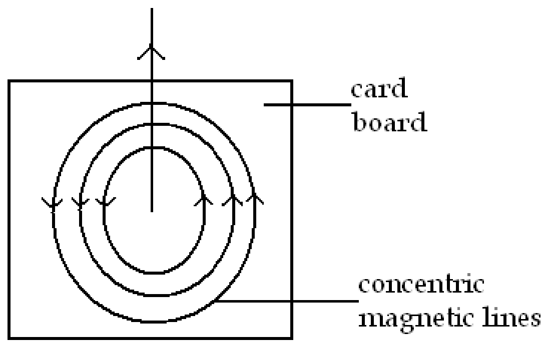
CHAPTER ELEVEN

MAGNETIC EFFECT OF AN ELECTRIC CURRENT

When electric current flows in a wire, magnetic field is created around the wire.

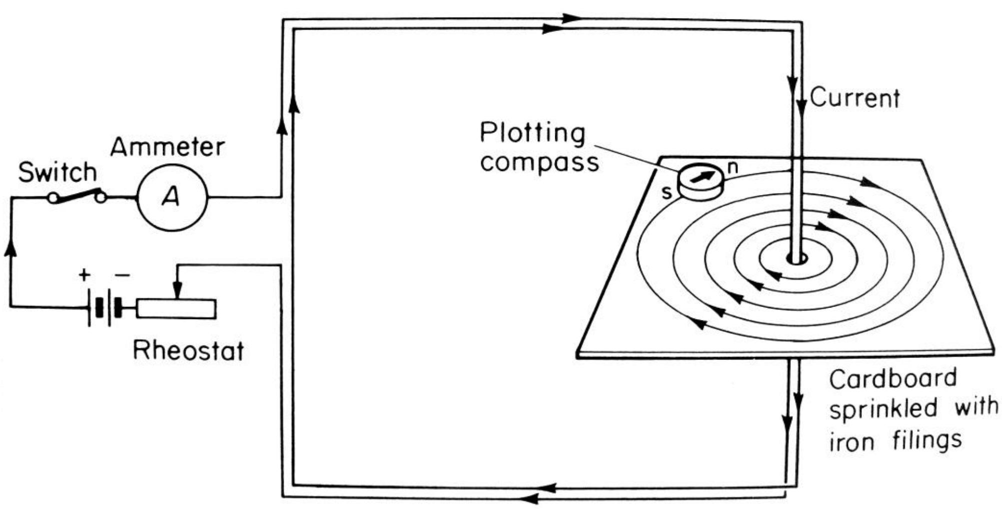


The direction of the magnetic field (flux) depends on the direction of the current in the wire.

Ampere's Swimming Rule

Imagine an observer to be swimming along the wire in the direction of the current and facing the needle, and then the north pole of the needle will be deflected towards his left hand.

Magnetic flux pattern due to a current in a long straight wire



- A large rectangular coil consisting of about twenty turns of insulated copper wire is set up vertically with one of its vertical sides passing through a hole in the centre of a piece of a cardboard supported horizontally as shown in the figure above.
- A current of about 3A may be passed though the coil from a 6V battery in series with a rheostat, an ammeter and a switch.
- A fine layer of iron fillings is then sprinkled on the cardboard; the current is switched on and the card tapped gently.
- The fillings set in series of concentric circles about the wire as center.
- A small plotting compass placed on the card indicates the direction of the flux.
- If the current is reversed by changing over the battery connections, the compass needle will swing round and point in the opposite direction, but the pattern of the flux remain unchanged.

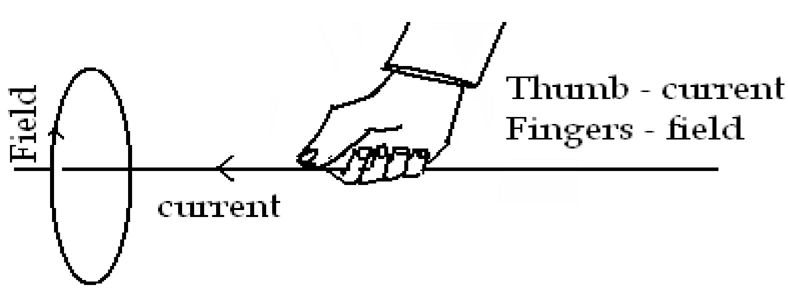
The direction of the magnetic field can be predicted by Maxwell's screw rule and the right hand grip rule.

