Electricity and Magnetism

Saturday, October 31, 2020 4:22 PM

4.1:
Simple Phenomena of Magnetism

Magnets are materials that naturally occur in planet Earth. Common magnetic materials are Iron, Nickel, Cobalt and Steel.

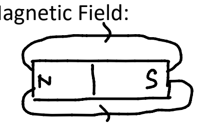
Magnetic materials can attract/repel other magnetic materials. This force is called magnetic force and this occurs due to the interaction of the material's magnetic field.

Properties of magnets:
1) Like poles repel
2) Unlike poles attract
3) Magnetic poles attract ferromagnetic materials (This is otherwise known as induced magnetism)

Take an example when a permanent magnetic is placed near a lump of iron. The lump of iron will be attracted and if left for some time, the lump of iron will be magnetized.

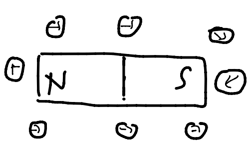
It is important to know that iron is categorized as 'soft' and that it is easily magnetized and demagnetized. On the other hand, steel, which is an alloy mostly made up of iron, has opposite characteristics. It is hard and harder to magnetized. However, it retains its magnetic properties for a longer period of time.

Magnetic Field:



N→S

Experiment to demonstrate



Place compass around magnet. The north arrow will point in such a way when combined would look like the arrow drawn above.

Methods of Magnetization:
1) Stroking: Stroke ferrous material (unmagnetized) with a magnet's North pole from one end to another. Repeat for more than 15 times. Stroke should be in one consistent direction. The end in which you start stroking will be the material's North pole as well
2) Direct current: Wire the material around a circuit and let direct current flow through it

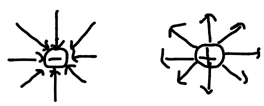
Methods of Demagnetization:
1) Heating: Heating the magnet for extended periods of time will cause it too lose its magnetic properties
2) Hammering
3) Alternate Current

Permanent vs Electromagnet:
1) Electromagnets are designed for it to lose and gain its magnetic properties

with ease. Examples are relay switches and the machine used in scrapyards to lift cars up
2) Permanent magnets are used in compass, loudspeakers and video tapes

4.2:
Electrical Quantities

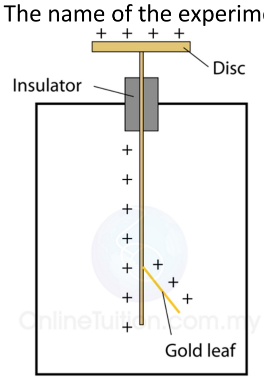
Electric charge:
Electrical charges are of two types, positive and negative. Just like magnets, like charges repel and unlike charges attract. The magnitude of charge is measured in the unit coulombs.
An electrical field is a region where electric charges experience a force. This force is otherwise known as electrostatic force.



The direction of the arrows shows the direction a positive charge would move if placed in a magnetic field. Henceforth, if placed near a positive charge, it would repel and move away, unlike what will happen of placed near a negative charge.

With respect to electric charges, an object can be positively or negatively charged through certain procedures. The removal of electrons will cause the object to the positively charged and the opposite is true. An experiment can also be setup to detect the presence of these charges.

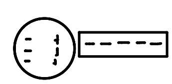
The name of the experiment is the gold lead electroscope experiment.



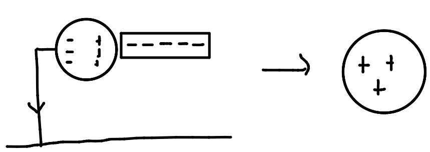
1) When a charged object is brought ear the top, the electrons in the electroscope either move to the disc or away. This either causes the gold lead to bend of rep
2) There is no difference if the charged object is allowed to touch the disc

http://spmphysics.onlinetuition.com.my/2013/08/gold-leaf-electroscope.html

Charging by Induction:
1) An isolated metal sphere is stationary. Bring a negatively charged rod towards the sphere. The rod will repel the electrons in the sphere to the edge.



