Pressure

Definition of Pressure

Pressure is defined as **force acting per unit area.**

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

where:

- ρ is the pressure (SI unit: pascal , Pa)
- F is the force (SI unit: newton, N), and
- A is the (contact) area (SI unit: square metre, m^2)

Note: $1 \pu{Pa} = 1 \pu{N/m^2}$

Transmission of Pressure in Hydraulic System

Submerge:

- A syringe that has a plunger with a small cross-sectional area,
- A syringe with a plunger with a large cross-sectional area, and
- A rubber tube

into coloured water.

Fill the smaller syringe completely with the coloured water. Squeeze any air bubbles out of the rubber tube. Leave the larger syringe cross-sectional areas unfilled.

Connect each end of rubber tubing to the nozzle of each syringe. Remove the set-up from the coloured water.

To move both plungers at a constant speed, either plunger may be pressed separately.

1. Compared to the force needed to be exerted on the plunger with the larger cross-sectional area, a smaller force needs to be exerted on the plunger with the smaller cross-sectional area
2. When the smaller plunger is moved by a given distance, the larger plunger moves by a shorter distance and vice-versa.

Pascal's Principle

When pressure is applied to an enclosed incompressible liquid, the pressure is **transmitted equally** to all other parts of the liquid.

Hydraulic Press

1. A force F_X is exerted on piston 1. The pressure exerted at point X is $\rho_X = \frac{F_X}{A_X}$
2. This pressure is transmitted equally to every part of the liquid, including to point Y.
3. A force, F_Y is applied onto the base of piston 2
4. Thus,

   $$\rho_X = \rho_Y \\ \frac{F_X}{A_X} = \frac{F_Y}{A_Y}$$

   Equivalently, $\frac{F_X}{F_Y} = \frac{A_X}{A_Y}$
5. Since $A_X < A_Y$, $F_X < F_Y$
6. Since the liquid is incompressible, the volume displaced at point X is equal to the volume displaced by point Y.

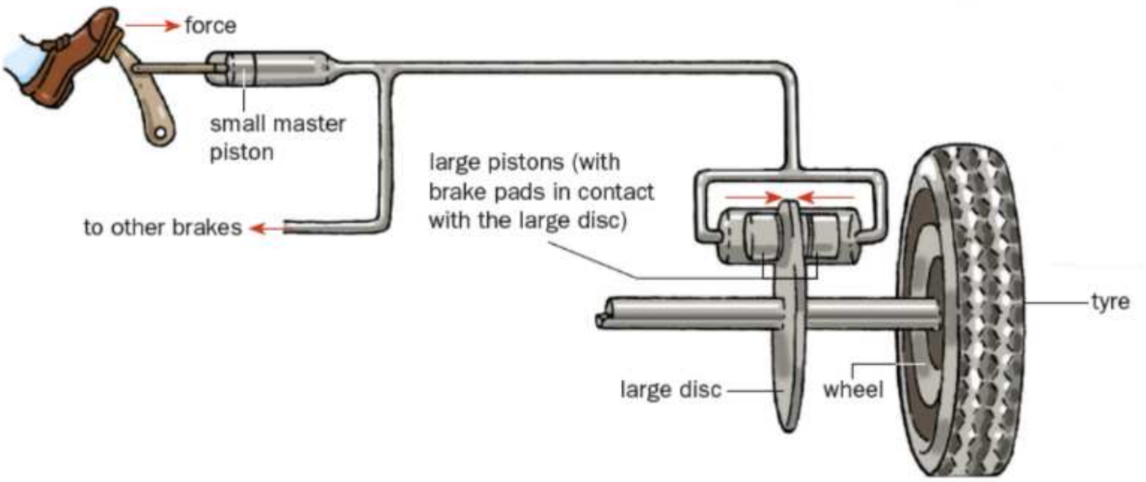
   $$V_X = V_Y \\ A_X d_X = A_Y d_Y$$

   Equivalently, $\frac{A_X}{A_Y} = \frac{d_Y}{d_X}$
7. Since $A_X < A_Y$, $d_X < d_Y$
8. To summarise, $\frac{F_X}{F_Y} = \frac{A_X}{A_Y} = \frac{d_Y}{d_X}$

Suggest why a hydraulic press does not work properly if the hydraulic liquid contains gas bubbles

A gas is compressible. Pressure will not be transmitted equally between the pistons.

Hydraulic Brake System



Each large piston exerts a force that is equal to the force exerted by the driver multiplied by the ratio of the cross-sectional area of the large piston to the cross-sectional area of the small piston.

$$\frac{F_{small}}{A_{small}} = \frac{F_{large}}{A_{large}}$$

$$F_{large} = F_{small} \times \frac{A_{large}}{A_{small}}$$

Density

Definition

Density is defined as mass per unit volume.

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

When an insoluble solid is placed in a liquid, the soild will:

1. **float** of its (average) density is **less than** that of the liquid.
2. **sink** of its (average) density is **greater than** that of the liquid.
3. be **suspended** of its (average) density is **equal to** that of the liquid.

Pressure due to a liquid column

Formula for liquid pressure

Consider a cuboidal liquid column of density ρ, base area A and a depth h. The atmosphere (of pressure p_0) exerts a downward force F_0 on the top of the liquid. There is an upward force F acting at the bottom surface of the liquid, which is at pressure ρ. The liquid column is in equilibrium and the gravitational field strength is at g.

1. $V = Ah$
2. $m = \rho \times V \times g = \rho Ahg$
3. weight, $W = m \times g = \rho Ahg$
4. Since the column is in equilibrium, by Newton's first law,
    - Upward force = sum of downward forces
    - $F = F_0 + W$
    - $pA = p_0A + \rho Ahg$
    - Dividing both sides of the equation by A
    - $\frac{pA}{A} = \frac{p_oA}{A} + \frac{\rho A h g}{A}$
    - $p = p_0 + \rho gh$
5. The pressure difference between the top surface and the base of the column is caused by the liquid column. Thus,
6. Pressure due to the liquid column = $p - p_0 = \rho gh$

The pressure due to a liquid column is:

$$p = \rho gh$$

where:

- p is the pressure due to the liquid column (SI unit: pascal, Pa)
- ρ is the density of the liquid (SI unit: kg/m^3)
- g is the gravitational field strength (SI unit: N/kg), and
- h is the **depth** (**not depth**) of the liquid column (SI unit: metre, m)

Note

- The pressure due to the liquid column does **not** depend on the shape, cross-sectional area and the volume of the container.

Pressure with atmospheric pressure in liquid column

$$p = p_0 + \rho g h$$

Barometer

A barometer is an instrument that can measure atmospheric pressure.

A long tube is completely filled with mercury. Then, it is inverted into a trough/reservoir that also contains mercury. Some mercury flows into from the tube into the reservoir, whereas the remaining mercury remains in the tube is supported by atmospheric pressure.

1. **Atmospheric pressure**, p_0, acts on the surface of the mercury in the **trough**.
2. The **vaccuum** exerts no pressure on the mercury in the tube.
3. The thick glass tube, which is about 1m long, contains mercury.
4. At point X, which is at the **same level** as the surface of the trough, the **mercury** exerts a **pressure, $\boldsymbol{p_X}$** , that **equals atmospheric pressure, $\boldsymbol{p_0}$** .
5. The **distance** h of between the mercury levels in the tube and the trough is measured with a metre rule.

Units of Pressure

- The pascal (Pa) is the SI unit of pressure

- 1 atm = $1.01 \times 10^5 Pa$
- 1m Hg (pronounced "one metre of mercury") is the pressure due to a 1-metre deep column of mercury. The density of mercury is 13 600 kg/m^3.
    - **Note:** 1m Hg (a unit of pressure) ≠ 1m (a unit of length)

Manometer

A manometer is an instrument used to measure the **difference** in the pressure of **liquids or gases.**

$\boldsymbol{p_{gas} > p_0}$	$\boldsymbol{p_{gas} < p_0}$
$p_{gas} = p_0 + \rho gh$	$p_{gas} + \rho g h = p_0 \\ p_gas = p_0 - \rho g h$

Light

Reflection

Laws of Reflection

1. The first law of reflection states that the **incident ray, reflected ray**, and the **normal** at the point of incidence all lie in the **same plane**.
2. The second law of reflection states that the **angle of incidence, *i*** is **equal** to the **angle of reflection, *r***.