Maxwell's screw rule

Imagine a screw being screwed along the wire in the direction of the current. The direction of rotation of the screw gives the direction of magnetic field.

Right hand grip rule

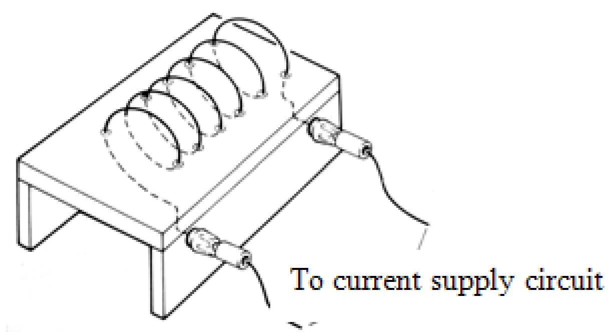
Imagine the wire to be grasped in the right hand with the thumb pointing along the wire in the direction of the current. The direction of the fingers will give the direction of the magnetic flux as shown below.



Magnetic field due to solenoid

The solenoid produces a magnetic flux when an electric current is passed through it. One end of the solenoid acts as a N pole and the other the S pole. A coil is connected in series with a battery, ammeter, a rheostat and a switch. The current should be adjusted to at least 20A as it is not possible to multiply the effect.

a)



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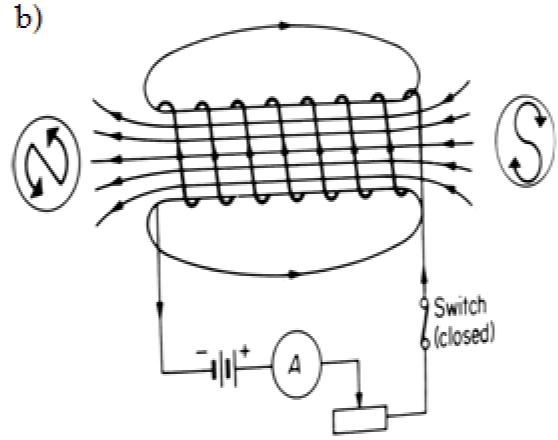
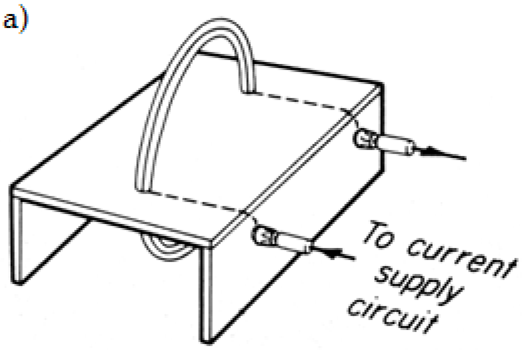


Rule for the polarity of a coil carrying a current

- When viewing one end of the coil, it will be of N polarity if the current is flowing in an a**N**ticlockwise direction, and of S polarity if the current is flowing in the clockwi**S**e direction. b)
- Then figure above illustrates an easy way of remembering this rule, by attaching arrows to the letters N and S.

Magnetic flux due to a short circular coil

a)



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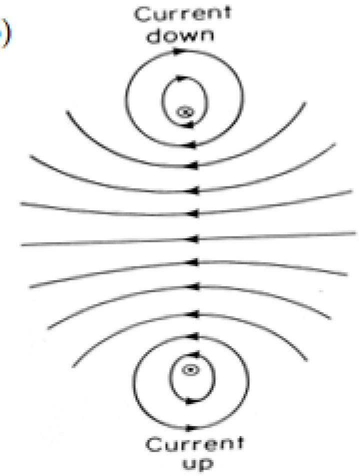
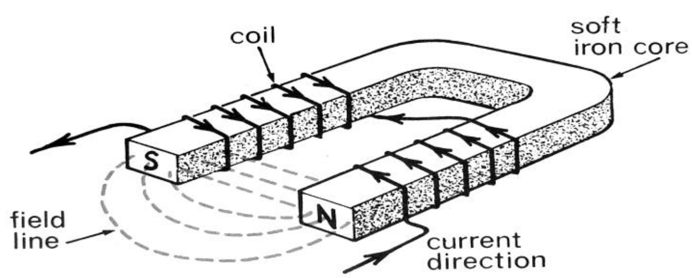


- When the current is passed through a short circuit coil, the pattern of the magnetic flux is show in the figure (b).
- The magnetic flux at the centre of the coil is straight and is perpendicular to the plane of the coil.

