YEAR 11 IGCSE PHYSICS **SHORTHAND NOTES**
Chapter 4 Electricity and Magnetism
Prepared by: Chern Jiek Lee

4.1 Simple phenomena of magnetism

Magnets have these **properties**:
-has a **magnetic field** around it
-has 2 opposite **poles** (**North** or north-seeking pole and **South** or south-seeking pole) which exert forces on other magnets. *Like poles **repel** and unlike poles **attract**.*
-will attract magnetic materials by **inducing** (**permanent** or **temporary**) magnetism in them.
-will exert little or no force on a non-magnetic material

Induced magnetism: magnets attract materials by inducing magnetism in them, in other words the material becomes a magnet as well. The side of the material facing the magnet will become the opposite pole as the magnet.

Ferrous material: magnetic – anything which contains iron, nickel, or cobalt can be magnetised

Non-ferrous material: non-magnetic e.g. copper, grass, ketchup, butter, wood, ass-gravy (poop) etc.

Magnetisation methods:
-inducing magnetism produces a weak magnet. It can be magnetised strongly by **stroking** with one end of a magnet, in one direction.
-the most effective method is to place the metal in a long coil of wire (**solenoid**) and pass a large DC (**direct current**) through the coil.

Demagnetisation methods:

-SMASH IT WITH A HAMMER, dropping etc.
-heating to a high temperature
-solenoid method but with alternating current

Iron vs. steel: iron is a **soft** ferromagnetic material meaning it will magnetise and demagnetise easily. Steel is a **hard** ferromagnetic material meaning it is hard to magnetise and demagnetise. Soft ferromagnetic materials are used to create temporary magnets, for example the magnets which lift cars in a rubbish dump, or the magnet in a circuit breaker. Hard ferromagnetic materials are used to create permanent magnets like fridge magnets, horse-shoe magnets.

The magnetic field lines go from north to south. The north pole of a magnet can be found by placing a compass near the magnet. The needle will point the direction of the magnetic field line.

4.2 Electrical quantities

Electrical charge, *Q* consist of either '+' or '-' charge. The SI unit for charge is in coulomb. Like charges repel each other while opposite charges attract. Electrons are the cause of the charge. Remember that electrons are negatively charged. Each electron has a charge of 1.6×10^{-19} C. When electrons flow into a neutral object, the object becomes negatively charged. Likewise when electrons are removed from a neutral object it becomes more positively charged.

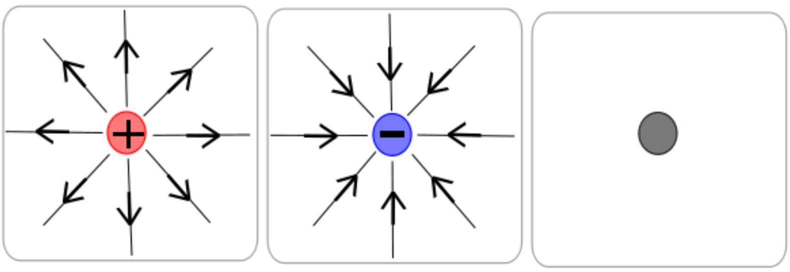
Current, *I* is defined as the rate of charge flow in a circuit.

$$I = \frac{Q}{t}$$

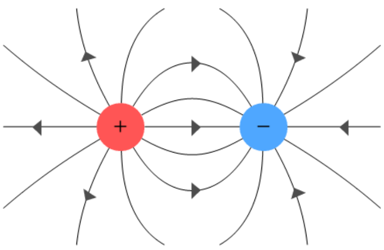
Where *I* is the electric current measured in ampere (A), *Q* is the charge (C) and *t* is the time is seconds.

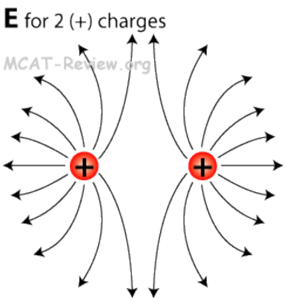
Note: The current always flows in the opposite direction of the electron.

An **electric field** is a region where electrical charges experience electric force. They are usually represented by arrow lines. '+' charges have arrows that are pointing outwards while '-' charges have arrows that are pointing inwards (see below). Also a stronger electric field is indicated by more lines. The field is also stronger at the source and vice versa.



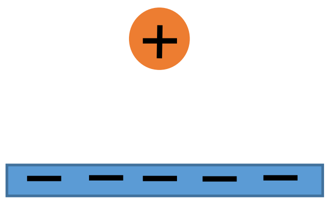
You can combine '+' and '-' fields to get more exotic shapes (see below).

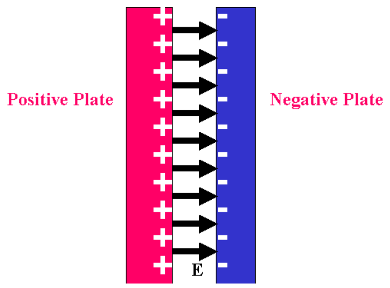




1.25×10^{18} electrons flow through a conductor in 5 seconds. Calculate the current flowing in the conductor.

Try these…….





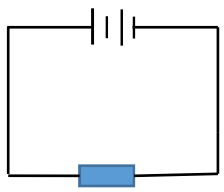
Potential difference is defined as the work done to transfer one unit of charge across two points of different potential (charge).

$$V = \frac{W}{Q}$$

Here V is the potential difference in volts (V), W is the work done in _________ and Q is the charge in ____________.

