Physics notes – Electric power
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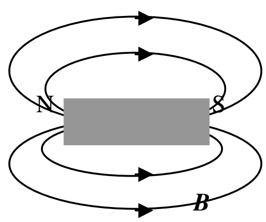
Magnetic fields

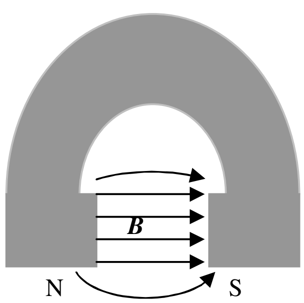
Magnetic field B in the region surrounding a magnet is a quantity used to describe the magnetic effect due to the presence of the magnet. It is a vector quantity.

To give a visual picture, lines (curves) are drawn on paper to indicate the existence of a magnetic field. These lines are called **magnetic field lines**.

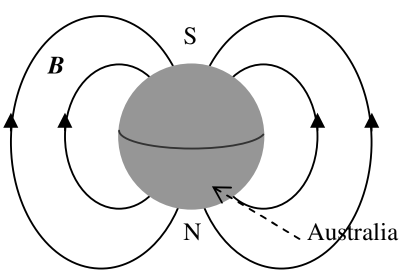
Example 1 *A bar magnet*
When the bar magnet is suspended with a thread, the end attracted towards the north pole of the earth is labelled as N (north). The other end is S (south).



Example 2 *A horse-shoe magnet*



Example 3 *The earth*

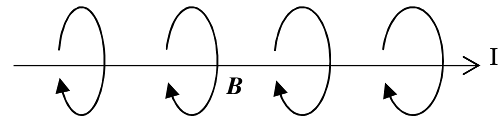


By convention, magnetic field lines always point away from N (the **north magnetic pole)** towards S (the **south magnetic pole)**. The north magnetic pole (sometimes called the north seeking pole) of a compass points in the same direction as the magnetic field lines. A stronger magnetic field is indicated by closer magnetic field lines. The lines do not cross each other because the magnetic field cannot be pointing in more than one direction at any location.

Electromagnetism

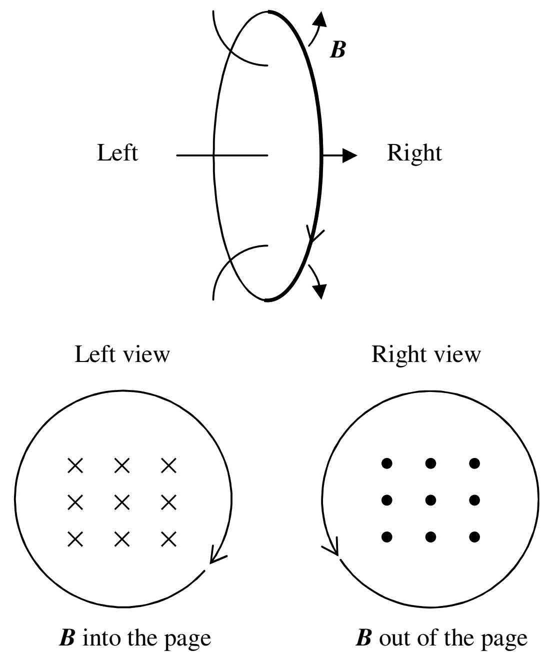
A device that uses electric current to generate magnetic field is called an **electromagnet**. The examples in the previous section are called **permanent magnets**.

Magnetic field of a current-carrying wire



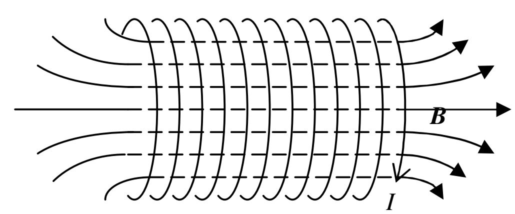
The direction of the magnetic field can be determined by the **right-hand-grip rule**.

Magnetic field of a current-carrying loop of wire



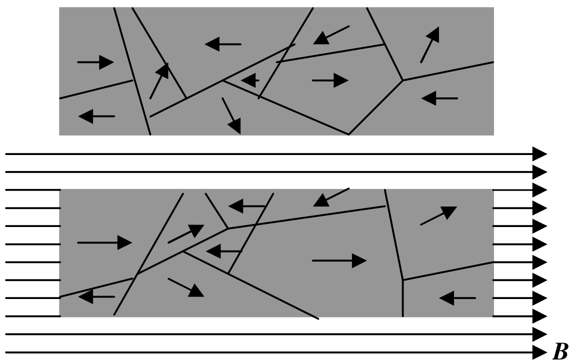
Magnetic field of a solenoid

A solenoid is a continuous coil of insulated wire with the radius of the coil much less than the length.

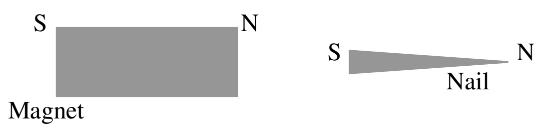


The magnetic field inside the solenoid is uniform.

A piece of iron is normally unmagnetised and made up of **domains** (regions that behave like tiny magnets) that are randomly arranged. When it is placed in a magnetic field those domains whose magnetic orientation is parallel to the external magnetic field grow larger at the expense of the others, and the piece of iron becomes magnetised. By placing a soft iron rod inside a solenoid its magnetic field can be greatly enhanced.

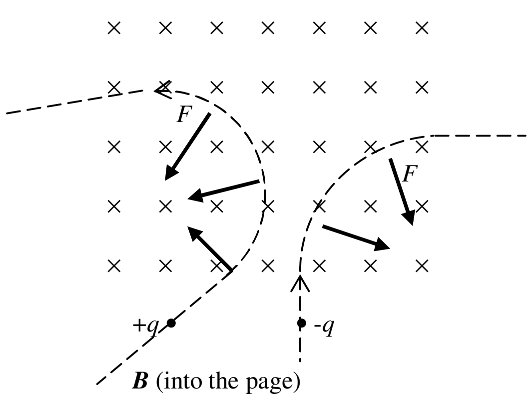


Example 1 Explain how a magnet can pick up unmagnetised iron nails and paper clips.



