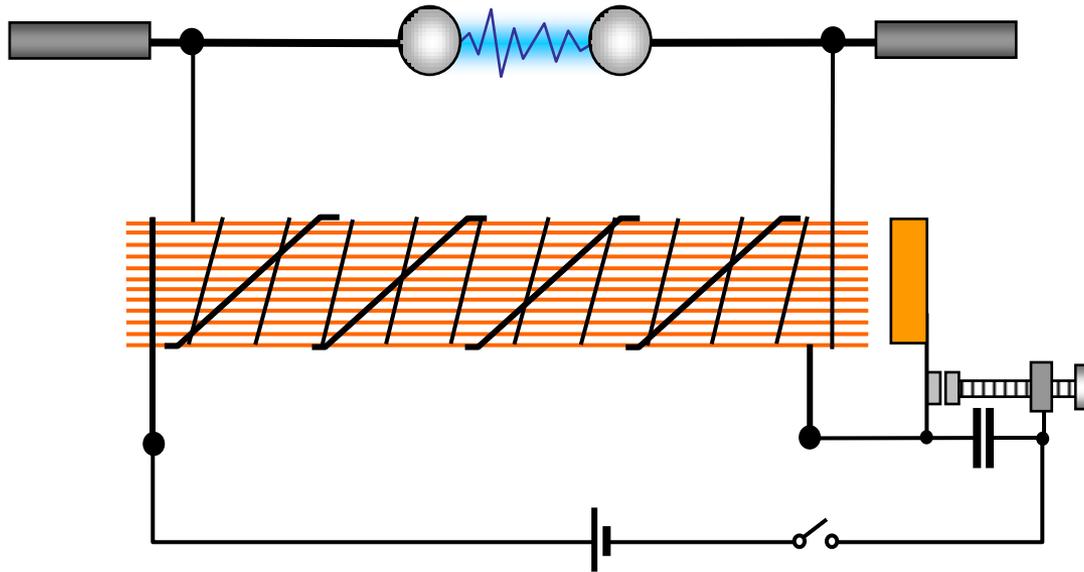
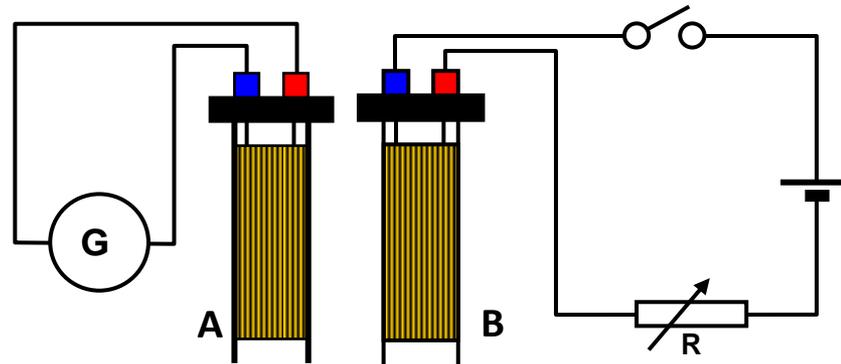


Electromagnetic induction (16-19)



Electromagnetic induction



Coil A is connected to a galvanometer and coil B is connected to a battery and has direct current flowing through it. Coil A is within the magnetic field produced by B and an e.m.f. can be produced in A by moving the coils relative to each other or by changing the size of the current in B. This can be done by using the rheostat R, switching the current on or off, or (c) using an a.c. supply for B.

