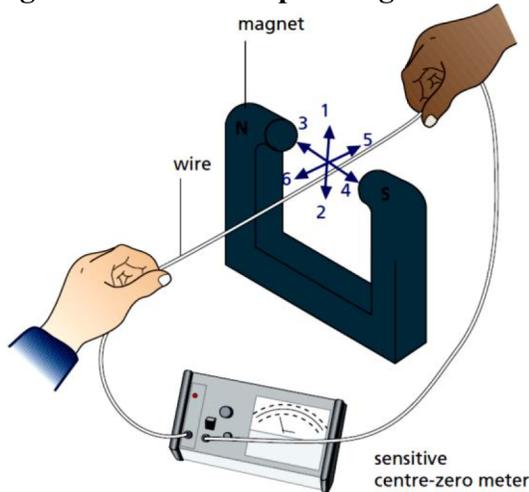


Electromagnetic induction

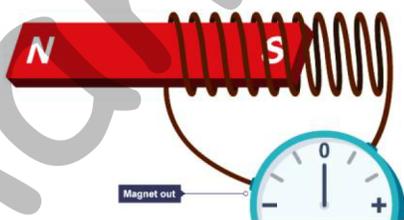
➤ Two ways of investigating the effect follow.

a) Straight wire and U-shaped magnet:



- First the wire is held at rest between the poles of the magnet.
- It is then moved in each of the six directions shown in Figure and the meter observed.
- Only **when it is moving upwards** (direction 1) or **downwards** (direction 2) is there a deflection on the meter, indicating an induced current in the wire.
- The deflection is in opposite directions in these two cases and only lasts while the wire is in motion.

b) Bar magnet and coil:



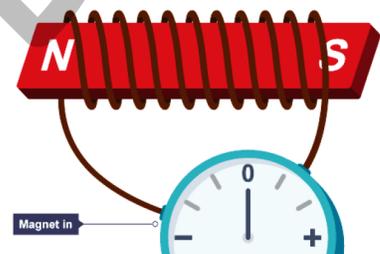
- A magnet and a coil of wire can be used to produce an electric current.
- A voltage is produced when a magnet moves into a coil of wire.

➤ This process is called electromagnetic induction.

1. A bar magnet rests outside a wire coil connected to an ammeter showing no current.
2. The magnet moves into the coil of wire and the ammeter registers positive current flow (Figure 4.69 b).

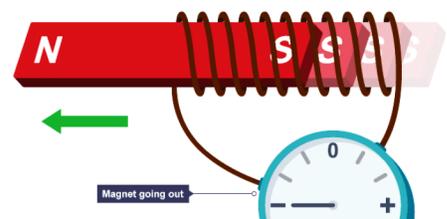


3. The magnet is stationary within the coil of wire, there is no current flow (Figure 4.69 c).

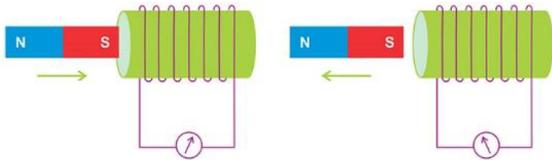
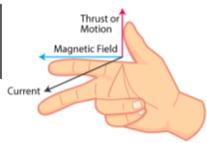


Notice that no voltage is induced when the magnet is still, even if it is inside the coil.

4. The magnet moves out of the coil of wire and the ammeter registers negative current flow.



- The direction of the induced voltage is reversed when the magnet is moved out of the coil again.



- It can also be reversed if the other pole of the magnet is moved into the coil.
- If the coil is part of a complete circuit, then a **current** will be induced in the circuit.
- The size of the induced EMF is proportional to the rate at which the field lines are cut:
 - If the field lines are **cut** at a **faster rate**, the EMF will increase

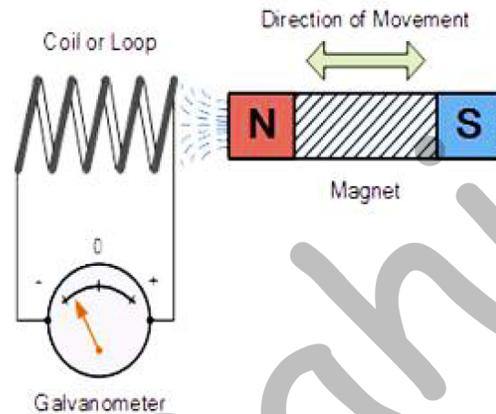
- ❖ The factors affecting the magnitude of an induced e.m.f.
- ❖ To increase the induced EMF:
 - **Moving the wire (or magnet) faster**
 - **Using a stronger magnet** (increasing the number of field lines)
 - **Adding more turns to a coil** (assuming a coil is being used, and not just a wire)

