TOPIC 4

ELECTROMAGNETIC EFFECTS

MAGNETIC FIELD DUE TO ELECTRIC CURRENT:

Magnetic field in a current carrying conductor (right hand screw rule):

- 1. A conductor carrying current creates magnetic field around it.
- 2. The strength of the magnetic field can be increased by increasing the current. In IGCSE course we are only interested in finding the direction of this magnetic field.
- 3. In order to determine the direction of the magnetic field around a current carrying conductor we apply <u>right hand</u> <u>screw rule</u>. According to this rule if a right-hand thumb held in a way that it is pointing towards the direction of the conventional current (means flow of positive charges from positive terminal to negative terminal of the battery), then the direction of rotation of the fingers gives the direction of the magnetic field (N-S) around the conductor.

Other fingers give the direction of the field

Magnetic field due to solenoid (right hand grip rule):

- 1. Solenoid is a long cylindrical coil with number of turns. It produces magnetic field similar to that of a bar magnet.
- 2. In solenoid the direction of the magnetic field can be found by applying the <u>right hand grip rule</u>.
- 3. According to this rule if the fingers of the right hand grip the solenoid in the direction of the flow of conventional current, the thumb points towards the north pole.
- 4. Higher the number of turns or larger the current in the coil, it gives the stronger magnetic field.
- 5. Permanent magnets can be made by allowing molten ferromagnetic metals to solidify in such solenoid fields.
- 6. **Relays** and **electric bells** are the good example of use of magnetic field due to a current carrying conductor.

<u>Relay:</u>

Relay is an electrical device in which large current circuit can be operated by a low current dc circuit. Referring to the diagram, when the switch **S** is closed, the iron core inside the solenoid becomes magnetized. It attracts the iron armature, which is pivoted. The upper limb of

the armature causes the contacts in the secondary circuit **XY** to close, thus activating that large circuit. The next figure shows the circuit symbol for relay. The NO is normally open relay and NC is normally closed relay.







Reed relay:

A **reed relay** is a type of relay that uses an electromagnetic coil to control switching. The contacts are ferro-magnetic material and electromagnet acts directly on them without requiring any armature to move them (as shown in figure). It is sealed in a long, narrow glass tube, the contacts are protected from corrosion, and are usually plated with silver, which has very low resistivity but is prone to corrosion when exposed. When the coil magnetized the reed contacts attract each other and complete the circuit. To switch off the relay the coil needs to be demagnetized.



Electric bell:

When switch is on, current will flow through the circuit, and this will energize the electromagnet. The electromagnet will attract the striker rod, causing the striker to hit the bell. As the striker hit the bell the contact breaks and de-energizing the electromagnet. The flexible metal spring, pulls back the striker rod and the hammer and restoring contact at the screw. This cycle is repeated as long as the switch is on or push button is depressed.



ELECTROMAGNETIC EFFECTS:

- 1. When a current carrying conductor is placed in between the magnetic poles, the conductor experience motion. This motion is due to a force is called **motor force**.
- 2. This force is a result of interaction of following two magnetic fields:
 - a. the magnetic field due to magnet and
 - b. magnetic field around a current carrying conductor.
- 3. The direction of motion is perpendicular to the direction of magnetic field (north to south) and direction of conventional current in the conductor.
- 4. The strength of motor force is proportional to the following four factors:
 - a. Length of the conductor,
 - b. strength of magnetic field,
 - c. size of the current in the conductor,
 - d. angle between the magnetic field lines and the conductor. Motor force is maximum if the angle is 90 degree and minimum force if the angle is zero.
- 5. Fleming's Left hand rule: Fleming's left hand rule helps us to determine the direction of motor force. According to this rule, extend the thumb, forefinger, and the middle finger of left hand in such a way that all three are mutually perpendicular to each another. If the forefinger points in the direction of the magnetic field from north to south pole and middle figure points in the direction of conventional current from positive to negative, then thumb points in the direction of motor force. Make sure that the direction of current should be from positive to negative terminal of the battery that is the direction of conventional current.



6. Common example of current carrying conductor in between the magnet is DC motor.

DC electric motor:

- 1. ADC electric motor consists of a rectangular coil of insulated wire, which makes up the moving part of the motor, N-S poles of a permanent magnet, pairs of commutators and carbon brushes.
- 2. When the current is switched on in the coil, it exists in opposite directions along the two opposite sides of the coil, generating equal but opposite motor force, which form a torque that rotate the coil.
- 3. The force on the coil carries it past the point where the current is short-circuited, and beyond that point, the current is reversed in the coil, but forces remain in the same directions, ensuring the continuous rotation of the coil while there is current in the coil.



- 4. If the direction of the current, or the poles of the magnet, are reversed, rotation will proceed in the opposite direction. The combination of magnetic field, current and force are shown in the diagram. Note that heat is also produced, so there is never a 100% conversion of electrical energy into kinetic energy.
- 5. Commutator act as current-reversing switch after every half-revolution of the coil.
- 6. The carbon brushes serve to make contact between the battery and the rotating commutators. They are mounted on an insulated shaft of the motor, not shown in the picture.