2) Wire will be attached from the ground to the sphere. This is called Earthing and electrons will flow to the ground
3) Remove the wire and then the rod after some time and the sphere will have a net positive charge



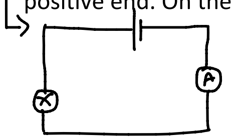
Conductors vs Insulators:
1) Conductors are materials which allow charges to easily flow through it.
2) Insulators, on the other hand, does the exact opposite. They do not have mobile charges.
3) Metals are good conductors due to presence of free moving electrons which

allows charges to easily flow

$$I = \frac{Q}{t} = C/s \rightarrow A\text{(amperes)}$$

Current:
Current is defined as the rate of flow of charge.
A device known as ammeter is able to measure current. This device is always arranged in series within the circuit.

In a circuit, we have positive and negative terminals. Electrons flow from negative to positive terminal as it is negatively charged and hence, is attracted to the positive end. On the other hand, current travels in the opposite direction.

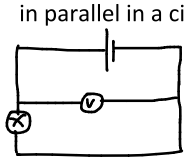


Electromotive force:
Electromotive force is defined as the energy per unit charge that is supplied to drive charge around one complete circuit.

It is measured in volts.

$$\text{Emf} = \frac{\text{Energy}}{\text{Charge}} \rightarrow \frac{J}{C} = V$$

Potential Difference:
Similar to electromotive force, it is also measured in volts. A device known as voltmeter is used to measure this quantity and unlike an ammeter, it is arranged in parallel in a circuit.



The reason why one must be arranged in series and the other parallel is beyond the syllabus but it is beneficial for understanding.

In a series circuit, current is constant all throughout. If we arrange the ammeter in parallel, value of current will differ, resulting in inaccurate results. Not to mention, ammeter has low resistance and hence, if placed in parallel, will disrupt the flow of charge around the circuit.

Opposite is true for voltmeter. In parallel circuits, voltage is constant. Not to mention, voltmeter has very high resistance and placing it in series will also disrupt the flow of charge.

A way to memorize which is constant in which circuit is through this phrase I came up with: **C**urrent **S**eries is **Parallel Voltage**

Resistance:

In constant voltage, resistance increase will cause a decrease in current.
In constant resistance, increase in voltage will cause increase in current.
Hence,

$$I = \frac{V}{R} \qquad R(\Omega) \rightarrow \text{ohms}$$

Resistance of a uniform wire:

$$R = \frac{\rho \times L}{A}$$ resistivity

An analogy would be this:
Resistance is directly proportional to length. Think of a swimming pool. The longer it is, the harder it is to get across. Same concept is being used
On the other hand, resistance is inversely proportional to area. Think of a room. The more packed it is (small area due to very small spaces for empty space), the harder it is to get across

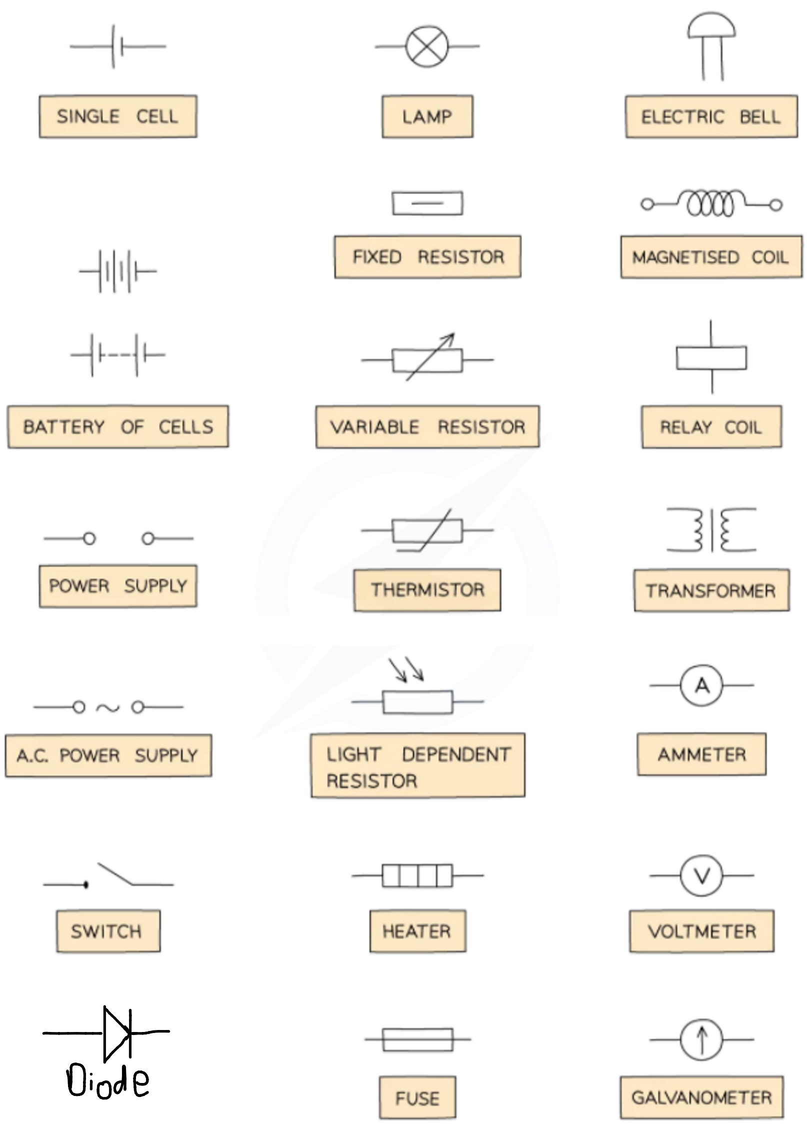
Electrical Power:
Definition of power remains the same which is the rate of energy being used.
Here, the equation changes.