❖ **Note That:**

When discussing factors affecting EM Induction:

- ✓ Make sure you state:
 - “Add more turns to the coil”
- ✓ And not just:
 - “Add more coils”
 - (This second one means something slightly different)
- ✓ Likewise, when referring to the magnet, use the phrase:
 - “A stronger magnet”
- ✓ And not:
 - “A bigger magnet”
 - (Large magnets are not necessarily stronger)

Faraday's law



- To ‘explain’ electromagnetic induction Faraday suggested that a voltage is induced in a conductor whenever it ‘cuts’ magnetic field lines, i.e., moves *across* them, but not when it moves along them or is at rest.
- If the conductor forms part of a complete circuit, an induced current is also produced.
- Faraday found, and it can be shown with apparatus like that in Figure that the induced p.d. or voltage increases with increases of
 - (i) The **speed of motion** of the magnet or coil,
 - (ii) The **number of turns** on the coil,
 - (iii) The **strength of the magnet**.

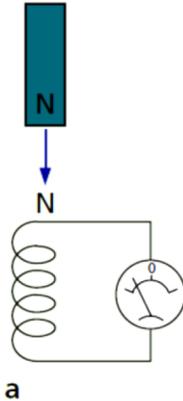
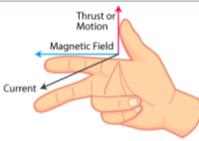
- These facts led him to state a law:

Faraday's law: The size of the induced p.d. is directly proportional to the rate at which the conductor cuts magnetic field lines.

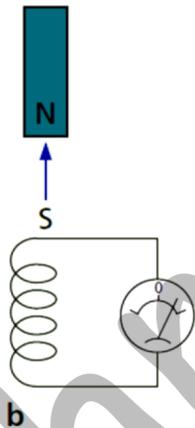
Lenz's law

Lenz's law: The direction of the induced current is such as to oppose the change causing it.

- In Figure a, the magnet approaches the coil, north pole first.



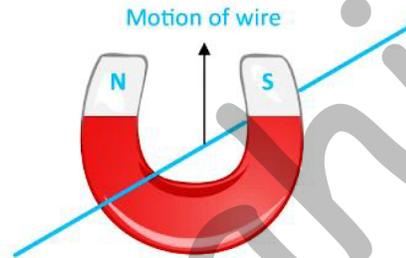
- According to Lenz's law **the induced current should flow in a direction that makes the coil behave like a magnet** with its top a north pole.
- The downward motion of the magnet will then be opposed since like poles repel.
- When the magnet is withdrawn, the top of the coil should become a south pole (Figure b) and attract the north pole of the magnet, so hindering its removal.



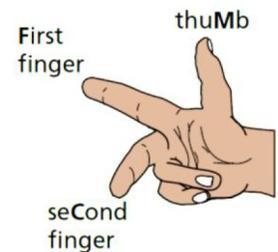
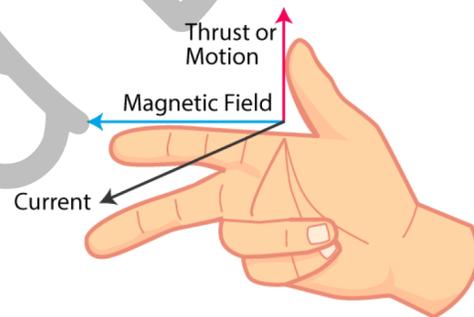
- The induced current is thus in the opposite direction to that when the magnet approaches.
- Lenz's law is an example of the **principle of conservation of energy**.
- If the currents caused opposite poles from those that they do make, electrical energy would be created from nothing.
- As it is, mechanical energy is provided, by whoever moves the magnet, to overcome the forces that arise.

Fleming's right-hand rule

- For a straight wire moving at right angles to a magnetic field a more useful form of Lenz's law is **Fleming's right-hand rule** (the 'dynamo rule').

