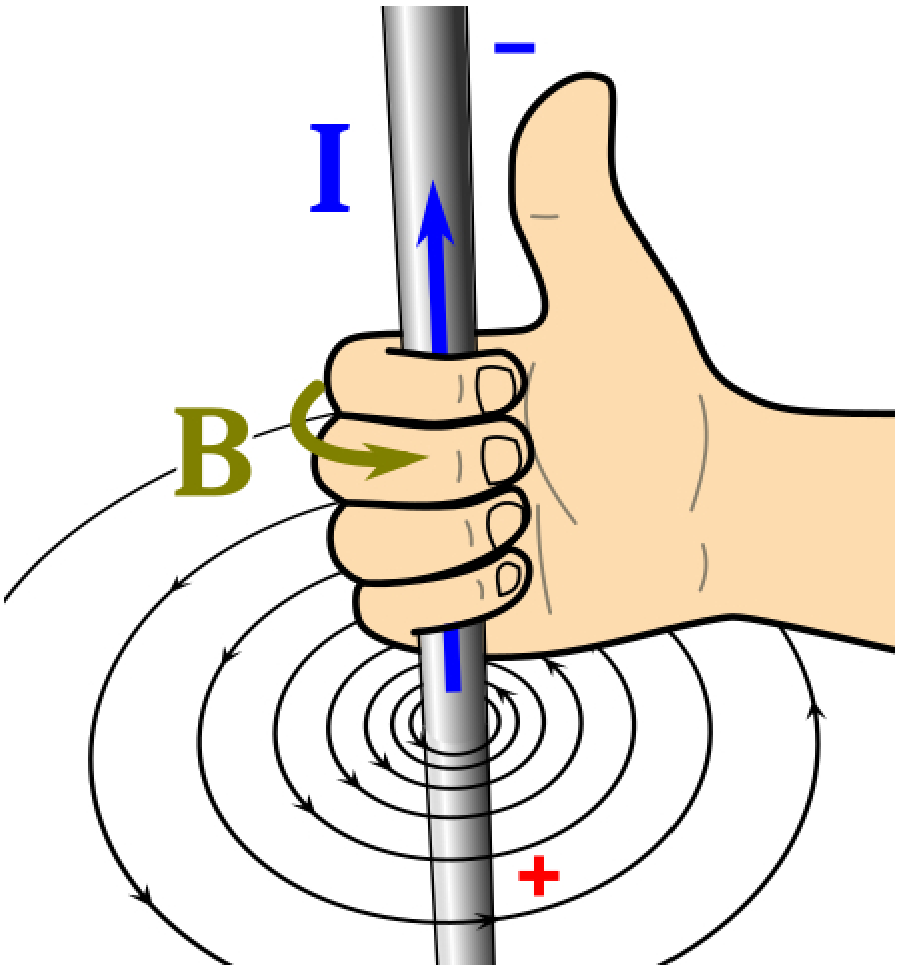


Fig. 24: Right-hand grip ruleMikeRun, CC BY-SA 4.0, via Wikimedia Commons

Magnetic Field Due to Currents in Straight Wires

Pattern and Direction

The magnetic field around a straight current-carrying wire forms concentric circles centered along the wire. The field direction follows the right-hand **grip** rule: if you grip the wire with your right hand so your thumb points in the direction of the current flow (conventional current, from positive to negative), your fingers will curl in the direction of the magnetic field lines.

Variation of Strength

The strength of the magnetic field decreases with increasing distance from the wire. The field intensity follows an inverse relationship with the distance, so the field gets weaker as you move farther away from the wire.

Effect on Magnetic Field

- Changing Magnitude of Current: Increasing the current makes the magnetic field stronger, with closer and denser field lines (more lines in the same area). Similarly, decreasing the current weakens the field, causing the lines to spread out and become less dense (less lines in the same area).
- Changing Direction of Current: Reversing the current direction changes the magnetic field's direction around the wire. The field lines now flow in the opposite direction compared to the direction at the start. (as told by the right hand grip rule)

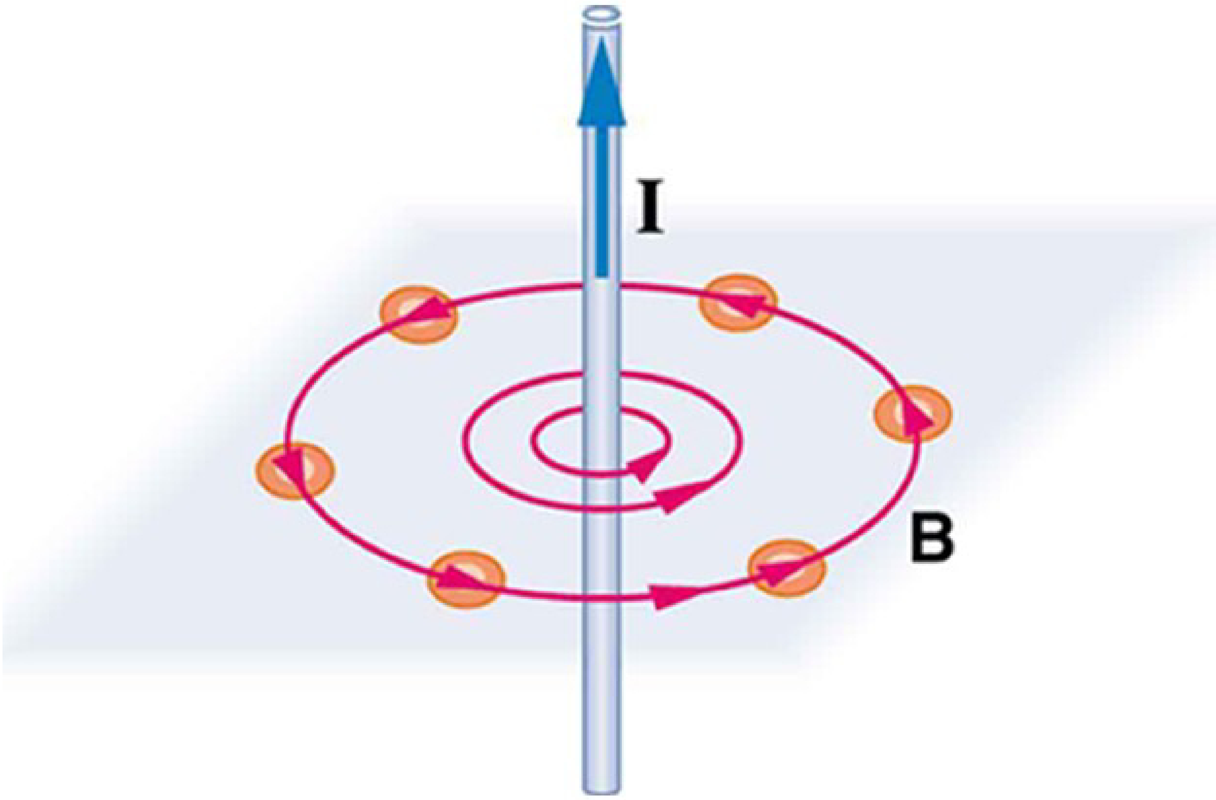


Fig. 25: Magnetic Field Due to Currents in Straight WiresOpenStax, CC BY 4.0, via Wikimedia Commons

Magnetic Field Due to Currents in Solenoids

Pattern and Direction

In a solenoid (a coil of wire), the magnetic field inside is strong and nearly uniform, running parallel to the central axis of the solenoid. The field direction follows the right-hand rule: if you wrap your fingers around the solenoid in the direction of the current flow, your extended thumb points to the north pole of the solenoid.

Variation of Strength

Inside the solenoid, the magnetic field strength is relatively constant, producing a strong and uniform magnetic field along its axis. However, outside the solenoid, the field is relatively weak and spreads out, resulting in a less uniform and weaker magnetic field compared to the inside.

Effect on Magnetic Field

- Changing Magnitude of Current: Increasing the current strengthens the magnetic field inside the solenoid, making the field lines more uniform and concentrated along its axis. Decreasing the current weakens the field.
- Changing Direction of Current: Reversing the current direction in the solenoid also reverses the magnetic field's direction inside. The field lines that previously flowed in one direction now flow in the opposite direction along the solenoid's axis.