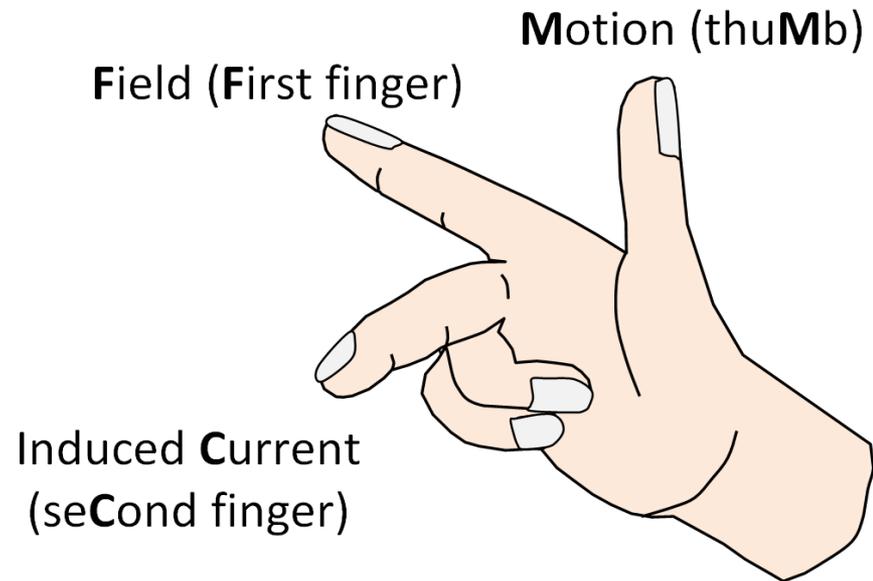
(An e.m.f. could also be produced in A by replacing B with a permanent magnet and moving this relative to A.)

Faraday's laws

- If magnetic flux through a coil is altered then an e.m.f. will be generated in the coil. Faraday discovered that an e.m.f. could be generated by either:
 - (a) moving the coil or the source of flux relative to each other or by
 - (b) changing the magnitude of the source of magnetic flux in some way.Note that the e.m.f. is only produced while the flux is changing.
- Faraday summarised the results of his experiments as follows:
 - (a) An e.m.f. is induced in a coil if the magnetic flux through the coil changes
 - (b) The magnitude of the induced e.m.f. depends on
 - (i) the rate of change of flux,
 - (ii) the number of turns on the coil, and
 - (iii) the cross-sectional area of the coil.Points (ii) and (iii) simply refer to the amount of change of flux. The faster the flux is changed the greater is the e.m.f. produced.

Fleming's right hand rule

Fleming proposed a simple rule for giving the direction of the induced current in one of Faraday's experiments.



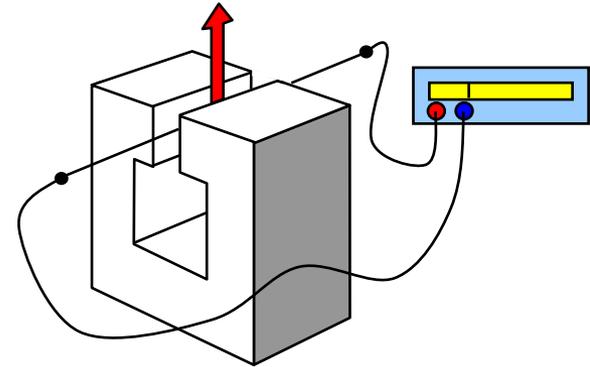
If the thumb and first two fingers of the right hand are held at right angles and the first finger is pointed in the direction of the magnetic field and the thumb in the direction of motion then the second finger gives the direction of the induced current .

Induced e.m.f

When the magnetic flux through a coil changes an e.m.f. (E) is generated in the coil.

$$E = -d(N\Phi)/dt = -Nd\Phi/dt$$

where N is the number of turns in the coil and Φ the magnetic flux through one coil.



The quantity $N\Phi$ is known as the flux linkage and is measured in webers.

The quantity $d(N\Phi)/dt$ is the rate of change of flux linkage in webers per second.

When a conductor moves through a constant magnetic field the e.m.f (E) generated between the two ends of the conductor at any moment is $E = - Nd\Phi/dt$

where N is the number of conductors cutting the flux (There is only one wire cutting through the field in the diagram and so in this example $N = 1$).

Induced e.m.f in a straight wire

A straight conductor of length L is moved through a field of flux density B . If the conductor moves with velocity v at right angles to the field then the flux cut per second will be BvL (since the conductor will sweep out an area vL every second).