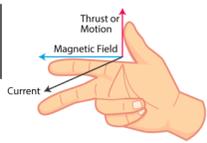


- When moving a wire through a magnetic field, the direction of the induced EMF can be worked out by using the **Right-Hand Dynamo rule**:



- **To use the rule:**

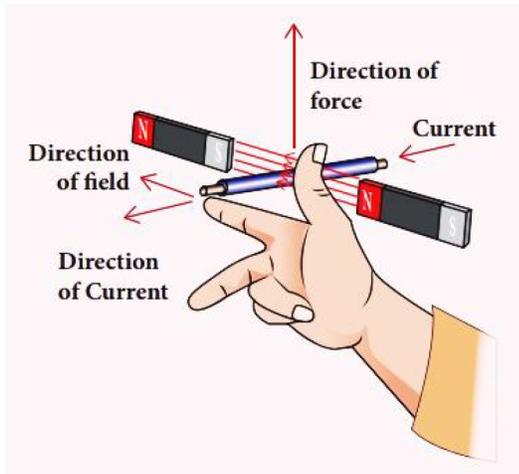
Start by pointing the **first finger** (on your right hand) in the direction of the field (**F**irst **F**inger **F**ield)
Next, rotate your hand so that the **thumb** point in the direction that the wire is **moving** in (**T**hu**M**b **M**otion)



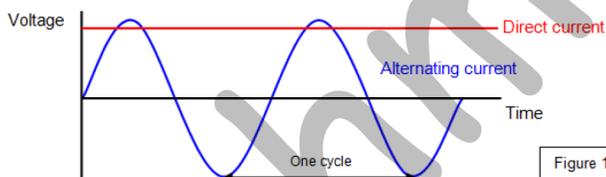
Your Second finger will now be pointing in the direction of the current (or, strictly speaking, the EMF)
(SeCond Current)

- **The direction of the induced EMF always opposes the change that produces it**
- This means that any magnetic field created by the EMF will act so that it tried to stop the wire or magnet from moving

Example on how to use Dynamo rule



Alternating vs Direct Current

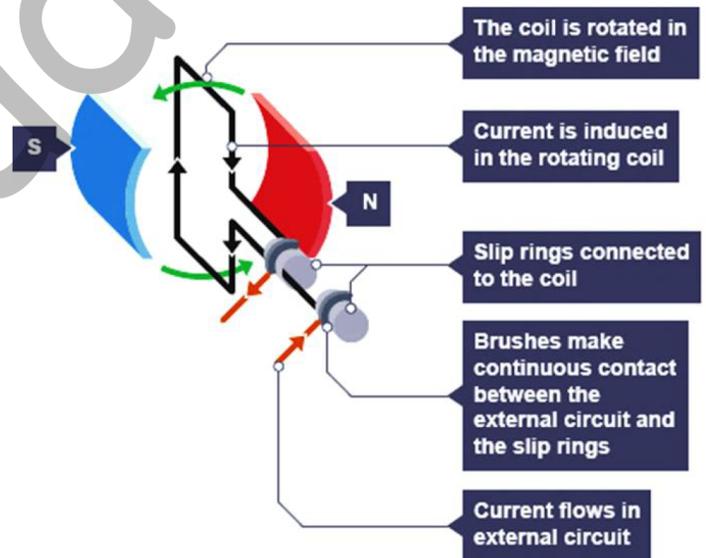


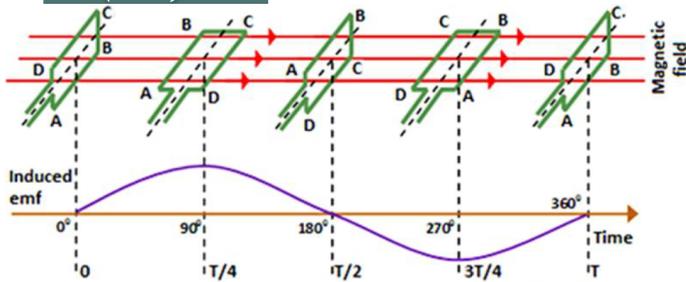
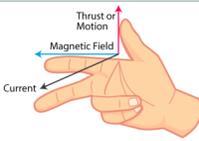
- **An alternating current (a.c.) is one that continuously changes its direction, going back and forth around a circuit.**
- **A direct current (d.c.) is one that is steady, constantly going the same way around a circuit, from positive to negative.**

AC generator (alternator)

- The effect of producing electricity from magnetism was discovered by *Faraday* and is called **electromagnetic induction**.
- An electric current in a conductor produces a magnetic field.
- These are made by coiling wire carrying a current around a magnetic core.
- The simplest alternating current (a.c.) generator consists of a rectangular coil between the poles of a C-shaped magnet.
- The ends of the coil are joined to two **slip rings** on the axle and against which **carbon brushes** press.
- When the coil is rotated it cuts the field lines and a voltage is induced in it.