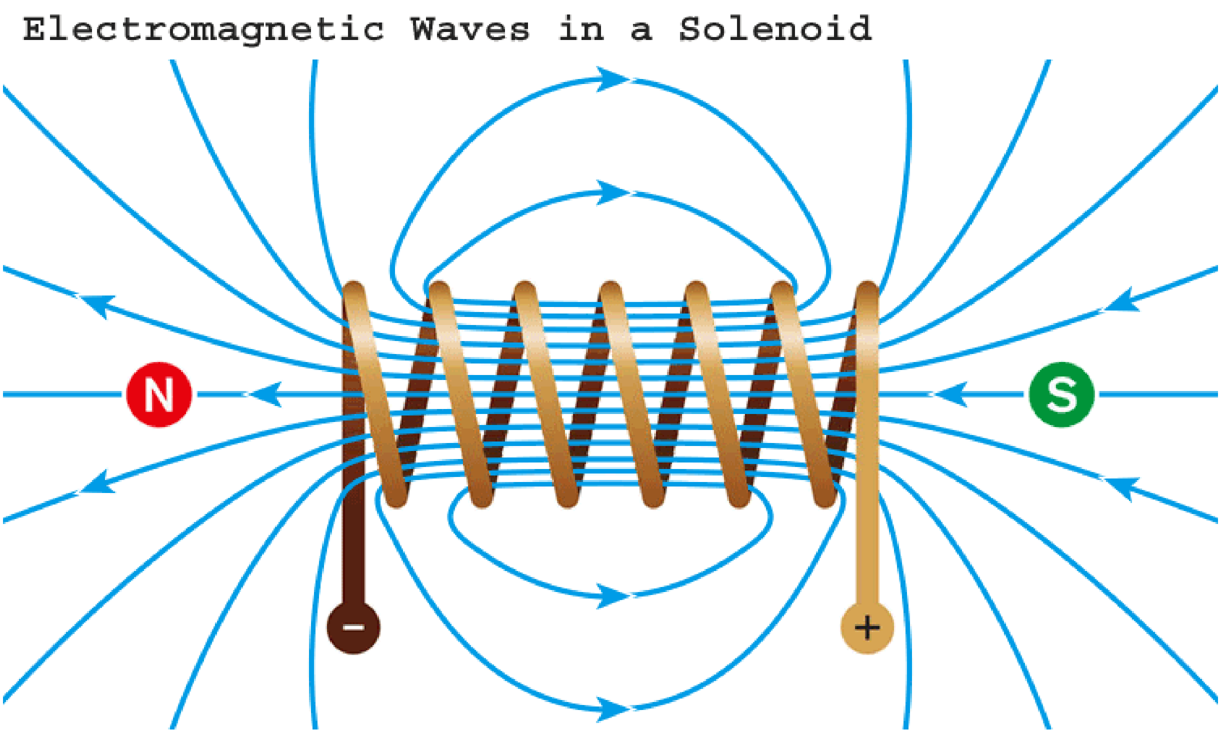


Fig. 26: Magnetic Field Due to Currents in SolenoidsRajiv1840478, CC BY-SA 4.0, via Wikimedia Commons

Experiment

To identify the pattern of the magnetic field (including direction) due to currents in straight wires and solenoids.

Materials needed

- A long straight wire (e.g., copper wire)
- A battery or power supply
- Compass needle or small magnetic needle
- Iron filings
- A solenoid (a coil of wire)

Experiment for Straight Wire

- Place the compass needle near the straight wire without touching it.
- Connect the wire to the battery or power supply to create a current flow through the wire.
- Observe the compass needle's movement; it will align itself perpendicular to the wire, showing the direction of the magnetic field around the wire.

The compass needle points in a circle around the wire, showing the magnetic field's concentric pattern.

Experiment for Solenoid

- Sprinkle iron filings around the solenoid (coil of wire).
- Connect the solenoid to the battery or power supply to pass current through it.
- Observe the pattern formed by the iron filings; they will align along the length of the solenoid, indicating the direction of the magnetic field inside the solenoid.

The iron filings align along the length of the solenoid, illustrating a uniform magnetic field inside the coil.

Application of the magnetic effect of a current

Relays

Relays are devices that use the magnetic effect of a current to act as remote-controlled switches.

They use the magnetic effect of a current to create an electromagnetic coil that controls a switch.

When a small electrical current flows through the coil, it generates a magnetic field that attracts a metal arm, closing or opening the switch, and allowing larger currents to be controlled.

Examples include using relays in household appliances, motor control circuits, and safety systems.

GIF of a relay in action

As you can see from the GIF above, as the electromagnet is switched on, a pivot attached to a metal is attracted to the electromagnetic.
The pivot pushes on the metal attached to it as it pulled by the electromagnet. This causes both the pieces of metal (which act as a switch) to join together and turn on another circuit.

Loudspeakers/Speakers

Speakers use the magnetic effect of a current to convert electrical signals into sound waves.

When an electric current passes through a coil in the speaker, it creates a magnetic field that interacts with a permanent magnet, causing the speaker cone to vibrate and produce sound

Examples of speakers/loudspeakers include audio systems (home theatres), televisions, and mobile phones, laptops.

To understand speakers, we must know that sound is simply vibrations at a specific frequency.

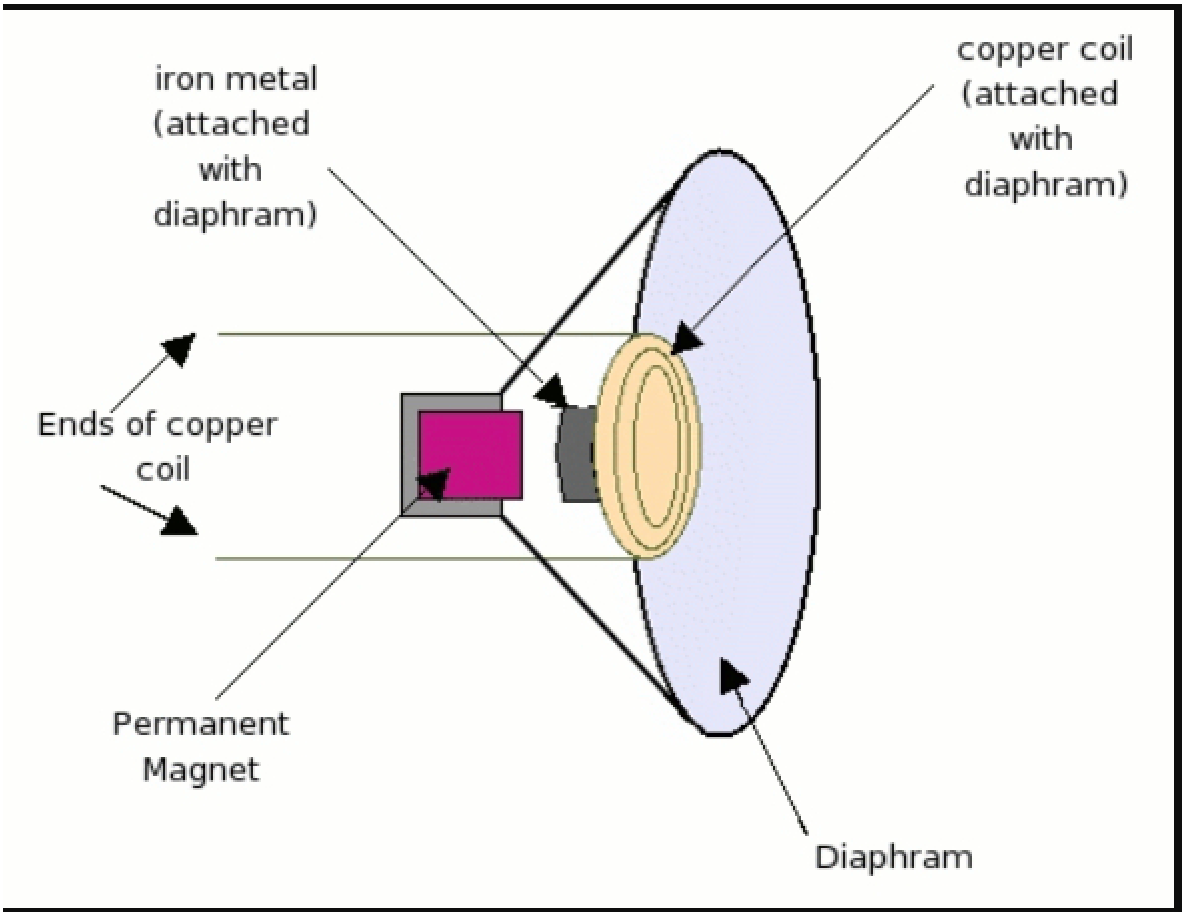


Fig. 27: Diagram of a speakerSBudiMasdar, CC BY-SA 4.0, via Wikimedia Commons

The speaker converts electrical energy (audio signal from a source, such as a mobile phone) into mechanical energy

When the audio signal passes through a coil of wire wrapped around a cone-shaped diaphragm, it creates a changing magnetic field due to the interaction with a permanent magnet.

This changing magnetic field causes the coil and diaphragm to vibrate rapidly which causes the diaphragm to push and pull the surrounding air, creating sound waves (vibrations).

