Module 2: Motors and Generators

1. Motors use the effect of forces on current-carrying conductors in magnetic fields.

Revision: A **moving charged particle** creates a magnetic field. Thus a **current carrying conductor** produces a magnetic field around it, the direction determined by the right hand grip rule shown. A **solenoid** is a coil of insulated wire that carries an electric current such that the magnetic fields form a similar shape to a bar magnet. The pole can be determined by another right hand rule as shown. An **electromagnet** is a solenoid with a **soft iron core** which greatly amplifies the effects of the solenoid, the strength of which can be increased by increasing the current, increasing the coils, or increasing the amount of iron in the core.

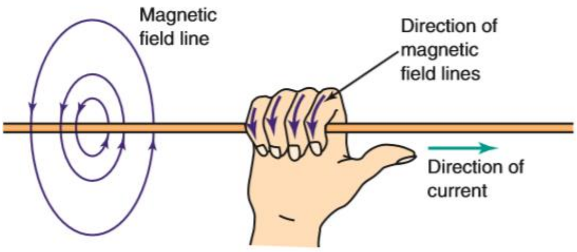


Figure 6.5 *The right-hand grip rule*

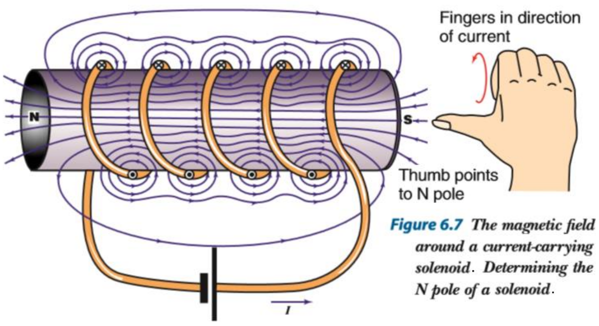


Figure 6.7 *The magnetic field around a current-carrying solenoid. Determining the N pole of a solenoid.*

Students learn to:

- When a **current carrying conductor** is placed in an **external magnetic field**, the magnetic field around the conductor produced by the moving charges interacts with the external magnetic field such that the conductor **feels a force**, described by the **right hand push rule**. This effect is known as the **Motor Effect** and was discovered by Michael Faraday. The magnitude of this force is related to four things:

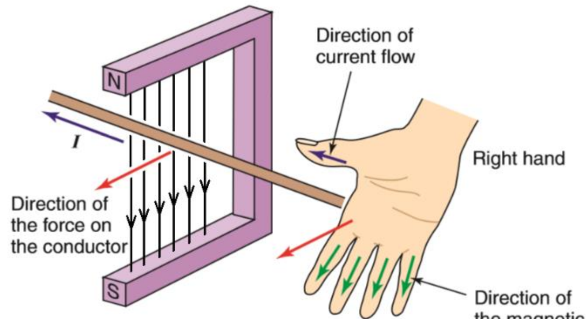
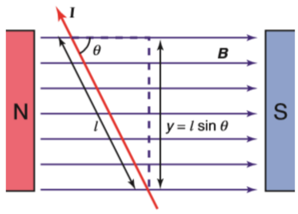


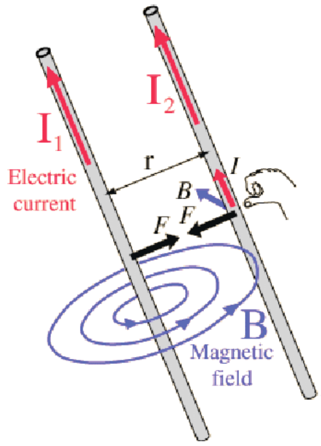
Figure 6.11
The right-hand push rule for a current-carrying conductor

  - The **strength of the external magnetic field** [B, tesla (T)] is directly proportional to the strength of the force, a great magnetic field causes a greater effect.
  - The **magnitude of the current through the conductor** [I, amps (A)] is also directly proportional due to the increased drift velocity, and hence force, of the moving charged particles.
  - The **length of the conductor immersed in the field** [l, metres (m)] is again directly proportional, as more charged particles to act on.
  - The **acute angle between the conductor and the field** affects the strength. The force is maximum when the conductor is at right angles, zero when the current is parallel. Therefore the force is directly proportional to the sine of θ where θ is the acute angle between the field and the conductor.

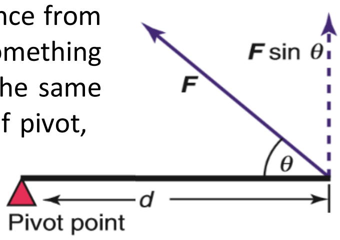


  These factors can then be combined to discern the magnitude of the motor effect, given by the equation $F = BIl\sin\theta$.

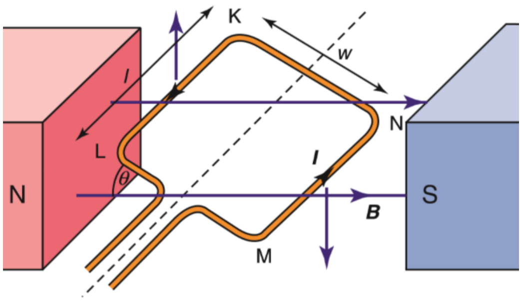
- Due to the motor effect, two **parallel current carrying conductors** can interact with the magnetic fields produced by each other and thus feel a force. Using the right hand push rule on each conductor, it can be discerned that two conductors whose currents are running the **same direction** produce an **attractive force** towards each other. The opposite is true, if the current is in **opposite directions** the force is a **repulsive force**. This is because the magnetic field of one wire cannot interact with itself, it **only experiences the force** from the other. This can be calculated such that if the current is: ***same direction = attract***, ***opposite direction = repel***. The magnitude of this force is directly proportional to the magnitude of the currents in each wire and the length of the conductors that are parallel, but inversely proportional to the distance between the conductors. This can be formulated as follows, $\frac{F}{l} = k\frac{I_1 I_2}{d}$, where F is the force (N), l length (m), I_1 & I_2 current through both conductors (A), d distance between (m), and k is the magnetic force constant so units match up.