$$P = I \times V$$

Since $P = \frac{W}{t}$ $W = I \times V \times t$

4.3:
Electric circuits

4.3.1:
Circuit Diagrams



https://www.savemyexams.co.uk/notes/igcse-physics-cie-new/4-electricity-magnetism/4-3-electric-circuits/4-3-1-circuit-diagrams/

You need to be able to recognize, draw and understand the function of these components.

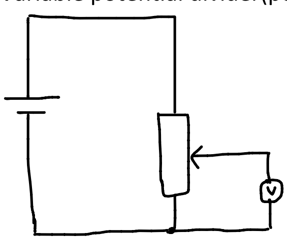
4.3.2:
Series and Parallel Circuits

Characteristics of series circuits:
1) Current is same at every point
2) Voltage splits
3) Total resistance is the cumulative resistance of each resistor
4) If one bulb malfunctions, entire circuit stops working as current can only travel through one path

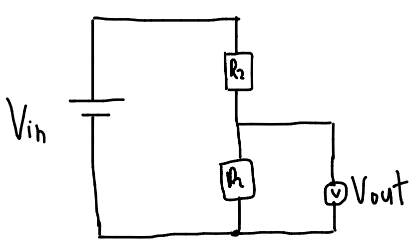
Characteristics of parallel circuits:
1) Voltage is same at every point
2) Current splits
3) $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \dots \frac{1}{R_n}$
4) If one component breaks down, circuit still can function as there is more than one path

4.3.3:
Action and use of circuit components

Variable potential divider(potentiometer):



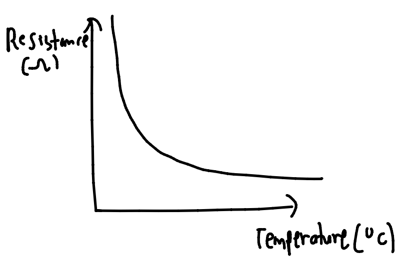
Sliding the contact point will change the reading of the voltmeter.

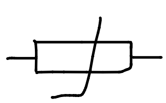


$$V_{out} = \frac{R_1}{R_1 + R_2} \times V_{in}$$

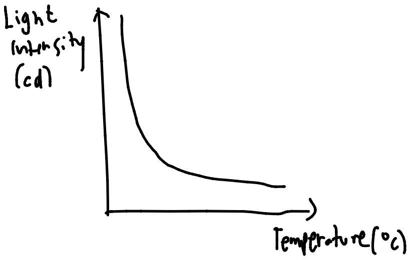
Thermistors and light dependent resistors are examples of input transducers. They take in quantity and convert it into electrical signal(voltage/resistance).

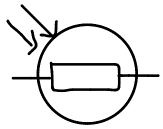
In thermistors, the greater the temperature, the lower the resistance. It is often used in fire alarms. This will be demonstrated at the end of the sub-unit.