4.5.4 Force on a current-carrying conductor

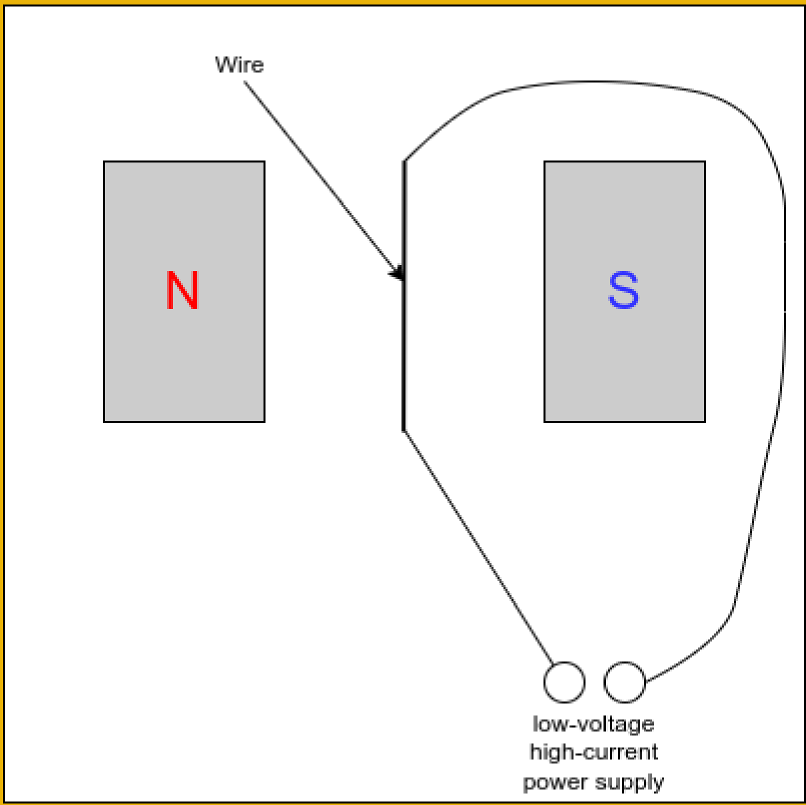
A wire carrying a current in a magnetic field experiences a force.

Experiment

To demonstrate the Force on a Current-Carrying Conductor in a Magnetic Field

1. Place the straight wire on a flat surface.
2. Put two magnets (as shown in the diagram) on each side of the wire.

3. Connect the wire to a low-voltage, high-current power supply.
4. Now turn on the power supply.



Once you turn on the power supply, you will notice that the wire has moved.
This is because the magnetic field of the two magnets around it interacts with the magnetic field of the current-carrying wire, causing a force to be exerted on the wire, causing it to move or deflect.

If the current in the wire is reversed, then the wire will move in the other direction.
If the current in the wire is increased, the magnetic field of the wire will also increase, causing the wire or move/deflect even more (because more force).

We use the fleming's left-hand rule to find the direction the wire moves in.

Fleming's left-hand (motor) rule

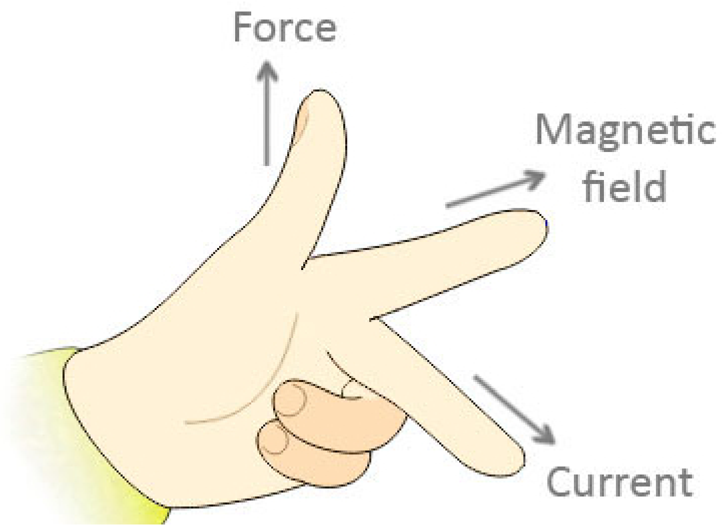


Fig. 29: Fleming's left-hand ruleMmikkor, CC BY-SA 4.0, via Wikimedia Commons

The left-hand rule is used to determine the direction of force in a conductor.

If you align the thumb with the direction of the current and the forefinger (index finger) with the direction of the magnetic field, then the middle finger will point in the direction of the resulting force experienced by the conductor.

We use this rule for d.c. motors and also for **beams of charged particles in a magnetic field**.

4.5.5 The d.c. motor

The motor effect refers is when a current-carrying conductor experiences a force when placed in a magnetic field, causing it to move.

If the wire is in a shape of a coil, then forces act on both the sides of the coil.
These forces can cause the coil to rotate or experience a turning effect.
If the coil is free to move, it will start to rotate.

The turning effect (also known as torque is the rotational force that tends to cause an object to rotate around a pivot point.

In simple words, the turning effect is a force that makes something spin or rotate.

Factors affecting turning effect

There are 3 factors which affect the turning effect:

- the number of turns on the coil
- the current
- the strength of the magnetic field

The number of turns on the coil

Increasing the number of turns on the coil increases the turning effect.

This is because it **increases the magnetic moment** of the coil, resulting in a stronger interaction with the magnetic field.

The current

Increasing the current flowing through the coil also increases the turning effect.

This is because it **strengthens the magnetic field** produced by the coil, again resulting in a stronger interaction with the magnetic field.

The strength of the magnetic field (stronger magnets)

Increasing the strength of the external magnetic field also increases the turning effect on the coil. This is because a stronger magnetic field exerts a greater force on the coil.

Simple d.c. electric motor

A simple motor which works from direct current (d.c.) consists of the following:

- A coil (usually rectangular or circular) mounted on an axle
- 2 magnets
- Brushes
- Commutator/Split rings (NOT SLIP RINGS)

It works by passing electric current through a coil placed in a magnetic field.

The split-ring commutator, which is basically a rotating switch, helps reverse the direction of the current in the coil every half-turn. The split-ring commutator rotates with the coil.

Brushes allow the current to flow into the coil continuously, enabling the motor's **constant/sustained** rotation.

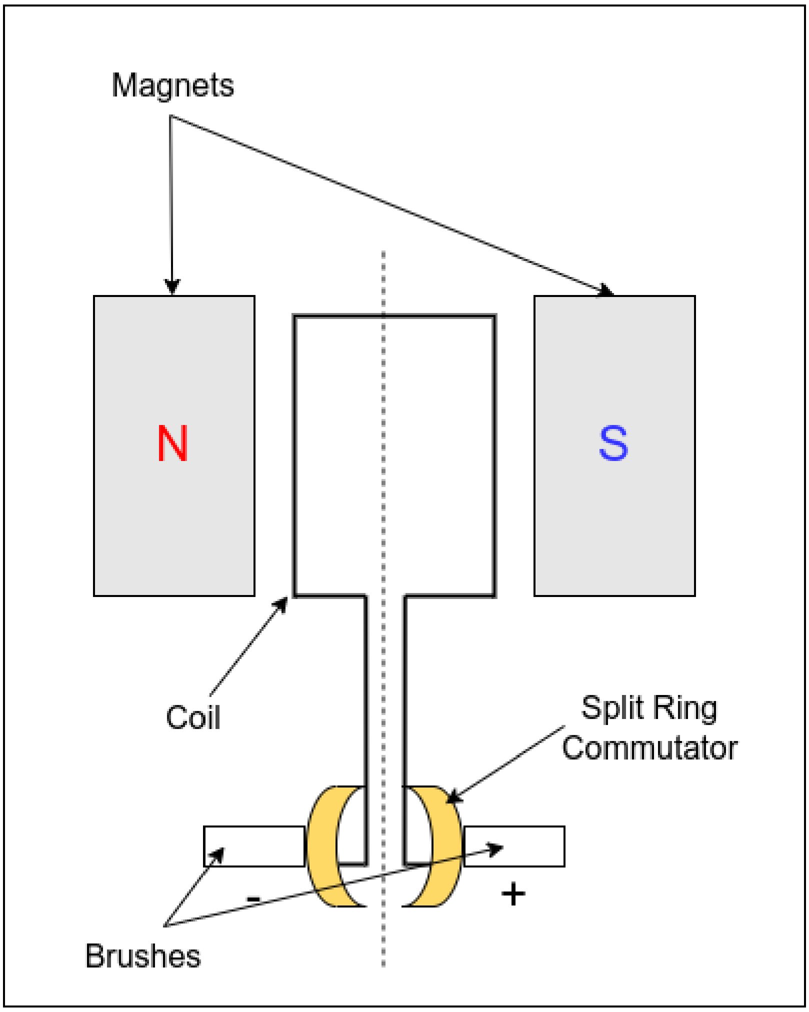


Fig. 30: D.C. Motor diagram

Basically, the brushes provide power to the split rings, which are connected to the coil.