EFFECTS OF ELECTROMAGNETISM:

What is Electromagnetic Induction?

- 1. **Definition:** Electromagnetic induction is a process in which a conductor cuts through a stationary magnetic field lines (or conductor placed in a changing magnetic field) causes the production of a voltage across the conductor. The voltage produce is called **induce EMF** and causes current called **induce current**.
- 2. The movement of conductor (or magnet) should be perpendicular to the magnetic lines.
- 3. Changing magnetic field across conductor is <u>called magnetic flux</u> <u>linkage</u>.
- 4. The law of electromagnetic induction was first presented by Michael Faraday in 1831 and therefore it is also called Faraday's law of electromagnetic induction.
- 5. This phenomenon is used in design of electric generators and transformers.
- 6. The size <u>of induce emf</u> or <u>induce current</u> produce is proportional to:
 - a. The relative speed of the motion of conductor and magnet;
 - b. The number of turns in the coil;
 - c. The strength of the magnet.

Lenz's Law:

This law is named after the German physicist Heinrich Friedrich Lenz (1804–1865), who announced it in 1833. Lenz's law enables us to determine the direction of the induced current in the coil. It states that:

The direction of an electromagnetically-induced current will be such as to oppose the motion producing it.

Fleming's right- hand Rule:

Fleming's right hand rule helps us to predict the direction of induce current relative to the motion of conductor. According to this rule, extend the thumb, forefinger, and the middle finger of the right hand in such a way that all three are mutually perpendicular to each another. If the forefinger points in the direction of the magnetic field from north to south and thumb points in the direction of motion of conductor then middle finger points in the direction of the induce current. The induce current is always from negative to positive direction, that is opposite to the direction of conventional current.





sensitive galvanometer



alternating current (AC) generator:

When a coil of conducting wire is rotating in a magnetic field, by means of any external energy source, the electromagnetic induction results in an induced current through the loop. In this way, mechanical energy is converted to electrical energy. The device is called a **Generator**.

The generator will produce an electromotive force that will change as sine wave with the changing angle made by the coil with the magnetic field lines. Thus the direction of the current will vary, and the current so produced is called an <u>alternating current</u>.

The AC generator has two slip rings. The function of slip rings is to rotate with the coil and provide the alternate positive and negative induce current to the output carbon brushes. The carbon brushes are fixed with the body of the generator to maintain the contact with the rotating coil.

Note that this is similar to DC electric motor: the motor converts electrical energy into mechanical energy, while the generator converts mechanical energy into electrical energy.

The graph shows the changing alternating current with time during the one cycle of rotation. Whenever the rotating coil is in vertical positions, the size of alternating current or voltage is minimum (i.e zero). The current or voltage is maximum whenever the coil is in horizontal positions. The first half of cycle gives positive current output and second half negative current output.





The transformer:

When two coils are placed side by side and the current in one coil is switched on and off or changed, a voltage is induced in the neighboring coil. The effect is called **mutual induction**.

When an alternating current exists through the primary coil wrapped around one side of iron core as in the diagram, the alternating voltage causes an alternating magnetic field to be set up inside the iron core. This in turn induces an alternating voltage in a secondary coil wrapped around the opposite side of the core. In the way the secondary coil gives out an alternating current.





The size of the voltage in the secondary coil is depend on the ratio of the number of turns wrapped around the sides of the iron core, according to the formula

$$\frac{Primary\ coil\ voltage\ (Vp)}{Secondary\ coil\ voltage\ (Vs)} = \frac{no\ of\ turns\ in\ prinary\ coil\ (Np)}{no\ of\ turns\ in\ secondary\ coil\ (Ns)}$$

If the input voltage is greater than the output voltage, the transformer is called a **step-down transformer**, while if the output voltage is greater than the input voltage, the transformer is a **step-up transformer**.

Step up transformers:

 $V_s > V_p$, $n_s > n_p$ and $I_s < I_p$

Step down transformers:

 $V_p > V_s$, $n_p > n_s$ and $I_p < I_s$

Figure (A) is the circuit symbol for step-down transformer and figure (B) is the circuit symbol for step-up transformer.

Transformers are very useful devices. They are found wherever the voltages of alternating power supplies are to be modified.

Energy in transformer:

If the PD is step-up in a transformer, the current is step-down in the same proportion. In an ideal transformer the energy is conserved and the transformer is 100% efficient. That means that the power of the transformer remains same in primary and secondary coils.

$$P_p = P_s$$
$$V_p \times I_P = V_s \times I_s$$
$$\frac{V_p}{V_s} = \frac{I_s}{I_n}$$



For ideal transformer if the PD is doubled the current is halved. In real transformer, it is more than halved due to small energy losses in the transformer arising from the following three causes.

<u>Resistance of winding</u>: The winding of the copper have some resistance and heat and therefore it loses some power from primary coil. Large transformer has to be oil-cooled to prevent overhearing.