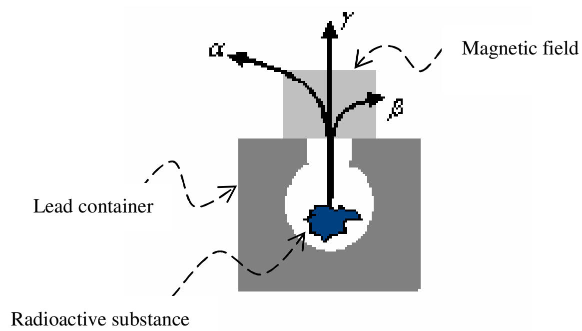
The magnet causes the domains (inside the iron nails) whose magnetic orientation is parallel to the magnetic field (of the magnet) to grow larger at the expense of the other domains. The iron nails become magnetised and attracted by the magnet.

Magnetic force on a moving charge in a magnetic field



Use the **right-hand slap rule** to determine the direction of the magnetic force on the moving positive charge in the magnetic field. The magnetic force is always perpendicular to both the magnetic field and the direction of motion of the charge. If the positive charge is replaced by a negative charge, the force is in the opposite direction.

Example 1 The α, β and γ radiations emitted from a radioactive substance can be separated by means of a magnetic field across the path of the radiations.

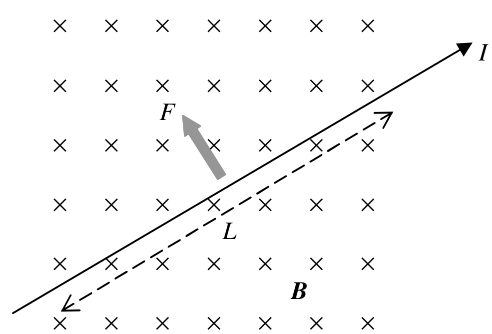


Example 2 Charged cosmic ray particles (e.g. electrons) from outside the earth tend to strike the earth more frequently near the poles than at other places. When these charged particles enter the earth's magnetic field, they will be deflected and spiral around the magnetic field towards the poles.

Example 3 Bringing a magnet close to a television screen will distort the picture.

Example 4 An aeroplane is flying west in level flight near the south pole, where the earth's magnetic field is directed close to upward. As a result of the magnetic force on the free electrons in its wings, the **left** wingtip will have more electrons than the other. If the plane is flying east the magnetic force still pushes the electrons to the left causing the left wingtip to have more electrons.

Magnetic force on a current-carrying wire placed in a magnetic field



Again the direction of the magnetic force on the wire can be determined by using the right-hand slap rule. The magnetic force is always perpendicular to both the magnetic field and the current.

The magnetic force F is directly proportional to the magnetic field B, the length L of the section of the wire inside B and the electric current I in the wire.

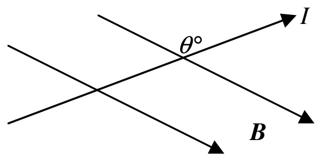
$$F \propto B, F \propto I, F \propto L, \therefore F \propto BIL$$

The force is at its maximum when the wire is perpendicular to B (as shown in the diagram) and is given by $F = BIL$ when F is measured in N, B in T, I in A and L in m.

If there are n wires side by side with the same current (as in a coil), $F = nBIL$.

If the wire is at an angle $\theta°$ other than 90° with the magnetic field B, the magnetic force on the wire is $F = BIL\sin\theta°$.

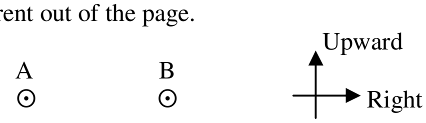
The angle $\theta°$ is defined as shown below.



When the wire is parallel to B, i.e. $\theta° = 0°$ or $\theta° = 180°$, $F = 0$.

Example 1 Determine the direction of the magnetic force between two parallel wires carrying electric current in (a) the same direction and (b) opposite directions.

(a) The following diagram shows two parallel wires A and B, each carrying current out of the page.



A generates an upward magnetic field at B, causing B to experience a magnetic force to the left. B generates a downward magnetic field at A, causing A to experience a magnetic force to the right. It is an attractive force between A and B.

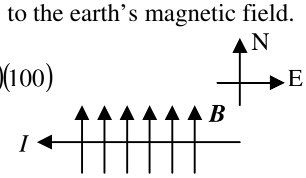
(b) The following diagram shows two parallel wires A and B, A carries current out of the page, and B into the page.

A generates an upward magnetic field at B, causing B to experience a magnetic force to the right. B generates an upward magnetic field at A, causing A to experience a magnetic force to the left. It is a repulsive force between A and B.

Example 2 A horizontal overhead power line carries a current of 5000A from east to west. The earth's magnetic field has a magnitude of 40.0 μT horizontally and is directed toward the north. Find the magnitude and direction of the magnetic force on 100m of the conductor due to the earth's magnetic field.

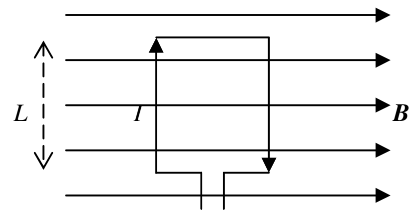
$F = BIL = (40.0\times10^{-6})(5000)(100)$

= 20.0 N to the ground.



Magnetic force on a current-carrying loop in a magnetic field

To simplify the situation, consider a rectangular loop placed in a magnetic field.

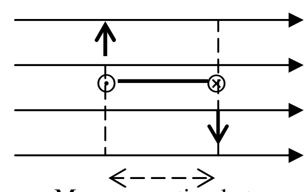


The force on the upper and the lower sides of the loop is zero. The force on the left side is $F = BIL$ into the page, while the force on the right side is $F = BIL$ out of the page. These two forces form a **force couple**, which has a turning effect (**torque**) on the loop.

In translational motion, a force changes the velocity of an object. In rotation, a torque changes the **angular** (rotation) speed of an object.

Now look at the top view of the loop in the magnetic field at different stages of its rotation.

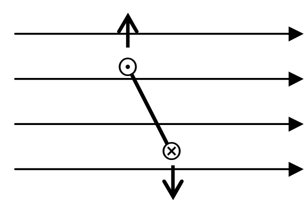
1)



Max. separation between the two lines of force

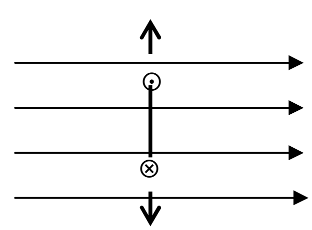
The force couple exerts a clockwise torque on the loop causing it to speed up the rotation.