But the rate of cutting flux is equal to the e.m.f. induced in the conductor.

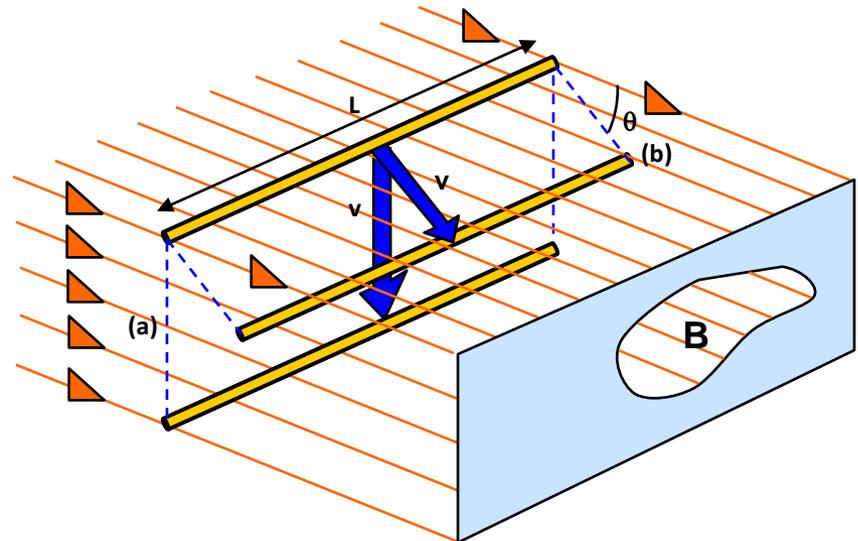
Therefore:

$$E = BLv$$

If the conductor cuts through the flux at an angle θ , where θ is the angle between the magnetic field and the direction of motion

$$E = BLv \sin \theta$$

the maximum e.m.f. is generated when the conductor moves at right angles to the field. ($\theta = 90^\circ$ and so $\sin \theta = \sin 90 = 1$).



Induced e.m.f in a rotating coil (1)

A coil of N turns and area A is rotated at a constant angular velocity ω in a magnetic field of flux density B , its axis being perpendicular to the field. When the normal to the coil is at an angle θ to the field the flux through the coil is $BAN \cos \theta = BAN \cos (\omega)t$, since $\theta = \omega t$.

The e.m.f (E) generated between the ends of the coil is:

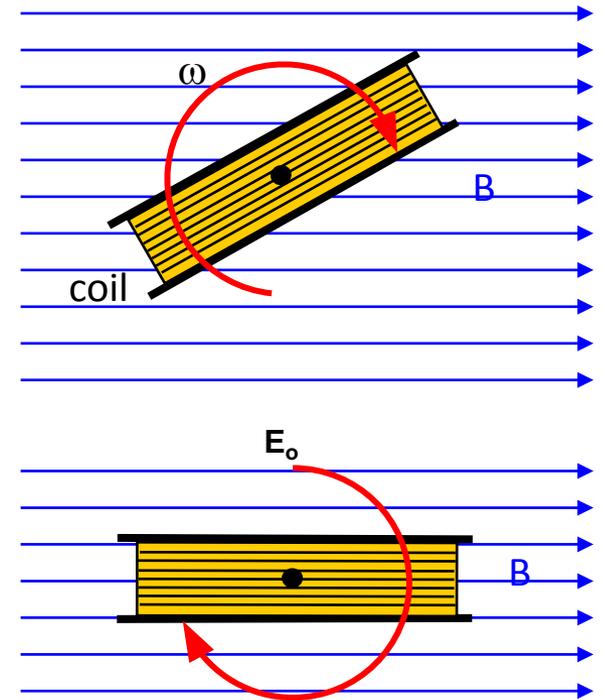
$$E = BAN\omega \sin \theta = BAN\omega \sin(\omega t)$$