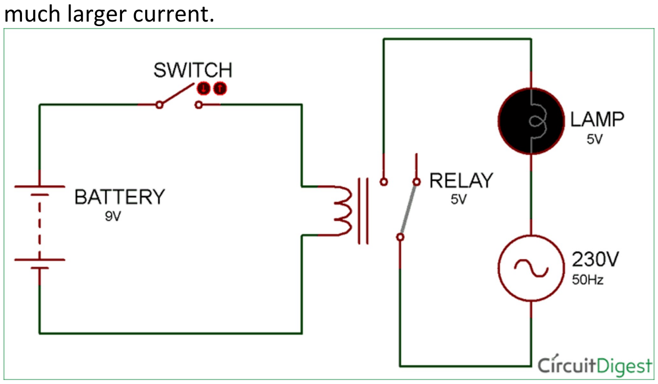


In light dependent resistors, the greater the light intensity, the lower the resistance. It is often used in burglar alarm and sensors.





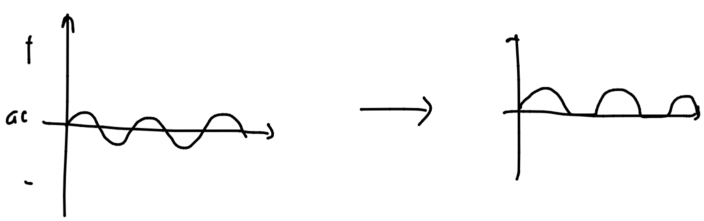
A relay is an electromagnetic switch which uses a small current to switch on a much larger current.



https://circuitdigest.com/electronic-circuits/simple-relay-switch-circuit-diagram

1) When the switch is closed and current is flowing, this current creates a magnetic field in the coil.
2) This attracts the relay and causes it to close
3) The 2nd circuit then experiences a flow in charge as well

Diodes are devices which allows current to flow in one direction only. As such, diodes can convert alternate current to direct current and this is otherwise known as rectification.

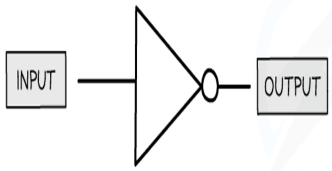


4.4:
Digital Electronics

Two types of signal:
1) Digital signal is a type of signal where it only has 2 states. This two states are used interchangeably(on or off ; high or low ; 1 or 0)
2) Analogue signal is a type of signal where it varies continuously in amplitude

Logic gates are the basic building blocks of any digital system. It is an electronic circuit which incorporates input(s) and one output in different relationships.

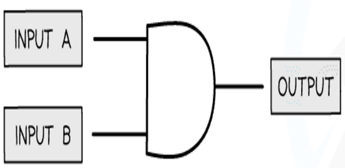
- A **NOT** gate:
  - Has a single input and one output.
  - Will output a **1** if the input is **NOT 1**



INPUT	OUTPUT
1	0
0	1

Outputs a 1 if the Input is NOT 1

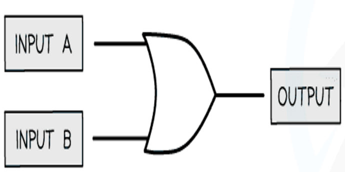
- An **AND** gate:
  - Has two inputs and one output
  - Will output a **1** if both the first input **AND** the second input are **1**



INPUT A	INPUT B	OUTPUT
0	0	0
0	1	0
1	0	0
1	1	1

Outputs a 1 if both A AND B are 1

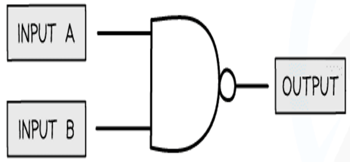
- An **OR** gate:
  - Has two inputs and one output.
  - Will output a **1** if either the first input **OR** the second input is **1**



INPUT A	INPUT B	OUTPUT
0	0	0
0	1	1
1	0	1
1	1	1

Outputs a 1 if either A OR B are 1

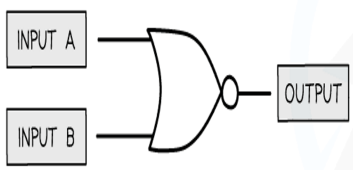
- A **NAND** gate:
  - Has two inputs and one output
  - Will output a **1** so long as the first input and the second input are not both **1** (**NOT AND**)



INPUT A	INPUT B	OUTPUT
0	0	1
0	1	1
1	0	1
1	1	0

NAND is short for NOT AND – the opposite of an AND gate

- A **NOR** gate:
  - Has two inputs and one output
  - Will output a **1** if neither the first input **NOR** the second input is **1**



INPUT A	INPUT B	OUTPUT
0	0	1
0	1	0
1	0	0
1	1	0

NOR is short for NOT OR – the opposite of an OR gate

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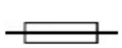
4.5:
Dangers of Electricity

Electricity, when mishandled, can cause severe repercussions.

