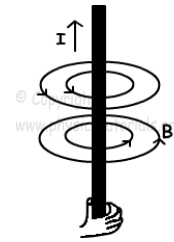
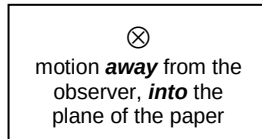
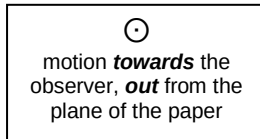


## Electromagnetism: Motors and Generators Alternating Current

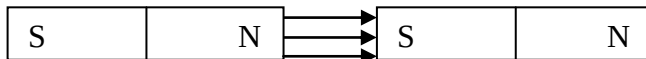
**SUMMARY**  
**Machines**  
**p.276 – 296**

### REVISION: MAGNETISM GR 11

- A **magnetic field (B)** exists around a current carrying conductor.
- This notation is used to indicate direction in the plane of the paper:



- The direction of the **conventional current (I)** in a conductor is from the positive pole of the battery to the negative pole.
- The **magnetic field (B)** outside a magnet is from North to South.

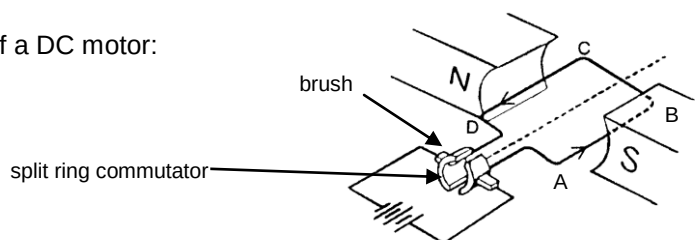


### THE DIRECT CURRENT MOTOR

- The **electric motor** operates using the **motor effect**: a **current** carrying conductor experiences a **force** in a **magnetic** field.

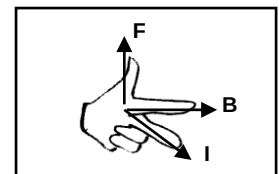


- The built of a DC motor:

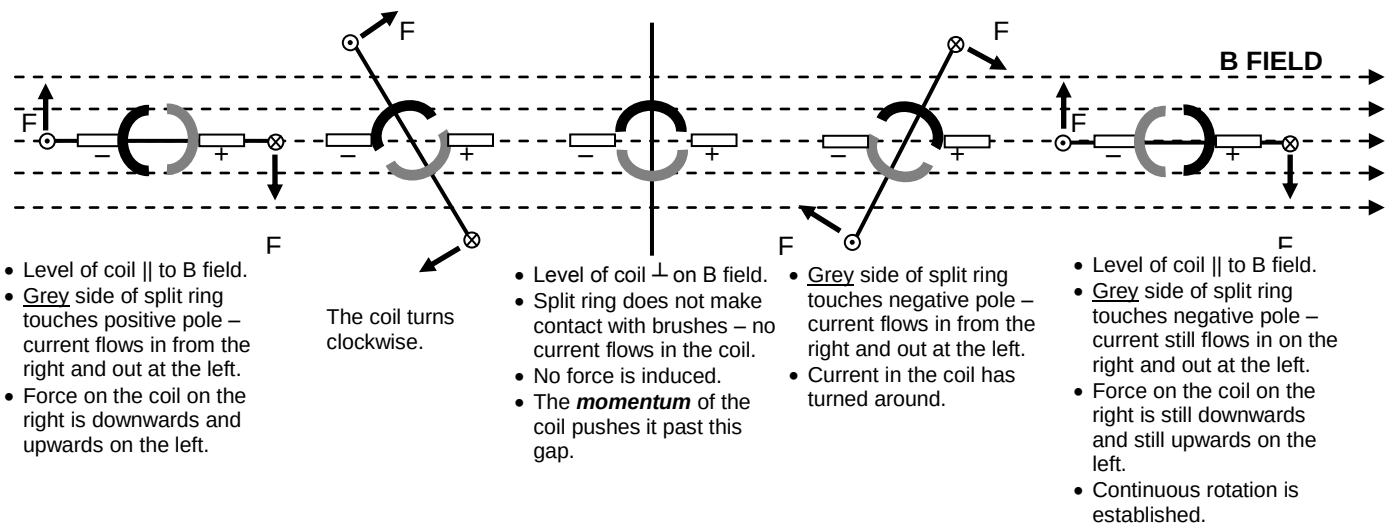


This is a DC motor: it uses a direct current source and has a split ring commutator.