The maximum value of the e.m.f (E_0) is when $\theta (= \omega t) = 90^\circ$ (that is, the coil is in the plane of the field)

$$\text{Maximum e.m.f: } E_0 = BAN\omega$$

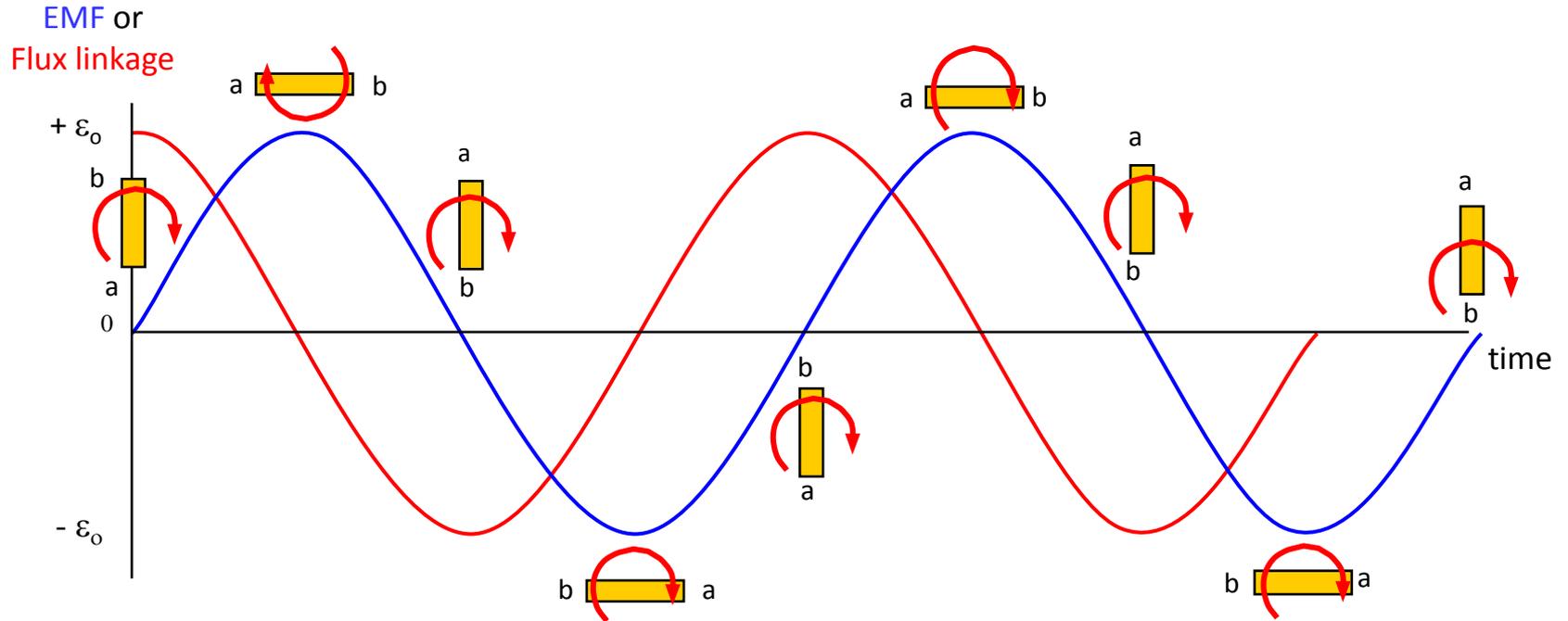
At this point the wires of the coil are cutting through the flux at right angles.

$$\text{The r.m.s. value of the e.m.f is } E_0 = BAN\omega/\sqrt{2}$$



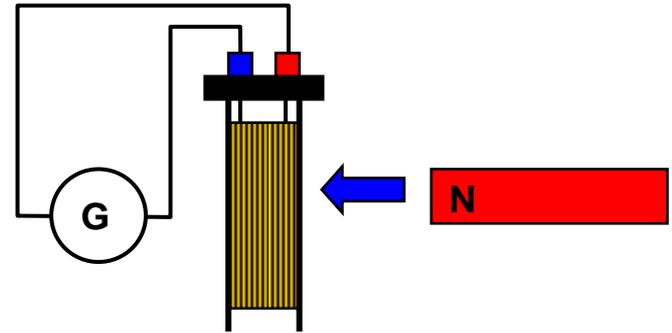
Induced e.m.f in a rotating coil (2)

The diagram below shows the variation in e.m.f induced as the coil rotates and also the flux linked by the coil during rotation.