Since the split rings move with the coil, a constant flow of reversing current is maintained, causing the motor to be in a constant loop of rotations.

Now you may ask what if none of the split rings are touching the brushes?
That can never happen, simply because the coil has enough inertia, causing the coil along with the split rings to overshoot and touch the brushes.

4.5.6 The transformer

A transformer is a device that transfers electrical energy from one circuit to another through electromagnetic induction. It is often used to step up or step down voltage levels in AC power systems.

Basically, it is a device that changes the voltage of an alternating current (AC) without changing its frequency.

It consists of three parts:

- A primary coil of insulated wire
- A secondary coil of insulated wire

- A soft iron core

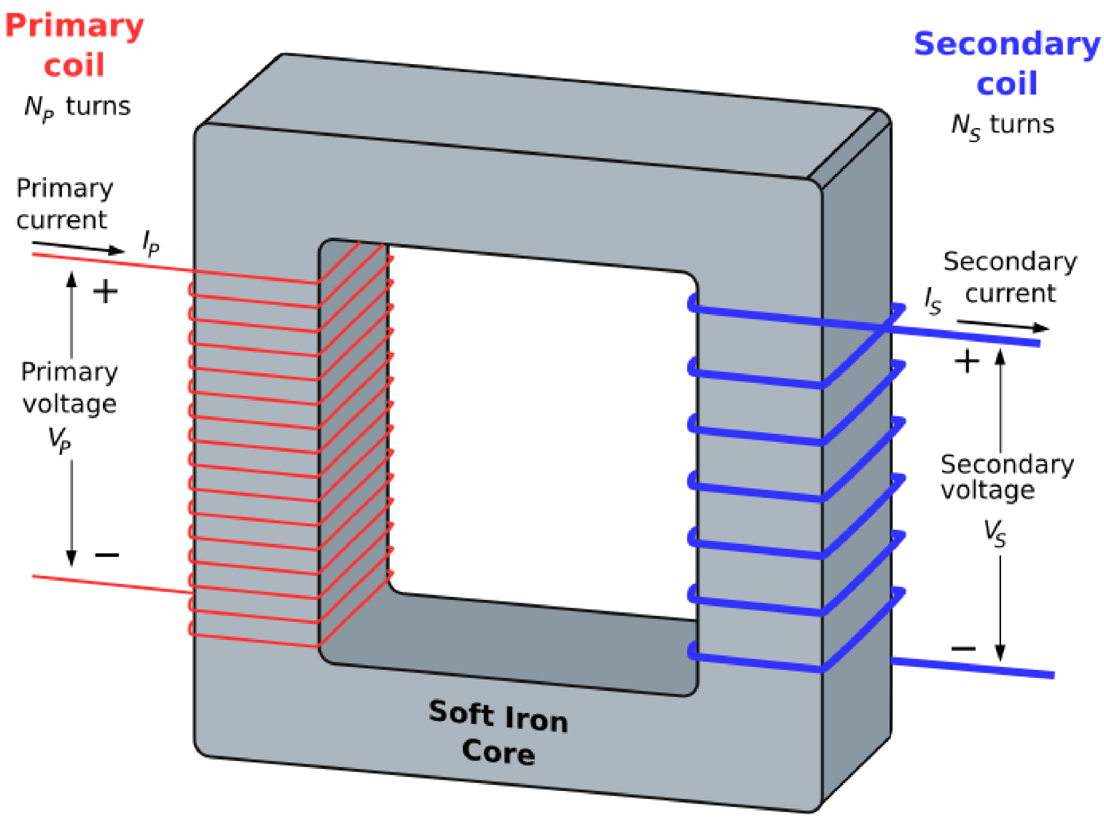


Fig. 31: Diagram of a transformerBillC at the English-language Wikipedia, CC BY-SA 3.0, via Wikimedia Commons

Mutual Induction

The principle of operation of a simple transformer is known as **mutual induction**.
Mututal induction is yet another example of electromagnetic induction.

When an alternating current (AC) flows through the primary coil wound around the iron core (as shown in the diagram above), it creates a varying/changing magnetic field in the core.

This changing magnetic field induces a voltage in the secondary coil.

Types of transformers

There are two types of transformers:

- Step-up transformers
- Step-down transformers

Step-up transformers increase the **voltage**
A step up transformer has more turns on the secondary compared to the primary

Step-down transformers decrease the **voltage**.
A step-down transformer has more turns on the primary compared to the secondary

Transformer equation

The ratio of the number of turns in the primary and secondary coils determines the voltage change. We use the following equation:

$$\frac{\text{primary voltage}}{\text{secondary voltage}} = \frac{\text{primary turns}}{\text{secondary turns}}$$

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

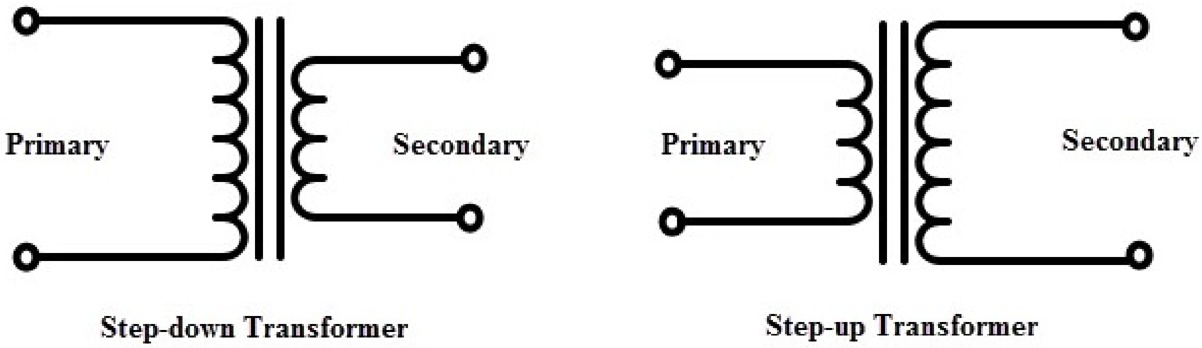


Fig. 32: Symbols for step-up and step-down transformers

Energy losses in a transformer

Transformers in real life are not 100% efficient. But while calculating, we assume that they are 100% efficent.

If a transformer is 100% efficient, the input power should be equal to the output power, as shown by this equation:

$$\text{power in primary} = \text{power in secondary}$$

$$I_p V_p = I_s V_s$$

where
I_p = Current in primary
I_s = Current in secondary

So in theory, if the voltage is doubled, the current is halved.

But if we talk about **transformers in real life**, then if the voltage is doubled, the current will be less than half, this is because of energy losses.

A few reasons for these energy losses are:

- Resistance of windings
  - The coils are made up of wound copper wire, which have a resistance, causing energy loss.
- Eddy currents

    - Currents called eddy currents are induced into the core as it is also in changing magnetic field, this causes heating and therefore energy loss.
- Leakage of field lines
    - All of the magnetic field lines produced by the primary may not reach/cut the secondary. This could be because of an air gap or bad design

Transmission of electrical power

Transformers are used to step up the voltage before the electricity is sent through power lines for long-distance transmission of electricity.

Once the electricity reaches its destination, other transformers at distribution step down the voltage to relatively safer levels for local distribution to homes and businesses.

We do this because there are many advantages of high-voltage transmission of electricity, such as:

- less heating, therefore more efficient
- allows for use of thinner wires
- fewer power stations
- lower current in cables
- transmit longer distances (without much power loss) due to lower current

Power loss in transmission cables

Power cables have resistance which can cause power loss.

To calculate power loss, we use the equation:

$$P = I^2 R$$

Where P = Power,
I = Current and
R = Resistance

This equation tells us that **power loss** is directly proportional to current

This is why we use high-voltage transmission to transfer power over long distances.