Resistance, R of a conductor is the opposition to an electrical current. The higher the resistance of a conductor the more work needs to be applied to push the same amount of current through a conductor (Think friction when pushing a box). Resistance is measured in ohms, Ω. Ohm's Law states that the potential difference, V is directly proportional to the current, I that flows through a conductor. This law is only obeyed provided that the temperature and other physical properties remain constant and that the conductor is ohmic. Ask me what is the difference between an ohmic and non-ohmic conductor.

Mathematical explanation,



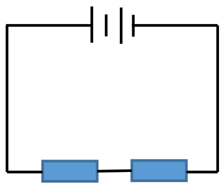
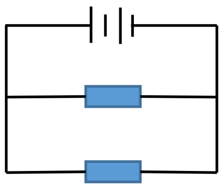
Several factors affect the resistance of a conductor:

1) *The length of the conductor*: The longer the length of the conductor, the _______________ its resistance.
2) *Diameter or area of the conductor*: The bigger the area of the conductor, the _________________ its resistance.
3) *Temperature of the conductor*: The higher the temperature of the conductor, the __________________its resistance.
4) *The type of material of a conductor*: depends on material type (conductive or insulative type).

The potential difference across a conductor is 240 V. What is the work done to transfer 20 C of charge across a conductor.?

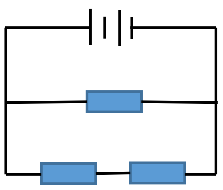
The potential difference across two metal plates is 120 V. What is the number of electrons transferred across the plate if 960 J of energy is dissipated during the process?

4.3 Electrical circuits

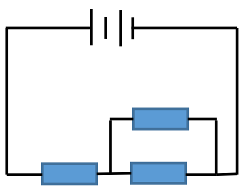
Series	Parallel
	
I =	I =
V =	V =
R =	R =

What if I combined the circuits?

Like this



Or…… Like this



Electromotive force (e.m.f) vs potential difference.

Welcome to the big confusion which is e.m.f and potential difference aka Volts! There is a very small distinction between the both of them so people often get confused. So pay attention…..

As you know (you should at this point…) the potential difference, V is defined as the work done to move a unit of charge across a component (i.e. resistors, capacitors, inductors, wires, etc.). Potential difference is measured in volts.

The definition for electromotive force or e.m.f of a cell is defined as the work done by the cell to drive a unit of charge around a complete circuit.

Electricity as energy and power

Recall that

$$V = \frac{W}{Q}$$

and

$$I = \frac{Q}{t}$$

and Ohm's law where

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

By playing around with both equations I can come up with different equations:

$$W = VIt$$

Proof:

$$W = I^2Rt$$

Recall that power is the rate of word done or rate of energy transferred i.e.

$$P = \frac{W}{t}$$

Depending on the info given in the question, the above equation can be written in many forms eg.

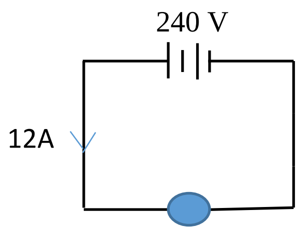
$$P = \frac{QV}{t}$$

$$P = VI$$

$$P = I^2R$$

Try proving

$$W = \frac{V^2}{R}t$$



Calculate the amount of energy dissipated after 5 minutes.

3.125x10^{19} electrons flow through a light bulb in 2.5 seconds when a battery with potential difference 3V is connected to the bulb. If the charge of electron is 1.6x10^{-19}C, calculate

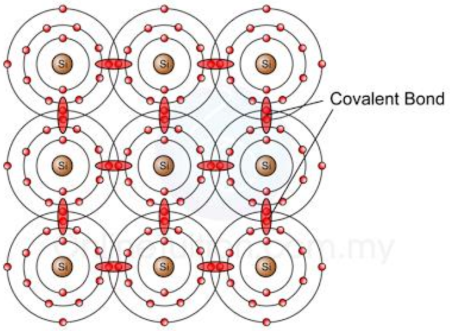
a) the energy dissipated

b) the electrical power

$$P = \frac{V^2}{R}$$

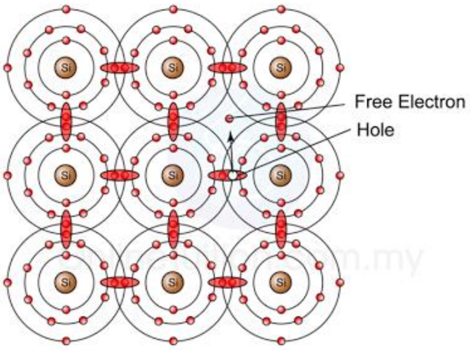
Action and use of circuit components

Semiconductor is a class of crystalline solid with conductivity between a conductor and an insulator. Examples of semiconductors are silicon, germanium, boron, tellurium and selenium.

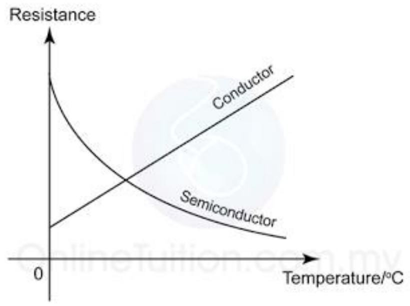


A silicon semiconductor has 4 valence electrons. Each of these 4 electrons are shared with another 4 silicon atoms to form 4 pairs of covalent bond. The bonded valence electrons are not free to move. Therefore it's not a good conductor at room temperature. At room temperature, a silicone crystal acts approximately like an insulator because only a few free electrons and holes are presence.