❖ Main components of AC generator

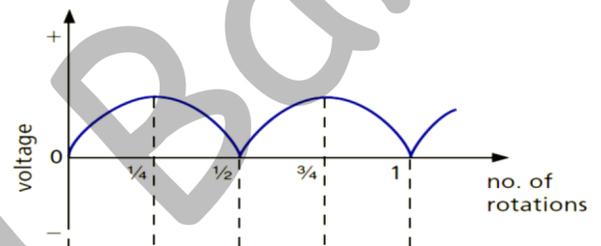
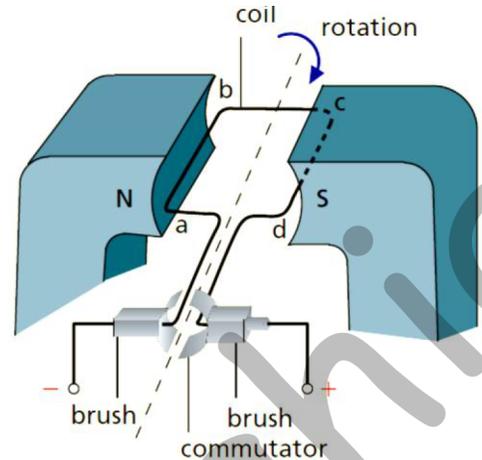




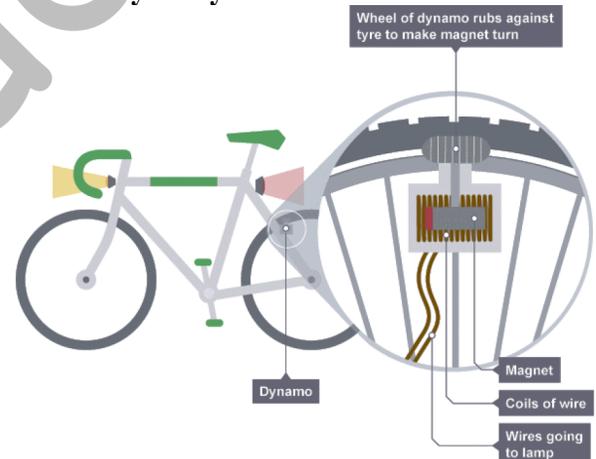
- As the coil moves through the **vertical** position no cutting occurs. The induced voltage is **zero**.
- During the **first quarter** rotation the p.d. **increases** to a maximum when the coil is **horizontal**.
- Sides **ab** and **dc** are then **cutting** the lines at the greatest rate.
- In the **second quarter** rotation the p.d. **decreases** again and is **zero** when the coil is **vertical**.
- After this, the direction of the p.d. **reverses** because, during the next half rotation.
- An alternating voltage is generated which acts first in one direction and then the other; it causes alternating current (a.c.) to flow in a circuit connected to the brushes.
- The **frequency** of an a.c. is the number of complete cycles it makes each second and is measured in **hertz (Hz)**, i.e. 1 cycle per second = 1 Hz.
- If the coil rotates twice per second, the a.c. has frequency 2 Hz. The mains supply is a.c. of frequency 50 Hz.

Simple d.c. generator (dynamo)

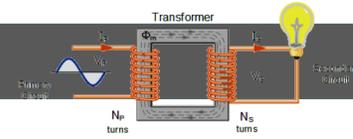
- An a.c. generator becomes a direct current (d.c.) if the **slip rings** are replaced by a **commutator**.