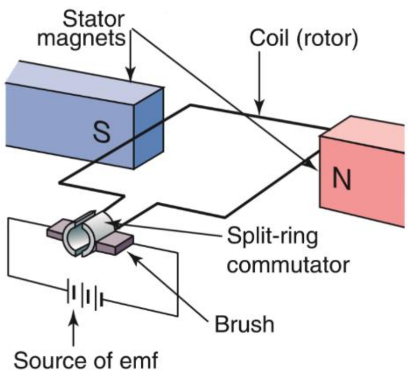
- **Torque** is the **turning moment** or the **rotational force** acting on a pivot point. It is the turning effect at a point and is a product of the force applied and the distance from the point that force is applied from, $\tau = Fd$. ie, it is easier to turn something the further away you are. Torque is not related to work, despite the same equation. Maximum torque is achieved **perpendicular** to the axis of pivot, thus the actual equation is $\tau = Fd\sin\theta$, shown right.



- If we examine the diagram below, KL and MN and always perpendicular to the magnetic field and thus are **under equal force upwards** throughout the rotation, regardless of the orientation of the coil. ML and NK are always parallel to the field so never have a force acting on them. These forces **produce a torque** along the rotational axis which is greatest when $\theta = 0°$ as this is when the force is perpendicular to the axis of rotation and decreases to 0 when vertical, under the relation $\cos\theta$. Thus when calculating the torque produced by the coil, ML and NK are ignored (as $F = 0$), but for KL and MN, $\tau = (BIl)(\frac{w}{2})\sin\phi$, as $\phi = 90° - \theta$. Thus torque for the entire coil is given by adding KL and MN, $\tau = BIl \cdot \frac{w}{2} \cdot \sin\phi + BIl \cdot \frac{w}{2} \cdot \sin\phi = BI(lw)\cos\theta$ Sine lw is the area of the coil, the force produced by the motor effect results in a torque for **any rotating coil** of exactly $\tau = nBIA\cos\theta$ where n is the number of coils, obviously adding more coils increases the torque directly.



- A **DC Electric Motor** converts **electric potential energy** into **rotational kinetic energy (torque).** It achieves this by passing an electric current through multiple coils in a constant magnet field producing the effects described above. The basic diagrammatic setup is shown right. If the effects above were all that required, as soon as the rotor coil passed vertical, the torque would be reversed as the currents would still be dragging the coil in the same direction, thus the coil would rock back and forth. Instead a **split ring commutator** is used to change the **direction of the current**, reversing the currents and thus keep the torque pushing in the same direction, as shown on the next page. The split in the commutator is placed so that as the coil rotates past vertical, the **graphite brushes** (terminals for the EMF) switch sides, changing the current. To change the speed of an electric



motor, the force acting on the coil can be increased ($F = BIl \sin\theta$), the coil width or **number of wrappings** can be increased, or **multiple banks** of coils can be added, as shown in the picture. These require a more technical layout (and hence description) but provide smoother torque throughout.

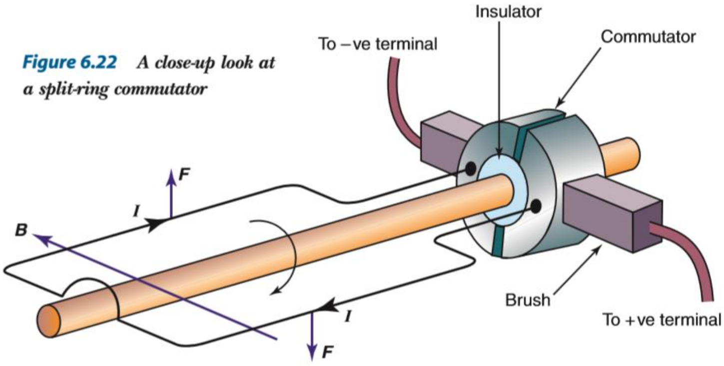
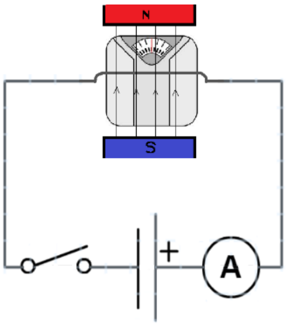


Figure 6.22 A close-up look at a split-ring commutator

- The **Stator Magnets** in an electric motor can be either **permanent magnets** or **electromagnets** (current carrying coils). This is achieved by the soft iron core, which the coil is wrapped around, will extend the magnetic field and make it more mouldable, the poles ending where the iron does.

Students:

- **Practical Investigation – The Motor Effect.** **Aim:** To demonstrate the motor effect. **Independent Variable –** the current through the wire; **Dependent Variable –** any change in weight.



Method: Set up a circuit such that a wire lies taped across a set of electronic scales between two opposing magnetic poles (static and uniform magnetic field), as shown below. Place something light (a block of foam) on top of the wire so that a weight is measurable and the wire can't escape. Then apply direct current both ways and at varying currents and measure the mass changes registered on the scales. **Results:** One current direction should reduce mass (as the wire pushes up, taking the load) while the opposite increases mass (pushes down). The amount of mass discrepancy should be proportional to the current passed through the wire. (can also just use suspended wire and watch it move, as this demonstrates qualitatively)
- The **Motor Effect is utilised** in both the **galvanometer** and the **loudspeaker**:
  - The **Galvanometer** is a device for measuring small DC currents, depicted right. When a current flows through the coil, it is amplified by the iron core attached to the coil and produces torque. The iron core is also attached to a **counter-balancing spring** such that increasing rotation requires increasing force. Also note that the stator are curved creating a **radial magnetic field** such that torque is constant despite the rotation.
  - The **Loudspeaker** converts EMF to sound energy and utilises **a circular horseshoe magnet**. The coil of wire sits between the two poles and is connected to the speaker cone. Thus as electrically encoded sound waves passed through the coil cause the speaker cone to compress the air resulting sound waves from the force applied by the coil, either sucking in or pushing out. Changing the **frequency** of the alternating current changes the **pitch** (faster movement) while changing the **amplitude** changes the **volume** (greater compressions).