2)



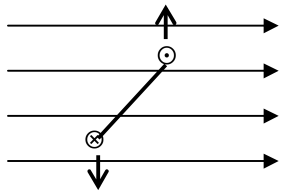
The two forces remain the same but the separation of the two forces is reduced resulting in a smaller clockwise torque. A smaller torque gives rise to a smaller rate of increase in the speed of rotation.

3)



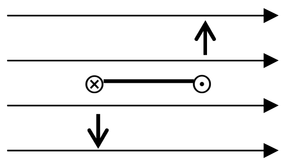
The two forces still remain the same but the torque is zero at this stage. However, the loop continues with its clockwise motion because of its angular momentum.

4)



Now the force couple exerts an anticlockwise torque on the loop causing it to slow down its clockwise rotation.

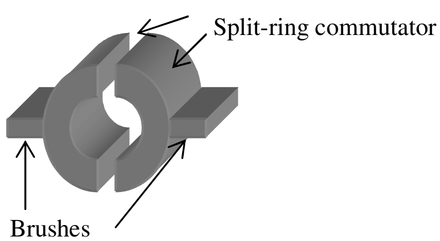
5)



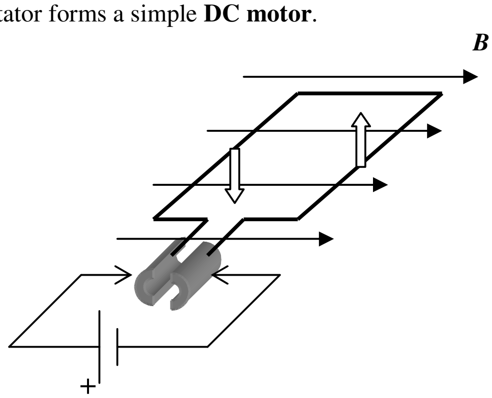
The anticlockwise torque causes the loop to come to a stop momentarily at this position and reverse its rotation, and the whole process repeats itself in the reverse direction.

Instead of reversing its rotation, the loop can be made to maintain its clockwise motion if the electric current is switched around when the loop reaches and passes the position shown in stage 3), resulting in a reversal of direction of the two forces. Now the torque is in the clockwise direction and the loop continues its rotation.

The device that is used to switch the current around is called a **split-ring commutator**.



A loop placed in a magnetic field and connected to a split-ring commutator forms a simple **DC motor**.

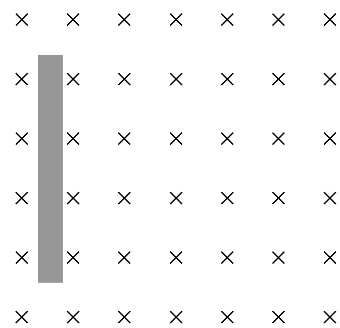


The split-ring commutator switches the direction of the current every half-turn.

Electromagnetic induction

The generation of electricity by means of magnetism is known as **electromagnetic induction**.
The current generated is called **induced current** and the voltage **induced emf**, ξ.

A simple generator of electricity

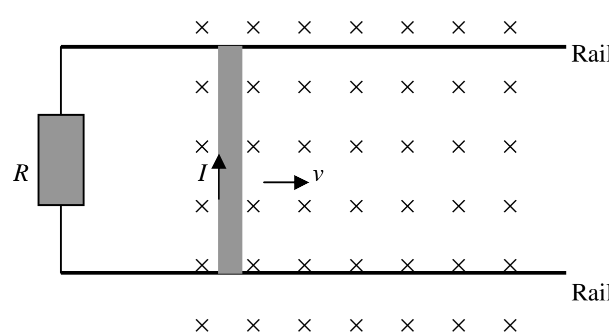


The conductor is pushed across the magnetic field. The charges within the conductor are carried in the same direction. The charges experience a magnetic force when they move in a magnetic field. Some electrons in the conductor are forced to one end of the conductor. Thus one end will have more electrons than protons and become negatively charged. The other end will have fewer electrons than protons and become positively charged. This separation of positive and negative charges establishes an electric potential (induced emf, ξ).

While the conductor is pushed, a (conventional) current flows in it and the conductor experiences a magnetic force opposite to the push. The current drops to zero when the desired induced emf is reached. At this point, the magnetic force becomes zero and the conductor continues its motion without the push.

This demonstrates the concept of **work** and energy. The electrical potential energy stored in the conductor is coming from the work done by the force in pushing the conductor.

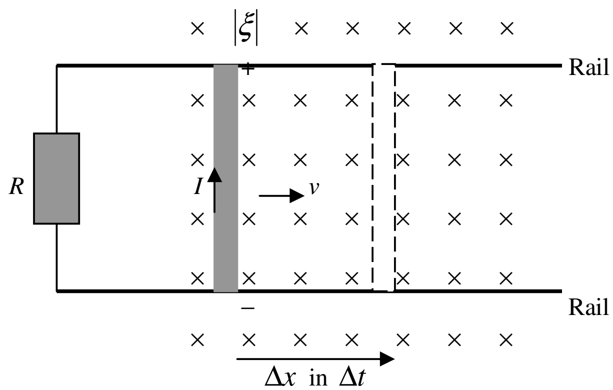
Using the electric potential energy



An external circuit of resistance R is connected to the conductor by two conducting rails on which the conductor slides along. A current I flows and a magnetic force opposes the motion. The conductor slows down to a stop when the generated electric potential energy is expended.

To keep the current flowing and more electrical energy dissipating in the external circuit *R*, more work must be done by the applied force to overcome the opposing magnetic force (resulting in zero net force) in order to maintain the motion of the conductor.

Work done equals electrical energy



Electrical energy dissipated in *R* = Work done by the applied force (equal in magnitude to the magnetic force, *BIL*), i.e. $|\xi| I\Delta t = BIL\Delta x$, $\therefore$ $|\xi|\Delta t = BL\Delta x$.

Hence $|\xi| = \frac{BL\Delta x}{\Delta t}$ ………. (a)

i.e. $|\xi| = BLv$ ……………. (b)

Equation (b) shows that emf ξ is directly proportional to the strength of magnetic field ***B***, the length of the conductor (inside the magnetic field) *L* and the speed *v* of the conductor.

Equation (a) suggests that there are other ways to induce emf besides the method of pushing the conductor across a magnetic field.