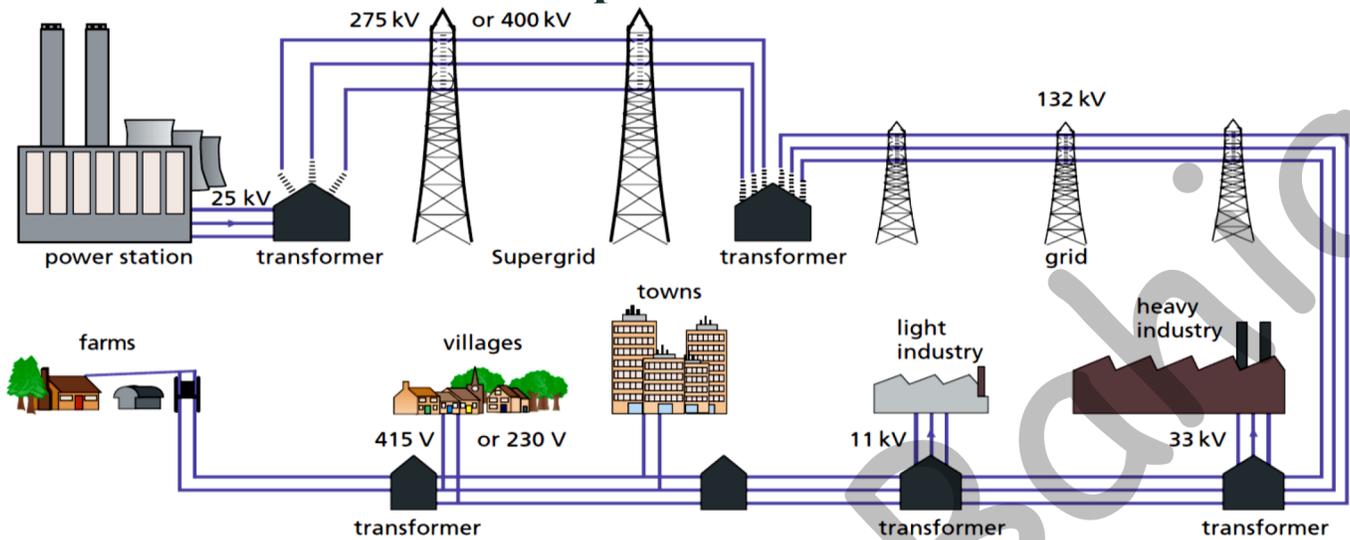
- One simple example of a generator is the **bicycle dynamo**.



- The dynamo has a wheel that touches the back tyre.
- As the bicycle moves, the wheel turns a magnet inside a coil.
- This induces enough electricity to run the bicycle's lights.
- The **faster** the bicycle moves, the **greater** the induced voltage - and the brighter the lights.

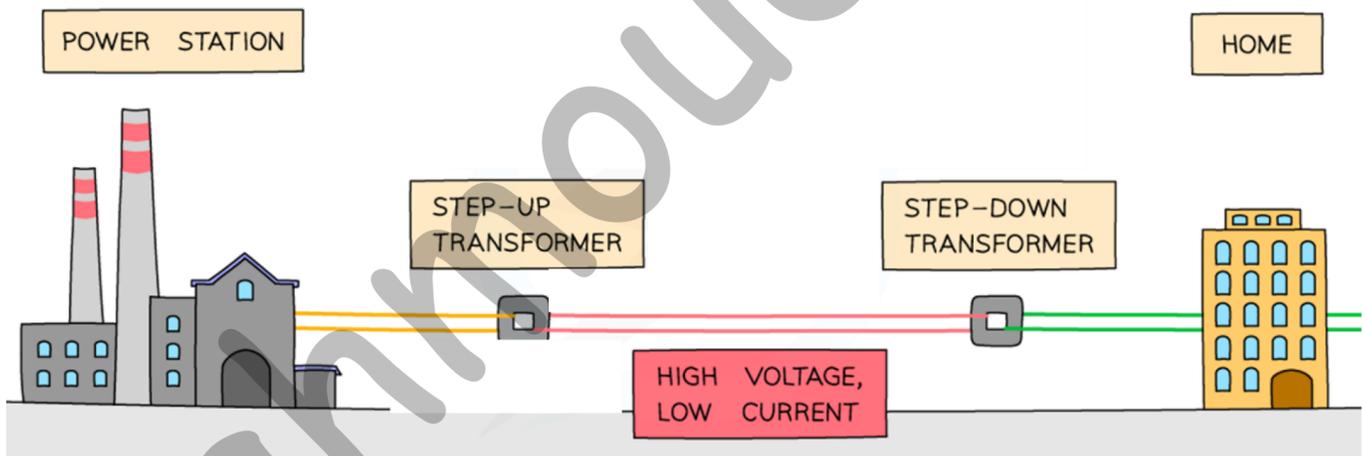


Transmission of electrical power



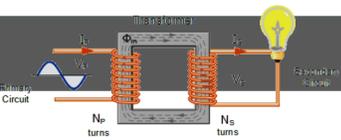
When electricity is transmitted along overhead cables, it is done at high voltages.