Lenz's law

The direction of the induced e.m.f. is such that it tends to oppose the change that produced it.

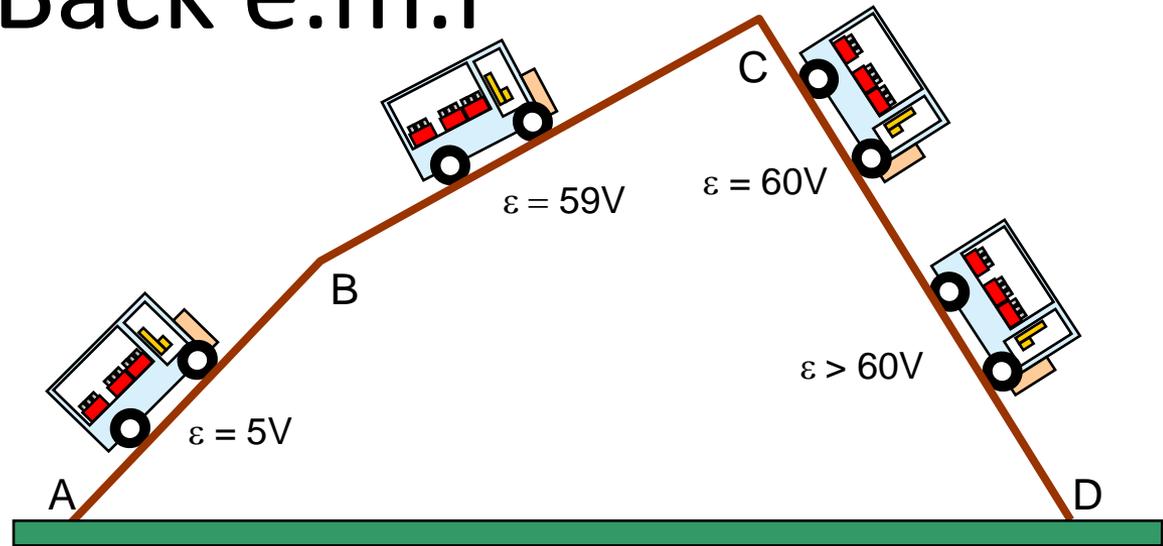


Consider the energy changes that occur when a magnet is moved towards a coil. Assume that the magnet is moved towards the coil with its north pole facing towards the coil. Now by Lenz's law this should induce a current in the coil such that the right-hand end of the coil (B) nearest the magnet is also a north pole. If this is true then it should repel the magnet and work must be done on the magnet to move it in against this repulsion.

The energy used goes to produce the induced e.m.f. in the coil.

Back e.m.f

As the car climbs the hill AB the motor is running slowly, the back e.m.f. is therefore low, a large current flows through the motor, giving a large torque. Chemical energy from the battery is converted to potential energy of the car.



The car now goes up section BC. The slope is much shallower, the motor speeds up and so the back e.m.f. rises. The current through the motor is therefore low. The car now descends the section CD. The speed increases so that the back e.m.f. rises to 60 V, and energy is supplied to just overcome friction. Further down the hill the car is moving faster and the back e.m.f. is greater than 60 V and so the motor acts as a dynamo, storing up energy in the battery. The current flowing produces a torque which tends to oppose the motion and so acts as a brake.