Characteristics of an Image Formed by a Plane Mirror

1. It is **laterally inverted.**
2. It is the **same shape** and **same size** as the object
3. It is **upright**
4. It is **virtual**
    - A virtual image **cannot be formed on a screen**
    - (Real) light rays do not meet at the image position.
5. Its **image distance** from the mirror is the **same** as the **object distance** from the mirror.

Types of Reflection

- For **both** regular and irregular surfaces, the laws of reflection apply to each ray.

Regular Reflection

- On **smooth surfaces**, reflection is **regular**.
- Parallel incident rays have the same angles of incidence and refraction.
- The **reflected rays** travel in the same direction.

Irregular (Diffuse) Reflection

- On __rough / irregular surfaces, __reflection is **diffused**. (Sometimes, the roughness may not be detectable by the naked eye.)
- The normal at different points of the surface are not parallel to one another.
- Thus, even if the incident rays are parallel, they have different angles of incidence and reflection. The **reflected rays** travel in **different directions**.
- The overall diffused image is made up of many image points at different locations.

Refraction

- **Refraction** is the **bending** of light as it travels from one optical medium to another with a **different refractive index**.
- Refraction is caused by a **change in the speed of light** as light travels from one medium to another medium.
- **Normal** is an imaginary straight line that is perpendicular to the surface of the medium.
- **Angle of incidence (*i*)** is the __angle __between the **incident ray** and the **normal**
- **Angle of refraction (*r*)** is the **angle** between the **refracted ray** and the **normal**
- The **incident ray**, the **refracted ray**, and the **normal at the point of incidence** all lies in the **same plane**.

Static Electricity

Electric Charge

- Types of charges:
  - Neutrons
  - Protons
  - Electrons

- If electrons are removed , the atom becomes positively charged . - If electrons are added , the atom becomes negatively charged . - If the number of negative and positive charges are equal , the object is electrically neutral - An atom that is charged is called an ion

- The law of conservation of charge is one of the fundamental laws of Physics
  - The net charge of a closed system remains unchanged.
  - The net charge of a system is the algebraic sum of the charges while taking into consideration the positive and negative signs of the charges.

Interaction Between Charges

- Like charges repel
- Unlike charges attract

Measuring Electric Charges

- The SI unit of electric charge is the coulomb (C).

- The amount of charge carried by an electron is $1.6 \times 10^{-19} C$

Electrical Insulators and Conductors

- Objects around us can be classified into two broad categories:

1. electrical insulators
2. electrical conductors

	electrical insulators	**electrical conductors**
motion of charged particles	charged particles (electrons) are not free to move about	charged particles (electrons) are free to move about
ability to conduct electricity	low	high
method of charging	by friction (e.g. rubbing)	by induction
examples	glass, perspex, silk wool	copper, steel, fluids with mobile charged particles

Electrostatic by Friction

- Some materials like silk and glass, gain static charges when they are rubbed together

Example:

- When the glass rod and silk cloth are rubbed together, electrons move from the glass rod to the silk cloth.
- The glass rod loses electrons and becomes positively charged.
- The silk cloth gains electrons and becomes negatively charged.
- The electrons transferred are not able to move freely in the silk cloth.
- They remain at the surface where the silk cloth was rubbed.
- Materials in which the electrons do not move freely are called insulators.

- Insulators are charged by friction (e.g. rubbing)
- Different materials have different affinities to electrons. Some attract electrons weakly, while others attract electrons strongly.

Electrostatic Charging by Induction

- Conductors cannot be charged by friction because mobile electrons can be easily transferred to and away from conductors.
- Metallic conductors can be charged by induction in which a conductor is charged without contact with the charging body.

Method 1: Charging two metal

1. Two metal spheres (conductors) on insulating stands are placed side by side.

- They are touching each other.

1. A negatively-charged rod is brought near, but not touching, sphere A. Like charges repel.

- Electrons in both spheres A and B are repelled to the far end of sphere B.
- sphere A has excess positive charges,
- while sphere B has excess negative charges.

1. While holding the negatively charged rod in place (near sphere A), move sphere B away from sphere A.
2. The charged rod is removed.

- Sphere A is now positively charged and sphere B negatively charged.
- Spheres A and B have an equal number of opposite charges.
- Both spheres have been charged by induction.

1. When the charged rod is removed *before* the two spheres are moved apart,

- The electrons will be redistributed in sphere A and B and both will become neutral again.

Method 2: Charging a single conductor by induction

1. A positively charged rod is brought near, but not touching, a metal conductor on insulating stand.

- The electrons in the conductor are drawn (attracted) towards the end near the positively-charged rod.

1. Without removing the positively-charged rod, the positively charged end of the conductor is earthed by touching it with a person's hand.

- Free electrons move from earth to the conductor through the person.
- This neutralises the positive charges on the end of the conductor.

> 💡 Earthing is a process which a conducting path is connected from a conductor to earth. This allows electrons to either flow into or out of the conductor. Earth refers to a large body of charge that remains electrically neutral regardless of the amount of charge that is added or removed from it.

1. When the charged rod is removed before the earthing process is stopped,

- The excess electrons in the conductor will flow to the earth and discharging occurs. The conductor will then become electrically neutral.

Neutralising/Discharging a Charged Insulator

- A charged object is neutralised by discharging the excess charges on it.

Discharging through heating

- The heat from the flame ionises the surrounding air particles.
- For a positively-charged glass rod, the ions neutralise the excess charges on the glass rod.

Discharging due to humid conditions

- Water molecules in air are electrical conductors
- For a negatively charged insulator, excess charges are transferred to the water molecule.

Neutralising / Discharging a Charged Conductor

- A charged conductor can be discharged through earthing
- When we earth a charged conductor, we provide a path (usually lower resistance and connected to the earth) for
  - excess electrons to flow away from the charged conductor, or
  - electrons to flow to the charged conductor if it has excess positive charges

Hazards and Applications of Electrostatics

Hazards of Electrostatics

1. **Lightning**

- The clouds are **charged by friction** between water molecules in the clouds and air molecules in the atmosphere.
- **Negative charges** accumulate at the **bottom** of the clouds.
- These **repel** the **electrons** near the surface of the earth, causing the **surface** of the Earth to be **positively charged**.
- When the accumulation of charges is large, the **air particles** are **ionised**.
- The **ionised air particles** provide a **conducting path** for the electrons in the clouds to reach the Earth.
- When the **electrons travel down** the conducting path to the Earth, **lightning** forms.

1. **Electrostatic discharge**

- Excessive charges may build up on objects due to **friction**
- Electronic equipment, such as computer boards and hard drives, can be easily damaged by electrostatic discharge.
- Such equipment is usually packed in **antistatic packaging**.

1. **Electrostatic discharge of vehicles**

- Electric charges can accumulate on trucks due to **friction** between
    - the road and the rotating tyres of the truck
    - the moving air molecules and the body of the truck
- When a **sudden discharge** occurs, this may cause **sparks** and **ignite** any flammable items that the truck might be carrying.

- Gas tankers are equipped with a **metal chain** at the rear end hanging/touching near to the **ground** to provide an **earthing path** for excess charges.
- During refueling, the gas tankers are also connected to an earth source to prevent static charges from accumulating on the body of the gas or fuel tanker.

Applications of Electrostatics

Photocopiers

- Photocopiers make use of static electricity to produce copies of documents.

1. The metal drum inside the photocopier is coated with **selenium**.

- Selenium is a **photoconductor** (light-sensitive semiconductor). It only conducts electricity in the presence of light. When no light shines on the selenium, it is a good insulator.
- The selenium coating on the drum is initially in the dark. Behaving as an insulator, it can be electrically charged. When the selenium is illuminated, it becomes conducting wherever light falls on it.
- The drum's surface is charged **positively** by a charged wire.

1. The original image to be photocopied is placed on a sheet of clear glass above the drum.

- An intense light beam is shone onto the image.
- The **darker** areas of the image reflect less light and therefore, the corresponding regions on the drum remain **positively** charged.
- The regions on the drum corresponding to the **lighter** areas conductive. Electrons from the surroundings, which are attracted to these regions, discharge them.