- A step-up transformer is used to raise the potential difference (voltage) before transmissions
- A step-down transformer is then used to step the potential difference back down to normal levels when it reaches its destination



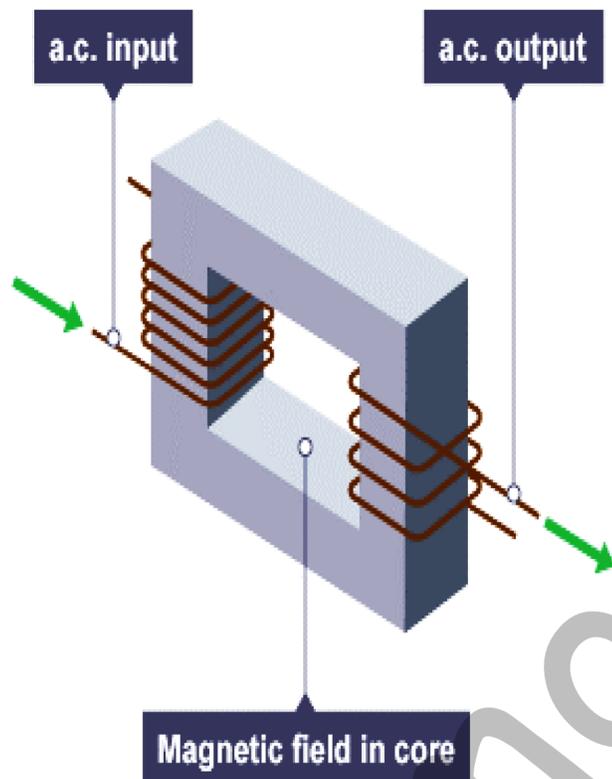
How High Voltage Reduces Power Loss?

- ✓ When electricity is transmitted over large distances, the current in the wires heats them, resulting in energy loss
- ✓ By raising the voltage at which the electricity is transmitted at, the same amount of power (energy per second) can be transmitted using a much smaller current (I)
- ✓ This results in less heat being produced in the wire and hence less energy loss



Transformer

- Transformers are used to **increase** or **decrease** the voltage of alternating currents.
- **OR** A device used to **step-up** or **step-down** the AC voltage.
- A transformer consists of **two coils** of wire wound on a **metal core**.



- A **step-up** transformer **increases the voltage** of a power source
- A step-up transformer has more turns on the secondary coil than on the primary coil
- A **step-down** transformer **decreases the voltage** of a power source
- A step-down transformer has fewer turns on the secondary coil than on the primary coil

Construction:

1. Consist of two coils, a **primary coil** and **secondary coil**.
2. The two coils are wound around a **soft iron core** made of thin iron sheets insulated from each other to minimize the effect of eddy

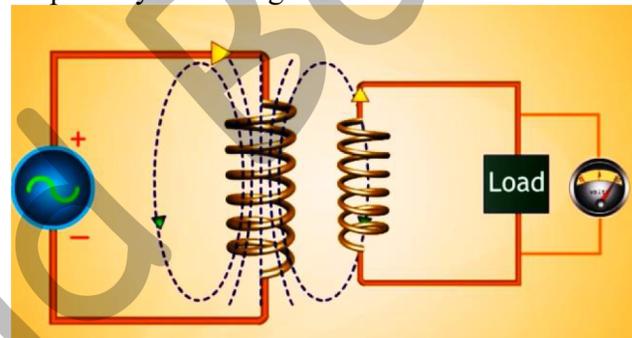
currents and to minimize the dissipated electric energy.

3. When an electric current pass in the primary coil a magnetic field is generated, the core makes the lines of such field to concentrate and cut by the secondary coil.

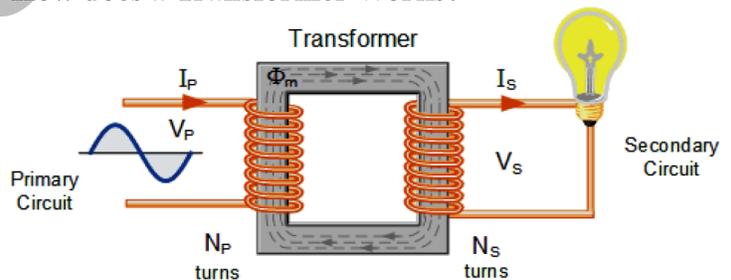
Principle of operation of a transformer:

Mutual induction between two coils

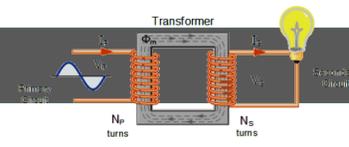
It is the generation of induced emf on the secondary coil due to the variation of current in the primary coil using AC current.