Free electron and hole



If a bonded electron absorbs heat energy from the surrounding, it may be promoted to a higher energy level. These electrons are free to move when they are at a higher energy level. If an electron is promoted to a higher level, a vacancy is left in the valence shell, and it is called a hole. A hole has the tendency to pull electrons therefore it carries a positive charge. Both free electrons and holes can help to conduct electric current making the semiconductor conducive. As the temperature increases, more electrons get promoted thus creating more holes. Therefore, it can be said that conductivity increase as the temperature increases.

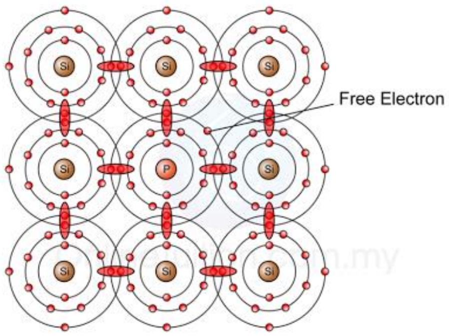


Since electrons carry a negative charge and holes carry a positive charge, when a potential difference is applied to the semiconductor, the electrons and holes will start to flow. The electrons will flow to the negative terminal while holes will flow to the positive terminal.

Doping a semiconductor

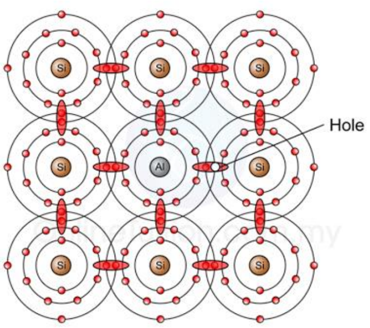
One way to increase the conductivity of a semiconductor is by doping. Doping is the a process of adding a small amount of impurities to a semiconductor called *dopants*. Semiconductors are named after the types of impurities doped

1) *the n-type semiconductor*



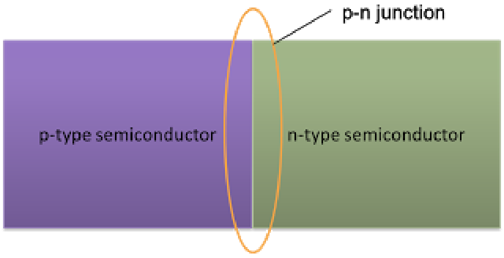
Produced by doping pentavalent atoms into a semiconductor. Form ________ covalent bonds with the silicon atoms around. Since pentavalence atom has 5 electrons, there is __electron left over and it is a free electron. More pentavalance means greater conductivity for the semiconductor. Since negative charge carrier (the electrons) outnumber the positive charge carrier (the holes), the semiconductor is called an n-type semiconductor, where n stands for negative.

2) *the p-type semiconductor*



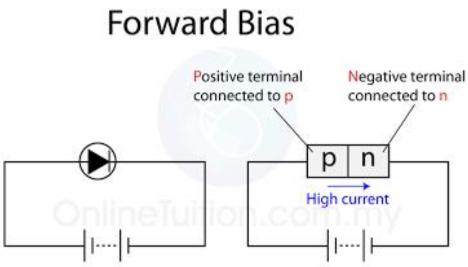
Produced by doping ____________ atoms into a semiconductor. Forms __ covalent bonds with the silicon atoms around. Since the trivalent atom has only three valence electrons and each neighbour shares one electron, only seven electrons are in the valence orbit. This means a hole exists in the valence orbit of each trivalent atom. The more trivalent impurities that is added, the greater the conductivity of the semiconductor. Since the ____________ carrier outnumber the ______________ carrier, the semiconductor is called a p-type of semiconductor, where the p stands for positive.

Diodes

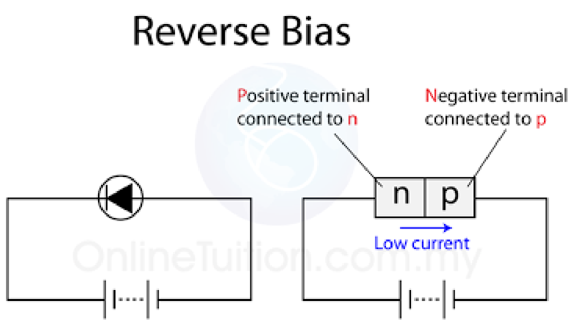


We can produce a single crystal with p-type semiconductor on one side and n-type on the other side. The border where both regions meet is called the p-n junction. At the junction, electrons from the n-type semiconductor will be attracted to the holes in the p-type semiconductor. As a result the holes and electrons at the junction disappear, forming a depletion layer. At the same time the p-type semiconductor becomes more negative and the n-type becomes more positive. This results in potential difference across the p-n junction. This potential difference is called the junction voltage. The junction voltage prevents the charge carrier from flowing across the depletion layer.