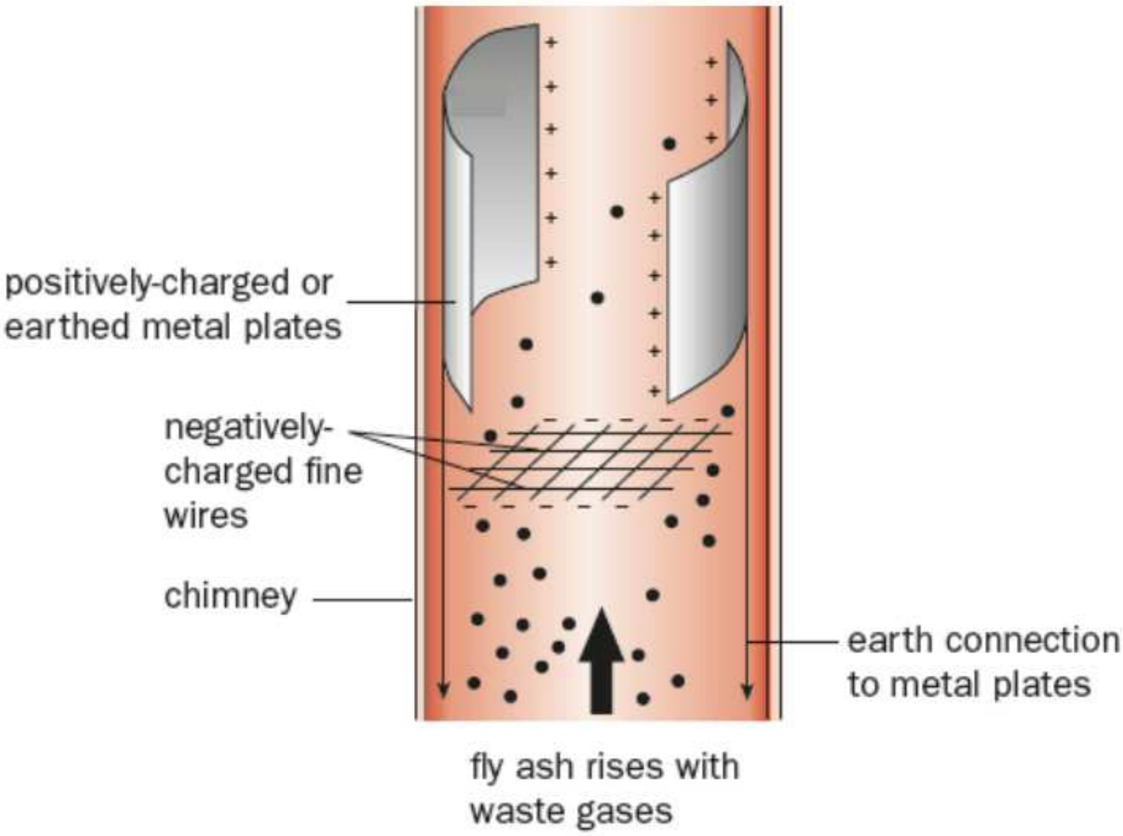
1. The drum continues turning, and the positively-charged image on the drum attracts the **negatively-charged** toner powder.

2. A **positively-charged** sheet of paper is passed over the drum's surface.

- The paper attracts the **negatively-charged** toner and the image is formed on the paper.
- The paper is heated and pressed to fuse the toner powder to the paper permanently.

Electrostatic Precipitator

- The electrostatic precipitator is used to remove fly ash from the exhaust of a chimney.



Removing fly ash from the exhaust gas

The fly ash (smoke and dust particles) is passed through a negatively charged wire grid making the particles to become negatively charged. The negatively charged particles are passed through positively charged or earthed plates which attract the negatively charged particles. Hence, air emitted into the atmosphere is cleaner. The fly ash are collected and used in making cement.

Spray Painting

- The electrostatic spray painter is used to provide an even coat on the part to be painted.

Even Coating

As the paint leaves the nozzle, the droplets are charged by friction. These made all the paint droplets to have the same charge and repel each other. Hence, they spread out evenly. Less paint is needed because the charged droplets are all attracted to the object (neutral or positively charged).

Electromagnetism

Magnetic Effect of a Current

Properties of the Magnetic Field of a Current-carrying Conductor

- A current-carrying conductor produces a **magnetic field** around it.

Methods to Determine the Magnetic Field Around The Wire

1. Grip the wire with your right hand such that your thumb points in the direction of current flow.
2. The direction in which your fingers curl indicates whether the magnetic field is clockwise or anticlockwise.

Symbols

- **Dot** at the middle shows wire carrying current **out** of the wire
- **Cross** at the middle shows wire carrying current **into** of the wire

Properties

- Magnetic fields of a long, straight current-carrying conductor are represented by **concentric circles** which are centered at the conductor itself.
- The **closer** the field lines, the **greater**, the magnetic field strength (or the **stronger the magnetic field**)

Factors affecting Magnetic Field Strength of a Solenoid

- A solenoid is a coil of insulated wire coiled into a cylinder shape.
- The magnetic field of a solenoid resembles that of a bar magnet.
- The **Right-hand Grip Rule** can be applied to the solenoid to determine the direction of the magnetic field inside the solenoid.
    - Curl your **fingers** around in the direction of the **current** flow.
    - Your **thumb** will point to the **North** pole.

Factors that affect the strength of an electromagnet.

The magnetic field strength of a solenoid can be increased by:

1. Increase the magnitude of the **current**
2. Increase the **number of turns on the solenoid**, or
3. Placing a soft iron core within the solenoid to concentrate the magnetic field lines.

Note: The magnetic field strength **inside** the solenoid is stronger than the magnetic field strength outside the solenoid.

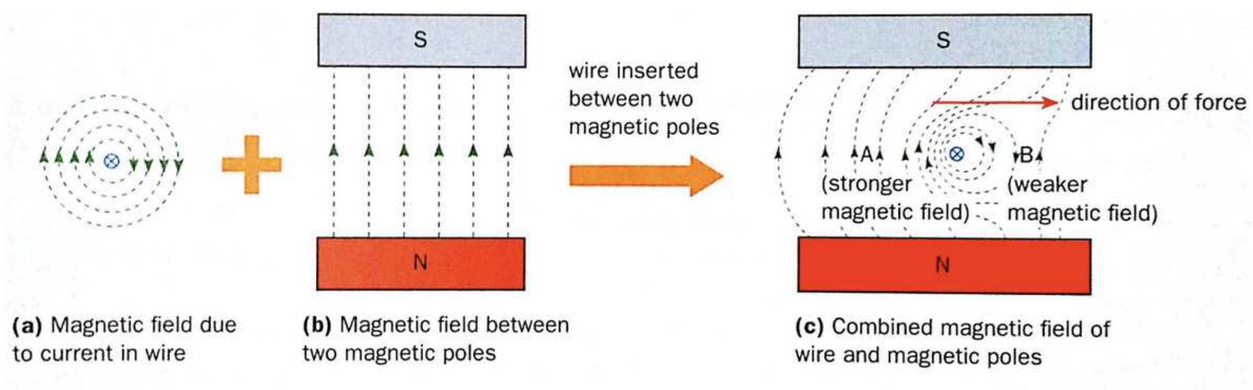
Force on a Current-carrying Conductor (Lorentz Force)

Cases	**Observations**
Spacing Between Magnets (Field Strength)	The wire gets a larger force when the spacing decreases (magnetic field gets stronger)
Reversing Current Flow Direction	The wire gets a force in the opposite direction when direction of the current is reversed.
Reversing Magnetic Field Direction	The wire gets a force in the opposite direction when direction of the magnetic field is reversed.

Conclusion

The **magnetic force** produced on the current-carrying wire:

1. **Increases** when the **magnetic field** gets **stronger**
2. **Reverses** in direction when the direction of the **electric current** is **reversed,** and
3. **Reverses** in direction when the direction of the **magnetic field** is **reversed**



- The diagram shows how the magnetic fields, produced by a current-carrying wire and a pair of magnets, interact with each other.
- There is a stronger magnetic field on the one side of the wire at A. All the magnetic field lines at A act in the same direction.
- There is a weaker magnetic field on one side of the wire at B. The magnetic field lines of the current carrying conductor act in the opposite direction of that of the magnet.
- The **interaction** between the **current flowing in the conductor** and the **external magnetic field** produced a **force acting on the conductor.**
- The direction of the force acting on the conductor can be determined by Fleming's left hand rule.

