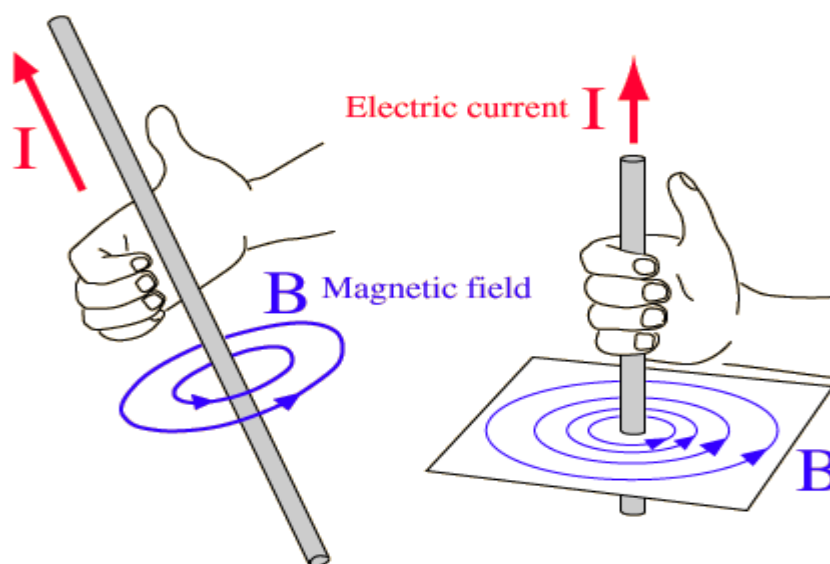


TRAINING:	BASIC	PREPARED BY; OCHEPA MOSES
COURSE:	ELECTRONICS	
MODULE:	ENGINEERING SCIENCE AND PRINCIPLES	DATE;
COURSE UNIT:	ELECTROMAGNETISM	TIME; HOURS

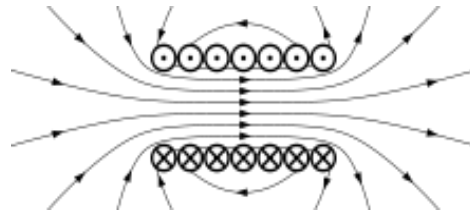
MAGNETIC FIELD DUE TO ELECTRIC CURRENT

The magnetic field lines around a long wire which carries an electric current form concentric circles around the wire. The direction of the magnetic field is perpendicular to the wire and is in the direction the fingers of your right hand would curl if you wrapped them around the wire with your thumb in the direction of the current direction;



If the current direction is reversed, the lines of flux are also reversed and when switched off, the pattern and direction will disappear indicating that magnetic field is produced by electric current. If the current is increased, the strength of the field is increased and field strength decreases as we move away from the current-carrying conductor.

When the magnetic fields are formed by electric current, it is usual to portray the effect as seen below;



When we consider a screw driven away and towards a viewer,

- The circle with a star/cross represents current flowing away from the viewer (viewing the screw head).
- The circle with a dot/point represents current flowing towards the viewer (viewing the pointed end of the screw).

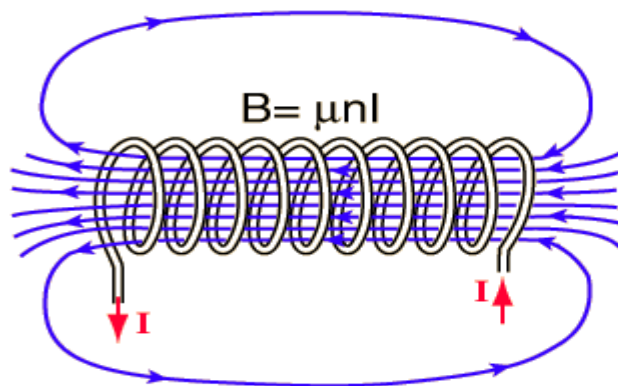
THE SCREW RULE

The direction of the magnetic lines of flux is best remembered by the screw rule. It states that:

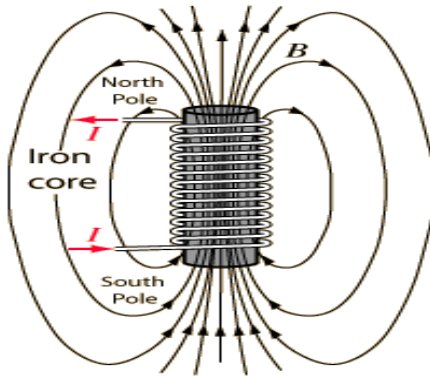
If a screw is turned along a conductor in the direction of the current, the direction of rotation of the screw is the direction of the magnetic field.