Forward bias

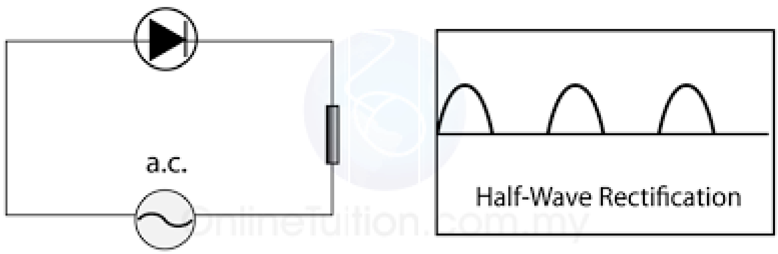


In a forward bias arrangement, the negative source is connected to the n-type material and vice versa. Current has no problem flowing in a forward-biased silicone diode.

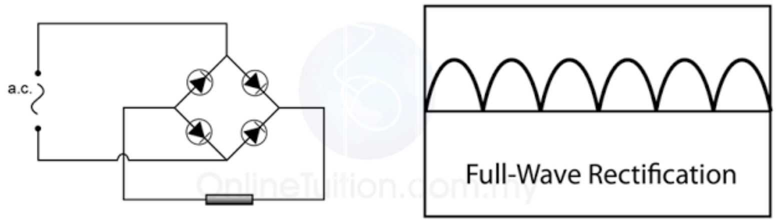


If you turn the dc source around, you will get reverse-bias arrangement…………..
The negative battery terminal attracts the holes while the positive terminal attracts the electrons. Because of this the electrons and holes flow away from the junction widening the depletion layer.

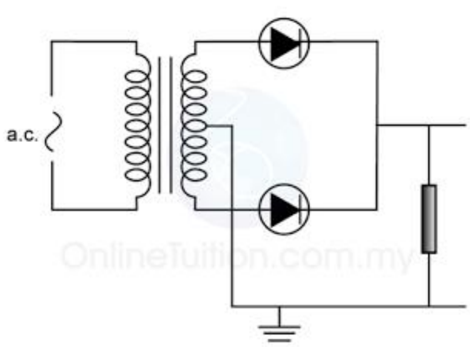
So you might at this point think why do we need this……… We need this for something called half-wave rectification. Diodes are known commonly as rectifiers. They can be used to change a.c. to d.c. The image below shows how a diode allows only the positive half of the original a.c. current to pass through.



You might be asking at this point if there is a half-wave rectification is there a full-wave rectification? As it turns out, there is…..



This can be done using a bridge rectifier or using a transformer and two diodes shown below

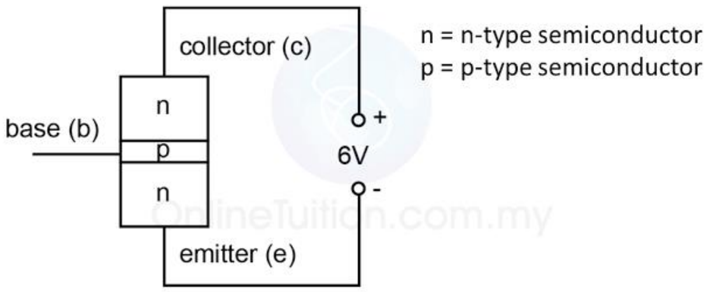


After which we can smoothen the peaks using a capacitor. A capacitor charges up when current flows from the diode, then discharges through the load when the current from the diode is zero. Now the current is finally useful.

Transistors

Another application of semiconductors are transistors. A transistor consists of

a) the emitter (e),
b) the base (b)
c) the collector (c)



In a transistor, the emitter emits charge carriers (free electrons or holes). The charge carriers move towards the base. The charge carriers will then pass through the thin base layer and to be collected by the collector. There are 2 types of transistors:

a) npn transistor
b) pnp transistor

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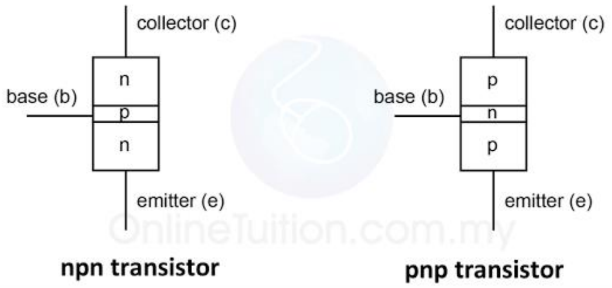
<tr><td colspan="2">
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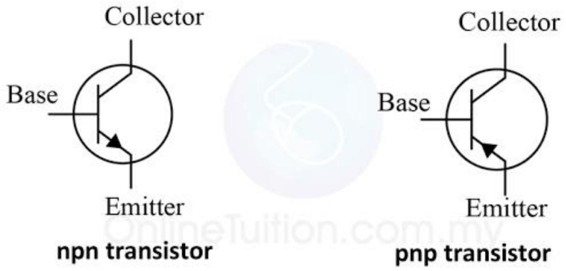
<tr><td colspan="2">
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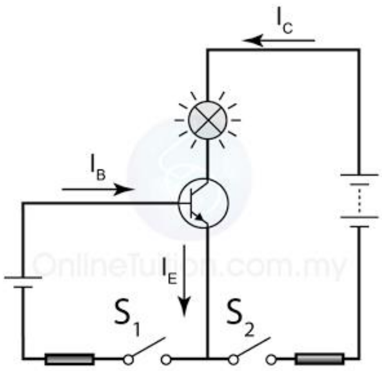


From the figure above you can see two circuits; the base and collector circuit.