Fleming's Left Hand Rule

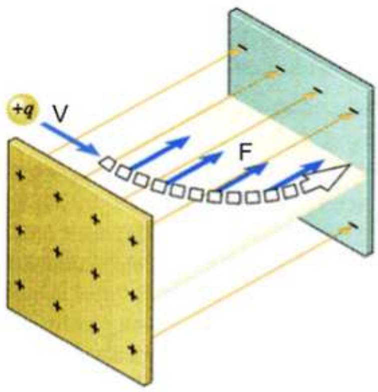
- Fleming's left-hand rule is used to find the direction of force when the direction of magnetic field and conventional current are known.
- The first three fingers are positioned at **right angles** to each other.

1. Thumb: **Force** on conductor
2. First finger: **Field** (magnetic field)
3. Second finger: Conventional **Current**

Force on a Moving Charge in a Magnetic Field

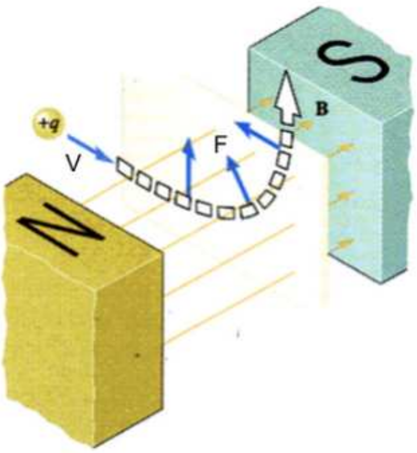
- Fleming's left-hand rule can be applied to all **moving charges.**
- **NOTE:** For a beam of **charged particles** (e.g electrons or protons), we need to follow the direction of the **conventional current**, which is **opposite in direction to the motion of negative charges.**

Electric Force on Positive Charge



Electric force is parallel to the plane of the electric field.

Magnetic Force on Positive Charge



Magnetic force is perpendicular to the plane of the electric field.

- While an electric force is always exerted on a charge within an electric field, a magnetic force is only exerted on a charge within a magnetic field if it is **moving.**
- For a **stationary** charge within a magnetic field experiences **zero magnetic force.**
- For a **moving charge**, the direction of the force acting on the charge is perpendicular to the direction of travel.
- The **moving particle** is deflected in a **circular path** towards the centre of the circle.

The DC Motor

- A DC motor converts **electrical energy** into **mechanical energy**.
- A DC motor consists of the following components.
  - **Rectangular coil** connected in series to a battery and rheostat.
  - **Permanent magnets**

    - **Split-ring commutator**
        - The ends of the coil are **fixed** to the split-ring commutator
    - **Two carbon brushes**
        - The carbon brushes rub against the commutator and keep the coil connected to the battery.

When the switch is closed, current will flow through the (rectangular) **conducting coil.**

The sides of the coil lie in between two **permanent magnets**.

Forces are produced on the current-carrying wires of the coil as the magnetic fields interact, which cause the coil to rotate about its axle

The ends of the rotating coil are connected to two halves of a copper ring known as the **split ring commutator** and they **rotate together with the coil.**

Electric current is passed from the circuit to the two halves of the copper ring via two separate **carbon brushes**.

The rheostat is used to control the **amount of current in the coil**, which affects the **strength of magnetic forces** produced on the sides of the coil, the amount of the moment of these forces about PQ and hence the **rotational speed** of the coil.

How it Functions

- When an electric current flows through the coil ABCD, a **backward force is produced on side AB and an upward force on side CD** (using Fleming's left-hand rule).
    - This causes the coil to **rotate anticlockwise** about axis PQ.
- But when the rotating coil reaches **vertical position**, the split ring commutator (X and Y) **loses contact with the carbon brushes**, causing the current to be **cut off** and the forces to **disappear.**
- However, the **inertia** of the rotating coil keeps it rotating and the commutator to make contact with the brushes again but in the reverse manner.
- This **reverses the current direction in the coil**, and consequently side **AB now gets an upward force** while **CD gets a downward force.**
- This allows the coil to continue rotating in the same anticlockwise direction.

Total Moment

- The **total moment of the magnetic forces** and the **rotational speed** can be **increased by**:
    - **Increasing** the magnitude of the **current** in the coil.
    - Increasing the __number of turns __on the coil.
    - Inserting a **soft iron core** into the coil.
    - Using a **stronger** magnet.

Electromagnetic Induction

Electricity and Magnetism

Laws of Electromagnetic Induction

Faraday's law of electromagnetic induction

The magnitude of the electromotive force (e.m.f) induced in a closed circuit is directly proportional to the rate of change of the magnetic flux linkage through the area bounded by the circuit.

- Thus, the magnitude of the electromotive force (e.m.f) induced in a conductor is directly proportional to the rate at which magnetic field lines and the conductor cut each other.
- If the conductor is part of a closed circuit, the induced e.m.f produces an induced current through the conductor.

Lenz's Law

The direction of the induced electromotive force (and hence the direction of the induced current in a closed circuit) is such that its magnetic effect opposes the motion or change producing it.

- If the conductor is part of a closed circuit, the induced current produces induced magnetic poles that oppose the cause of the induced emf.

Electromagnetic induction when magnetic field strength changes

Faraday's experiments demonstrate electromagnetic induction by moving a pole of a magnet moves nearer or further away from a solenoid, such that magnetic field lines cut through the solenoid.

Case 1: S moves towards solenoid

1. The South pole of the magnet moves towards the solenoid
2. (By Faraday's law of induction,) the changing magnetic flux linkage through the solenoid (or the magnetic field lines cutting the solenoid) induces an e.m.f in the solenoid.
3. Since the circuit is closed, the induced e.m.f produces an induced current.
4. By Lenz's law, the magnet is repelled by the south pole induced on the right of the solenoid produced by the clockwise induced current when viewed from the right (using the right hand grip rule) that flows from B to A.

Case 2: N moves toward solenoid

1. The **north** pole of the magnet moves **toward** the solenoid.
2. (By Faraday's law of electromagnetic), the **changing magnetic flux linkage** through the solenoid (or the magnetic field lines cutting the solenoid) **induces** an **e.m.f** in the solenoid.
3. Since the circuit is **closed**, the induced e.m.f produces an **induced current.**
4. By Lenz's law, the magnet is repelled by the **north pole induced on the right** of the solenoid produced by the **anticlockwise induced current** when viewed from the right (using the right-hand grip rule) that flows from A to B