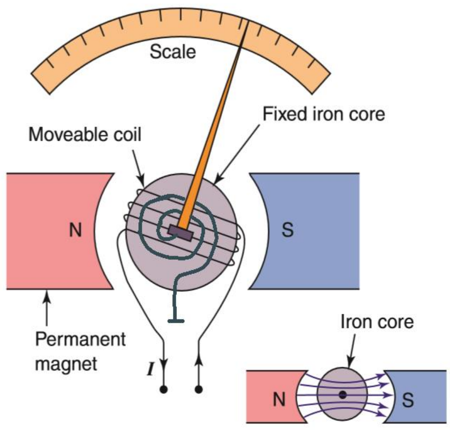
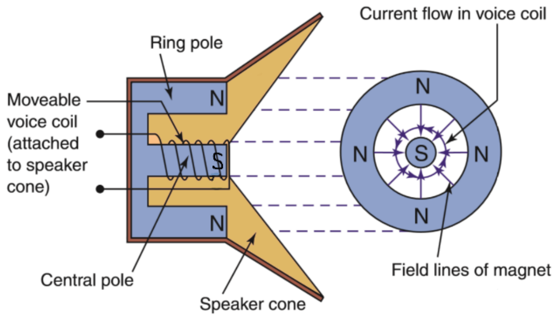


Figure 6.27 The galvanometer



2. The relative motion between a conductor and magnetic field is used to generate an electrical voltage.

Students learn to:

- **Michael Faraday** discovered in 1831 that when a magnet is moved close to a conducting coil, a momentary **electric current is generated** within the coil. He noticed that when you moved a north **pole near a coil**, a small current was produced; when it was removed the current flowed opposite. If the pole merely held there stationary however, nothing would happen. A similar, but opposite, effect was noticed with a south pole. Faraday also noticed that if the magnet was **moved faster**, the current spike was greater than if moved slower.
- A **magnetic field** is represented diagrammatically via lines that flow in the direction the field does, their density representing strength. These field lines are known as **flux** lines. **Magnetic flux** is the number of these lines, the amount of magnetic field, passing through an area, and is measured in **weber** (Wb). Thus magnetic flux is found by $\Phi_B = BA$. It is important to note that magnetic flux is only measured perpendicular to the area sampled, thus only consult the perpendicular component; if the field is parallel there is no flux passing through the area.
- The strength of the magnetic field, B, is known as **magnetic flux density** and is the amount of flux passing through a unit area; it is measured is **Tesla** (T) which is weber per square meter (Wb m^{-2}).
- To induce a current, an **electromotive force (ε)** needs to be present and Faraday noted that an emf was produced by a changing magnetic field. Faraday's Law of Induction states "*The induced emf in a circuit is equal in magnitude to the rate at which the magnetic flux through the circuit is changing with time*". Faraday's law written in equation form is thus $\mathcal{E} = -\frac{\Delta\Phi_B}{\Delta t}$ where the **negative sign** indicates **Lenz's Law**. Induction always produces an emf but only does this transform into current through a conductor when the **circuit is closed**, thus forming an **area**. The magnetic flux in induction is the **flux passing through this area**, the area of the coil. When a coil rotates through a stationary magnetic field, the flux density still changes, thus it is the relative motion on which induction relies on.
- **Lenz's Law** stated is "*An induced emf always gives rise to a current that creates a magnetic field that opposes the original change in flux through the circuit.*" Thus the direction of the current can be predicted, as right. This law is a direct result of the **Conservation of Energy**, as energy is being used to push the magnet closer to the ring, some of this energy is used to **create the current**, thus conserving energy. If it were the other way around, a circular effect would be created and we generate energy for nothing. In an **electric motor**, there is **relative motion** between the magnetic field and the coil, and according to Lenz's Law this creates an emf, known as the **back emf**.

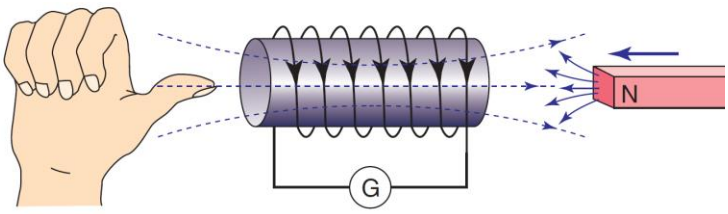
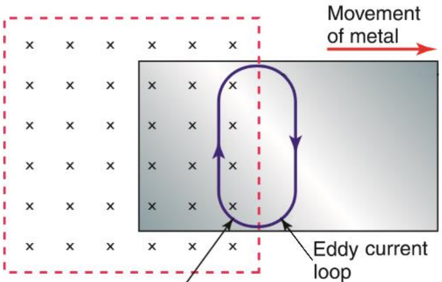


Figure 7.10 *The N pole of a magnet approaches a coil. Note that the induced magnetic field of the coil repels the approaching N pole.*