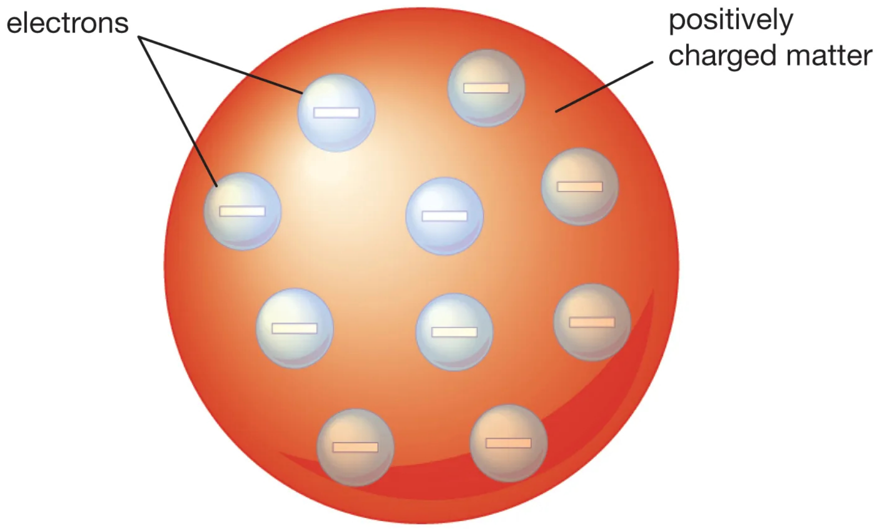
The lower the current, the lower the loss of power/energy.

Chapter 5

5.1 The nuclear model of the atom

Plum pudding model

An early theory known as the plum-pudding model regarded the atom as a positively charged sphere in which negative electrons were distributed all over it (Image below)



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Later, rutherford proposed a new "nuclear" model in which all the positive charge and most of the mass of an atom formed a dense core called the **nucleus**. The nucleus was surrounded by negatively charged electrons some distance away.

Ions

A normal atom is neutral while an ion has a charge, either positive or negative, such as $^{3+}$, $^{2-}$ or just $^{+}$ ($^{1+}$).
This happens when an atom either gains or loses electrons causing the electron and proton number to not be equal.

The Nucleus

The nucleus consists of protons and neutrons. It contains most of the mass of the atom.
The neutrons and protons collectively are known as nucleons.

A = mass number
Z = proton number
neutrons = A - Z

Isotopes and nuclides

Isotopes of an element are atoms that have the same proton number but different number of neutrons.
Hydrogen has three isotopes, protium ($^1_1\mathrm{H}$), deuterium ($^2_1\mathrm{H}$) and tritium ($^3_1\mathrm{H}$).
Water made using deuterium ($^2_1\mathrm{H}$) is called heavy water which has a freezing point of 3.8°C, a boiling point of 101.4°C and a density of 1.108 g/cm^3.
A nuclide is an atom of an element characterised by the mass number A and the proton number Z.
Radioactive isotopes are termed radioisotopes.

Nuclear energy

Einstein predicted that if the energy of a body changes by an amount E, it's mass changes by an amount m given by the equation. (basically, if the energy of a body changes, its mass also changes)

$$E = mc^2$$

where c = speed of light (3×10^8)

The decrease of mass in any reaction is known as the mass defect.

Fission

The break up of a large nucleus into smaller parts is known as fission.
An example of this is when atoms of uranium-235 naturally decay, they emit high-speed neutrons.
If one of these hits the nucleus orf a neighbouring uranium-235 atom, the nucleus may break and cause a chain reaction to start.

$$^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \longrightarrow ^{144}_{56}\mathrm{Ba} + ^{90}_{36}\mathrm{Kr} + 2\,^{1}_{0}\mathrm{n}$$

The mass defect in this reaction is large and happens mostly because of the kinetic energy of fission fragments.

Nuclear reactor (Fission)

Heat from the nuclear reactor produces steam for the turbines to generate power.
The chain reaction occurs at a constant rate which can be controlled using control rods which are made from either boron or cadmium.

Parts of a nuclear reactor

Moderator: This is the graphite core which slows down the fission neutrons. It pumps carbon dioxide gas as a coolant.
Heat exchanger: The heated gas transfers energy to pipes containing cold water so that the water boils to produce steam
Concrete shield: It protects workers from gamma emissions and escaping neutrons.

Fusion

In fusion, light nuclei join together to make heavier ones. However, this can result in a loss of mass and release of energy.

$$^{2}_{1}\mathrm{H} + ^{3}_{1}\mathrm{H} \longrightarrow ^{4}_{2}\mathrm{He} + ^{1}_{0}\mathrm{n}$$

Research is still being done on the controlled fusion of isotopes of hydrogen to form helium.
The source of sun’s energy is nuclear fusion.

5.2 Radioactivity

Background radiation

We are all exposed to background radiation, both natural and artificial.

- Cosmic rays are high-energy particles from the sun which are mostly absorbed by the atmosphere but some reach the earth’s surface
- Radon gas in the air
- Homes built from granite rocks which emit radioactive radon gas
- Radioactive potassium-40 is present in food and is absorbed by our bodies.
- Various radioisotopes are used in certain medical procedures
- Radiation is produced in the emissions of nuclear power stations and testing of nuclear bombs

Ionising effect of radiation

Ionisation is the process by which atom or molecule becomes an ion.
For example, a lighted match or a radium source can discharge a charged electroscope when brought near its cap.

Geiger-Muller (GM) Tube

The GM Tube is a tube used to detect alpha, beta and gamma radiation.

It detects ionizing radiation by measuring the electrical pulses produced when radiation interacts with the gas.

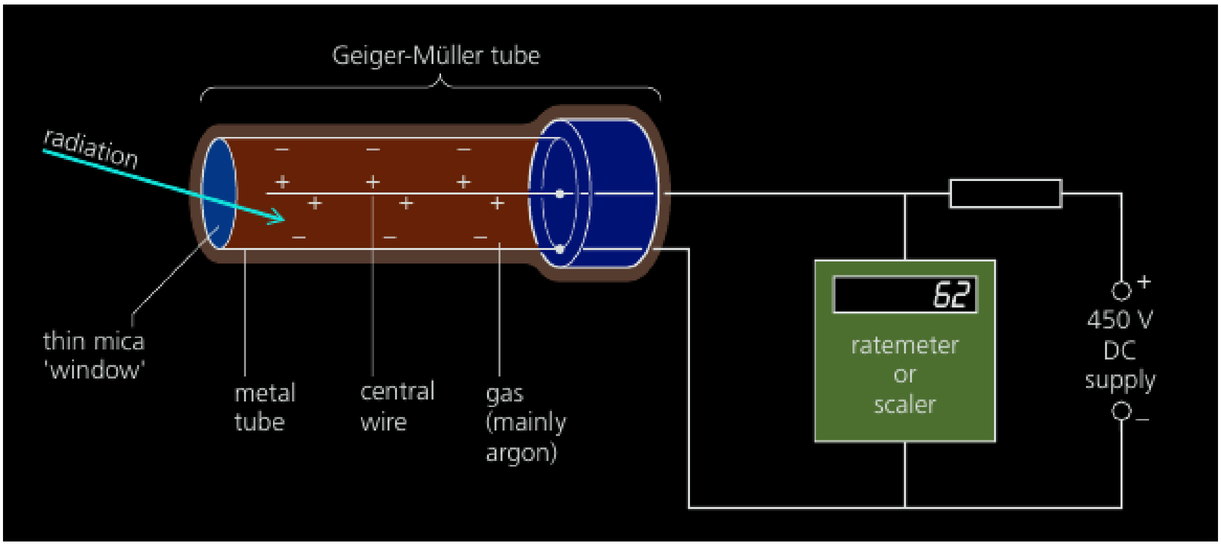

Fig. 1: Diagram showing a GM Tube

Count-rate corrections

Count-rates measured using a GM Tube need to be corrected by subtracted the background radiation count rate from the measured count-rate.

3 types of nuclear emission

type of radiation	alpha particles (α)	beta particles (β)	gamma rays (γ)
	each particle is 2 protons + 2 neutrons (it is identical to a nucleus of helium-4)	each particle is an electron (created when the nucleus decays)	electromagnetic waves similar to X-rays
relative charge compared with charge on proton	+2	−1	0
mass	high, compared with betas	low	–
speed	up to 0.1 × speed of light	up to 0.9 × speed of light	speed of light
ionizing effect	strong	weak	very weak
penetrating effect	not very penetrating: stopped by a thick sheet of paper, or by skin, or by a few centimetres of air	penetrating, but stopped by a few millimetres of aluminium or other metal	very penetrating: never completely stopped, though lead and thick concrete will reduce intensity
effects of fields	deflected by magnetic and electric fields	deflected by magnetic and electric fields	not deflected by magnetic or electric fields

Alpha Particles

They can be stopped by a thick sheet of paper and have a range in air of only a few centimeters since they cause intense ionisation.
They are deflected by electric and magnetic fields.
Americium (Am-241) is a pure alpha-particle source which is used in smoke detectors

Beta particles

A beta particle is a high-energy electron
They can be stopped by a few millimeters of aluminium and some have a range in air of several metres.

Their ionising power is less than that of alpha particles.
They are deflected by electric and magnetic fields.
Strontium (Sr-90) emits beta particles only.