How does a Transformer Works?

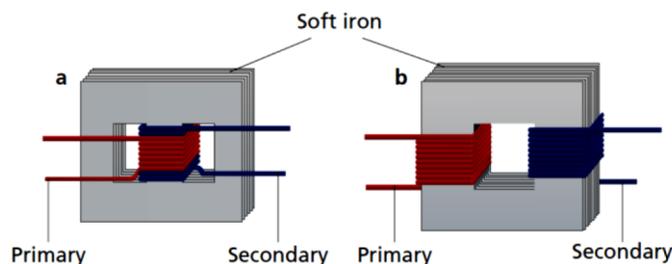


- When an alternating current is supplied to the primary coil, a changing magnetic field is produced by the primary coil.
- This field passes through the soft iron core and through the secondary coil
- The changing field in the secondary coil induces an EMF
- This EMF is also alternating and has the same frequency as the original current



Transformer equation

- A **transformer** transforms (changes) an alternating voltage from one value to another of **greater** or **smaller** value.
- It has a **primary coil** and a **secondary coil** wound on a complete **soft iron core**, either one on top of the other or on separate limbs of the core.



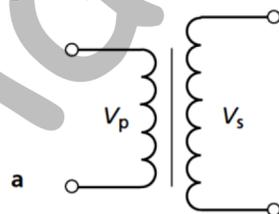
- An alternating voltage applied to the primary induces an alternating voltage in the secondary.
- The value of the secondary voltage can be shown, for a transformer in which all the field lines cut the secondary, to be given by:

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

In symbols

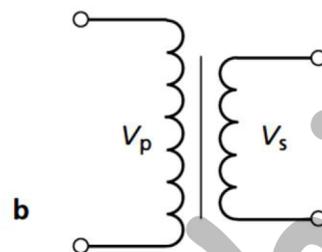
$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

- A **step-up transformer** has more turns on the secondary than the primary and V_s is greater than V_p (Figure a).



- For example, if the secondary has twice as many turns as the primary, V_s is about twice V_p .

- In a **stepdown transformer** there are fewer turns on the secondary than the primary and V_s is less than V_p (Figure b).



Energy losses in a transformer

- If the p.d. is stepped up in a transformer, the current is stepped down in proportion.
- This must be so if we assume that all the electrical energy given to the primary appears in the secondary, i.e. that energy is conserved and the transformer is **100% efficient** or **'ideal'** (many approach this efficiency).

Then:

$$\text{Power in Primary} = \text{Power in secondary}$$

$$V_p \times I_p = V_s \times I_s$$

- So, for the ideal transformer, if the p.d. is doubled the current is halved. In practice, it is more than halved, because of small energy losses.

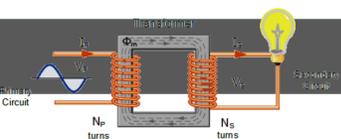
Worked example

A transformer steps down the mains supply from 230 V to 10 V to operate an answering machine.

a What is the turns ratio of the transformer windings?

b How many turns are on the primary if the secondary has 100 turns?

c What is the current in the primary if the transformer is 100% efficient and the current in the answering machine is 2 A?



Solution:

a Primary voltage, $V_p = 230 \text{ V}$

Secondary voltage, $V_s = 10 \text{ V}$

$$\text{Turns ratio} = \frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{10 \text{ V}}{230 \text{ V}} = \frac{1}{23}$$

b Secondary turns, $N_s = 100$

From a,

$$\frac{N_s}{N_p} = \frac{1}{23}$$

$$\therefore N_p = 23 \times N_s = 23 \times 100 \\ = 2300 \text{ turns}$$

c Efficiency = 100%

\therefore power in primary = power in secondary

$$V_p \times I_p = V_s \times I_s$$

$$I_p = \frac{V_s \times I_s}{V_p} = \frac{10 \times 2}{230} = \frac{2}{23} = 0.09 \text{ A}$$

❖ **Note:** In this ideal transformer the current is stepped up in the same ratio as the voltage is stepped down.