The following are the list of hazards that we all can avoid:
1) Damaged insulation: We know that electricity flow through wires and these wires are insulated with cables usually made up of rubber. If this wears away, touching it may cause an electric shock.
2) Overheating of cables: When too much current is passing through a wire(short circuit), it may cause it to heat up really and may potentially cause fire.
3) Damp conditions: There lies a common saying where we are told to not touch sources of electricity if our hands are wet. This is because the water can act as conductor and hence as a path for the electrical current to travel

Note: Pure water cannot conduct electricity. However, the water we usually associate with have dissolved minerals and ions. This is why water can conduct electricity.

Fuse:
Fuses are devices which causes the circuit to 'break' when current is too high to prevent the damage of other circuit components.



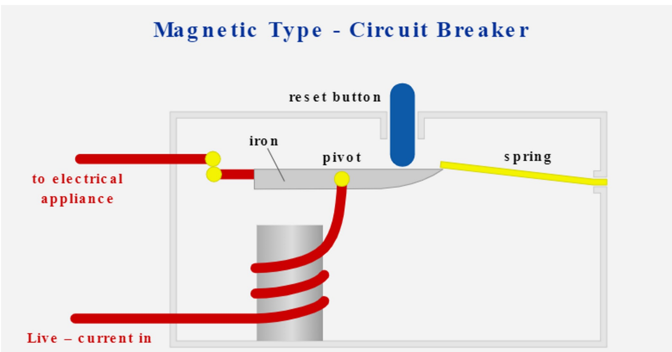
Fuses are usually made up of thin piece of metal. When too much current is flowing, this thin piece of metal will melt and break the circuit.

Fuse ratings should always be a bit higher than the total current of the circuit. If it is lower, the fuse will break a lot of times despite no overheating going on(hence fuse must always be replaced). Placing it too high would also defeat the initial purpose of having a fuse.

Circuit Breaker:
These days, circuit breakers are preferred compared to fuses due to several reasons:

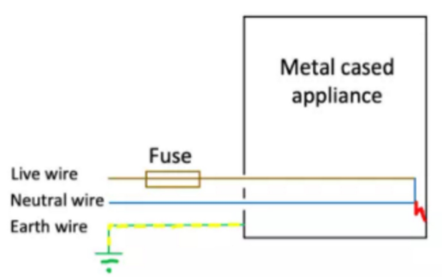
- Circuit-breakers respond quicker than fuses.
- Circuit-breakers are more reliable.
- Circuit-breakers are more sensitive.
- Unlike fuses which only operate once and need to be replaced a circuit-breaker can be reset

Not to mention, fuses require the current to go up a certain rating for it to melt. However, current below this rating may already be of harm to the user.



A circuit breaker uses an electromagnet. When the current becomes too large, the iron core becomes strongly magnetized. This causes the iron latch to be attracted and hence, breaking electrical contacts. This process can be reseted.

Another method we can implement is to the "Earth wire". Majority of electrical appliances have metallic cases.



https://www.savemyexams.co.uk/igcse-physics-edexcel-new/revision-notes/mains-electricity/electrical-safety/
By using an earth wire, the electrical current can flow from the appliance to earth easily. This is because the wire itself is of low resistance. When this occurs, it causes a surge in current and hence the fuse can melt. This method is an additional precaution to complement a fuse.

4.6:
Electromagnetic effects

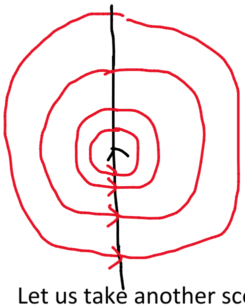
4.6.1:
Magnetic effect of a current

If a wire is carrying current, a weak magnetic field is produced. It has several features we need to be aware of:
1) These field lines are represented by circles
2) The field closes to the wire is the strongest
3) An increase in current causes the strength of the field to increase
4) As we move further away from the source, the circles representing the field lines become larger(see example below)

In order to determine the direction of the magnetic field, we use a technique called the right -hand grip rule. Imagine giving a thumbs up to someone. Your thumb will point up and your 4 other fingers are wrapped towards your palm.