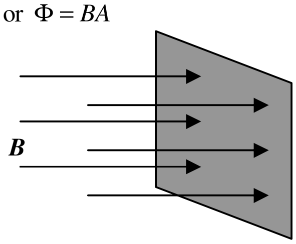
In equation (a) $L\Delta x$ represents a change in area ΔA where the magnetic field passes through, and $B\Delta A$ represents a **change in magnetic flux** $\Delta\Phi$ if we define magnetic flux $\Phi = BA$.

$$\therefore |\xi| = \frac{\Delta\Phi}{\Delta t}.$$

Magnetic flux Φ

Magnetic field ***B*** is often called **magnetic flux density**, i.e. magnetic flux per unit area. Magnetic flux Φ can be pictured as the number of magnetic field lines passing perpendicularly through a region of area *A*.

$B = \frac{\Phi}{A}$, or $\Phi = BA$

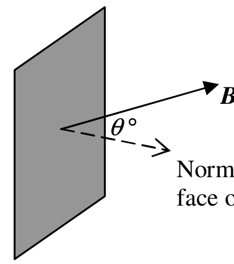


Shaded region area *A*

If ***B*** is not perpendicular to the plane of region, the magnetic flux is given by

$$\Phi = BA\cos\theta°,$$

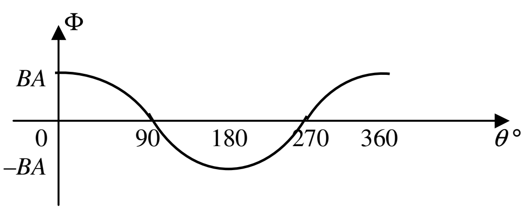
where $\theta°$ is the angle between ***B*** and the direction that the region facing (normal to the plane of the region).



As $\theta°$ increases from 0°, Φ decreases.

Φ is maximum (= *BA*) when $\theta = 0°$, i.e. ***B*** is perpendicular to the plane of the enclosed region.

$\Phi = 0$ when $\theta = 90°$, i.e. ***B*** is parallel to the plane of the enclosed region.



Magnetic field is measured in tesla (T), magnetic flux is in weber (wb) and area in m^2.

$$1 \text{ T} = 1 \text{ wb m}^{-2}$$

At the surface of the earth, $B \approx 10^{-4}$ T.

Example 1 A circular loop (radius = 10 cm) of copper wire is placed inside a uniform magnetic field of 0.10 T. Calculate the magnetic flux enclosed by the loop if the magnetic field is (a) perpendicular, (b) parallel, to the plane of the loop.

(a) $\Phi = BA = 0.10 \times (\pi \times 0.10^2) \approx 0.003$ wb.

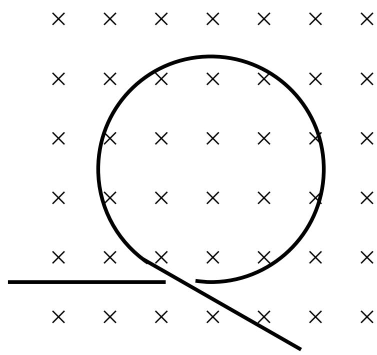
(b) $\Phi = 0$.

Ways to change the magnetic flux Φ

According to $\Phi = BA\cos\theta$ magnetic flux can be changed by changing *B*, *A* or *θ*.

Changing the area A to change the flux Φ

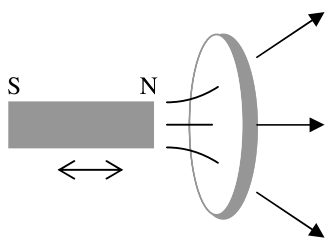
E.g.



Pulling or pushing the two ends decreases or increases the area enclosed by the loop.

Changing the magnetic field to change the flux Φ

E.g.

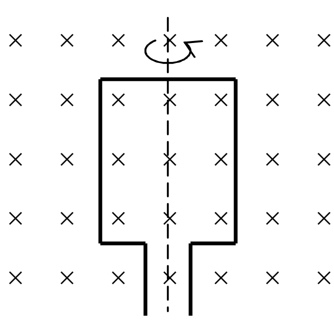


Moving the magnet closer to (or away from) the loop increases (or decreases) the magnetic field through the loop.

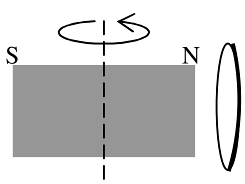
Changing the angle θ *to change the flux* Φ

This is done by either rotating a loop in a magnetic field or rotating a magnet near a loop.

E.g.



or



Faraday's Law

Faraday investigated quantitatively the factors that influence the magnitude of the emf induced. He found that it is directly proportional to the rate of change of magnetic flux and the number *n* of closely wrapped loops in the circuit.

Average induced emf, $\xi_{av} = -n\frac{\Delta\Phi}{\Delta t}$.

Instantaneous induced emf, $\xi = -n\frac{d\Phi}{dt}$. (Not required in VCE)

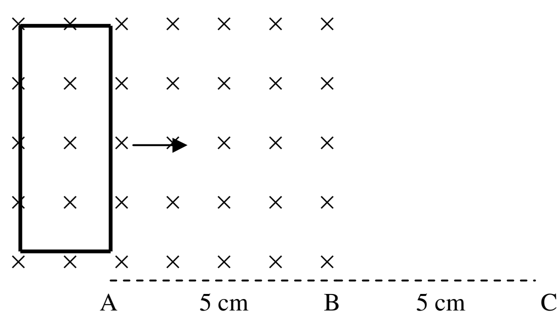
The minus signs in the equations indicate in which direction the induced emf acts. This is to be discussed later.

Example 1 A 250 loop rectangular coil makes a 90° rotation from a position of zero flux in 0.25 s. The coil has dimensions 8.0 cm by 6.0 cm and it is placed in a uniform magnetic field of 100 μT. Find the magnitude of the average induced emf during the interval.

$$|\xi_{av}| = n\frac{|\Delta\Phi|}{\Delta t} = 250\times\frac{(100\times10^{-6})(0.080\times0.060)-0}{0.25}$$
$$= 4.8\times10^{-4}\text{ V}$$

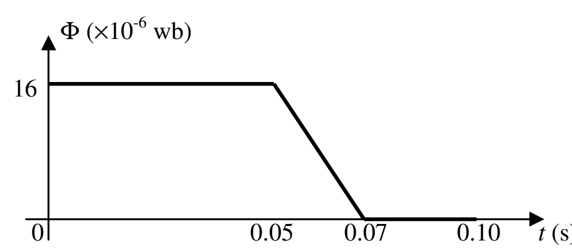
Example 2 A 8.0 cm by 2.0 cm rectangular loop is pulled out of a magnetic field of 100 μT at a constant velocity of 1.0 ms^{-1}. The loop has a resistance of 0.5 Ω.