ELECTROMAGNETS

An electromagnet is a temporary magnet made by winding an insulated copper wire round soft iron core. Soft iron is used for making temporary magnets because it is easily magnetized and easily demagnetized.



Factors affecting the strength of electromagnet

1. Increase in the number of turns.

2. Increase the current i.e. its magnitude.

3. Placing an iron core inside a coil.

4. Increase the surface area of the electromagnets.

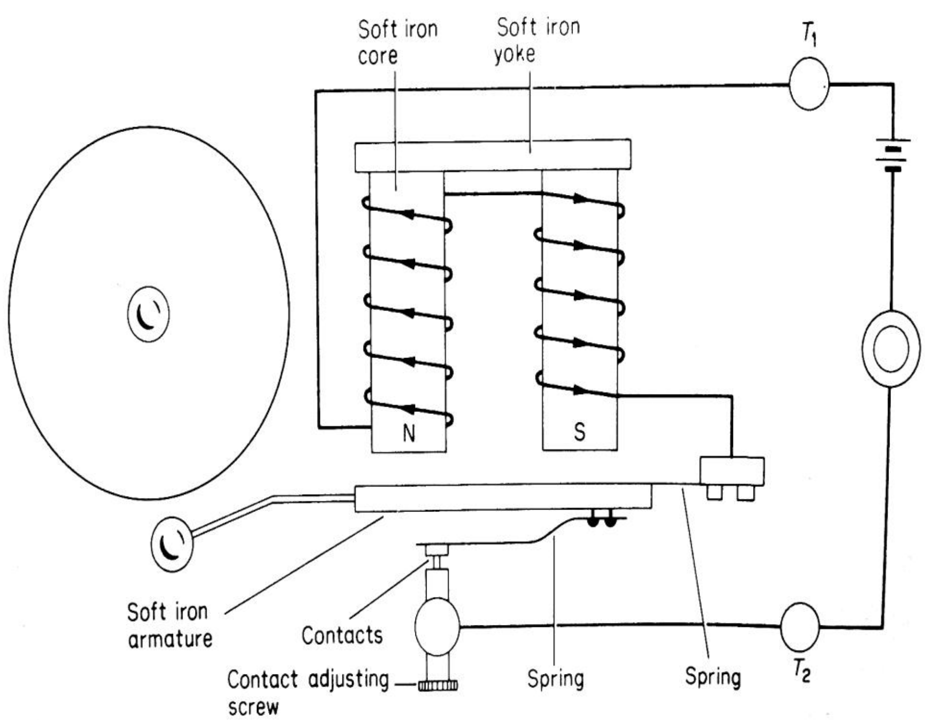
5. Using soft iron instead of steel.

Application for electromagnetism

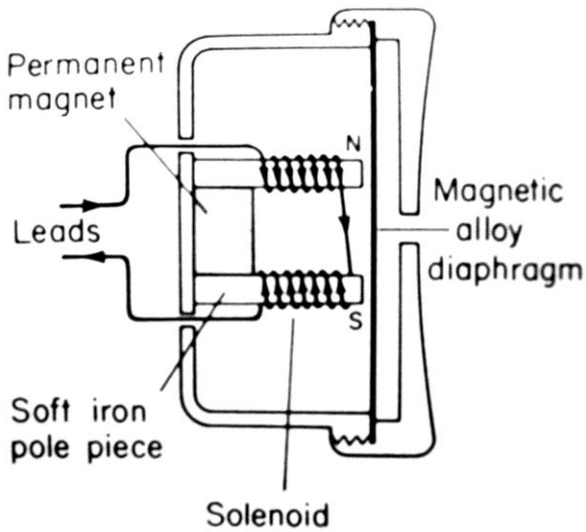
- Electric bell,
- Telephone system(microphone),
- Loud speakers,
- Electric motors,
- Galvanometers.

Electric Bell

- An electric bell consists of a hummer, a gong soft iron armature, contact adjusting screw, a bell push which is the switch, steel spring and an electromagnet which is made of two coils wound in opposite direction on two iron cores.
- When the current flows in the circuit, it causes iron core to be electromagnetized.
- It attracts the soft iron armature and the circuit breaks at the contact point causing the electromagnet to lose its magnetism.
- The spring of steel which holds the armature back so that the points are in contact again, thus the process is repeated with the continued striking of the gong by the hummer.