- However this **back emf** is opposite in direction to the supply emf hence the name. The total emf across the circuit is **supply minus back**. This makes sense as the faster the coil rotates, the higher the flux change, the greater the back emf and hence less force to accelerate the coil. Ignoring friction, back emf would hence increase until it **equalled supply emf**, the lack of current suddenly applying no force and the coil would spin at a **constant velocity.** Thus the slower the motor rotates, the higher the total current passing through the system. If the motor slows down enough, this current can burn out the motor and thus most motors are protected by a **switchable resistor** to reduce the high currents produced when the motor starts up, once it reaches speed, back emf takes over.
- **Lenz's Law** does not just apply to coils but can affect any metal object. When subject to a change in flux, an **eddy current**, similar to the **circular swirls left in water**, is formed as shown right. On

the left hand side of the line, the **positive charges** (metaphorically as we got current wrong with convention) experience a force (right hand push) up the page as they are moving (current) relative to the field. Once free of the field (when they reach the right) they complete the circuit (again, metaphorically) to balance the charge thus causing swirling currents in the metal as it passes. Eddy currents are effectively the **reverse of the motor effect,** the magnetic field moving across the charged particles causes them to move. Note that eddy currents **always occur perpendicular** to the change in flux.



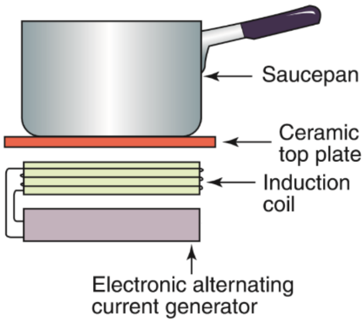
The eddy current loop can be explained in terms of the right-hand rule.

Students:

- **Practical Investigation – Faraday's Experiments. Aim:** to model Faraday's experiments about induction. **Independent Variables** – distance between coil and magnet, strength of magnet, relative motion between the two; **Dependent Variable** – electric current produced. **Method:** connect a coil to a galvanometer. Recording all readings on Galvanometer, push the north pole of a bar magnet near the coil, leave it stationary and pull it out. Repeat with south pole. Repeat varying speed of movement. Repeat instead moving the coil. Repeat with a super magnet. **Results:** as above.

Variable	Response in Galvanometer
North pole in	Spike in current
Stationary	No current
North pole out	Spike in current but opposite direction
South pole	Same as north but opposite in direction
Relative velocity	Spike in current is much higher but obviously shorter
Moving coil	Same, as motion is relative
Super magnet	Much greater current spikes

- **Induction Cooktops**. When **eddy currents** are created, they inevitably cause heat in the same way a current does, thus the loss of energy. This can be utilised however, in **Induction Cooking** where eddy currents are produced and intensified in various cooking utensils. The cooktop generates a **rapidly changing magnetic field** by applying 24 kHz AC to an induction coil. This $\Delta\phi_B$ causes **electric collisions** and **general agitation** of the lattice. When the eddy currents are confined to a very small region, the heat is much more intense thus metals with a **thin skin depth** work much better. Alloys of steel are most efficient but **copper does not work**, the relative skin depth is too great to provide efficient heating. Induction cooktops are 84% efficient as opposed to normal electric cooktops with 74% efficiency and gas with 43% efficiency; therefore they are more **environmentally friendly** and **cheaper** (ignoring installation costs). They are also **safer** as, especially with purpose built induction saucepans, there is no **exposed heated metal** except in contact with the food.



- **Electromagnetic Braking**. As a piece of metal moves through a magnetic field, the right hand push rule indicates eddy currents are produced in a **upward direction** as positive charges are moving relative to a magnetic field. However once those **eddy currents** are established, the right hand push rule shows that the upward movement of the positive charges creates a **retarding force** on those charges in the direction

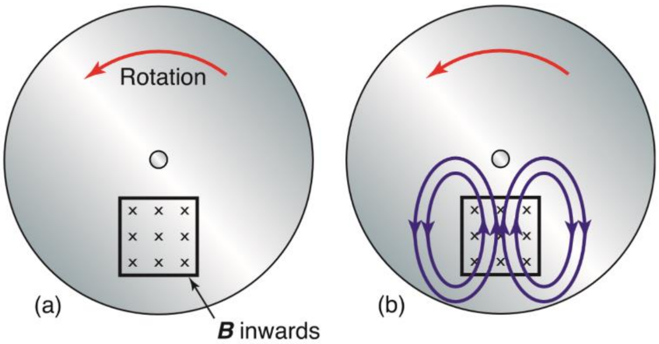
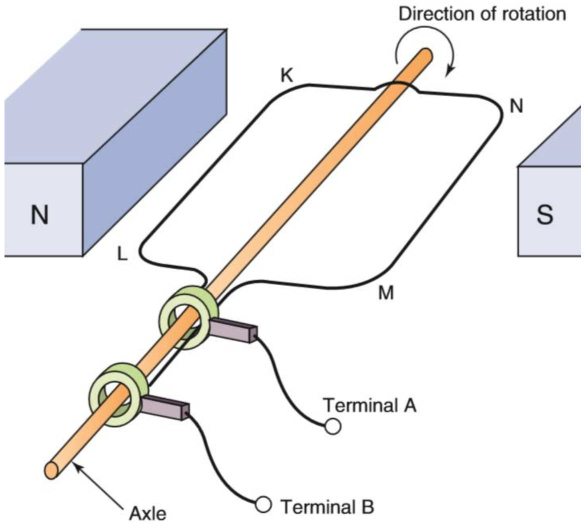


Figure 7.14 *(a) A rotating metal disk acted upon by a magnetic field (b) The current that flows in the disk*

opposing movement. This causes breaking. As the **relative motion** causes both eddy current and force, the magnitude of the **retarding force is proportional to the velocity** of the metal, thus electromagnetic brakes provide **perfectly smooth breaking**. They are utilised in trains, both on the wheel and the tracks, but also in theme park rides where smooth, hard breaking is required that is beyond the safety of any cost effective friction brake. Eddy current brakes are **quiet, frictionless,** and require next to **no maintenance**. However we have very **little real world experience** with eddy brakes, they can **interfere with train communication** equipment, cause **structural problems** due to heat in the rails, and are now being rejected over **regenerative brakes** in many situations.