The diagram below shows the location of the loop at $t = 0$.



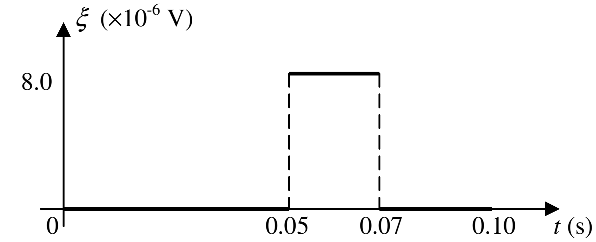
$v = 1.0$ ms^{-1}, $\therefore$ it takes 0.01 s to move 1 cm. As the loop front moves past B, the flux decreases at a constant rate until the loop rear reaches B.

Graph of magnetic flux as a function of time from A to C



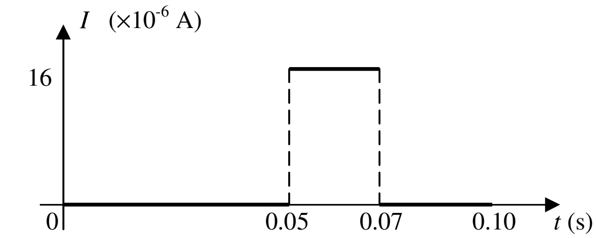
Graph of induced emf as a function of time

$\xi_{av} = -\frac{\Delta\Phi}{\Delta t}$



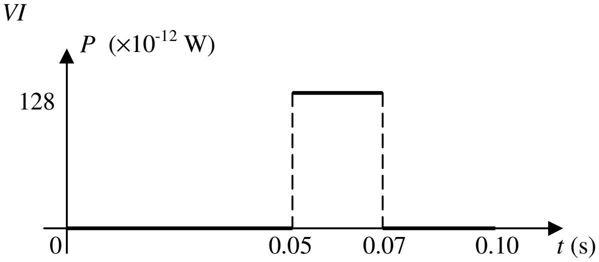
Graph of the induced current in the loop as a function of time

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

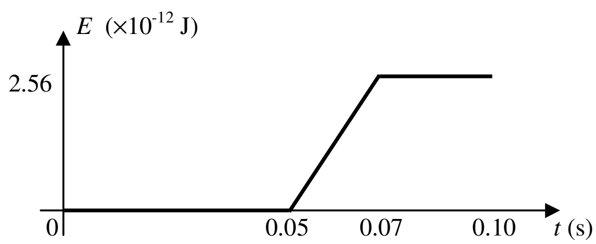


Graph of power dissipated in the loop as a function of time

$P = VI$



Graph of energy dissipated in the loop as a function of time
(Energy is given by the area under the *P*-*t* graph)



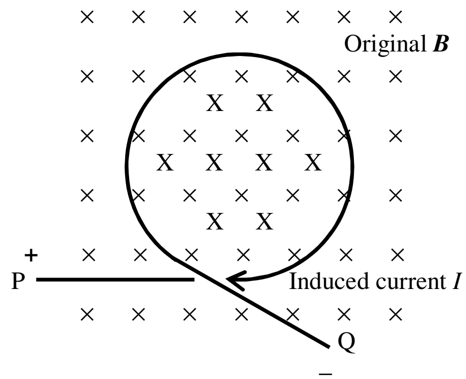
Direction of induced current and polarity of the output terminals of a generator – Lenz's law

An induced current in a closed conducting loop will flow in such a direction that it *opposes* (the minus sign in $\xi_{av} = -\frac{\Delta\Phi}{\Delta t}$) the original change in magnetic flux that produces it.

This is known as **Lenz's law** and it is used to determine the direction of the induced current in a closed conducting loop if there is a change in magnetic flux.

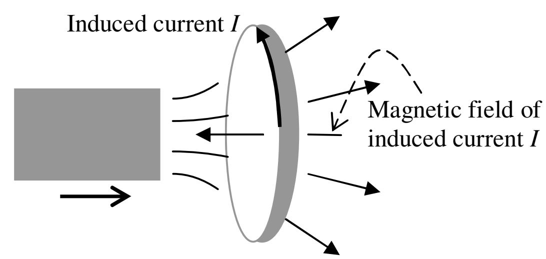
For an open loop, use Lenz's law to find the direction of the induced current and then determine the polarity of the terminals of the loop.

Example 1 A loop with enclosed area changing (e.g. decreasing) in a constant magnetic field



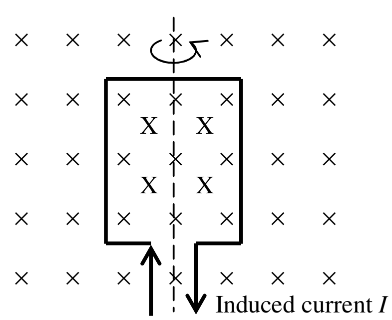
When the enclosed area decreases the original magnetic flux through the loop (into the page) decreases. According to Lenz's Law, the induced current generates magnetic field X (hence flux) through the loop (into the page) to make up for (to *oppose*) the decrease in flux. To achieve this, the induced current *I* flows clockwise, making terminal P positively charged, (i.e. electrons flow anticlockwise and accumulate at terminal Q, making it negatively charged).

Example 2 A loop in a changing magnetic field, e.g. moving a magnet towards the loop



The magnetic field increases as the magnet moves towards the loop resulting in more flux to the right through the loop. The induced current *opposes* the flux increase by generating magnetic field to the left inside the loop. To achieve this, the induced current flows anticlockwise (viewing from the magnet side).

Example 3 A rotating loop in a uniform magnetic field, e.g. the loop rotates anticlockwise (viewing from above)

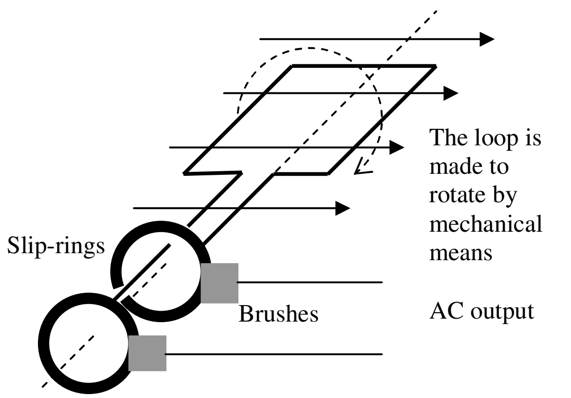


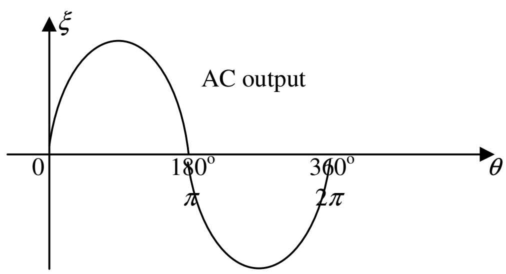
As the loop rotates from the orientation shown in the diagram, the flux decreases because there are less magnetic field lines passing through the loop into the page. To *oppose* this, the induced current *I* flows clockwise (viewing the page) in order to generate more magnetic field X into the page through the loop.