Gamma emissions

These are the most penetrating and can be stopped only by many centimeters of lead. They ionise a gas even less than beta particles.
They are not deflected by electric and magnetic fields.
They have low wavelengths and a high frequency
Cobalt (Co-60) emits gamma radiation and beta particles but can be covered with aluminium to provide pure gamma radiation.

Gamma particles have no charge therefore they aren't attracted to neither positive nor negative points
Beta particles are negatively charged and are attracted to positive points
Alpha particles have a charge of 2+ and they are attracted to negative points.

Particle tracks

When air containing alcohol vapour is cooled enough, saturation occurs. If ionising radiation passes through that air, further cooling causes the saturated vapour to condense on the ions created. The result is a white line of tiny liquid drops which shows up as a track when illuminated.

In a diffusion cloud chamber, alpha particles show straight and thick tracks.
Very fast Beta Particles produced thin and straight tracks while slower ones produced short, twisted and thicker tracks
Gamma emissions eject electrons from air molecules, the ejected electrons behave like beta particles in the cloud chamber.

Alpha Particles	Beta Particles	Gamma Emissions
thick and straight tracks	Fast: thin and straight tracks Slow: short, twisted and thicker tracks	Ejects electrons from air molecules which act like beta particles.

The bubble chamber has now replaced the cloud chamber. In a bubble chamber, the radiation leaves a trail of bubbles in liquid hydrogen.
Because the density of the atoms in the liquid is higher, the tracks are better defined and clearer. The sign of the charge can be deduced from the way that the path curves inside it.

Radioactive decay

It is the emission of an alpha particle or a beta particle from an unstable nucleus. During alpha or beta decay, the nucleus changes to that of a different element, which could be unstable itself. They cannot be controlled and are spontaneous and random.

Alpha decay

An alpha particle is a helium nucleus which has 2 protons and 2 neutrons. When an atom is decayed by the emission of alpha particles, it’s nucleon number decreases by 4 and its proton number by 2. Example:

$$^{226}_{88}\mathrm{Ra} \longrightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$$

Beta decay

In beta decay, a neutron changes to a proton and an electron.

$$\text{neutron} \longrightarrow \text{proton} + \text{electron}$$

The proton remains in the nucleus and the electron is emitted as a Beta Particle.
The new nucleus has the same nucleon number but its proton number increases by one since it has one more proton.
Example of Radioactive carbon, carbon-14 decaying to nitrogen.

$$^{14}_{6}\mathrm{C} \longrightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\mathrm{e}$$

Gamma emission

After emitting an alpha or beta particle, some nuclei are left in an excited state.
Rearrangement of the protons and neutrons occurs and a burst of gamma emissions are released.

Half-life

The time taken for half the nuclei of an isotope in any sample to decay is known as half-life.

Decay curve

Activity = average number of disintegrations per second of a sample
If an isotope’s activity falls from 80 to 40 in 10 minutes and then 40 to 20 in another 10 minutes, then it’s half-life is 10 minutes.

Uses of radioactivity

Radioactive substances a.k.a radioisotopes have many uses, some of them are listed below:

- Smoke alarm
- Sterilisation
- Thickness gauge
- Diagnosis and treatment of cancer
- Tracers
- Archaeology

A detailed explanation of these uses can be found in the cambridge igcse physics book by hodder education.

Safety precautions

- Exposure time to the radiation should kept to a minimum
- The distance between a source and a person should be kept as large as possible
- people should be protected by the use of shielding which absorbs the radiation

In industries, workers are protected by lead and concrete walls.
They also wear a radiation dose badge that keep a check on the amount of radiation they've been exposed to over a specific period of time. If it exceeds the safe limit, then the worker is not allowed to work until the time period ends

Chapter 6

6.1 Earth and The Solar System

6.1.1 The Earth

Our solar system is known as the milkyway.

There are 8 planets in our solar system.

A solar system is basically a group of celestial objects known as planets which revolve around a star.

Each planet in a solar system follows a specific path called an orbit.

The Earth rotates on an imaginary line called its axis, which is slightly tilted.

One rotation of the earth takes approximately 24 hours.

The sun does not move, the earth revolves around it. So when the earth rotates, one side is facing towards the sun, while the other is facing away from the sun therefore causing day and night.

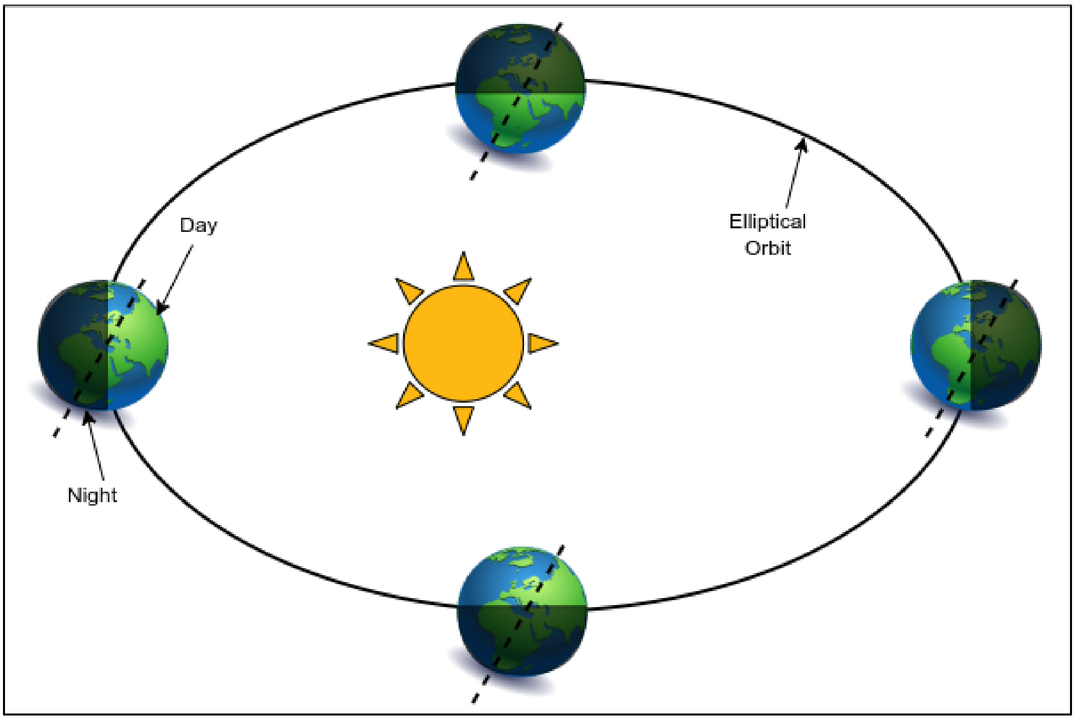

Fig. 1: Diagram showing day and night

The earth completes a revolution around the sun in it's orbit in approximately 365 days.

The seasons

There are two factors which cause seasons:

- Motion of earth around the sun (revolution) which takes 365 days
- The tilt of the earth's axis (which is about 23.5°)

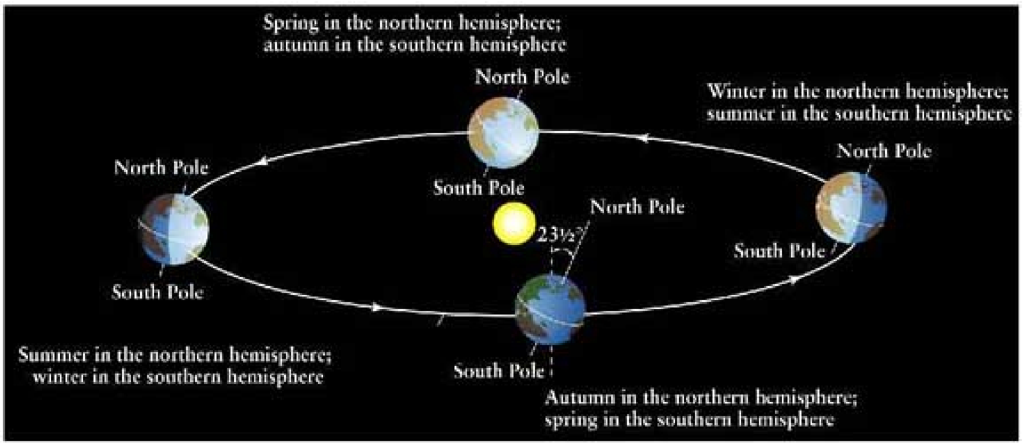

Fig. 2: SeasonsSwathiha97, CC BY-SA 4.0, via Wikimedia Commons

The moon

The moon is a satellite of the earth which revolves around the Earth. One revolution of the moon around the earth takes approximately one month.
The moon, similarly to the earth, also rotates on its own axis but one rotation also takes approximately one month, which is way more than that of the earth.