Now, your thumb represents the direction of the current whereas where your 4 other fingers point to represent the direction of the magnetic field.

Example:

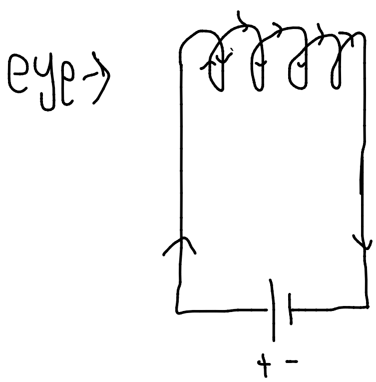


The magnetic field direction is

Notice how as we get further from the source, the distance between successive circles increases.

Let us take another scenario where the magnetic field produced is due to coils.
There are 2 methods to determine the direction and I will illustrate both of them.

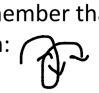
Example:



The first technique works like this:

Imagine as if you were looking from the left side of the circuit. You will see the coil either moving in the clockwise or anticlockwise direction.

Here in this example, the coil is moving in the clockwise direction.
If it is clockwise, the side you are viewing from becomes N.
Vice versa is true. If it is anticlockwise, the side you are viewing from becomes S.

The second technique also employs the right hand grip. **Imagine if you were to grip the coil from the top. Your fingers must follow how the current flows.** Referring to the first example, remember that current flows from positive to negative. If we were to imagine the path of the current, we will see that it travels in this direction:  If you were to grip in this direction, you will find your thumb naturally point to the left.

This hence becomes your North.

As you can see, both methods gives identical results. Try find practice problems in the web and try out both techniques. You may find yourself being more comfortable with one of them.

4.6.2:
Electromagnetic Induction

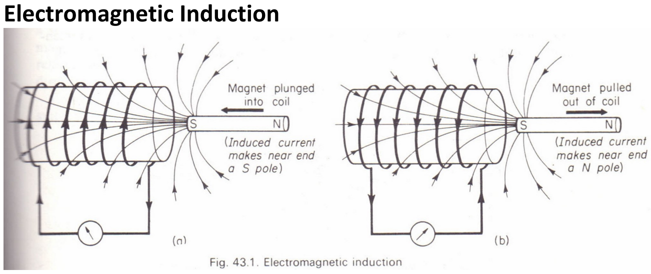


Fig. 43.1. Electromagnetic induction

Lenz's law states that the direction of the induced current will always oppose the change producing it

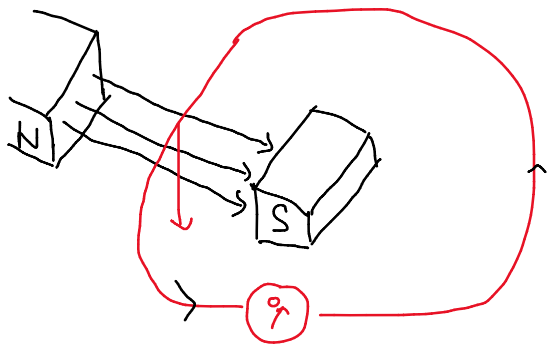
https://physicsmax.com/faradays-experiments-electromagnetic-induction-8053
The concept we discussed earlier shows how a wire carrying current has a magnetic field.

Here, we see how emf can be induced. When the bar magnet is pushed into the coil, an emf is induced. Here, the coil is stationary and what is being moved is the magnet itself.

Emf is induced as when the magnet is being pushed inside the coil, the magnetic field lines are being cut by the current. This induces emf.

The induced emf can be increased by:
1) Using a stronger magnet
2) Moving the magnet faster
3) By increasing the number of turns on the coil

Another method of inducing emf is by doing the opposite. In the experiment above, the wire is stationary whereas the magnet is moving. Here, what we can do is move the wire and allow the magnet to remain stationary.



Changing the poles of the magnet being pushed to the coil will switch where the arrow will point

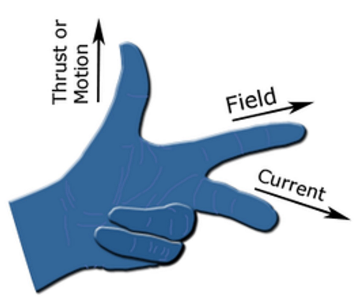
Here, we are applying the exact same concept. Emf can only be induced if the current cuts through the magnetic field. Instead of moving the magnet, we move the wire so as to cut through the magnetic field(the lines move from N-->S). If the wire **does not perpendicularly cut through the magnetic field**, no current is induced.