Telephone receiver (ear piece)

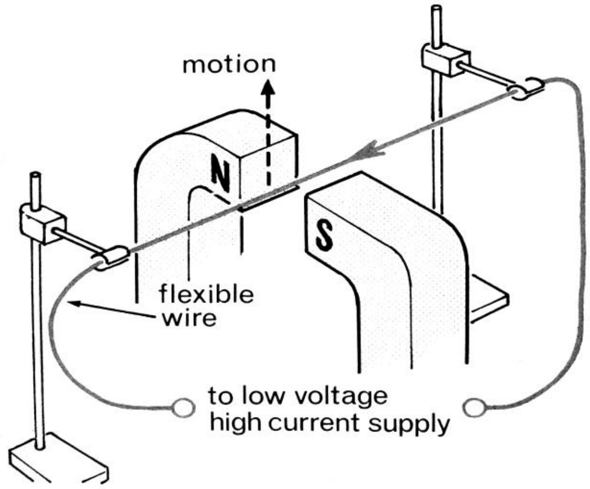


- A microphone changes sound energy into electrical energy which travels along the telephone cables and is changed back in to sound by the receiver.
- The varying current from the microphone passes through the coils of an electromagnet. This pulls the diaphragm towards it, by a distance which depends on the current.
- When a person speaks into the microphone at the other end of the line a varying electric current is set up having the same frequency as the sound waves. A similar electric current is caused to pass through the solenoids in the earpiece.
- As a result, the diaphragm moves in and out and produces sound waves that are a copy of these that entered the microphone.

ELECTRIC MOTORS

The motor effect

A wire carrying a current in a magnetic field experiences a force. If the wire can move it does.

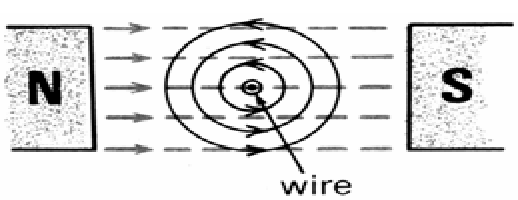


- **Demonstration:** In the figure above, the flexible wire is loosely supported in the strong magnetic field of a C-shaped magnet. When the switch is pressed, current flows in the wire which jumps up as shown. If either the direction of the current or the direction of the field is reversed, the wire moves downwards.

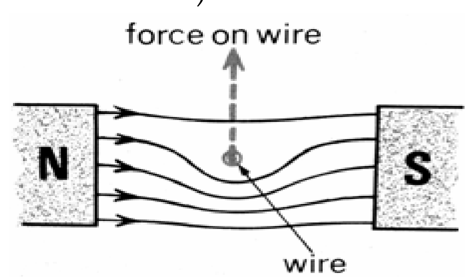
- **Explanation:** In the figure a. below, is a side view of a magnetic field lines due to the wire and the magnet. Those due to the wire are circles and we will suppose their directions are as shown. The dotted lines represent the field lines of the magnet and their direction of to the right.

- The resultant field obtained by combining both fields is shown in the figure (b) below. There are more lines shown below than the above the wire since both fields act in the same direction below but in opposite above.

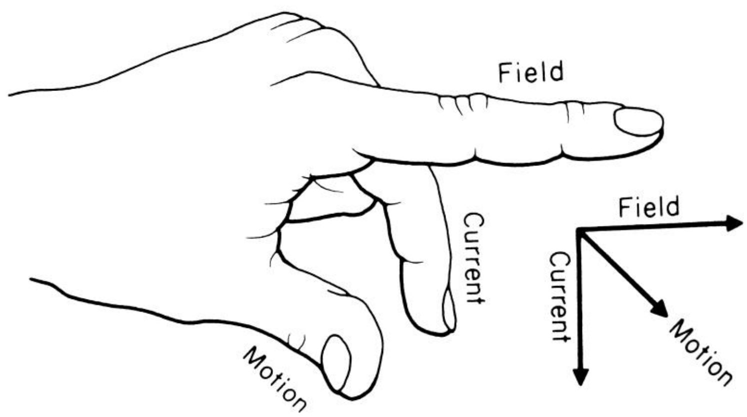
a)



b)



Fleming's left-hand rule (motor rule)



- Hold the thumb and first two fingers of the left hand at right angle to each other with the **F**irst finger pointing in the direction of the field. And the se**C**ond one in the direction of the current, then the thumb points the direction of the Thrust (motion or force).