This movement of the moon causes the moon to appear in different shapes, these “shapes” are known as phases of the moon.

The moon has 8 phases as shown below.

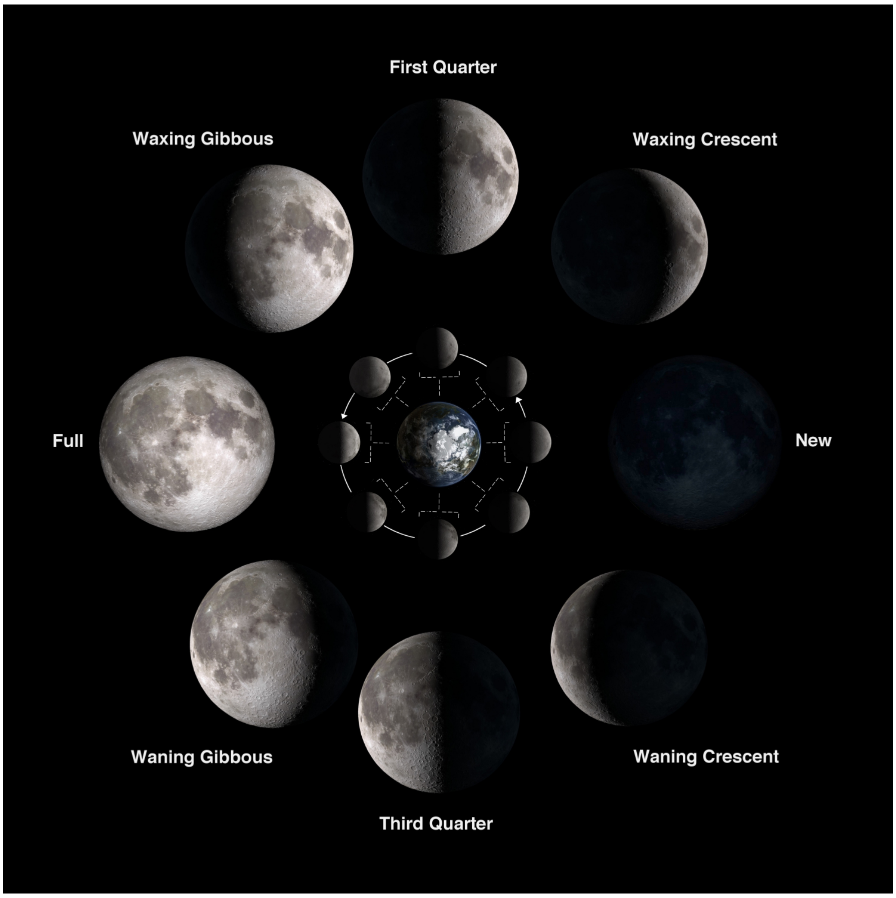

Fig. 3: Phases of the moon

Average Orbital Speed

To calculate the average orbital speed, we use the following formula:

$$\text{Average orbital speed} = \frac{\text{Circumference of orbit}}{\text{Time taken for one orbit}}$$

Orbital Period = time taken to complete

$$v = \frac{2\pi r}{t}$$

where v is the velocity
r is the average radius of the orbit and
t is the orbital period

6.1.2 The Solar System

The solar system is a collection of celestial bodies, including the Sun, planets, moons, asteroids, comets, and other smaller objects, **bound together by gravity**.

The Solar System consists of:

- one star, the Sun.
- Eight named planets in order from the Sun: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.
- Minor planets such as dwarf planets (e.g., Pluto)
- Asteroids in the asteroid belt.
- Moons, that orbit the planets
- Smaller solar system bodies like comets and natural satellites.

The sun

The sun makes up most of the mass of the Solar System (more than 99%).

The force responsible for keeping objects like planets in orbit around the Sun is the gravitational attraction exerted by the Sun, which pulls them towards it and keeps them moving in their orbits.

The force that keeps an object in orbit around the Sun is the gravitational attraction of the Sun.

Asteroids

An asteroid is a small rocky body that orbits a star.
They are much smaller than planets and therefore are considered to be minor planets.

Asteroid Belt is a region between Mars and Jupiter containing numerous small rocky bodies.

Moons

Moons, also known as natural satellites, orbit various planets, such as Earth's Moon.

Comets/Smaller bodies

Comets are celestial objects composed of **ice**, **dust**, and **gas**.
When comets are close to the sun, they develop a bright head and a long tail.

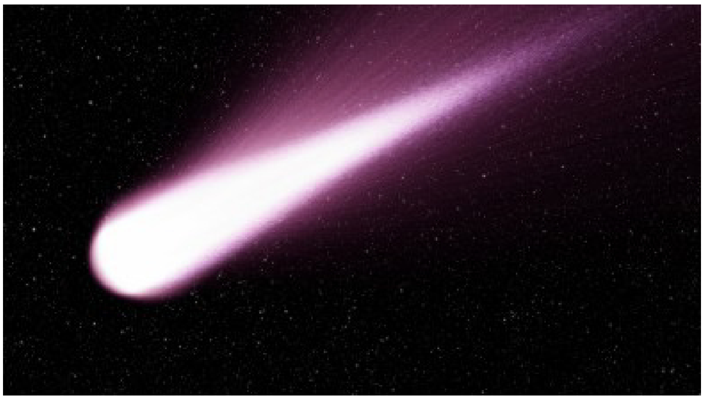

Fig. 4: A comet

Orbits

Orbits are the curved paths followed by celestial objects, such as planets, moons, asteroids, and comets, as they revolve around a more massive body, typically a star like the Sun, under the influence of gravity.

Planets, minor planets and comets have **elliptical** orbits. (Check out figure 1)
As you may notice in figure 1, the Sun is **not at the centre** of the orbit, because it is elliptical.
The sun is only at the center of the orbit when the orbit is approximately circular.

The accretion model

The accretion model is a theory that explains the formation of our Solar System and other celestial bodies in the universe.

The Sun was formed about 4.6 billion years ago from a massive cloud of hydrogen gas and dust (collectively known as nebulae) in space that collapsed under gravity.

The planets were formed from the leftover materials in the **accretion disk**, a flat, rotating disk of gas and dust that surrounded the young Sun.

Dust and gas particles from this *cloud* came together due to gravitational attraction and grew in size in an **accretion process**, forming planets.

> The accretion process is the gradual accumulation of matter by particles clumping together, ultimately forming larger and more massive objects, like planets, through gravitational attraction.

Planets

There are 8 planets in our solar system.
We vaguely classify them into 2 categories:

- Inner Planets
- Outer Planets

Inner Planets	Outer Planets
1. Mercury 2. Venus 3. Earth 4. Mars	1. Jupiter 2. Saturn 3. Uranus 4. Neptune
Rocky	Gaseous

Inner Planets	Outer Planets
Small	Giant
High Density	Low Density

This can be explained by the accretion model described above.

The inner planets are small, rocky, and have a higher density because they formed closer to the hot center of the disk, causing the light (in mass) molecules (such as hydrogen, helium, water and methane) to be in a gaseous or liquid form instead of a solid form, leading the planets to be formed with heavier matter with high melting points such as metals, making the planet dense.

However, far from the sun, these light molecules could exist in solid form, causing the outer planets to be large, gaseous and less dense because they will be made up of these light molecules.

Planet	Av distance from Sun /million km	Orbit time round sun /days or years	Surface temperature /°C	Density /kg/m³	Diameter /10^3 km	Mass /10^{24} kg	Surface gravity /N/kg	No. of moons
Mercury	57.9	88 d	350	5427	4.8	0.330	3.7	0
Venus	108.2	225 d	460	5243	12.1	4.87	8.9	0
Earth	149.6	365 d	20	5514	12.8	5.97	9.8	1
Mars	227.9	687 d	-23	3933	6.8	0.642	3.7	2
Jupiter	778.6	11.9y	-120	1326	143	1898	23.1	79
Saturn	1433.5	29.5y	-180	687	120	568	9.0	82
Uranus	2872.5	84y	-210	1271	51	86.8	8.7	27
Neptune	4495.1	165y	-220	1638	50	102	11.0	14

From this table, we can gather the following information:

Orbital Distance

Mercury has the shortest distance from the Sun, while Neptune is the farthest.

As we move farther from the Sun, the average distance increases.

Orbital Speed

Orbital speed decreases as distance from the sun increases.

Orbital Duration

Similarly to orbital distance, mercury has the shortest orbital duration, completing one orbit around the Sun in 88 days, while Neptune takes the longest at 165 years.

The farther the planet is from the Sun, the longer it takes to complete one orbit.

Density

Jupiter has the lowest density, while Earth has the highest density.

The inner planets (Mercury, Venus, Earth, Mars) tend to have higher densities compared to the outer planets (Jupiter, Saturn, Uranus, Neptune), which have lower densities.