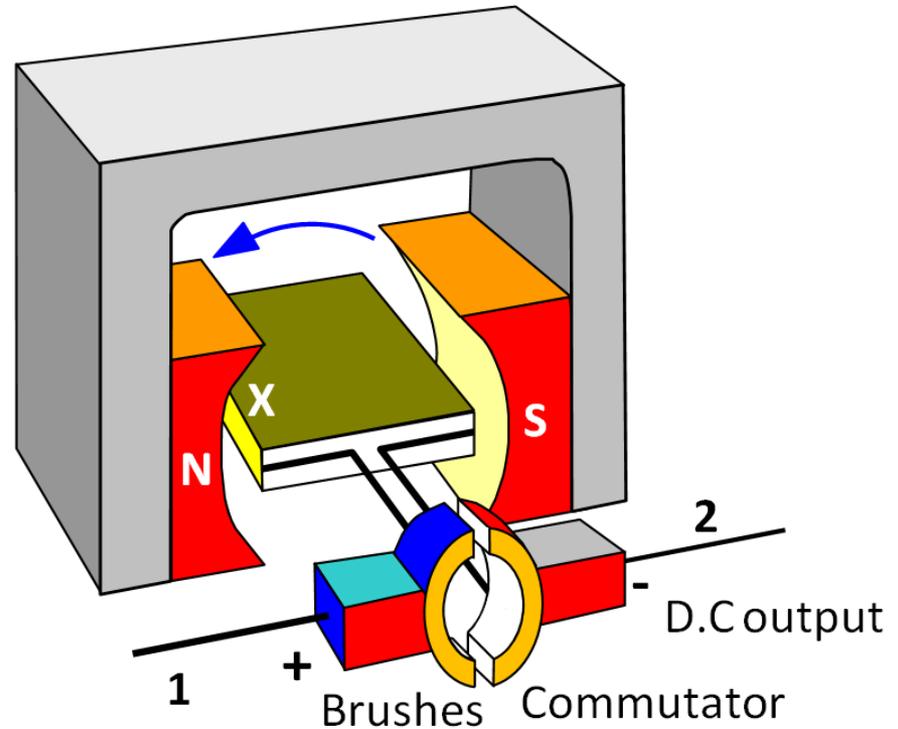
If the supply e.m.f. is E , the back e.m.f. be ε , the resistance of the coil R and the current through the coil I . Then

$I = [E - \varepsilon]/R$ since e is proportional to the angular speed (ω) the greater ω the smaller I .