Eddy current: The changing magnetic flux in the iron core of a transformer above will induce an emf, not only in the primary and secondary coils, but also in the iron core. The iron core is a good conductor and due to induce emf in iron core, the currents also induced. This current is called eddy currents in a direction which, by Lenz's law, acts to weaken the flux created by the primary coil. The presence of eddy currents in the core create heating effect which results in loss of power.

Leakage of magnetic field lines: All the magnetic field lines produced by primary may not cut the secondary, especially if the core has air gaps or is badly designed.

Use of transformers in national grid system:

The electricity is carried around the country by national grid system. They are transmitted at very high voltage to reduce the energy loss. To minimise the power loss in transmitting electricity, the current has to be kept as low as possible. This can only be achieved by increasing the voltage. The higher the current, the more the transmission wires will be heated by the current and the more energy is wasted as heat. The higher voltage of about 400,000V is achieved by using step-up transformers and transmitted through the grid system. This voltage is then reduced by step-down transformers to 230V before it supplied to homes.



Advantage of alternating current mains supply:

- 1. To reduce the energy loss in the transmission lines,
- 2. To decrease the cost of transmission cables as it requires thinner cables to transmit low ampere current.

DEFLECTION OF CHARGED PARTICLES:

in magnetic field:

An electron beam (red arrow towards right) entering the magnetic field (B) a right angles to the field experience force due to the magnetic field around it. The direction of the deflection is given by the 'Fleming's right hand rule' method (right hand method is for the beam of negative charges that is electrons and left hand method is for positive charges).

In figure the dots represent the direction of magnetic field going inside the paper and electron moving towards right perpendicular to the

direction of field. The electron experiences the force F perpendicular to the field and the direction of motion of the electron.

in electric field:

An electric field is a region where an electric charge experiences a force. In the figure the two metal plates behave like a capacitor that has been charged by connecting to the voltage supply. A uniform electric field is created between them and is represented by equally spaced lines going from upper plate to the lower plate. When the beam of negatively charge electrons enters the electric field perpendicular to it, it attracts towards the positively charged plate and follows a curved path.



THERMIONIC EMISSION:

It is the emission of free electrons from a hot metal surface. The emitting surface is in an evacuated valve

directly heated with a hot wire. The cloud of electrons produced near the plate could be accelerated away by placing a second anode plate and applying potential difference. The hotter the cathode the greater the current and more number of electrons produce per second.

Thermionic emission occurs because the free electrons within the metal are given sufficient energy to escape from the surface of the metal. This energy is provided by the heater of the filament.

The streams of electrons that are emitted from the cathode are called <u>cathode rays</u>. Following are the properties of cathode rays.

- 1. They have rectilinear propagation,
- 2. they cause fluoresces,
- 3. they posses kinetic energy which change to heat energy when they brought to rest,
- 4. they are deflected by electric and magnetic field,
- 5. they can produce x-rays if they are of sufficiently high energy.

The minimum energy, which depends upon the type of metal, is required for electrons to escape from the nucleus-electron bond. This minimum energy is called <u>threshold energy</u>.





Cathode ray oscilloscope:



Cathode rays were discovered in late 1800 by J.J. Thomson. There are consists of stream of electrons emitted from heated cathode. Anode the positive terminal attracts the electrons from the cathode. The hole in the anode allows the electron to pass through it creating a beam of electrons shoots out in forward direction. This whole setup is called electron gun.

<u>Deflecting the electron beam:</u>

The beam of electrons behaves like an electric current but without the wire. It means it can be deflected by electric field. In CRO the Y-plates are charged by the input signal provided from the source. When the alternating voltage is connected at the Y-plates, they attract the electrons towards the positive terminal and repel at the negative terminal. The continuous change of potential at the Y-plates moves the beam up and down.

The X – plates are called time-base circuit. It moves the beam horizontally at constant speed. Repeating this process means a horizontal line appear on the screen.

With the time-base circuit switched on and a variable signal connected to Y-plates, CRO will display the wave form picture on the screen.

<u>Measuring potential difference (or voltage):</u>

Oscilloscope measures time-varying voltages and gives you a graph of voltage (y-axis) vs. time (x-axis). In terms of connection in the circuit they are exactly like voltmeters. It has two terminals which are connected across the two points where you want to measure the voltage. However, what you get from an oscilloscope is not what you get from a voltmeter. When you measure a signal with an oscilloscope, you get a scaled picture of the voltage-time



function on the screen. That picture might look like this one if you were measuring a sinusoidal voltage, in which the amplitude of a waveform expresses the voltage and width expresses time period (T).



There are two settings on the oscilloscope:

- volts/cm or volts/div: this setting represents the vertical axis or y-axis of the screen. It is used to measure the voltage of the source applied.
- Time base in ms/div or µs: this setting represents the horizontal axis or *x*-axis of the screen. It is used to measure the time period of the source wave applied. From the time period the frequency of the oscillation can be calculated by the formula.

$$T = \frac{1}{f}$$

ms and μ s are the time period in millisecond and microsecond of the wave.