3. Generators are used to provide large scale power production.

Students learn to:



- A <u>**Generator**</u> transforms **kinetic energy** into **electric energy** using **Faraday's Law of Induction.** They utilise stator magnets (electric or permanent) and a rotor coil attached to an axle. The axle turns causing a **change in flux** which thus produces a current through the coil which completes the circuit. Adding an **iron core to the coil intensifies** the change in flux thus increases the efficiency of the generator, similarly adding more coils also helps. The **frequency** and **amplitude** of the voltage produced is affected by the speed the coil rotates, if the speed is doubled, then both frequency and amplitude also double.
- In fact a **generator** is the inverse of a motor and uses essentially the same parts. They both utilise stator magnets to provide a uniform magnetic field within which a coil rotates. The crucial difference is a motor aims to **generate kinetic energy through electric**, while a **generator generates electric through kinetic**. Thus the current is supplied in a motor to produce the rotation but a generator supplies rotation to produce current. Thus the <u>**structure is essentially identical**</u> but the <u>**function is inverse**</u>.
- As discerned when studying motors, if the axle rotates smoothly, then the current produced will follow a **sinusoidal curve** and will alternate as a result. AC generators simply take advantage of this by attaching <u>**slip rings**</u> connected to **graphite brushes** which then directly transfer the voltage. The slip rings are attached to the rotor and rotate with it as shown right. Note that when discerning which way the current flows, because of Lenz's Law, it is the back emf produced in a generator so the **current flows opposite** to what it does in a motor for the same direction of rotation. DC generators are **literally the reverse** of DC motors, they contain a split ring commutator to

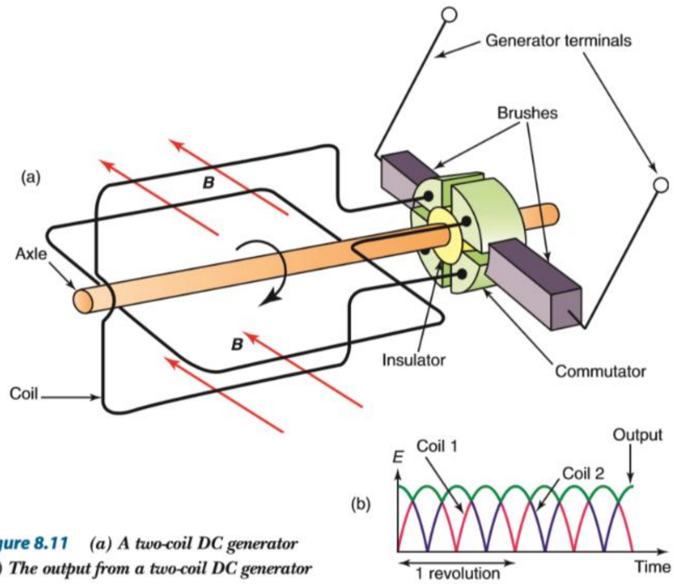


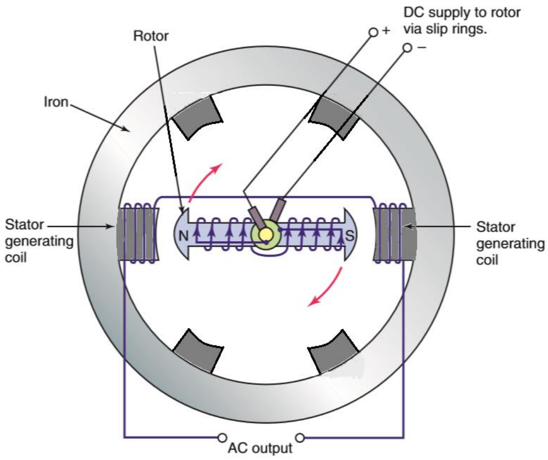
Figure 8.11 *(a) A two-coil DC generator*
(b) The output from a two-coil DC generator

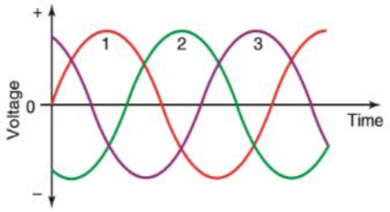
ensure the current stays in one direction. They do produce a **sinusoidal curve** however but this can be reduced by adding more banks of coils. In this situation only one coil is being used at a time so emf is being wasted.

- The main form of energy loss is **resistive loss** in the **long transmission lines.** Energy production rarely occurs near the consumer, often near coal fields or dams. The power loss of a line is given by $P_{Loss} = I^2R$. Thus, significant losses of power occur with high currents, thus the **current is kept as low** as practically possible with voltage inversely becoming massive (most are transmitted at 330 kV). This requires **increased safety,** including large poles, high insulators and corridors through the native environment, but the biggest voltages are often in unpopulated areas. Careful **choice of conductor** can also minimise resistance and hence power loss. Induction in the towers is kept to a minimum due to the distance from the lines caused by insulators. Power loss occurs in **distribution transformers**. These are discussed more in the next dot point.
- The development of **AC generators**, as described above, has had **major impacts on society and the environment**. AC as an electrical source is much easier and cheaper to produce and distribute than DC. As transformers only work on AC, it makes it easy to step-up/step-down voltages allowing for **cheap**, **long distance power distribution**. This has made electricity readily available to almost the entire globe and caused an electrical revolution. As a result, increasing amounts of manual labour was achieved by machines, reducing the number of **unskilled jobs** causing **unemployment** issues. It also created a dependency on electricity for our way of life, such that a power failure could cause **economic collapse.** A hitherto non-existent **night life** is a direct result along with reduced daily labours, increasing convenience and leisure. However these social benefits are **not equal** due to financial discrepancies between developed and developing countries, and this social inequality is furthered by the economic and political power of the **global electricity lobby** which utilises its influence for purely economic reasons. The environmental impact of this electricity boom is also immense. Power lines need corridors due to the high voltages which **destroy native habitat** all across the country. Nuclear power plants produce **radioactive waste** lasting for millennia which, if not stored correctly, can have disastrous natural impacts. The fumes from coal fired power plants not only cause **acid rain** but contribute massively to **climate change** and the environmental destruction it will cause. In conclusion, we have **not learnt to deal with** the ramifications of AC generators and the associated electrical revolution for **holistic social and environmental benefit**, as of yet.