Slip-rings and split-ring commutators

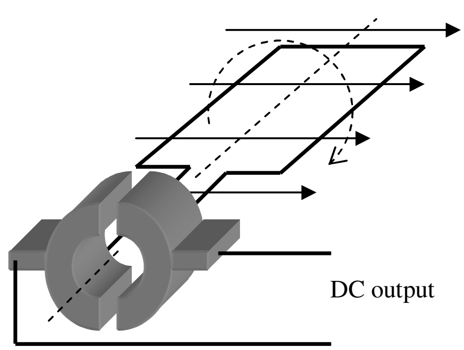
Alternating emf induced in a rotating conducting loop in a magnetic field is made accessible by means of **slip-rings**. Each ring is connected to one end of the loop and electrically connected by a metal brush to the rest of the electric circuit.

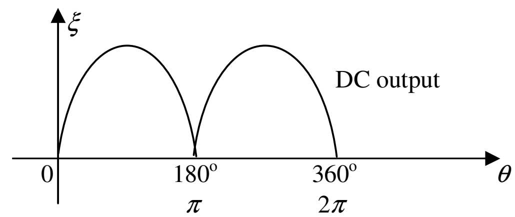
The loop, the magnetic field (either from a permanent magnet or an electromagnet), the slip-rings and the metal brushes form an **AC generator** (also known as **alternators**)





If a split-ring commutator is employed instead of slip-rings, the device is a **DC generator**.



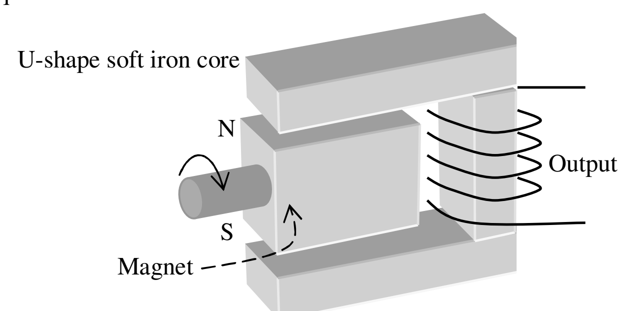


Comparing DC motors and DC generators

The DC generator above has the same construction as the DC motor discussed previously. In fact the same device can be used as a motor or a generator. It is a generator when mechanical energy is used to turn the loop and changed to electrical energy. It is a motor when electrical energy is used to rotate the loop and becomes mechanical (kinetic) energy.

AC generators (Alternators)

Alternating emf can also be induced by rotating a permanent magnet or electromagnet close to a fixed coil. External circuit is connected to the terminals of the coil, and no slip rings are required.

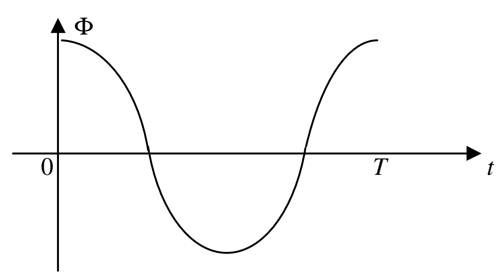


Sinusoidal AC voltages

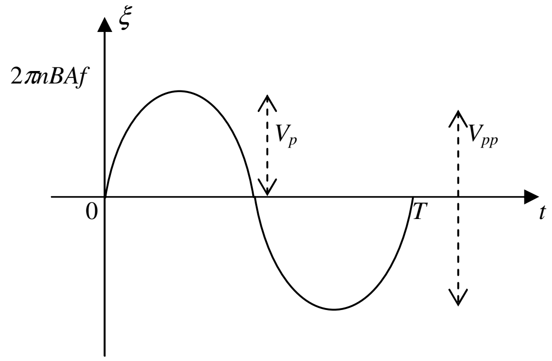
When a loop of area *A* rotates uniformly in a constant magnetic field *B*, the resulting emf is a sinusoidal voltage.

Uniform rotation means that the loop rotates at constant angular speed (radians per second) $\omega = 2\pi f$, where *f* is the frequency of rotation (number of revolutions per second) and $f = \frac{1}{T}$, *T* is the period of rotation.

$\therefore \theta = \omega t$ and $\Phi = BA\cos\omega t$.



Since $\xi = -n\dfrac{d\Phi}{dt}$, therefore $\xi = nBA\omega \sin \omega t$ or $\xi = 2\pi nBAf \sin 2\pi ft$.



The amplitude of the sinusoidal voltage is called the **peak voltage** V_p ,

$$V_p = 2\pi nBAf \ .$$

The peak voltage is directly proportional to the number *n* of loops in the coil, the magnetic field strength *B*, the size (area *A*) of each loop and the frequency *f* of rotation.

V_{pp} is called the **peak-to-peak voltage**.

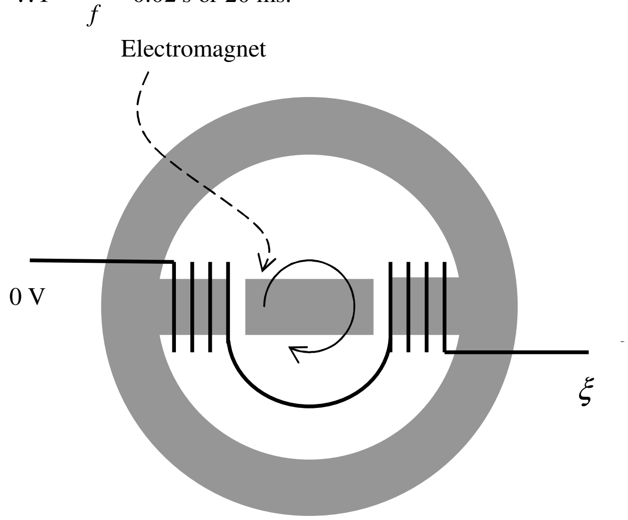
Example 1 What are the effects of doubling the frequency of rotation of the coil on the induced emf?