The induced emf can be increased by:
1) Using stronger magnet
2) Moving the wire faster
3) Increasing the length of the wire in the magnetic field

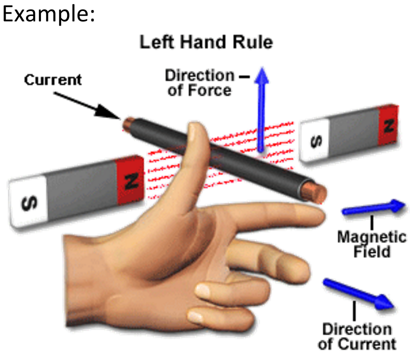
If the movement of the wire is reversed(in this case it would flip to the top), direction of emf induced would reverse as well.

4.6.3:
Force on a current-carrying conductor
If a wire carrying a current cuts through a magnetic field, a force will act upon the wire.

The direction of this force can be determined from a rule called Fleming's Left Hand Rule.



Example:

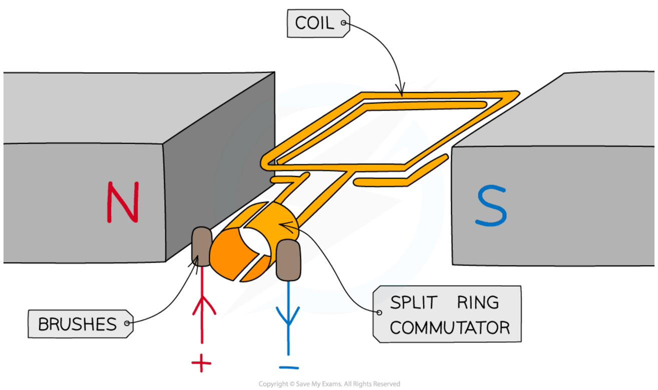


Notice how, as previously discussed, the magnetic field must be perpendicularly cut by the current

https://www.electrical4u.com/fleming-left-hand-rule-and-fleming-right-hand-rule/

4.6.4:
DC Motor

D.C motor is used to convert electrical energy to kinetic energy.



Here, we see the coil being placed in between the two magnet. When current is being carried, with respect to Fleming's Left Hand rule, the coil will jerk perpendicular to the direction of the magnetic field. This causes a turning effect and hence causes the coil to spin.

The magnitude of spinning can be increased by:
1) Using stronger magnet
2) Increase the current
3) Increase number of turns in the coil

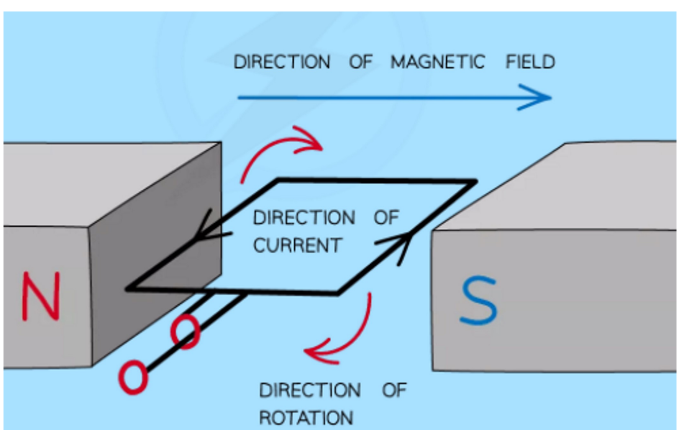
Logically speaking, when one side of the coil turns, the other coil will spin in the opposite direction as the current is now travelling in the opposite direction. This is why there are split rings and carbon brushes.

The commutator turns with the coil. Whenever the coil reaches a vertical position, the two sides of the commutator swap brushed and hence, the flow of the current is reversed. This causes the coil to always spin the same direction.

D.C motors are used in household appliances such as mixers, blenders and fans.

4.6.5:
A.C Generator

A.C generator is used to convert kinetic energy to electrical energy. Think of how your generator is 'switched on.' A certain movement is needed to jump start the system.



https://www.savemyexams.co.uk/notes/igcse-physics-cie-new/4-electricity-magnetism/4-6-electromagnetic-effects/4-6-3-a-c-generator/

Generators and motors are incredibly similar in structure but do very different things. In a motor, current is running through the coil which causes it to cut the magnetic field. This then causes the coil to experience a force.