- The **direction of the force in conductor CD** can be determined by Fleming's LEFT hand motor rule:
  - Place the first 3 fingers of the left hand mutually at right angles;
  - the forefinger in the direction of the magnetic field (B);
  - the mid finger in the direction of the conventional current (I);
  - then the thumb shows the direction of the force (F)
  - (∴ In the sketch CD moves upwards.)
- Force (motion) is induced only if there is an angle between the magnetic field (B) and the current carrying conductor (∴ I).
  - The force (motion) is a maximum if the angle between B and I is 90°.
  - The force is zero if the angle between B and I is 0° or 180°; ∴ if the B field and I are parallel. (With the coil in the horizontal position, as in the sketch, there is no force on part BC.)
- The DC motor uses a **split ring commutator**: it changes the direction in the coil after each half cycle of rotation. It enables the coil to continue rotation in one direction.
  - The commutator consists of two halves that are insulated from each other. Each half is in contact with the other pole of the battery for a half cycle.
  - The split ring moves with the coil.



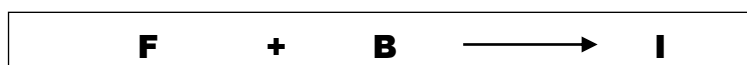
- **Brushes** maintain **electrical contact** between the rotating commutator and the external circuit ( $\therefore$  the battery).
  - The brushes are not fixed to the coil and do not turn with the coil.
- Refer to the sketch on the previous page. The DC motor works as follows:



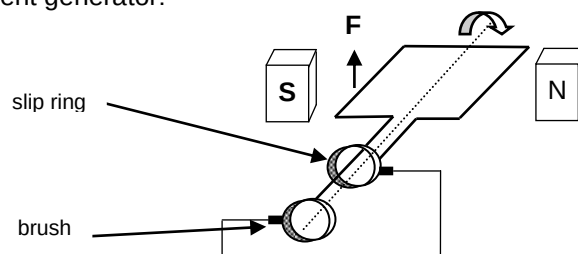
- In a motor **electrical energy** is transferred into **mechanical energy**.
- The **magnitude of the induced force (motion)** can be enlarged by
  - stronger external magnets;
  - increasing the number of turns in the coil;
  - increasing the electric current.
- Practical DC motors have many angles and multiple split rings so that the motor can operate more smoothly.

## THE ALTERNATING CURRENT GENERATOR

- The generator works on a principle called **electromagnetic induction**:
  - when a **force** causes a conductor to move in a **magnetic field**, an **emf** is induced in the conductor. The emf then induces a **current**.



- The built of an alternating current generator:

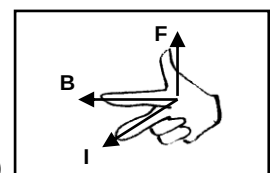


This is an AC generator: it has slip rings and generates alternating current.

- The **direction of the induced emf in the left side of the coil** can be determined by Fleming's RIGHT hand dynamo rule:

- Place the first 3 fingers of the right hand mutually at right angles;
  - the forefinger in the direction of the magnetic field (B);
  - the thumb in the direction of the force (F) on the conductor;
- $\rightarrow$  then the mid finger shows the direction of the induced emf.

( $\therefore$  The current in the left side of the coil runs from the plane of the page  $\therefore \odot$ .)



- The AC generator uses two **slip rings**: it allows the current in the external circuit to constantly alternate.
  - A slip ring is attached to each end of the coil.
  - The slip rings move with the coil.
- Brushes** maintain **electrical contact** between the rotating slip rings and the external circuit.
  - It takes the induced current away.
  - The brushes are not fixed to the coil and do not turn with the coil.
- Faraday's law for electromagnetic induction** states that the **induced emf ( $\epsilon$ )** is directly proportional to the rate of change of magnetic flux in the conductor.

$$\epsilon = - \frac{N \Delta \phi}{\Delta t}$$

$N$  = number of turns in coil  
 $\frac{\Delta \phi}{\Delta t}$  = rate of change of magnetic flux