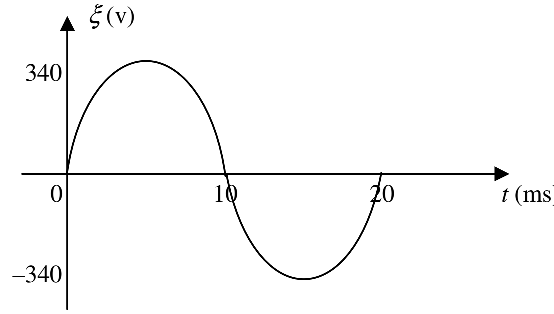
The period of the sinusoidal voltage will be halved, and the amplitude will be doubled.

AC power supply

The power delivered to homes are generated by rotating an electromagnet between two connected coils at f = 50 Hz,

$\therefore T = \dfrac{1}{f} = 0.02$ s or 20 ms.





$V_p \approx 340$ V, $V_{pp} \approx 680$ V

Example 1 In a power station does the generator stop turning, slow down its rotation or keep on turning at the same frequency when there is no one using electricity?

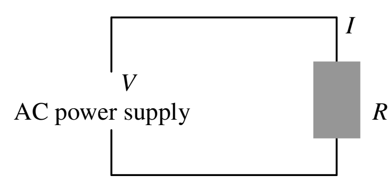
Ideally it keeps on turning at the same frequency (50 Hz) due to its own inertia.

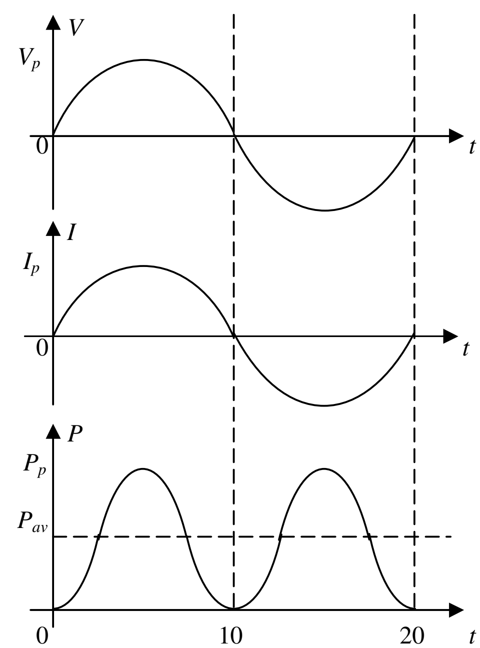
rms voltage and rms current

The two quantities, rms voltage V_{rms} and rms current I_{rms} are introduced to simplify the calculation of the average power P_{av} of an AC power supply.

$P_{av} = V_{rms} I_{rms}$, where $V_{rms} = \dfrac{V_p}{\sqrt{2}}$ and $I_{rms} = \dfrac{I_p}{\sqrt{2}}$ by definition.

Example 1 Explain why $P_{av} = V_{rms} I_{rms}$.





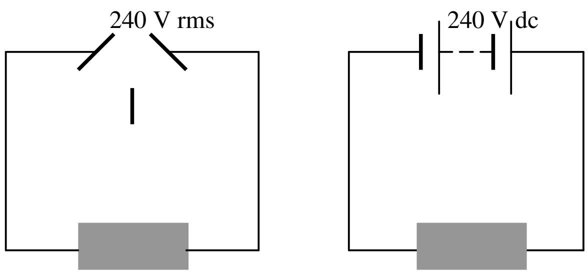
The area under the P vs t graph represents energy, and it is the same as $P_{av} \times \Delta t$.

Mathematically, $P_{av} = \frac{1}{2} P_p = \frac{1}{2} V_p I_p = \frac{V_p}{\sqrt{2}} \times \frac{I_p}{\sqrt{2}}$.

Therefore, $P_{av} = V_{rms} I_{rms} = \frac{V_{rms}^2}{R} = I_{rms}^2 R$.

For our AC power supply, $V_{rms} = \frac{340}{\sqrt{2}} = 240$ V, and it is equal to the power supply of 240 V dc.

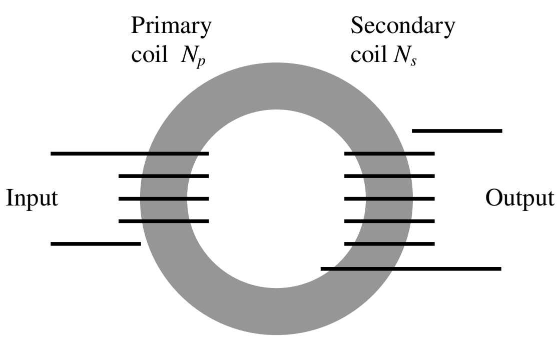
The following diagrams show the same electric heater connected to the two power supplies. The same amount of heat energy is generated if the heater is on for the same duration.



Transformers

A **transformer** is an electrical device which changes the voltage of a power supply without changing the amount of power (*VI*) to be delivered.

A simple transformer consists of two coils of insulated wire, with different numbers of turns, wound around a doughnut shape soft iron core.



The primary (input) winding of N_p turns is connected to an alternating emf generator. The secondary (output) winding of N_s turns is connected to a load resistance *R*.

How does a transformer work?

The alternating current at the primary winding gives rise to an alternating magnetic field inside the soft iron core. The secondary winding is linked to the primary through the core, a changing magnetic field in the core results in a changing magnetic flux in the secondary winding. According to Faraday's Law of electromagnetic induction, $\xi = -n\frac{d\Phi}{dt}$, an emf is induced in the secondary winding.

If the voltage at the primary winding is constant, there is zero induced emf (i.e. 0 V) at the secondary winding.

Step-up and step-down transformers

In a **step-up transformer**, $N_s > N_p$ and the output voltage is higher than the input voltage. In a **step-down transformer**, $N_s < N_p$ and the output is lower than the input.

For a transformer, $\frac{V_s}{V_p} = \frac{N_s}{N_p}$. This is known as the **transformer equation**.

For an ideal (i.e. 100% efficiency) transformer, there is no power loss within the transformer and therefore, the output power equals the input power.

$$P_s = P_p$$
$$V_s I_s = V_p I_p .$$
$$\therefore \frac{I_s}{I_p} = \frac{V_p}{V_s} = \frac{N_p}{N_s} .$$

A real transformer is typically 99% efficient, i.e. $P_s = 0.99 P_p$.