S1	S2	B1	B2
Open	Open	Does not light up	Does not light up
Close	Open	Light up	Does not light up
Open	Close	Does not light up	Does not light up
Close	Close	Light up	Light up

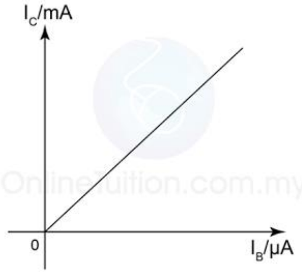
Basically what the above table is showing is that the collector circuit is controlled by the base circuit. Current will flow in the collector circuit when there is current going through the base. However, when base current, I_B is zero the collector current, I_C is automatically zero as well. In general,

$$I_E = I_B + I_C$$

where I_E is the emitter current. Another thing is that

$$I_E > I_C > I_B$$

The most important role of a transistor is current amplification. A transistor can be used to amplify current changes because a small change in the base current, I_B produces a large change in collector current, I_C. The following graph shows the relationship between the base current and collector current:



The ratio of I_B/I_C is called the amplification factor.

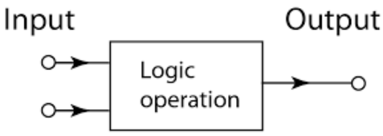
$$Amplifcation\ Factor = \frac{I_C}{I_B}$$

Applications of transistor:

1) Sound amplifier
2) Automatic switch

Logic gates

A logic gate is a physical device that performs a logical operation on one or more logical inputs and produces only one logical output. Basically…….



The input or output is either high (1) or low (0). The 5 basic logics gates are

a) AND
b) OR
c) NOT
d) NAND
e) NOR

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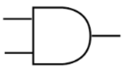
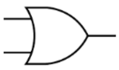
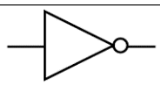
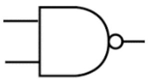
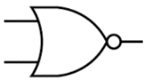
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>$X=A\cdot B$</td><td>$X=A+B$</td><td>$X=\overline{A}$</td><td></td><td></td></tr>
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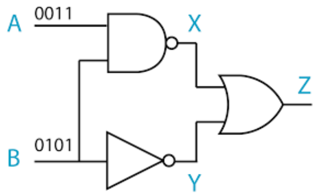
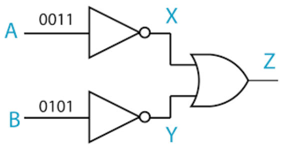
Logic gates can also be combined



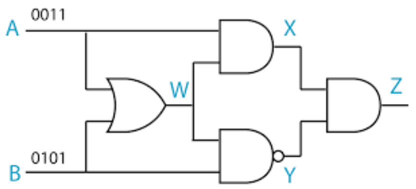
INPUT	
A	B
0	0
0	1
1	0
1	1

OUTPUT		
X	Y	Z



INPUT	
A	B
0	0
0	1
1	0
1	1

OUTPUT		
X	Y	Z
1		1
1	0	
0		1
	0	0



INPUT	
A	B

OUTPUT		
X	Y	Z

4.4 Dangers of electricity

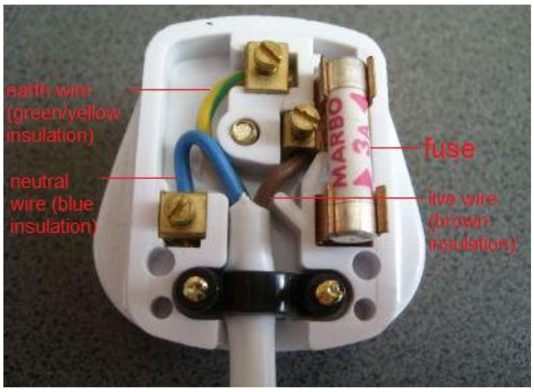
Damaged insulation: contact with the wire (live wire especially) due to gap in the insulation causes electric shock which can cause serious injury or shock.

Overheating of cables: when long extension leads are coiled up, they may overheat. The current warms the wire, but the heat has less area to escape from a tight bundle. This might cause a fire.

Damp conditions: water can conduct a current, so if electrical equipment is wet someone might get electrocuted YAY!

Fuses: a thin piece of wire which overheats and melts (the fuse 'blows') if the current is too high. It is placed on the live wire before the switch. This prevents overheating and catching fire. A fuse will have a specific current value (e.g. 13A) so when choosing a suitable fuse you must use the one which can have the lowest current value but over the current value of the appliance.

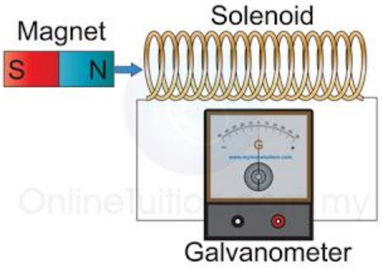
The plug:



Circuit breakers: an automatic switch which if the current rises over a specified value, the electromagnet pulls the contacts apart, breaking the circuit. The reset button is to rest everything. It works like a fuse but is better because it can be reset.

4.5 Electromagnetic effects

When a magnet (a permanent one) is moved in and out of a solenoid, the magnetic field flux of the magnet is being cut by the coil. This in turn induces an e.m.f in the wire. If the solenoid is connected to a closed circuit as seen below, the induced current will flow through the circuit. The production of electric current by changing magnetic field is called electromagnetic induction. Current is only induced when the magnet or solenoid is moving relative to one another. The direction of induced current can be determined from Lenz's Law and Faraday's Law.