- If the wire is not at right angles to the fields, the force is smaller and is zero if it is parallel to the fields.

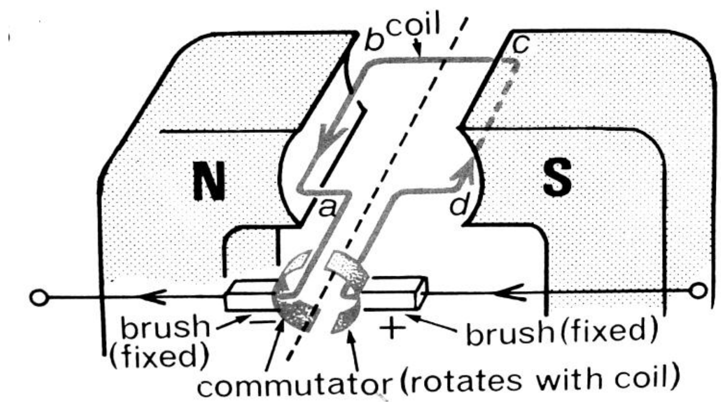
Force exerted on the wire carrying a current in a magnetic field depends on:

1. The strength of the magnetic field.
2. The amount of the current in the conductor.
3. The length of the wire in the magnetic field.

Simple d.c electric motor

- A simple motor to work from direct current (d.c) consists of a rectangular coil of wire mounted on an axel which can rotate between the poles of a C-shaped magnet, as shown in figure below.
- Each end of the coil is connected to half of the split ring of copper, called *commutator*, which rotates with the coil.
- Two carbon blocks, the *brushes*, are pressed lightly against the commutator by springs. The brushes are connected to an electrical supply.

- If Fleming's left hand rule is applied to the coil in the position shown, we find that side *ab* experiences the upward force and the side *cd* a downward force. (No forces act on *ad* and *bc* since they are parallel to the field.) These two forces form a *couple* which rotates the coil in a clockwise direction until it is vertical.
- The brushes are then in line with the gaps in the commutator and the current stops.
- However, because of its inertia, the coil overshoots the vertical and the commutator halves change contact from one brush to the other.
- This reverses the current through the coil and so also the directions of the forces on its sides. Side *ab* is on the right now, acted on by the downward force, whilst *cd* is on the left with an upward force. The coil thus carries on rotating clockwise.



- ***Back emf*** is the emf set up in opposition to the emf applied to a motor as a result of rotation of a coil in a magnetic field.

- The direction of rotation depends on the following:
  1. Direction of current.
  2. Magnetic field.

- **Note:** The speed of rotation increases if;
  1. The amount of current increases.
  2. The magnetic field is strong.
  3. Bigger number of turns.
  4. Large area of the coil.

Moving coil Galvanometer

- A galvanometer detects small currents or small p.d.s, often of the order of milliamperes (mA) or millivolts (mV). Some are even more sensitive.

- Current enters and leaves the coil by hair springs above and below it. When current flows, a couple acts on the coil (as in an electric motor), causing it to rotate until stopped by the springs.

- The greater the current the greater the deflection which is shown by a pointer attached to the coil.

The sensitivity of a galvanometer is increased by having:

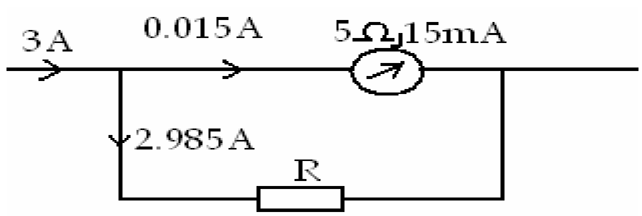
- More turns on the coil
- A stronger magnet
- Weak hair springs or a wire suspension

Conversion of a Galvanometer to ammeter or voltmeter

A galvanometer is a sensitive instrument and usually measures current in milliamperes. The instrument can be converted to an ammeter or voltmeter. To measure big current by connecting a very small resistance (ammeter) in parallel with the instrument. This is called shunting resistance and is very small compared to a galvanometer resistance.

Example-1: A galvanometer has a resistance of 5 Ω and gives a full scale deflection (f.s.d) when a current of 15 mA flows through it. Find the shunting resistance to convert it into ammeter which reads 3 A as maximum current.