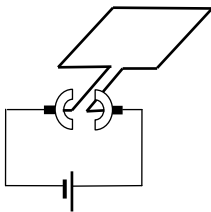
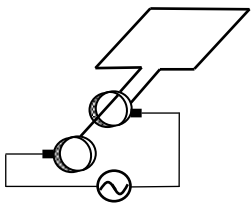
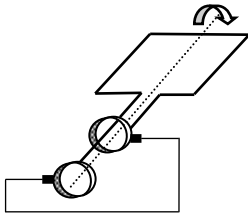
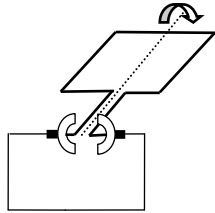
- The induced current (or emf) changes in direction every half revolution.  
 → This is an **alternating current**.
- In a generator **mechanical energy** is transferred into **electrical energy**.
- Alternating current generators are also called **alternators**.
- The magnitude of the induced emf can be enlarged by
  - stronger external magnets;
  - increasing the number of turns in the coil;
  - increasing the speed of rotation of the coil.

## TENSION AND POTENTIAL DIFFERENCE

- The word "**tension**" is sometime used as a synonym for potential difference.

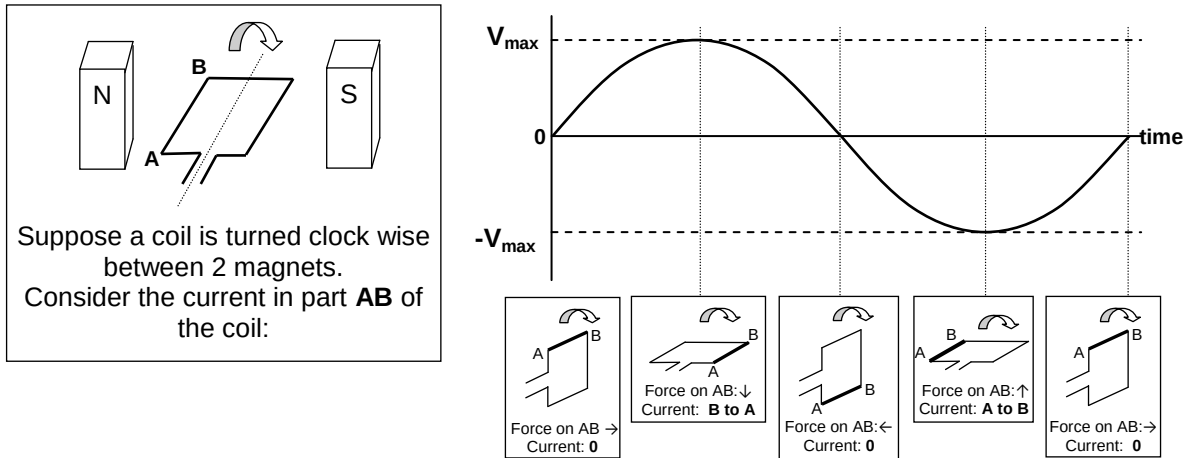
## MOTORS AND GENERATORS: ALTERNATING AND DIRECT CURRENT

- Compare the following machines when placed between the north and south pole of external magnets:

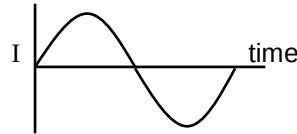
| MOTORS                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                | GENERATORS                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                   |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  <p><b><u>DC motor:</u></b></p> <ul style="list-style-type: none"> <li>• uses direct current;</li> <li>• uses a split ring;</li> <li>• induces uniform rotation.</li> </ul> <p><b><u>Uses:</u></b></p> <ul style="list-style-type: none"> <li>• disk drives in computers;</li> <li>• photocopiers;</li> <li>• CD-ROM drives.</li> </ul> |  <p><b><u>AC motor:</u></b></p> <ul style="list-style-type: none"> <li>• uses alternating current;</li> <li>• uses 2 slip rings;</li> <li>• induces uniform rotation.</li> </ul> <p><b><u>Uses:</u></b></p> <ul style="list-style-type: none"> <li>• washing machines;</li> <li>• electrical drills;</li> <li>• electrical fans.</li> </ul> |  <p><b><u>AC generator:</u></b></p> <ul style="list-style-type: none"> <li>• uses 2 slip rings;</li> <li>• induces alternating current.</li> </ul> <p><b><u>Uses:</u></b></p> <p>AC generators are used in the production of electricity at power stations.</p> |  <p><b><u>DC-generator:</u></b></p> <ul style="list-style-type: none"> <li>• uses a split ring;</li> <li>• induces direct current.</li> </ul> <p><b><u>Uses:</u></b></p> <ul style="list-style-type: none"> <li>• electroplating;</li> <li>• charge of batteries.</li> </ul> |

## ALTERNATING CURRENT

- For alternating current the emf (potential difference) alternates with time in a sine relationship.