Students:

- **Practical Investigation – Creating an Alternating Current. Aim:** To produce an alternating current. **Independent Variable** – the speed with which the AC generator is rotated; **Dependent Variable** – the frequency and amplitude produced by the generator. **Method:** attach an AC generator (slip rings) to a Cathode Ray Oscilloscope (CRO). Record the differing graphs produced by manually rotating the generator shaft at differing speeds. **Results:** a sinusoidal graph of current, and hence voltage, is produced. The faster the speed, the greater both the amplitude and frequency is.
- The (dis)advantages of DC and AC generators vary. Because the **brushes** in a DC generator must **constantly bridge gaps**, they **wear down** much more quickly than AC generators and thus require more **frequent replacement**. In DC generators the coil must rotate for the split ring commutator to function thus for larger currents, the **stress on the support structures** becomes large as the coils increase. AC stator and rotor sections however are interchangeable and are thus more suitable for large current production.





In commercial power production the magnets becomes the rotor allowing much larger coils to be used in three phase as shown. Three phase (only possible with AC) is also more useful as it reduces the distribution costs using less materials. DC generators however are able to produce much smoother currents as more coils are added, thus making them useful for uses requiring constant output. This is not possible with AC without a rectifying and smoothing circuit.

- **Thomas Edison** (1847-1931) and **George Westinghouse** (1846-1914) engaged in a titanic "**battle of currents**" to try and secure the method of **power delivery** for the USA. Edison was already **well established in the electricity business**, he had invented the electric light, electric motors, dynamos (DC generators), the phonograph, and more. He also already had developed a **DC distribution system for New York City** supplying electricity for street lighting, etc. However DC current could not be **transformed** thus **power loss** limited stations to several kilometres from the consumer. Thus his company, the General Electric Company was already well established when they did not pay Nikola Tesla for redesigning the dynamos they used. Tesla then fully developed the AC system, including motors (induction) and generators to accompany, which Westinghouse bought for $1,000,000. Edison saw Westinghouse as a competitor as **AC is a much better system**. As a result, he published papers to defame AC and performed public demonstrations during which he **killed hundreds of animals** to demonstrate the danger of AC. He also advised NYC to use **AC electrocution** (tried to call it the Westinghouse chair) as the method of execution, which he tried to term being 'Westinghoused'. However the deciding factor came when Westinghouse won the contract to build the **Niagra Falls Power Plant** with AC. This was because he demonstrated during the 1981 International Electrical Exhibition in Frankfurt, Germany, that his system could travel 180 km with only 23% power loss. Thus **Westinghouse secured AC as the preferred power distribution system**. Interestingly, with the development of solid state switching, it is now economically viable to transport DC long distances.
- To distribute electricity, the following concerns must be addressed:
  - Transmission lines must be **insulated**. Electricity sparks 1 cm for every 10 kV is dry air, thus 330 kV requires 33 cm of gap, which increases with humidity. Thus insulators are used to stop current leaking through metal support towers to the ground. Suspension insulators are used over 33 kV, disc shaped as right to increase leakage path and to make it harder for wet dust and grime to become a conductor. The insulators themselves are often made from glass or ceramic.
  - Many power lines have a normally unused wire connecting them called the **continuous earth wire**. This acts to carry current if a fault develops, or dissipate lightning strikes. As this wire is often the highest point of the line, the lighting strikes it and the power surge runs harmlessly into the earth, protecting substations from any sudden power surge.

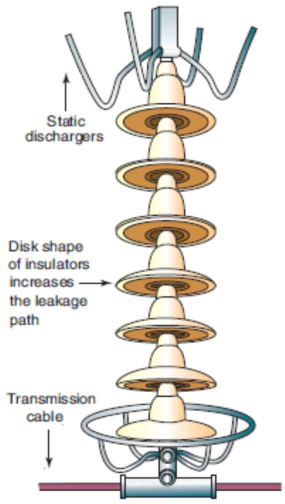
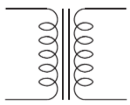


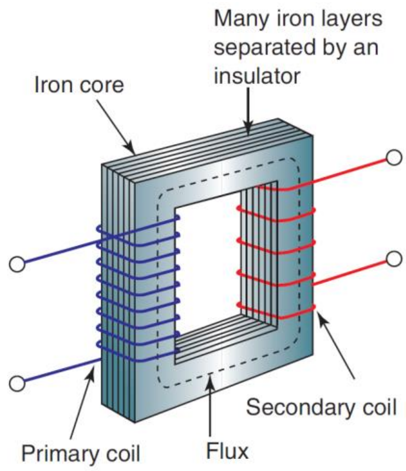
Figure 8.23 Suspension insulator used for high voltage transmission lines

4. Transformers allow generated voltage to be either increased or decreased before it is used.

Students learn to:



- **Transformers** are used to change the voltage applied through a circuit into another voltage in a different circuit. They are used in many different electrical devices that require voltages other than those provided. They work because when the AC is passed through the primary coil, as on next page, magnetic flux is induced within the iron core which in turn induces a current within the secondary coil. Depending on the amount of coils in primary vs secondary, the voltage is stepped up or down. Their circuit symbol is displayed above.