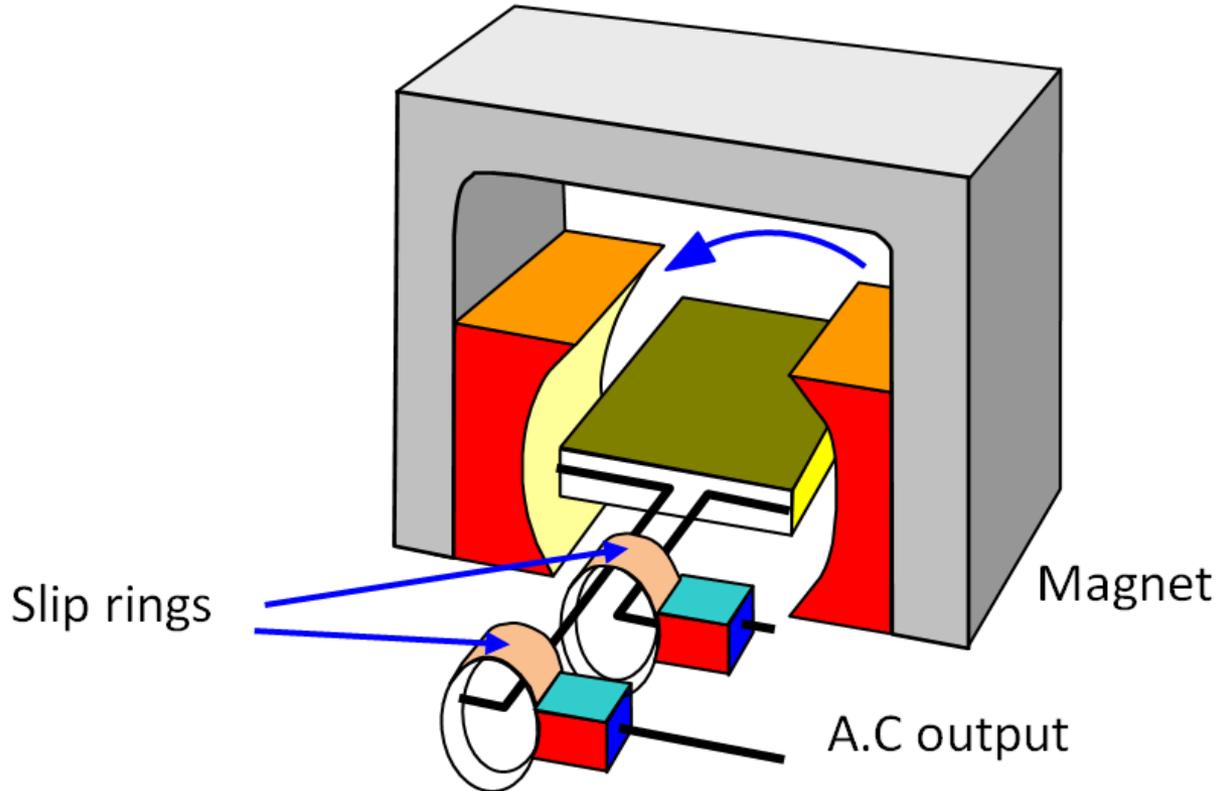
D.C generator

As the coil rotates the side of it that is cutting downwards through the field (marked X in the diagram) is always in contact with brush 1. That means that brush 1 always has the same positive (Fleming's right hand rule).

In the same way the side of the coil that is going up is in contact with brush 2. The device that ensures that the two brushes always have the same polarity is called a **COMMUTATOR**.



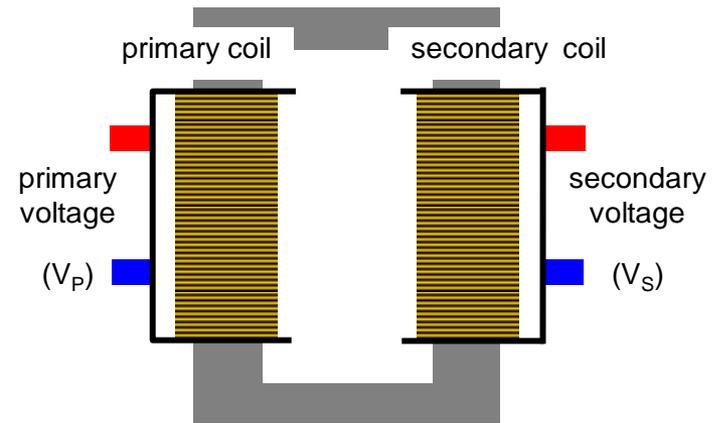
A.C generator



As the coil rotates between the poles of the magnet, the sides of the coil cut through the magnetic field and so a voltage is produced and a current flows in the coil. The faster the coil rotates the faster will it cut the magnetic field and the bigger will be the output voltage.

Transformers

A transformer consists of two coils known as the primary and secondary, wound on a laminated iron former that links both coils. The former, or core, must be laminated otherwise large eddy currents would flow in it. The laminations are usually E-shaped, and the primary and secondary are wound one on top of the other to improve magnetic linkage.



An a.c. voltage is applied to the primary and this produces a changing magnetic field within it. This changing magnetic field links the secondary coil and therefore induces an e.m.f. in it. The magnitude of this induced e.m.f. (V_s) is related to the e.m.f applied to the primary (V_p) by the equation:

$$V_s/V_p = - n_s/n_p$$

where n_p and n_s are the number of turns on the primary and secondary coils respectively. The negative sign means that the voltage induced in the secondary is 180° (or π) out of phase with that in the primary.

Transmission of electricity