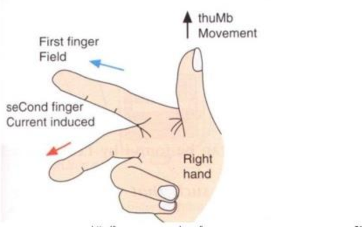


Faraday's Law: The *magnitude* of the induced e.m.f. is directly proportional to the rate of change of magnetic flux through a solenoid or the rate of the magnetic flux being cut. In a nutshell what he was trying to say was move the magnet faster or use a stronger magnet or increase the number of coils in the solenoid.

Lenz's Law: The induced current always flows in the direction that *opposes the change in magnetic flux*. This law obeys the conservation of energy principle. Work is done to move the magnet against the repulsive force. This work done is converted to electric energy (current).

Induced EMF and Current in a Straight Wire

When a *straight conductor* (e.g. wire) moves and cut a magnetic field (example is on the right pane), e.m.f. will be induced across the conductor. If the conductor is a complete circuit, current will flow in the conductor. The direction of current can be determined by using Flemming's RHR.



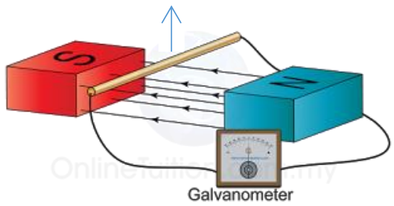
Induced EMF and Current in a Solenoid

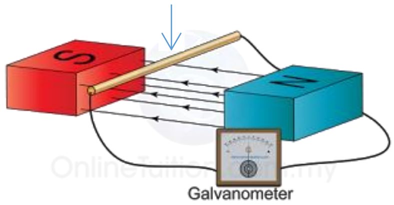
When a bar magnet is moving into a solenoid, the solenoid will cut the magnetic flux of the bar magnet. This will induce a current and e.m.f. in the solenoid. The induced current will produce another magnetic field around it. The pole of the magnetic field and direction of the induced current can be determined by using Lenz's Law.

Some applications of electromagnetic induction are:

1) DC Generator
2) AC Generator

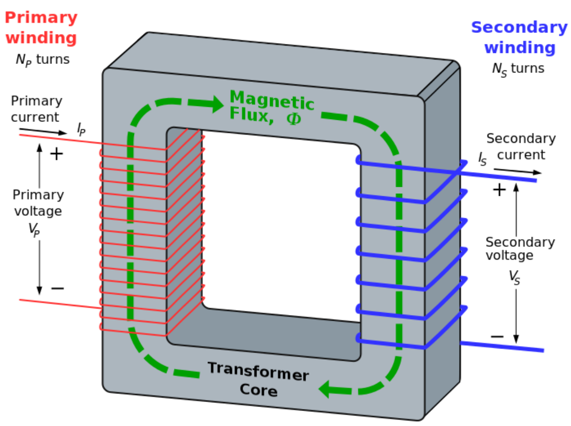
Current induced in a straight wire example. Find the direction of the induced current.





Transformer

A transformer is a device that is used to *raise or lower the potential difference of an alternating current*. Shown below is a typical transformer with all its components



Important: The input current goes through the primary winding first before exiting through the secondary winding.

A transformer consists of a primary and secondary coil wound on a soft iron core. When an a.c current flows in the primary coil, a changing magnetic flux is generated around the primary coil. The changing flux is transferred to the secondary coil through the iron core. The flux is then cut by the secondary coil, hence inducing an e.m.f in the secondary coil. The magnitude of the output voltage can be controlled by the ratio of the number of primary and secondary coil.

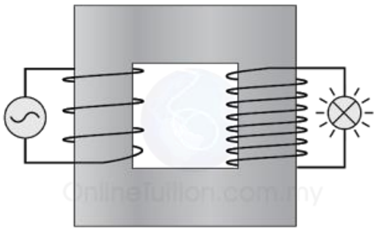
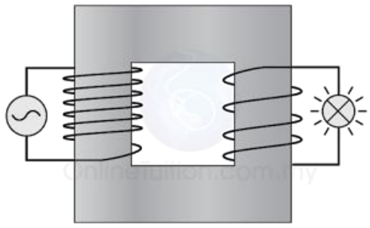
Important: The current in the primary circuit must be a.c. because a.c. can produce changing magnetic flux. A changing magnetic flux is needed to induce e.m.f. in the secondary coil. The induced current is also a.c. and has the same frequency.

A transformer is used to step down a mains voltage of 240 V a.c. to 24 V a.c. If this transformer has a primary coil of 20000 turns, how many turns are there in the secondary coil?