In the above equations, V_s, V_p, I_s and I_p can be all rms values or all peak values.

Example 1 A transformer for a radio reduces 240 V to 9.0 V. The secondary contains 30 turns and the radio draws 400 mA. Calculate (a) the number of turns in the primary, (b) the current in the primary, and (c) the power delivered.

The voltage and current are all given in rms values.

(a) $\frac{N_p}{N_s} = \frac{V_p}{V_s}$, $\therefore N_p = \frac{V_p}{V_s} \times N_s = \frac{240}{9.0} \times 30 = 800$.

(b) $\frac{I_p}{I_s} = \frac{V_s}{V_p}$, $\therefore I_p = \frac{V_s}{V_p} \times I_s = \frac{9.0}{240} \times 400 = 15$ mA.

(c) $P_{av} = V_s I_s = 9.0 \times \left(400 \times 10^{-3}\right) = 3.6$ W.

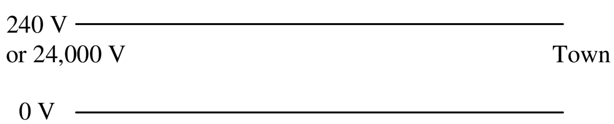
Transmission of electric power and power loss in the transmission lines

Power stations are often situated some distance from metropolitan areas and thus electricity is transmitted over long distances in transmission lines. Transmission lines are made of very good conductors but they do have resistance. Heat will be generated and dissipated in the air. Amount of heat dissipated in unit time is known as **power loss** P_{loss}, and is measured in Js^{-1} or W.

If there is a current I (amperes, A), and the total resistance of the transmission lines is R (ohms, Ω), $P_{loss} = I^2 R$.

Since $P_{loss} \propto I^2$, the size of the current have a large effect on the power loss in the transmission lines. For example, if the current is ten times, the power loss is 100 times. If the current is reduced to one tenth, the power loss becomes one hundredth.

Example 1 Electric power is supplied to a country town from a power station (output 120 kW) 10 km away. The transmission lines have a total resistance of 0.40 Ω. Calculate the power loss if the power is transmitted at (a) 240 V, and (b) 24,000 V.



(a) Power station output, $P = VI$, $I = \frac{P}{V} = \frac{120\times10^3}{240} = 500$ A.
Current in the transmission lines = 500 A.
Power loss in the transmission lines:
$P_{loss} = I^2 R = 500^2 \times 0.40 = 100$ kW.

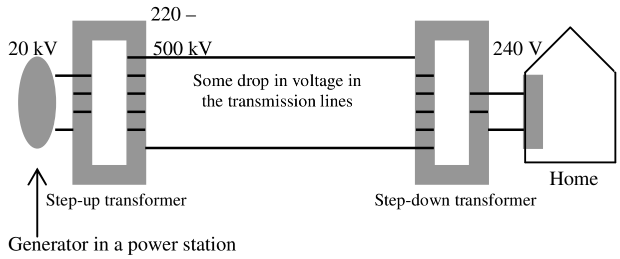
(b) Power station output, $I = \frac{P}{V} = \frac{120\times10^3}{24000} = 5.0$ A.
Current in the transmission lines = 5.0 A.
Power loss in the transmission lines:
$P_{loss} = I^2 R = 5.0^2 \times 0.40 = 10$ W.

The above example shows that power loss can be minimised if the power is transmitted at high voltages. The higher the voltage, the smaller is the current for the same power input and consequently lower power loss as heat in the transmission lines. It is for this reason that power is usually transmitted at very high voltages, about 500 kV.

A major reason alternating current (AC) is in nearly universal use, is that the voltage can easily be stepped up or down by a transformer.

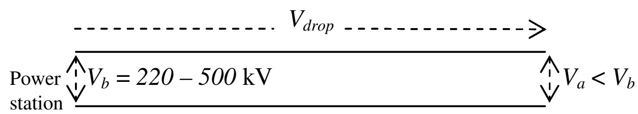
The output voltage of the generator in the power station is stepped up before transmission. Upon arrival in a city, it is stepped down in stages at electric substations prior to distribution.

The following diagram shows a schematic transmission circuit.



Voltage drops

The voltage at the input end of the transmission lines is always higher than the voltage at the other end because of the power loss. The difference in voltages is the **voltage drop**. Voltage drop is given by $V_{drop} = V_b - V_a$, where V_b and V_a are voltages before and after transmission respectively, or $V_{drop} = IR$, where I is the current in the transmission lines and R the total resistance of the transmission lines. $\therefore V_b - V_a = IR$.



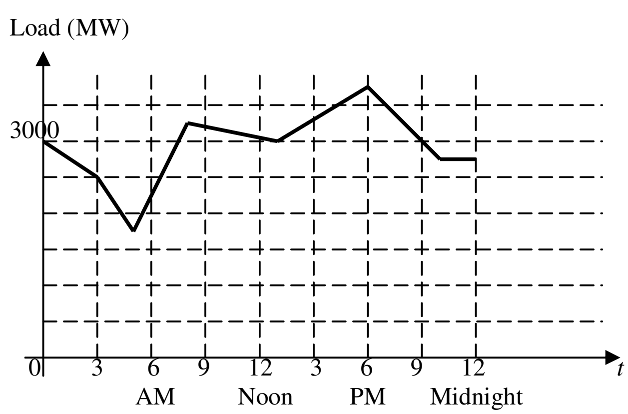
Since $V_{drop} \propto I$, higher consumption of electric power in homes, offices and factories will result in larger current in the transmission lines and hence a lower voltage supply (slightly lower than 240 V) during peak periods.

Example 1 Refer to the previous example, calculate the voltage drop and the voltage at the receiving end in each case.

(a) $V_{drop} = IR = 500\times0.40 = 200$ V, $V = 240 - 200 = 40$ V.

(b) $V_{drop} = IR = 5.0\times0.40 = 2.0$ V, $V = 24000 - 2 \approx 24000$ V.

Example 2 The following diagram represents a load curve which shows the demand for electricity in Victoria over a 24-hour period in winter.



Energy consumption over the 24-hour period
$= P_{av} \times \Delta t = 2900\times24 = 7.0\times10^4$ Mwh $\approx 2.5\times10^8$ MJ.
Transmission current is lowest at 5 AM, and highest at 6 PM.
Voltage (power point) is highest at 5 AM, and lowest at 6 PM.