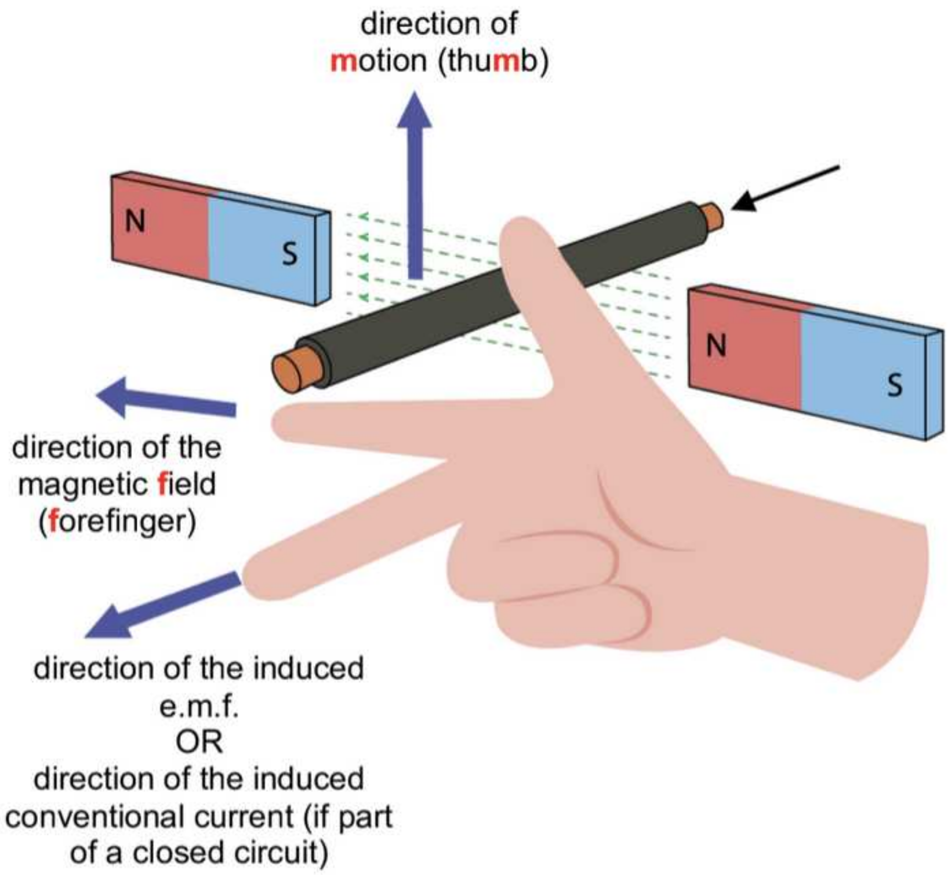
Case 3: S moves away from solenoid

1. The **south** pole of the magnet moves **away from** the solenoid.
2. (By Faraday's law of electromagnetic induction,) the **changing magnetic flux linkage** through the solenoid **induces** an **e.m.f.** in the solenoid.
3. Since the circuit is **closed,** the induced e.m.f. produces an **induced current.**
4. By Lenz's law, the magnet is attracted by the **north pole induced on the right of the solenoid** produced by the **anticlockwise induced current** when viewed from the right (using the right-hand grip rule) that flows from A to B.

Motional e.m.f. induced on a conductor moving through a magnetic field

When a conductor moves perpendicular through a magnetic field, an e.m.f. is induced on the conductor.

Fleming's right hand rule (for generators) shows the direction of the **induced e.m.f.**



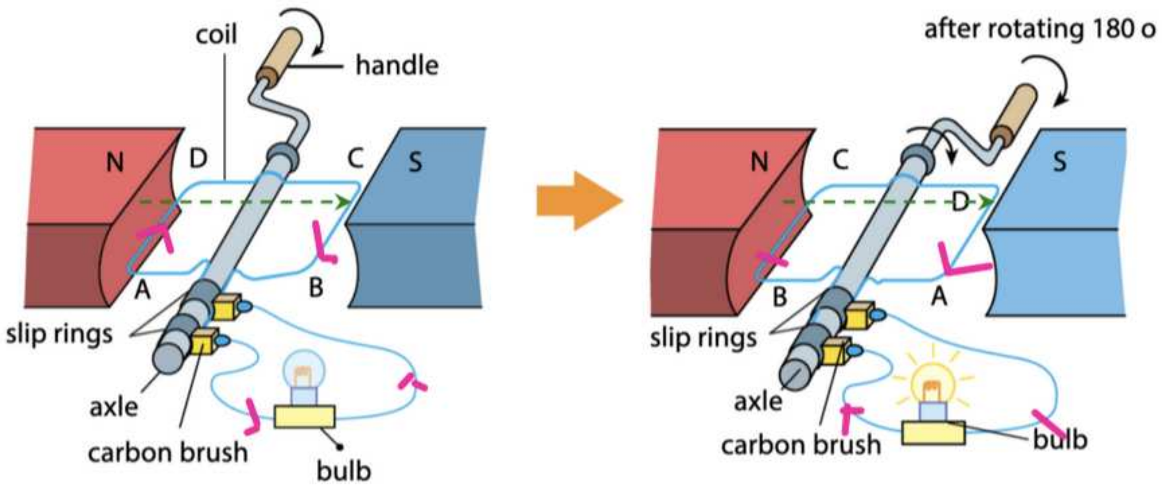
If the conductor is part of a **closed** circuit, the induced e.m.f. produces an **induced current** through the conductor.

Alternating Current (a.c.) Generator

As work is done to turn an a.c. generator, energy is transferred electrically by the alternating current to the connected electrical load, e.g.

- Simple rotating coil a.c. generator
- Simple rotating magnet a.c. generator

Simple Rotating Coil A.C. Generator



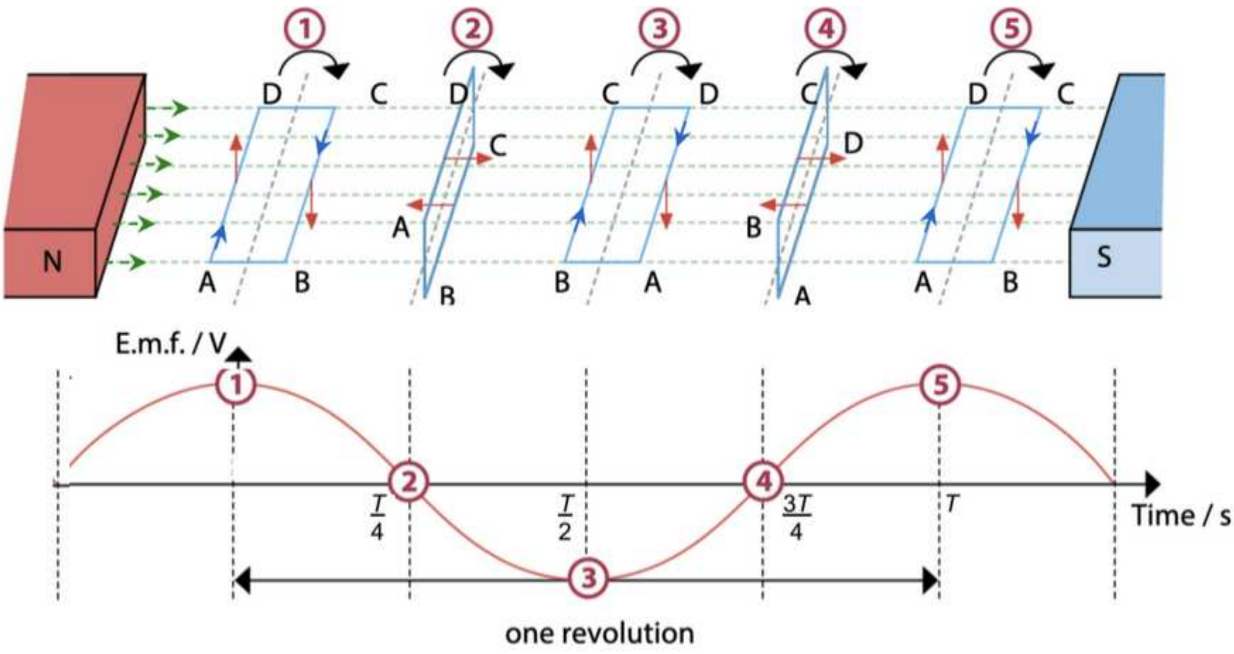
1. The coil is rotated by turning the handle
2. As the coil rotates between the two magnets, the **magnetic flux linkage** through the coil changes at a non-constant rate. (The coil **cuts the magnetic field lines** at a non-uniform rate)
3. By Faraday's law of electromagnetic induction, an **e.m.f** is **induced** in the rotating coil. Fleming's right hand rule tells us the direction of the induced e.m.f. in sides AD and BC.
4. In the **closed** circuit, the **induced alternating current** flows through the coil, the 2 slip rings, the carbon brushes and the bulb.

Function of the 2 Slip Rings

The 2 slip rings maintain **continuous electrical contact** between the rotating **coil** and the **external circuit** via the **carbon brushes**, so that the **induced current flows** through the closed circuit.

Graph of e.m.f output against time for a simple rotating coil a.c. generator

- The direction of the **induced current** through the coil **reverses every half turn** (alternating current)



The **maximum** induced e.m.f of an a.c generator can be **increased** by increasing the rate at which the coil cuts the magnetic field lines, e.g. by

1. increasing the **number of turns** of the coil
2. increasing the **magnetic field strength** (e.g. stronger magnets)
3. increasing the **speed of rotation** of the coil.
4. winding the coil on a **soft iron core** (to strengthen the magnetic field through the coil)

The **maximum induced current** can be **increased** by increasing the induced e.m.f or by **decreasing the resistance** of the coil.