- **Step-up and step-down transformers** are extremely similar in structure but differ in purpose. Both have **two inductively coupled coils wound on a laminated iron core**, as shown right. However step-up transformers have **more turns** in the secondary coil as this **increases the output voltage** whilst decreasing the output current. Step-down transformers have the opposite configuration, with **less turns** in the secondary coil producing **lower voltages**. Step-up transformers are used to increase voltages for **long distance transmission** at power stations whilst step-down transformers are used at substations to bring it **back to consumer levels**. Step-up transformers are used to produce the high voltages required for **cathode ray technologies** whilst step-down transformers are used in electronics, eg. **computers,** where low voltages are required for the components.
- The **relationship between primary and secondary coils** and voltages in a transformer is show right.

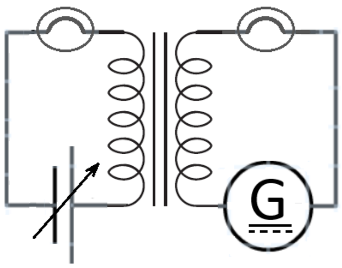
$$\frac{V_p}{V_s} = \frac{n_p}{n_s}$$

- The principal of **conservation of energy** states that energy is conserved, ie you cannot get more energy out of a transformer than you put in. Thus, if the voltage is to increase, the **current must decrease** ($P = VI$) as energy and hence power ($P = \frac{E}{t}$) must be conserved. This is logical as the **same flux threads** through both coils, the only **difference being the area** which is related to current. Some e**nergy may be lost as heat** within the transformer due to eddy currents but the max energy a transformer can produce is equal to the energy input, as there is no energy source within.
- Throughout the distribution system, **different voltages** are required. Massive voltages are used for long distance travel and these voltages become **progressively less** as the web diverges and comes closer to the consumer. Hence transformers are used in all of these **electricity substations** to change the voltage to the required level, eventually from the 330 kV to 415 V three phase.
- Standard **domestic mains power** is 240 V AC however not every **electrical appliance in the home** is capable of running that voltage. Most electronics, like computers, require voltages between 3-20 V so they require a **step-down transformer**. This can be **built into the appliance** or the transformer could be **included in the power lead**. Modern smart phones and other appliances that run on batteries require small voltages as well but need DC, whether to charge the batteries or that they are designed to run on DC, thus require a **rectifier** as well. Correspondingly, cathode ray technologies require voltages of 25 kV to function, thus they need a **step-up transformer**. Sometimes the one appliance will include **both step-up and step-down**, for instance a microwave, which requires low voltages for the electronic interface but high for the motor and transducer.
- With the development of **transformers**, it makes it easy to step-up/step-down voltages allowing for **cheap**, **long distance power distribution**. This has made electricity readily available to almost the entire globe and caused an electrical revolution. As a result, increasing amounts of manual labour was achieved by machines, reducing the number of **unskilled jobs** causing **unemployment** issues. Remote communities now have access to power expanding human settlement. A hitherto non-existent **night life** is a direct result along with reduced daily labours, increasing convenience and leisure. However these social benefits are **not equal** due to financial discrepancies between developed and developing countries, and this social inequality is furthered by the economic and political power of the **global electricity lobby** which utilises its influence for purely economic reasons. The transformer has changed our lives, creating a dependency on electricity that shapes society.

Students:

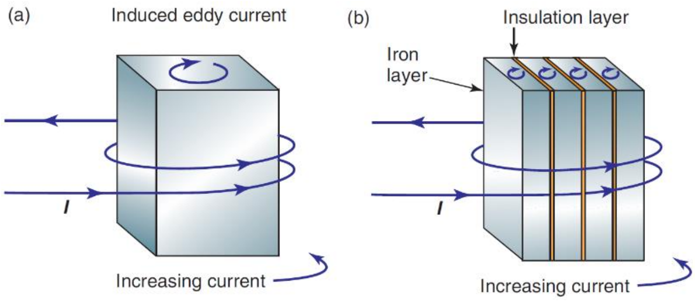
n_P	n_S	n_P:n_S	V_P	V_S	V_P:V_S
150	300	1:2	2	3.8	1:1.9
			6	12.2	1:2.0
			10	18.6	1.1.9
150	75	2:1	2	0	-
			6	0.3	20:1
			10	1	10:1
600	300	2:1	2	0.4	5:1
			6	2.4	2.5:1
			10	5	2:1
600	150	4:1	2	0	-
			6	0.6	10:1
			10	1.9	5.3:1

- **<u>Practical Investigation – Modelling a Transformer.</u>** **Aim:** to model the structure of a simple transformer. **Independent Variable –** the ratio of coils; **Dependent Variable –** the input/output voltage.



Method: using a transformer kit or an arrangement similar, construct a transformer circuit featuring a variable AC power source (power pack), a load (light globe) on each circuit side, two inductively coupled coils wound around an iron core (possibly laminated), and a multimeter attached to the secondary circuit. Change the ratio of the coils and record the secondary voltage corresponding to differing primary voltages. **Results:** as above.

- When the flux passes through the iron core, it induces **eddy currents** within the iron. Due to the **high resistance of iron**, these **<u>eddy currents cause significant heating</u>**, thus decreasing the power output of the transformer and its **efficiency**. This excess heating can also **damage the transformer** if left unchecked. One of the best ways to reduce this heating is to reduce the size of the eddy currents. As eddy current occur **perpendicular to the flux**, the core divided into thin sheets separated by **insular laminate**, as shown above. The flux is unaffected as it is focused parallel. Another method is to construct the core from ***ferrites*** which are complex oxides of iron and other metals. These *ferrites* are **good transmitters of magnetic flux** but **poor conductors of electricity**, thus preventing eddy currents. If heat is produced, it is dealt by **dissipating it to the environment**. This is achieved through **heat sink fins** which increase the surface area for dissipation, **black colouring** to help radiate heat to the environment, **ventilation and fan cooling**, and **oil (nonconductive) cooling**. All these techniques are used at substations.