- The graph for current (I) resembles the V graph:



- Normal arithmetic averages for V and I may not be used, because the average value for both is zero. **Rms averages** are used.
- The magnitude of the **emf** alternates continually between  $V_{\max}$  and 0. The “average” emf is called the **root mean square emf ( $V_{\text{rms}}$ )**:
 

$$V_{\text{rms}} = \frac{V_{\max}}{\sqrt{2}}$$
- The magnitude of the **current** also alternates continually between  $I_{\max}$  and 0. The “average” current is called the **root mean square current ( $I_{\text{rms}}$ )**:
 

$$I_{\text{rms}} = \frac{I_{\max}}{\sqrt{2}}$$
- Definition of rms averages:
  - The **rms value of AC potential** is the DC potential difference which dissipates the same amount of energy as AC.
  - The **rms value of AC current** is the DC current which dissipates the same amount of energy as AC.

## POWER

- Power (P)** = electrical energy that is transferred in one second. Electrical appliances supply an average power ( $P_{\text{average}}$ ):

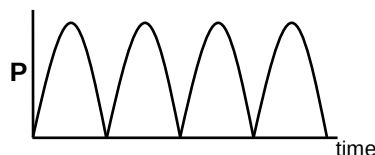
$$P_{\text{average}} = V_{\text{rms}} I_{\text{rms}}$$

$$P_{\text{average}} = I_{\text{rms}}^2 R$$

$$P_{\text{average}} = \frac{V_{\text{rms}}^2}{R}$$

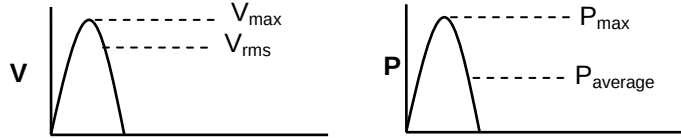
- Power is always a positive value:

For AC and DC generator:



- The value of  $P_{\text{average}}$  is equal to **half** of the peak value ( $P_{\text{max}}$ ). Therefore note:

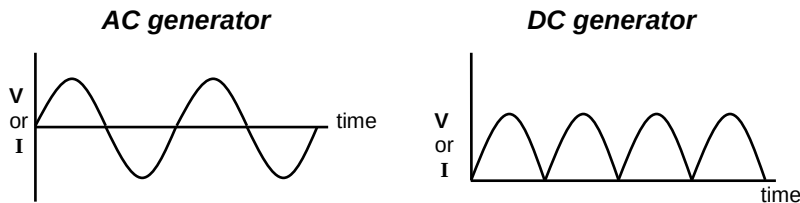
- $V_{\text{rms}} = \frac{1}{\sqrt{2}} V_{\text{max}} = 0,71 \times V_{\text{max}}$
- $I_{\text{rms}} = \frac{1}{\sqrt{2}} I_{\text{max}} = 0,71 \times I_{\text{max}}$
- but  $P_{\text{average}} = \frac{1}{2} P_{\text{max}} = 0,5 P_{\text{max}}$



- Appliances are always marked with average values.
  - E.g. An appliance is marked 220 V; 900 W. Then  $V_{\text{rms}} = 220 \text{ V}$  and  $P_{\text{average}} = 900 \text{ W}$ .
- Subscripts in ALL formulae are imperative. No marks for a formula without subscripts! Also, ALWAYS use subscripts when using Ohm's law:

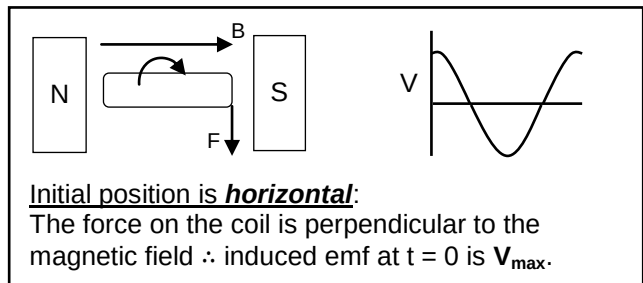
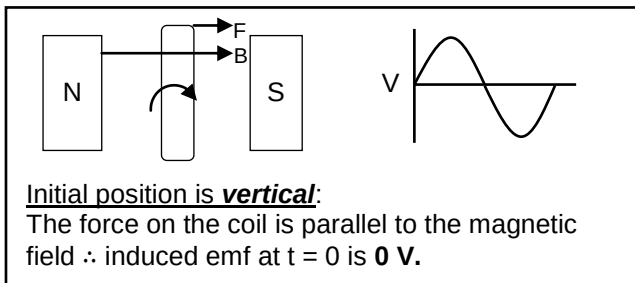
$$R = \frac{V_{\text{max}}}{I_{\text{max}}} \quad \text{or} \quad R = \frac{V_{\text{rms}}}{I_{\text{rms}}}$$