Surface Temperature

Venus experiences the highest surface temperature of 460°C, making it the hottest planet in our Solar System, while Uranus has the coldest surface temperature at -210°C.

Surface temperatures decreases as distance from the Sun increases.

However, this is one exception to this, venus has a high surface temperature (460°C) due to its dense atmosphere of carbon dioxide acting as a heat trap

Surface Gravity

Jupiter has the strongest surface gravity, measuring at 23.1 N/kg, due to its massive size, while Mercury and Mars have the lowest surface gravity at 3.7 N/kg.

Gravitational field strength of a planet

The gravitational field strength at the **surface of a planet** is **directly proportional** to the mass of the planet.

while the gravitational field strength **around a planet** is **inversely proportional** to the distance from the planet.

Travel times

To calculate the time taken by light to travel a specific distance in space, we use the following formula:

$$\text{Time} = \frac{\text{Distance}}{\text{Speed}}$$

Where speed is equal to 3×10^8 **m/s**
OR
speed is equal to 3×10^5 **km/s**

Gravity and Planetary motion

As a planet moves further away from the sun (distance from the sun increases), the strength of the sun's gravitational field decreases and the orbital speed of the planet also decreases.

> **Important**
>
> The strength of the Sun's gravitational field and the orbital speeds of the planets are inversely proportional to the distance from the Sun.

An object in an elliptical orbit travels faster when it is closer to the Sun, this is because the total energy of an object in an elliptical orbit is constant (law of conservation of energy).

As the object gets closer to the Sun, its potential energy decreases (as shown here) and its kinetic energy increases, increasing the speed of the object.

6.2 Stars and the Universe

6.2.1 The Sun as a star

The Sun is a medium-sized star consisting mostly of **hydrogen** and **helium**,
It radiates most of its energy in the infrared, visible and ultraviolet regions of the electromagnetic spectrum.

Nuclear reactions in stars

Stars are powered by nuclear reactions that release energy.
In **stable** stars the nuclear reactions involve the **fusion** of **hydrogen into helium**.

The **stable** star must have a hot enough core to carry out and maintain the nuclear reactions. This temperature is maintained by the large amounts of energy released by nuclear fusion.

The Sun is no exception to this and is also powered by nuclear fusion.

Some of the energy that is generated at the core is transferred to the outer layers of the star, causing the hydrogen gas to **glow** and emit electromagnetic radiation into space.

Colour and brightness of the star both depend on **surface temperature** which is **directly proportional** to the mass of the star.

6.2.2 Stars

A galaxy is a large collection of stars held together by gravity, each galaxy consists of many billions of stars.

Galaxies also consist of clouds of gas, mostly hydrogen and dust, collectively known as nebulae.

They also move in space, and many of them spin like swirling spiral discs.

We live in a galaxy known as the Milky Way and The Sun is a star in the Milky Way.
The Solar system is also located in the Milky Way.

Other stars in the Milky Way are much further away from the Earth than the Sun is.

Light-years

We measure astronomical distances in light-years.
One light year is the distance travelled by light in a vacuum in one year.

One light year is equal to 9.5×10^{15} m.

Origin of stars

- When Interstellar clouds of dust & gas (hydrogen), collapse under the force of gravitational attraction, they form a **protostar**.
- As the mass of the protostar increases, the temperature of its core also increases. (This happens because of the gravitational potential energy of the gas, is converted into kinetic energy, heating the core).
- When the core is hot enough, nuclear fusion starts, and hydrogen is converted into helium and a star is born.

- The protostar becomes a stable star when force of expansion (due to high temperature) pushing outwards is balanced out by the force of gravitational attraction pulling inwards.
    - If the mass of the star is very large, then it forms a blue or white star.
    - If the star has a smaller mass (like the Sun), it forms a yellow or red dwarf.

Life cycle of a star

When the star starts to run out of hydrogen as a fuel for nuclear reactions, it becomes unstable.
This happens because less energy being is produced by nuclear fusion, causing the forces to become unbalanced.
This causes the star to collapse inwards due to the force of gravitational attraction.

This causes the core to become extremely hot (change of potential energy into kinetic energy) causing the remaining hydrogen to burn and the surface to cool down.

A **red giant** is now formed.
But if the mass of the star is massive, a **red supergiant** is formed.

Low mass stars

- When the red giant runs out of helium, its core collapses under its own gravity.
- This releases enough energy to ejecte the outer layers of the star into space.
- The now collapsed corea becomes a white dwarf at the center, surrounded by a glowing shell of ionized gas called planetary nebula.
- The white dwarf eventually cools into a cold black dwarf.

High mass stars

- When the red supergiant runs out of helium, the core further collapses under gravity.
- This causes the core to get hot enough to start the nuclear fusion of carbon into oxygen, nitrogen and iron.
- After nuclear fusion stops, the star releases its energy in a supernova explosion.
- In the explosion, the star's brightness increases along with its temperature.
- When the core is hot enough, the fusion of nuclei into many elements heavier than iron occurs
- These heavy elements are thrown into space as nebula, and become available for the formation of new stars and planets of that star.
    - The center of the star then collapses into a dense neutron star, which spins rapidly and emits pulses of radio waves, creating a pulsar.
    - However, if the center of the star is extremely dense, a black hole is formed.

6.2.3 The Universe

The Milky Way is one of many billions of galaxies making up the Universe.

> **Important**
>
> The diameter of the Milky Way is approximately 100,000 light-years and contains over 800 billion stars.

The expanding Universe

Redshift

Redshift is the increase in the wavelength of light from a distant object, indicating that it is moving away from us (the observer).

In simpler words, Redshift is when the wavelength of light from distant galaxies increases. It occurs when galaxies are moving away.

The light emitted from distant galaxies appears redshifted in comparison with light emitted on the Earth.

The big bang theory (no, not the show)

The Big Bang Theory proposes that the entire universe was once compressed into a dense state and around 14 billion years ago, it exploded in a massive event called the Big Bang.

Since then, the universe has been expanding continuously.

Redshift in the light from distant galaxies is evidence that the Universe is constantly expanding.

Cosmic Microwave Background Radiation (CMBR)

Cosmic microwave background radiation (CMBR) refers to the microwave radiation of a specific frequency which is observed at all points in space around us.

This energy/radiation was produced by the big bang and still exists today in space in form of CMBR.

CMBR was produced shortly after the Universe was formed.

As the universe has constantly expanding and still is expanding, the CMBR has redshifted into the microwave region of the electromagnetic spectrum. (redshift is increase in wavelength)

Hubble's law

Important

Hubble's law

Hubble's law states that galaxies at greater distances move away from us with increasing velocity, and this relationship is proportional.

In simple words, the further a galaxy is from us, the faster it is moving away from us.

This can be written as:

$$v = H_0 \times d$$

where v = velocity (the speed at which the galaxy is moving away from the Earth),
d = distance (the distance of the galaxy from the Earth) and
H_0 = Hubble's constant

The hubble's constant is the ratio of the speed at which the galaxy is moving away from the Earth to its distance from the Earth.

Important

Calculating v

The speed at which a galaxy moving away from Earth can be measured by the change in the starlight's wavelength (due to redshift).
Starlight refers to the light emitted by stars, which is visible to us on Earth as tiny points of light in the night sky.

Calculating d

The distance (d) of a far galaxy can be determined by using the brightness of a supernova within that galaxy.

Current Estimate for hubble's constant

The current estimate for hubble's constant (H_0) is `2.2 × 10^-18 per second`

Age of the universe

The formula of the hubble's law can be rearranged to calculate the age of the universe.

The equation below represents an estimate for the age of the Universe.
It is also evidence for the idea that all the matter in the Universe was present at a single point

$$\frac{d}{v} = \frac{1}{H_0}$$

Note that, $\frac{d}{v}$ is the age of the universe, therefore we can say that:

$$\text{age} = \frac{1}{H_0}$$

Using this equation and the estimate of the hubble's constant (H_0) given above, we can calculate the age of the universe.

$$\text{age} = \frac{1}{H_0} = \frac{1}{2.2 \times 10^{-18}}$$
$$\approx 4.5 \times 10^{17} \text{ seconds}$$

One year has 365 days, one day has 24 hours, one hour has 60 minutes, and one minute has 60 seconds.

Using this information, we can calculate that one year has 31536000 seconds, or approximately 3.2×10^7 seconds.

So to calculate the number of years, we do the following:

$$\frac{4.5 \times 10^{17} \text{ seconds}}{365 \times 24 \times 60 \times 60}$$
$$\frac{4.5 \times 10^{17}}{3.2 \times 10^7}$$

which is equal to 14062500000 years, or approximately 1.4×10^{10} years.
and that in words is 14 billion years.

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