However, in a generator, we are trying to achieve the opposite effect. By rotating the coil, we are cutting the magnetic field which thus induces emf.

Remember, motor is used to convert electrical to kinetic energy whereas generator is used to convert kinetic to electrical energy,

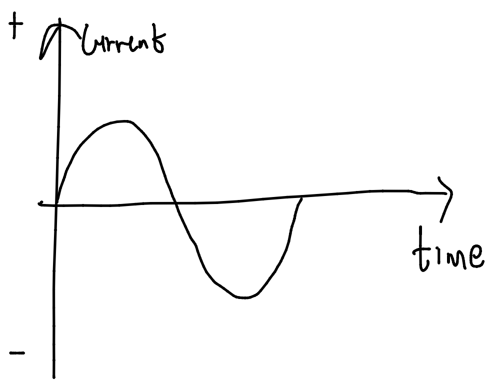
The magnitude of emf can be increased by:
1) Turning the coil faster
2) Using a stronger magnet
3) Increase number of turns in the coil

Instead of split rings, slip rings are used. Slip rings are used to transfer the current to the metal brushed while still allowing the coil to rotate smoothly.

In generators, instead of Fleming's left hand rule, Fleming's right hand rule is used. All the fingers still stands for the same thing.

Remember, motor utilizes FLHR whereas generators utilizes FRHR.

Per the name itself (A.C), the generator produces alternating current. The graph will look like this:



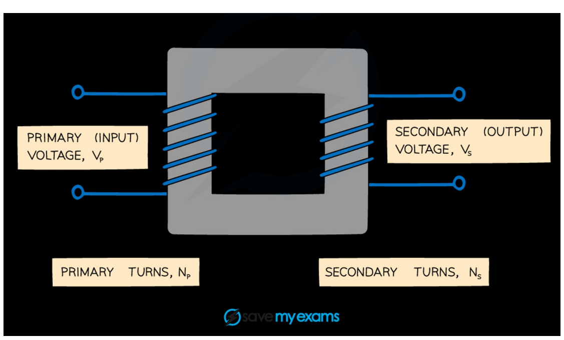
If we were to told to deduce in what position is the coil when it is producing maximum current, the answer would be when the coil is horizontal. With the same concept in mind, the coils would be in a vertical position when it is producing zero current.

This comes back with what was previously discussed. If the magnetic field is not cut perpendicularly, no emf is induced. The positioning of the fingers also tells the exact same story.

4.6.6:
Transformer

A transformer is made up of soft iron core. This is due to the fact that iron is easily magnetized and demagnetized.

Transformers are used to 'step up' or 'step down voltage.'



A step up transformer will increase the voltage and vice versa is true.
If we see from the example given above, we see that there are more coils in the primary input compared to the secondary output. This signifies that this is a step down transformer.

A key concept to understand is that in both sides, power is kept constant.

$$P = I \times V$$

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$$P = I \times V$$

$$I_1 \times V_1 = I_2 \times V_2$$

Hence, it is crucial to understand that when the voltage increases, the current must drop.

When we talk about transformers, alternate current is being used.

A formula we need to be familiar with is as of below:

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

Here, we see how the ratio of voltage is equal to the ratio of number of turns.

Transformers are being used a lot in our daily lives. More often than not, power stations are very farm from residential areas. Hence, when the electricity is being carried at such lengthy distances, energy is likely to be lost as heat.
Recall the equation where:

$$P = I \times V$$

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

$$P = I^2 R$$

Here, we see how if we transmit the electricity in high current, the magnitude of heat loss is high. This is why electricity is being transferred in very high voltage(hence low current) and thus, the transfer of electricity becomes much more efficient. When the voltage approaches near residential areas, a step down transformer is utilized as high voltage is not required for individual households.

Examination tips:

1) Memorize the formulas
2) Understand the difference between Fleming's left and right hand rule
3) Understand how we derived the AC generator graph
4) Understand what is equal in series and parallel circuits (Current series is parallel voltage)
5) Understand why high voltage is used when delivering electricity
6) Be able to determine the direction of the magnetic field in both wires and solenoids
7) Understand the hazards of electricity and how to prevent them