A transformer has 400 turns in its primary coil and 2000 turns in its secondary coil. An a.c. supply of 6V is connected to the primary coil and the secondary coil is connected to a 15W bulb, which lights up with normal brightness. If the transformer is ideal calculate,

a) the secondary voltage, V_s
b) the current in the secondary coil, I_s
c) the input power, P_{input}
d) and current in the primary coil, I_P

Step up vs step down transformer

Step-up transformer	Step-down transformer
	
$N_P < N_s$	$N_P > N_s$
$V_P < V_s$	$V_P > V_s$
$I_P > I_s$	$I_P < I_s$

In an ideal transformer the input power is equal to the output power. Recall from the previous section that for electricity

$$P = VI$$

Therefore input power,

$$P_{input} = V_P I_p$$

and output power

$$P_{output} = V_S I_S$$

For an ideal transformer,

$$V_P I_p = V_S I_S$$

Also,

$$\frac{V_P}{V_s} = \frac{N_P}{N_s}$$

However in real life applications no transformer is ideal. This is due to heat loss which causes the output power to be less than the input. Therefore the efficiency of a transformer is always less than 100%. Recall that efficiency is output over input.

$$Efficiency = \frac{P_{output}}{P_{input}} \times 100\%$$

There are 4 factors that cause energy loss in a transformer. In SPM you'll have to remember all of them.

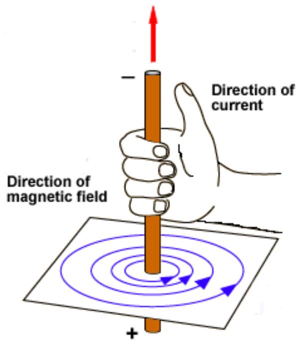
1) Heating effect in the coils
2) Eddy currents in iron core
3) Magnetisation and demagnetisation of the core
4) Leakage of magnetic flux

Electromagnets

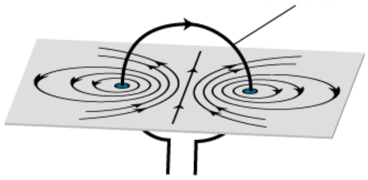
An electromagnet is a *temporary magnet* made by winding an insulated wire around a soft iron core, forming a coil known as a *solenoid*. When current passes through the solenoid it produces a magnetic field. The solenoid is said to magnetised and becomes and electromagnet.

Magnetic field patterns:

Straight wire

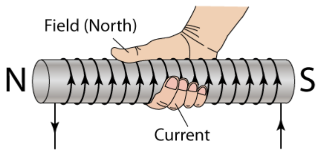


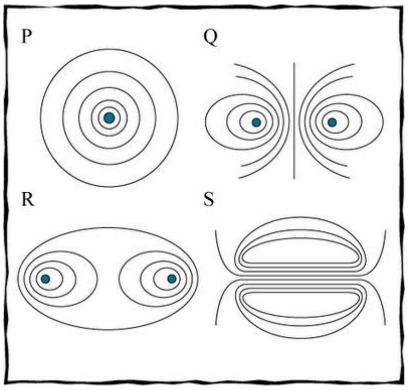
Use your Right Hand when you want to determine the magnetic field patterns! Your thumb is the direction of your current while your four fingers are the direction of the magnetic field.



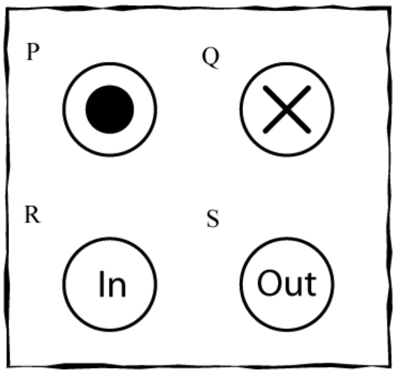
Magnetic field pattern generated by a flat coil

Magnetic field in solenoid



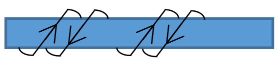


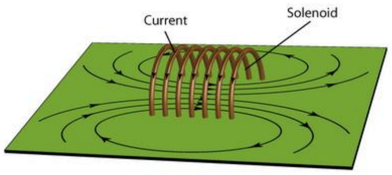
Which one shows the magnetic field lines generated by a) a coil and b) a straight wire?



Which one shows current a) coming out of the paper and b) going in to the paper?

Find the North Pole?





Magnetic field generated by a solenoid. The field pattern is resemble a long bar magnet.

The strength of a magnetic field is can be increased by:

1) Increasing the current
2) Increasing the number of turns per unit length
3) Using a soft-iron core within the solenoid

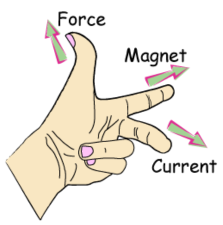
Applications of electromagnets:

1) Electric bell
2) Circuit breaker
3) Electromagnetic relay
4) Electromagnetic lift
5) Telephone earpiece
6) Dot matrix printer

Force on a current-carrying conductor

When a current-carrying conductor is placed a magnetic field, the interaction between two magnetic fields produces a force on the conductor.

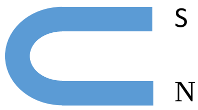
Use your left hand when you want to determine the direction of the force! This rule is called Fleming's left hand rule.



The forefinger, middle finger and thumb are perpendicular (90° degrees) to each other. The forefinger points along the direction to the magnetic field, middle finger points in the current direction and the thumb points along the direction of the force.

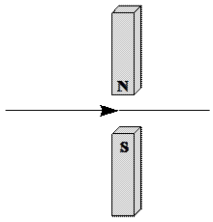
The strength of the force can be increased by:

1) Increasing the current
2) Using a stronger magnet
3) Using a longer wire
4) Arranging the wire perpendicular to the direction of the magnetic field

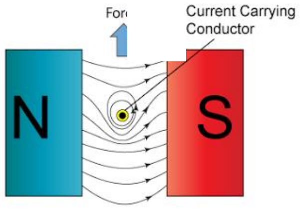


Draw the coils then indicate which direction the current should flow.