- For a DC generator the current / voltage also fluctuates between a maximum and zero, but the direction of the current / voltage does not change - it remains in the same direction.



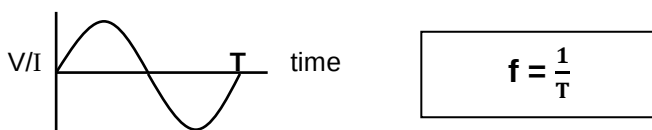
## GRAPHS

- When graphs are drawn, the initial position of the coil between the magnets is important:



## FREQUENCY AND PERIOD

- The **frequency ( $f$ )** of the AC tension / current = the number of cycles in one second.
- The **period ( $T$ )** of the AC tension / current = the time (in s) for a complete cycle.
- The **frequency ( $f$ )** (in Hertz) of an AC cycle is calculated from the period:



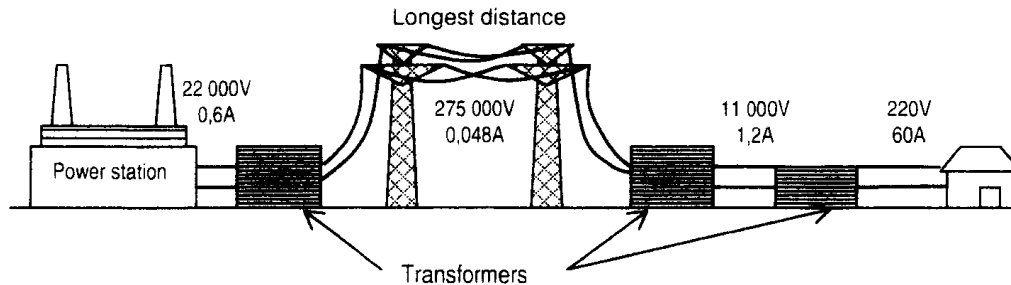
- Note the position of one period ( $T$ ) on a power graph!



## ADVANTAGES OF ALTERNATING CURRENT OVER DIRECT CURRENT

The most important advantage:

- Electrical energy in the form of alternating current can be transported economically over long distances at low currents and low energy loss. This is because alternating current voltage can be stepped up (increased) and stepped down (decreased) with transformers.



When AC voltages are stepped up, current decreases to a small value. ( $P = VI$ ; for constant  $P$ ,  $V \propto \frac{1}{I}$ .) A small current produces less heat and can be transmitted through a thin conductor. At the receiving station, voltages can be stepped down to the required value by using a step down transformer. The consumer of AC can live far from the place where AC is generated.

More advantages:

- AC is easy to generate.
- AC can be generated at high voltages, but not DC, because sparking starts at the commutator at high voltage. This causes damage to the commutator.
- High voltage AC generators are much simpler and cheaper than DC generators of the same range. It is because there is no commutator in AC generators. Commutators are the costly part and are easily damaged.
- Electric motors work more efficiently with AC.
- AC motors are simpler in construction, cheaper in cost and require less maintenance than DC motors.

## ADVANTAGE OF GENERATION OF AC IN A NUCLEAR PLANT VERSUS COAL

- Less pollution in a nuclear plant.

## SYMBOLS AND UNITS

|                                        |            |                                         |                  |
|----------------------------------------|------------|-----------------------------------------|------------------|
| current ( <b>I</b> )                   | ampère (A) | potential difference (emf) ( <b>V</b> ) | volt (V)         |
| rms current ( <b>I<sub>rms</sub></b> ) | ampère (A) | rms emf ( <b>V<sub>rms</sub></b> )      | volt (V)         |
| power ( <b>P</b> )                     | watt (W)   | resistance ( <b>R</b> )                 | ohm ( $\Omega$ ) |