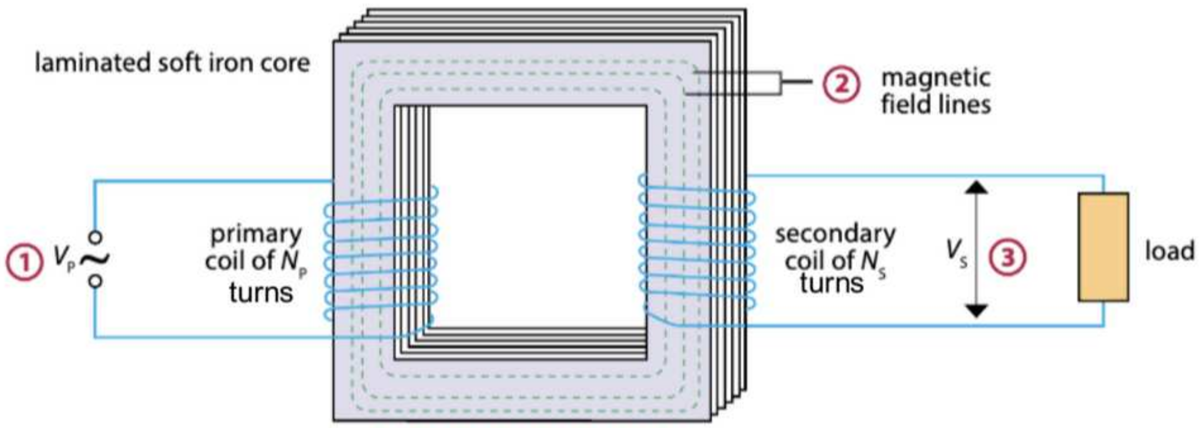
- **Doubling** the **number of turns** of the coil (without changing its frequency of rotation and the magnetic field strength) **doubles the maximum** induced e.m.f
- **Doubling** the **frequency of rotation** (i.e. halving the period) of the coil (without changing its number of turns and the magnetic field strength)
  - **doubles the maximum induced e.m.f** and
  - **doubles the frequency** (i.e. halves the period) of the induced e.m.f.

Transformers

A transformer is a device that can change a large alternating voltage (with a small current) to a small alternating voltage (at large current) and vice versa.

- A transformer does **not** work on direct current (d.c.)

Structure of a Transformer



1. The **alternating input voltage** $\boldsymbol{V_P}$ produces an **alternating current** $\boldsymbol{I_P}$ through the primary coil.
2. Current I_P produces an **alternating magnetic field** (which alternately increases and decreases in strength).
3. The **laminated soft iron core directs** the alternating **magnetic field** produced by the primary coil **toward** the **secondary coil.**
4. By Faraday's law of electromagnetic induction, the **changing magnetic flux linkage** through the secondary coil **induces** an **alternating output voltage** $\boldsymbol{V_S}$ in the secondary coil.
5. Since the secondary coil is part of a **closed** circuit, the alternating output voltage V_S produces an **alternating current** $\boldsymbol{I_S}$ through the secondary coil and the load.

Function of the laminated soft iron core

- The **core directs** the alternating **magnetic field** produced by the primary coil **toward** the **secondary coil**.

- **Iron**, a **soft magnetic material**, is chosen because it **magnetises and demagnetises quickly** in the presence of the alternating magnetic field produced by the primary coil.

Lamination

- However, the changing magnetic field produced by the primary coil also induces __eddy currents __that flow in little loops through the core.
- Some **energy** is **wasted** is being transferred to the **internal** (thermal) **store** of the core.
- A **laminated** soft iron core is made up of thin sheets of soft iron electrically insulated from each other (e.g. by coats of lacquer) reduces the path lengths of these eddy currents, and this **reduces** this unwanted **wasted energy**.
- The transformer allows the alternating input voltage, V_P, and the alternating output voltage V_S to differ, by having a **different number of turns** in the **primary and secondary coils**.

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

Efficiency of Transformer

$$\eta = \frac{P_S}{P_P} \times 100\% = \frac{V_SI_S}{V_PI_P} \times 100\%$$

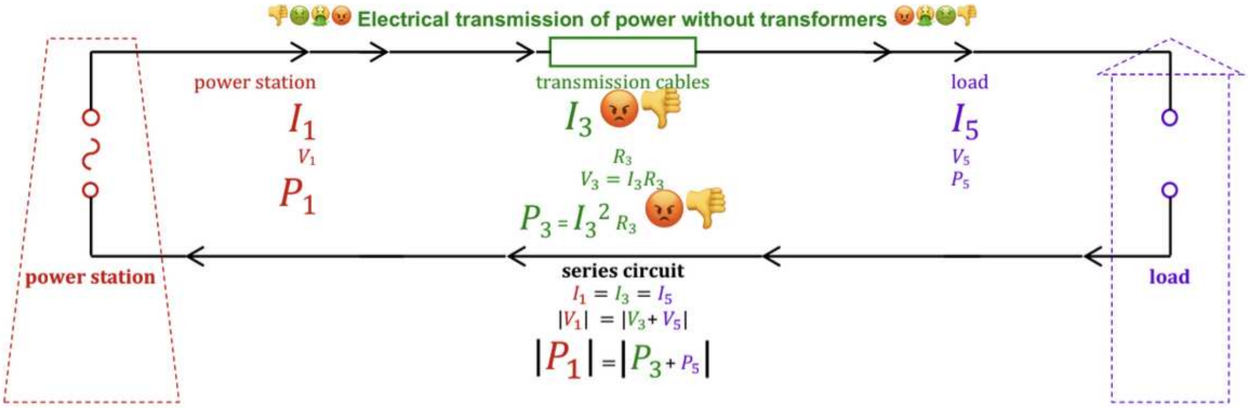
Ideal Transformer	**Non-ideal Transformer**
efficiency $\eta = 100$	efficiency $\eta < 100$
$\frac{V_SI_S}{V_PI_P} = 1$	
$\frac{I_P}{I_S} = \frac{V_S}{V_P} = \frac{N_S}{N_P}$	

For a **non-ideal** transformer, energy is wasted due to:

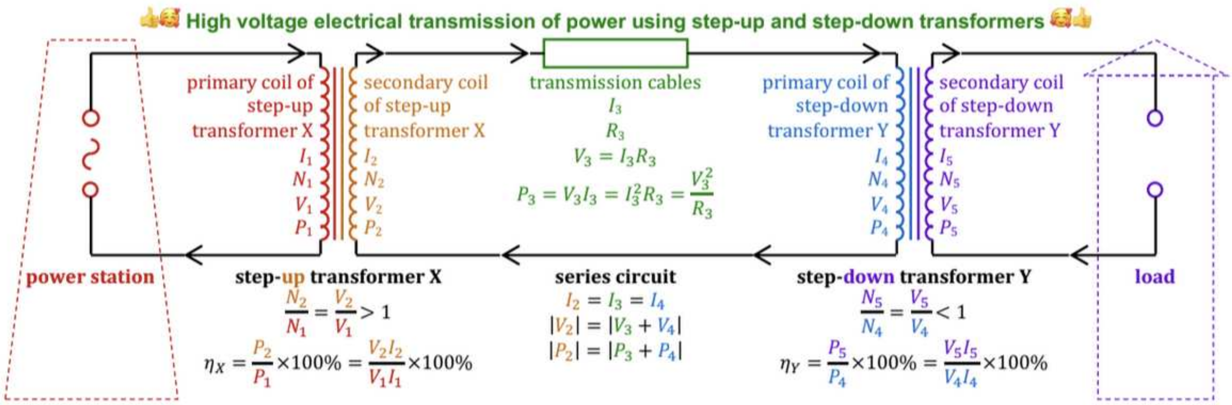
1. Energy being transferred to the internal stores of the coils when current flows through them, since the **coils** have some **resistance**.
2. Energy being transferred to the internal store of the core when **eddy current** flows through the core, since the **core** has some resistance

3. **leakage** of **magnetic field** lines between the primary and secondary coils.
4. **hysteresis loss** caused by the **flipping of the magnetic domains** in the core due to the alternating magnetic field produced by the primary coil. Energy is transferred to the internal store of the core.