Solution: For full scale deflection, the current through the galvanometer ,
= 15mA = 0.015A



The current that passes through the shunt,

3 – 0.015 = 2.985A

By ohm's law, $V = IR$

the p.d. across the galvanometer = p.d. across R

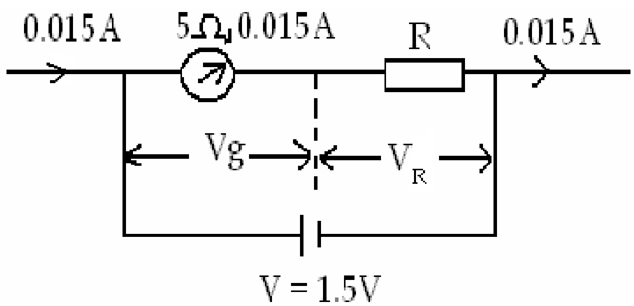
$$0.015 \times 5 = 2.985 \times R$$

$$R = 0.025\ \Omega$$

Voltmeter

A voltmeter is constructed such that it has a very high internal resistance so that no current should pass through it. In order to convert a galvanometer into a voltmeter a high resistance called a multiplier is connected in series with it.

Example-2: A galvanometer has a resistance of 5 Ω and gives a full scale deflection when a current of 15 mA flow through it. Suppose a maximum p.d of 1.5 V is to be measured using a galvanometer, find the value of the multiplier R required.



Solution :

For full scale deflection, the current through the galvanometer and *R = 0.015A.*

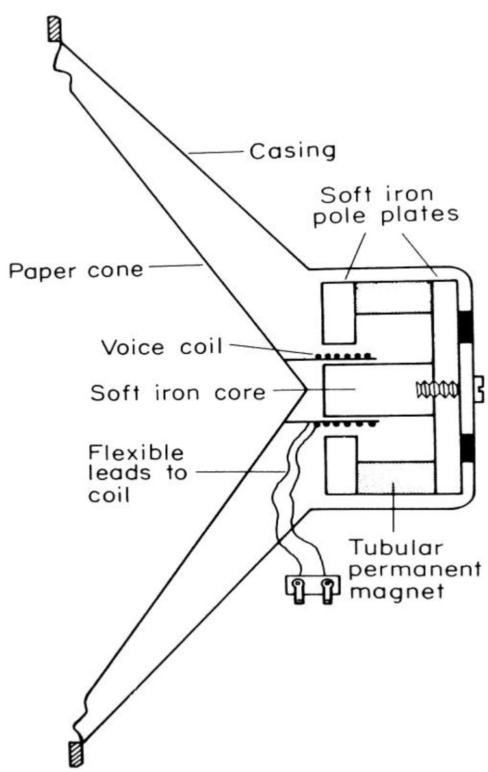
The p.d. across the galvanometer +p.d. across R = Voltage V being measured

The p.d. $= V_g + V_R$

$$1.5 = 0.015 \times 5 + 0.015 \times R$$

$$R = 95\ \Omega$$

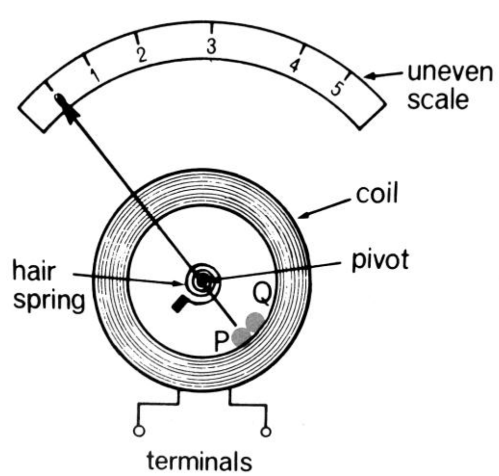
Moving coil loud speaker



- Electric pulses corresponding to sound enter through the leads, and end up in the voice coil.
- A force acts on the voice coil which then vibrates in accordance with Flemings left hand rule.
- The paper cone to which the voice coil is connected also ends up vibrating, and this sets the surrounding air in vibration, producing the required sound.

Moving iron meter (galvanometer)

- When current flows in the coil the two small soft iron rods P and Q are magnetized in the same direction.
- They repel. Q is fixed but P is attached to the pivoted pointer and moves away from Q until stopped by the hair spring.
- The larger the current the greater the repulsion.



Advantages of moving iron galvanometer:

1. It can measure both d.c and a.c.
2. It is simple and cheap to make.
3. It is light.

Disadvantages of a moving coil galvanometer:

1. It is less accurate than a moving coil galvanometer.
2. Its current is non uniform.