- As **<u>power loss</u>** is defined by $P_{loss} = I^2R$, the current is **squaringly proportional** to loss. Thus, if power had to be produced at a voltage used by the consumer, 415 V, this would result in **large currents and massive loss** that make it impractical for electricity to be delivered more than a few kilometres. Thus, for **efficient distribution**, current should be kept to a minimum, both physically and economically. This results in the **requirement of <u>massive voltages</u>** for long distance **transportation** whilst retaining the smaller voltages required by the consumer. **<u>Transformers</u>** are hence essential to step-up voltages from the power plant, the progressively step them down, as below. Thus, our **economical distribution** of power relies almost solely on transformers run with AC electricity.

Power Plant: 23 kV → Transmission Lines: 330 kV → Regional Station: 110 kV → Local Station: 33 or 11 kV → Commercial Use: 240/415 V

5. Motors are used in industries and the home usually to convert electrical energy into more useful forms of energy.

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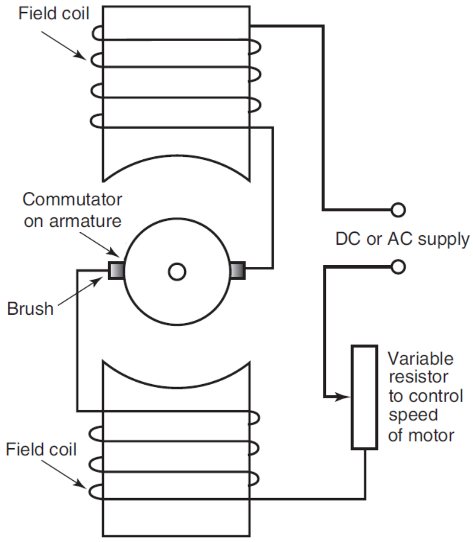
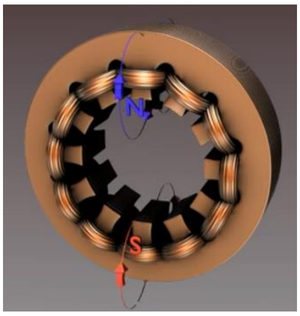
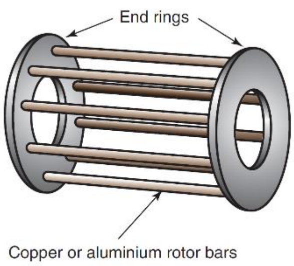


- There are two types of **<u>AC electric motors</u>**; those that run on **one phase** (the universal motor) and those that run on **three phase** (the induction motor). Both involve a **<u>stator</u>** and a **<u>rotor</u>**. The stator is an **electromagnet with a laminated iron core** (to reduce inefficiency). A standard single phase AC motor is literally the reverse of an AC generator. The **<u>Universal Motor</u>** is essentially a DC motor designed to run on either DC or AC. The rotor consists of many **coils wound** onto the armature. The stator is **electromagnets** connect in ***<u>series</u>*** to the coils via brushes and a commutator. Thus, when connected to AC, the **magnets change polarity simultaneously** with change of current in the coils, simulating DC. The Universal Motor is shown right. The most common three phase motor is the **<u>induction motor</u>**. Some induction motors must run on **single phase power**, as in drills, beaters, fans, etc. but the simplest is **three phase**. The stator has **at least three sets of electromagnets** as shown, each **pair connected** to one phase of power. This results in a **magnetic field that rotates through the core**. The rotor is constructed in the form of a **<u>squirrel cage</u>**, with **conductive bars** connected in a circle to two disk plates. This allows an induced current to **flow through the cage.** The magnetic flux is intensified by the **laminated iron** the rotor is built upon. The **<u>relative motion</u>** between the magnetic field and the bars **induces a current** (just like a DC generator) within the bars. This current in turn **interacts with the field** like a motor to produce a **torque** on the cage. Thus, the cage attempts to catch up to the magnetic field. When it does, there is no relative motion and hence no torque. Thus to do work, the rotor has to be spinning slower. The difference in motion is called the **<u>slip speed</u>**. The speed of the motor is also **equal to the frequency** of the current, in Australia 50 Hz.





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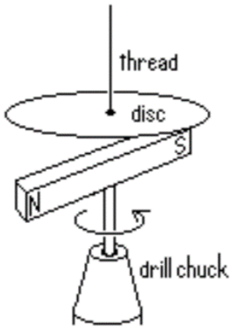

- **<u>Practical Investigation – Demonstrate the principle of an Induction Motor.</u>** **Aim:** to demonstrate the principle of an AC induction motor. **Method:** find an aluminium or copper disc and attach it to a string. Firmly attach a drill bit to a bar magnet as demonstrated in the setup shown. Spin the drill and observe the disc. Replace the disc with other, non-metallic objects and try at differing speeds. **Results:** if the substance conducts electricity, the disc should chase the magnet in the same way the induction motor works.
- **<u>Electrical energy</u>** is **<u>transferred</u>** and manipulated in **transformers** and this is used in the home and industry. Electrical energy is also transferred in **induction motors** between the stator and the rotor. Heat energy is also transferred from the **hot element** to the object being cooked in many electrical devices. Electrical energy is also **<u>transformed</u>**, for example into **radiant energy** in **light globes, microwave ovens, electromagnetic communication** and **medical imaging**. It is also transformed into **kinetic energy** through **motors**, used extensively in industry and the home. It can also be transformed into **chemical energy** through **recharging batteries**. The list goes on…