High Voltage Electrical Transmission of Power



1. Since the length L_3 is large, the resistance of the power cables, $R_3 = \frac{\rho_3L_3}{A_3}$ is significant.
2. Increasing the cross-sectional area A_3 of the transmission cables is impractical as thick cables are very expensive, heavy and difficult to suspend
3. To reduce the power $P_3 = I_3{}^2R_3$ wasted (transferred electrically to the internal stores of the transmission cables), the current I_3 through the transmission cables should be minimised.



High voltage electrical transmission of power reduces current I_3 through the transmission cables, and thus reduces the power $P_3 = I_3^2R_3$ wasted (transferred electrically to the thermal stores of the transmission cables)

1. Near the power station, transformer X steps up the voltage from V_1 to $V_2 > V_1$

2. Since the output power of the secondary coil of transformer X is $P_2 = V_2I_2$, a small current:

   - $I_2 = \frac{P_2}{V_2}$
   - flows through the secondary coil of transformer X

3. Since the secondary coil of transformer X, the transmission cables and the primary coil of transformer Y are connected in series, the same **small current** flows through the transmission cables and the primary coil of transformer Y

   $$I_{transmission} = I_2 = I_3 = I_4 = \frac{P_2}{V_2}$$

4. The power wasted (transferred electrically to the internal stores of the transmission cables)

   $$P_3 = I_3^2R_3 = \left(\frac{P_2}{V_2}\right)^2R_3$$

   is minimised.

5. By the conservation of energy, the more power $P_4 = P_2 - P_3$ is transferred to the primary coil of transformer Y.

6. In the series circuit, the voltage across the primary coil of transformer Y is $V_4 = V_2 - V_3$

7. Before consumption, transformer Y steps down the voltage from V_4 to $V_5 < V_4$

8. A.C generators are used in the production of power to be transferred electrically. If **D.C** generators are used, voltages **cannot** be **stepped up** or **down** by transformers.

Radioactivity

Composition of an Atom

- An atom is very tiny and typically has a size of **$1 \times 10^{-10} \pu{m}$**.
- It is made up of **subatomic particles** such as protons, neutrons and electrons.
- An atom consists of a positively charged nucleus and negatively charged electrons moving around the nucleus.
- The nucleus of an atom consists of two types of particles - protons and neutrons.
- Strong attractive electrostatic forces between the positively charged nucleus and negatively charged electrons hold the electrons to the atom.

Proton (atomic) Number Z.

- The **proton number *Z*** is the number of protons in an atom.
- The proton number is also known as the **atomic number**.
- In a neutral atom, the number of protons is the same as the number of electrons.
- Each element has a unique proton number.

Nucleon (Mass) Number A

- Proton and neutrons are called **nucleons**.
- The **nucleon number** is the total number of neutrons and protons in the nucleus of an atom.
- The symbol *A* is used to represent the nucleon number of an element.
- The nucleon number is also known as the **mass number.**
- The mass of an atom depends on the mass of nucleons in the nucleus of the atom as the mass of an electron is very small and thus negligible.
- To find the number of neutrons in an atom,

Number of neutrons

$$= A - Z$$

- Note that in nuclear physics and nuclear chemistry, the various species of atoms whose nuclei contain a particular number of protons and neutrons are called **nuclides.**
- The nucleus of an atom can be represented by the **nuclide notation:**

$$\ce{^{A}_{Z}X}$$

Isotopes

- **Isotopes** are atoms of the same element that have the same number of protons but different numbers of neutrons.
- Isotopes of the same elements have *identical* chemical properties.
- Example: carbon isotopes

Nuclear Decay

- **Nuclear decay** is also known as radioactive decay or radioactivity.
- Nuclear decay is a random process by which an unstable atomic nucleus loses its energy by emission of electromagnetic radiation or particle(s).
- The radiation emitted by a radioactive nucleus is *spontaneous* and *random* in direction.
    - Spontaneous decay means that the decay is not affected by environmental changes (e.g. temperature and pressure.)
    - Random decay means that the decay cannot be predicted which particular nucleus will decay next.
- A material containing unstable nuclei is considered radioactive.
- The instability of the atomic nuclei is because the nuclear forces within the nuclei are not enough to bind the nucleons together.
- Since the direction of the emissions and the time between emissions cannot be predicted, hence it is:
    - not possible to make the radioactive nucleus emit radiation by heating, cooling, chemical means or any other method;

    - not possible to predict when a radioactive nucleus will emit radiation; and
    - not possible to know the direction in which the emitted radiation will leave a nucleus.

Types of Nuclear Emission

There are three types of nuclear emission: **alpha (α) particles, beta (β) particles and gamma (γ) rays.** Different nuclear emissions have different compositions, ionising effects and penetrating abilities.

Ionisation refers to the ability to eject electrons from atoms to form positively charged cations. Since the atoms lose electrons, the number of protons is greater than the number of electrons. Thus, ions carry a charge. The nuclei of the same isotope will emit the same type of nuclear radiation. During alpha decay or beta decay, the nucleus changes to that of a different element.

Alpha Decay

- When a radioactive nucleus undergoes alpha decay:
    - it emits an alpha particle (identical to helium nucleus $\ce{^4_2He}$)
    - the nucleon number A decreases by 4
    - the proton number Z decreases by 2
- A **nuclide equation** involving nuclide notation can be used to represent the changes in the composition of the nucleus. The arrow in the equation means "reacts to form".

Example: Radium-226 (Ra) nucleus emits an alpha particle and decays to radon-222 (Rn).

$$\ce{^{226}_{88}Ra -> ^{222}_{86}Rn + ^4_2He}$$

Note that in a nuclear reaction, the **mass and charge are conserved.** Hence, before and after the reaction,

- The total number of neutrons and protons remain constant, and
- The total relative charge should also be the same (i.e. sum of proton number before and after decay should be the same.)

Beta Decay

- When a radioactive nucleus undergoes ß-decay:
  - it emits a ß-particle (an electron); and
  - the nucleon number A remains the same
  - the proton number Z increases by 1

Example

$$\ce{^{238}_{92} U -> ^{234}_90 Th + ^4_2He + 2 ^0_0\gamma}$$

Gamma Radiation

- Usually, when radioactive nuclei undergo alpha-decay or beta-decay, gamma radiation is also emitted.
- Example: When uranium-238 (U) emits an alpha particle, it decays to thorium-234 (Th) and two gamma rays of different energies are emitted.

$$\ce{^{238}_{92}U -> ^{234}_90 Th + ^4_2 He + 2 ^0_0 \gamma}$$

Measuring Ionising Nuclear Radiation

A **Geiger-Muller (GM) counter** is an instrument used to measure ionising nuclear radiation.

The SI unit for the amount of radioactivity is the **Becquerel (Bq)**. One becquerel (1 Bq) is equal to 1 disintegration per second. It refers to the amount of ionising radiation released when a radioactive atom (e.g. uranium) spontaneously emits electromagnetic radiation as a result of the radioactive decay.

Alternative unit: count rate: counts per second or minute

Why is ionising radiation still detected even if radioactive sources aren't brought into the environment?

Background radiation from natural or man-made sources is always present. These sources include cosmic radiation from outer space, nautrally occurring radioactive isotopes, man-made radioactive isotopes, radioactive waste from nuclear power stations, and so on.

How would this affect our results when measuring radioactivity from a radioactive substance?

In general, the results collected will not present an accurate account of the radioactivity of the substance being measured, since the radiation detected comes form the radioactive substance being investigated, as well as background radiation.

Suggest what could be done to get a more accurate account of the radioactivity of the substance being investigated.

The background count should be measured and subtracted from the total count.

Background Radiation

Background radiation refers to nuclear radiation in an environment where no radioactive source has been deliberate introduced.

Radiation is all around us. For example, we have learned in Unit 11 Electromagnetic Spectrum that the visible light and infraerd radiation are electromagnetic radiation from the sun. The microwaves and the radio waves are radiation used in communication systems. These are non-ionising radiation, thus they have little biological effect.

Ionising radiation is radiation with high energies that can knock off electrons from atoms to form ions. For example:

- Ionising electromagnetic radiation: Very high frequency ultraviolet rays, X-rays and gamma rays.

- Ionising nuclear radiation: Highly energetic particles from cosmic rays (from outer space) and from naturally occurring radioactive materials

Sources of background radiation that can be artificial (man-made) or natural:

Artificial Sources

- Medical X-rays
- Building materials
- Waste products from nuclear power stations

Natural sources

- Rocks
- Radon gas in the air
- Food and drink (e.g. food high in potassium such as bananas, carrots and salt may contain radioactive potassium-40).