Using the Left Hand Rule, state which direction the wire will move:

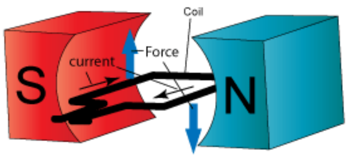


When current flows through a conductor, a magnetic field is generated. What happens when we place this conductor in a magnetic field? In which direction is the force pointing?

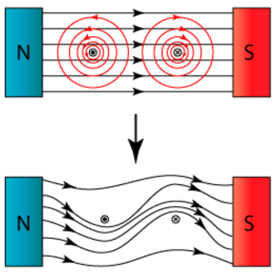


Catapult Field

If a current carrying a coil is placed in a magnetic field, pair of forces will be produced in the coil. This is due to the interaction of the magnetic field of the permanent magnet and the magnetic field of the current carrying coil.



Turning Effect of a Coil in a Magnetic Field

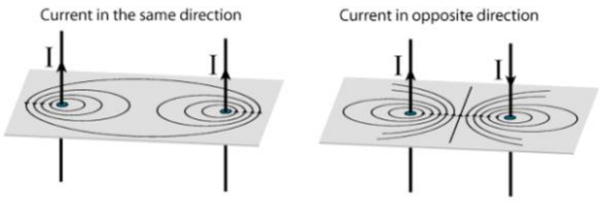


Interaction of the magnetic fields produces a catapult field

The direction of the force can be determined by Fleming's left hand rule. Since the current in both sides of the coil flow in opposite direction the forces produced are also in opposite direction. The 2 forces in opposite direction constitute a couple which produces a turning effect to make the coil rotate. Examples of electric equipment whose operation is based on this turning effect are

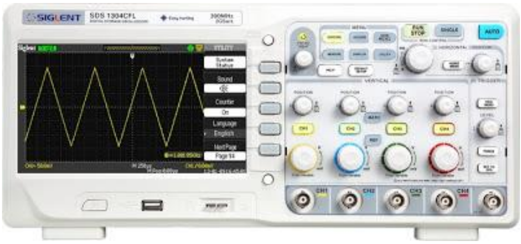
1) The direct current motor
2) The moving coil meter

When 2 current carrying conductors are placed close to each other, a force will be generated between them. If the current in both conductors flow in the same direction, they will ______________, whereas if the current are in opposite direction, they will ______________ each other. *Hint: Use Flemming's left hand rule and the right hand rule.*



Catapult field produced by 2 straight curretn carrying conductors

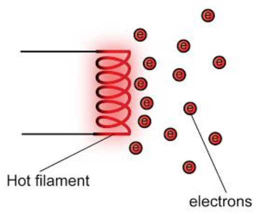
Cathode Ray Oscilloscope (CRO)



Cathode-ray tubes can be found in television screens and computer monitors. In laboratory, we use the crt in the oscilloscope to study waveforms. In SPM you must know

1) How crt is produced (Thermionic emission and electron gun)
2) The characteristics of crt
3) The structure of a Cathode Ray Oscilloscope
4) How to operate a Cathode Ray Oscilloscope
5) The uses of a Cathode Ray Oscilloscope

Thermionic Emission

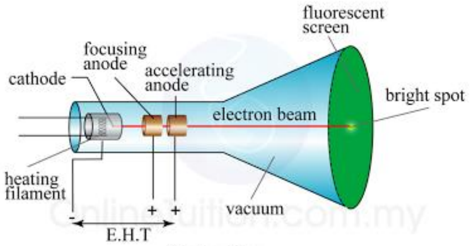


Thermionic emission is a process of emission of charge particle (known as thermion) from the surface of a heated metal. The charge particles are normally electrons.

Factors that affect the rate of thermionic emission:

1) Surface area of metal
2) Temperature of metal
3) type of metal

Electron Gun



Electron Gun

Structure of CRO

3 main components:

1) The electron gun
2) The deflecting plates.
3) A fluorescent screen.

If a high positive (anode) is placed in front of the heated metal, the emitted electronics will accelerate and form a beam of electrons. The device is called an electron gun. The beam produced is called the cathode ray. We can use a Maltese cross tube to investigate the characteristics of cathode ray.

Parts of Electron Gun	**Function**
Filament	To heat the cathode
Cathode	Release electrons when heated by filament
Grid	The grid is connected to a negative potential. The more negative this potential, the more electrons will be repelled from the grid and fewer electrons will reach the anode and the screen. The number of electrons reaching the screen determines the brightness of the light. Hence, the negative potential of the grid can be used as a brightness control.
Focusing anode	The other feature in the electron gun is the use of the anode. The anode at positive potential accelerates the electrons and the electrons are focused into a fine beam as they pass through the anode
Accelerating anode	

The deflecting plates

Part of the deflecting system	**Function**
Y-plate	The Y-plates will cause deflection in the vertical direction when a voltage is applied across them.
X-plate	On the other hand, the X-plates will cause the electron beam to be defelctred in the horizontal direction if a voltage is applied across them.

The fluorescent screen

1) The screen is coated with a fluorescent salt, for e.g. zinc sulphide.
2) When electrons hit the screen, it will excite the salt ions to produce a flash of light.