Natural background radiation accounts for about 80% of the radiation that we are exposed to. The amount of background radiation we encounter is usually well below the recommended limit of radiation exposure.

Half-Life

- Since nuclear decay is spontaneous, we will not know exactly when a particular nucleus will decay.
- Every nuclide has a fixed rate of decay. The **half-life** of a radioactive nuclide is the time taken for half the nuclei of that nuclide in any sample to decay.
- Predictions about the decay of a large number of nuclei of a particular nuclide can be made because it has a fixed half-life.

Nuclear Fission and Nuclear Fusion

Nuclear Fission

- **Nuclear fission** is a process in which a **parent nucleus** splits (usually into two **daughter nuclei**) and releases a huge amount of energy.
- The original parent nucleus becomes nucleus of two different elements.
- The daughter nuclei may be stable or may decay further
- There may be several possible fission products and it is important to check that the total number of nucleons and the total relative charge (proton number Z) before and after the reaction are the same.

Nuclear Fusion

- **Nuclear fusion** is a process in which two light atomic nuclei combine to form one heavier atomic nucleus and releases a huge amount of energy.
- Two atoms join to become another bigger atom of a different element.

Energy Changes During Nuclear Processes

- Nuclear fuel is a material used in nuclear power stations.
- Some examples of nuclear fuel are uranium and plutonium. Isotopes such as uranium-233, uranium-235 and plutonium-239 are commonly involved in nuclear fission.
- The nuclear fuels undergo nuclear reactions to release energy
- During **nuclear fission**, energy is transferred form the **nuclear store** of the unstable nucleus to:
    - the **kinetic** and **nuclear stores** of the daughter nuclei and neutrons
    - the **internal store** of the surroundings
- The internal store of the surroundings is used to heat the water so that it changes into steam.
- The neutrons produced in the nuclear fission will go on to split more nuclei.

- This creates a self-sustaining chain reaction taht is controlled in a nuclear reactor.
- The processes involved in mining, refining, purifying, using and disposing of nuclear fuel are collectively known as the nuclear fuel cycle.
- Energy can also be released from **nuclear fusion.**
- During nuclear fusion, energy is transferred from the **nuclear stores of the two nuclei to**:
    - The **kinetic** and **nuclear store** of the bigger nucleus.
    - The **internal store** of the surroundings.
- The internal store of the surroundings can be used in the electical power generation process.
- A lot of work is done to overcome the repusive forces between the positively charged nuclei during nuclear fusion
- Nuclear fusion cannot happen at low temperature and pressure as the two nuclei cannot come into close range of each other due to the repulsive forces.
- Hence, nuclear fusion requires **very high temperatures and pressures** and is currently not used in nuclear power plants.
- Example: Nuclear fusion can take place in the sun where temperature and pressure are high.
- Scientists and engineers are working on reactors where nuclear fusion can take place in a safe and controlled manner.

Uses Related to the Damage of Cells

Medical

Detection of Tumors - Gamma Rays

- Isotope, technetium-99, is used in the detection of tumours
- Small amount of isotope is taken into the body and travels to the internal organs
- A gamma camera is used to detect the gamma-rays emitted from the internal organs due to the technetium-99.
- The images formed will help in the diagnosis of tumours
- The isotope has a short half-life (6 hours) so it does not remain in the body for too long.

Gamma Knife Radiosurgery - Gamma Rays

- Gamma rays from a radioactive source (cobalt-60) are directed at the brain to destroy brain tumours.
- The isotope has a long half-life (5.3 years) so it remains in the body for a long time. Hence, only a small quantity over a long treatment time.

Cancer Treatment - Beta Particles

- Isotope, iodine-131, is used in the treatment of thyroid disorder.
- When small amount is taken into the body, it can destroy the thyroid cells including cancer cells.
- The isotope has a short half-life (8-days) so it does not remain in the body for too long.

Safety

Food Safety - Gamma Rays

- Fodo decays due to the actions of microbes
- Gamma rays can be used to kill the microbes so that the food is safe for consumption and can last longer.
- The isotope has a long half-life (a few years).
- Only a small quantity is needed over a long time.

Sterilisation of Medical Equipment - Gamma Rays

- Medical equipment such as syringes and scapels are kept in sealed packaging and exposed to gamma rays.
- The microbes present on the equipment will be killed and the equipment is sterile.
- Gamma rays can be used to kill the microbes so that the medical equipment is sterile
- The isotope has a long half-life (a few years)

Uses Related to Radioactive Decay and Half-life

Geology

Determine how old an object/material is - Alpha Particles

- The isotopes, uranium-238, is found in most rocks and has a half-life of 4.5 billion years
- The isotope decays to a stable isotope, lead-206.
- y determining the relative amounts of uranium-238 and lead-206 in a sample, the age of the rock can be known.
- The greater amount of lead-206 present, the older the rock.

Uses Related to the Penetrating Abilities and Ionising Effects

Safety

Smoke Detectors - Alpha Particles

- The isotope, Americium-241, is used in smoke detectors.
- When the alpha particles emitted fall on the detector, a current flows in the detector as alpha particles have high ionising ability.
- WHen smoke enters the detector, the smoke absorbs the radiation and disrupts the flow of current in the detector.
- The disruption triggers the detector's alarm.

Industrial

Measure the Thickness of Materials - Beta-particles / Gamma-rays

- Manufacturer needs to ensure that the materials are of uniform thickness.
- Beta particles or gamma rays from a radioactive source are directed at the material.
- A detector measures the amount of radiation passing through.
- If the material is too thick, the amount of radiation is low and vice-versa.
- Beta-particles are more suitable for thinner materials such as papers.
- Gamma rays are more suitable for slightly thicker materials such as metal plates.

Question: Why are alpha-particles not suitable?

Alpha particles have low penetrating power and will be absorbed by the materials most easily.

Hazards of Radioactivity

Protecting Ourselves from Radioactive Materials

Limit Contamination

If we are present at a site where there may have been a radioactive incident, we can take the following precautions.

1. Leave the immediate area quickly to avoid being contaminated with radioactive materials. Follow the directions of officials to the nearest safe building or area.
2. Remove the outer layer of the clothing as the radioactive materials may be on the clothing. Removing the clothing will reduce the risk of contamination.
3. Wash all exposed parts of the body with soap and lukewarm water. This removes radioactive materials that may be present on the body and reduces the risk of contamination.

Reduce Exposure

1. Reduce exposure time
    - Experiments involving radioactive materials should only be carried out in designated locations.
2. Increase distance between radioactive source and living tissue.
    - The intensity of all ionising radiation decreases with distance.
    - Use long tongs or remote-controlled device to increase the distance between radioactive materials and body.
3. Shielding
    - Wear materials that absorb the ionising radiation (e.g. lead-lined gloves)
    - Use thick concrete walls and lead-lined doors for rooms in which ionising radiation is used.
4. Storage
    - Store radioactive mateirals in a selaed container that will absorb hte radiation from the source (e.g. lead box)
    - This prevents the nuclear radiation from penetrating through the container and escaping into the air
    - Label the container with radioactive sign and keep in a secure place that is not accessible by anyone.

Summary

Property	**Alpha**	**Beta**	**Gamma**
Ionising Effect	Highest	Middle	Lowest
Penetrating Effect	Lowest (Paper)	Middle (Aluminium)	Highest (Lead concrete)
Representation	$\ce{^4_2He}$	$\ce{^0_{-1}\beta}$	$\ce{_0^0\gamma}$

Practical Planning

Steps

$$T = \frac{kd}{r^2}$$

Assuming you fix *d*,

1. Set up the apparatus as shown in the diagram (if a diagram is drawn)
2. Independent Variable: I change
    - *r*, the radius
    - Always the one easier to change
    - **Planning terminology**: "Use [instrument] to measure and record ..."
3. Dependent Variable: I observe
    - *T*, the time taken
    - **Planning terminology**: "Calculate ..."
        - Calculate **[physical quantity]** by using $\frac{1}{r^2}$
4. Repeat step ... to ... for ... further values of **[independent variable]**
5. Tabulate all the results for **[all measured and calculated quantities]**
6. Plot a graph of ... against ...