THE SOLENOID

A magnetic field set up by a long coil, or solenoid is similar to that of a bar magnet. If the solenoid is wound on an iron bar magnet, an even stronger magnetic field is proportional to the iron bar being magnetized



The magnetic field is concentrated into a nearly uniform field in the center of a long solenoid. The field outside is weak and divergent.



The direction of the magnetic field produced by the current I in the solenoid is found by:

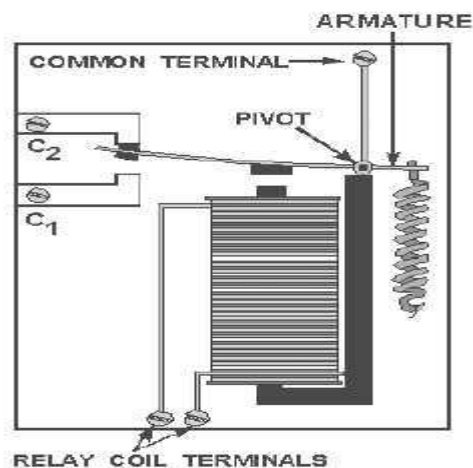
- The screw rule;** This states that if a normal right hand thread screw is placed along the axis of the solenoid and is screwed in the direction of the current, it moves (rotates) in the direction of the magnetic with magnetic field i.e from South to North.
- The grip rule;** It states that if the coil is gripped with the right hand, with the fingers pointing in the direction of the current, then the thumb, outstretched parallel to the axis of the solenoid points in the direction of the magnetic field.

ELECTROMAGNETS

The magnetic field inside the solenoid is practically uniform for a particular current and is also versatile, in as much that a variation of the current can alter the strength of the field. This provides the basis of many items of electrical equipment e.g relays, telephone receivers, bells and lifting magnets.

RELAY.

This is a pair of electrical contacts operated by an electromagnet. The contacts are either opened or closed when the electromagnet operates.



(TO CIRCUIT)

Fig. SIMPLE RELAY

When the coil is energized by connecting to the circuit by use of the relay coil terminals, the pivoted soft iron armature is attracted to the electromagnet and pushes against a fixed contact C_1 so that they are connected together, thus closing some other electrical circuit.

TELEPHONE RECEIVER

Whereas a transmitter or microphone changes sound wave into corresponding electrical signals, a telephone receiver converts the electrical waves back into sound waves.

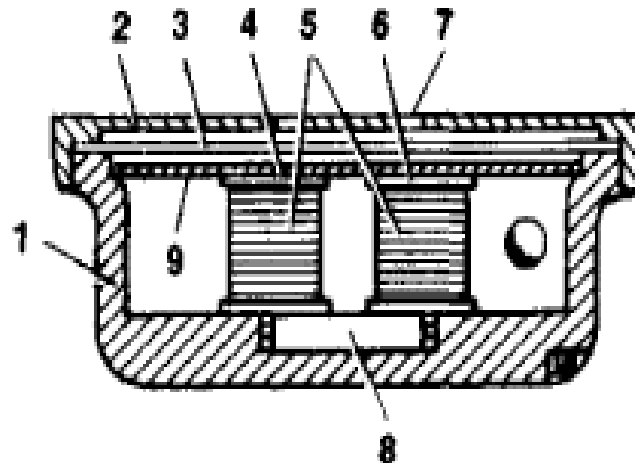


Fig. DESIGN OF A TELEPHONE RECEIVER

- | | | |
|-------------------------------|------------------------------------|----------------------|
| (1) plastic casing, | (2) outer cover with holes, | (3) diaphragm, |
| (4) pole pieces, | (5) windings of the electromagnet, | (6) coil former, |
| (7) holes in the outer cover, | (8) permanent magnet, | (9) plastic membrane |

It consists of a permanent magnet with coils wound on its poles. A thin flexible diaphragm of magnetic material is held in position near magnetic poles. The variation in current from the transmitter varies the magnetic field and diaphragm consequently vibrates thus producing sound variations corresponding to those transmitted.

FORCE ON A CURRENT-CARRYING CONDUCTOR

If a current-carrying conductor is placed in a magnetic field produced by permanent magnets, then the two fields interact and cause a force to be exerted on the conductor.

The force on the conductor in a magnetic field depends upon:

- i) the flux density of the field, B in Teslas
- ii) the strength of the current, I in amperes
- iii) the length of the conductor perpendicular to the magnetic field, L in metres
- iv) the direction of the field and the current.

When the magnetic field, the current and the conductor are mutually at right angles,

then: Force $F = B I L$ Newton's.

When they are at angle θ° to each other,

then; Force $F = B I L \sin \theta$ Newton's.

LOUD SPEAKER

The application of the force on a conductor is the moving coil loud speaker. The loud speaker is used to convert electrical signals into sound waves.

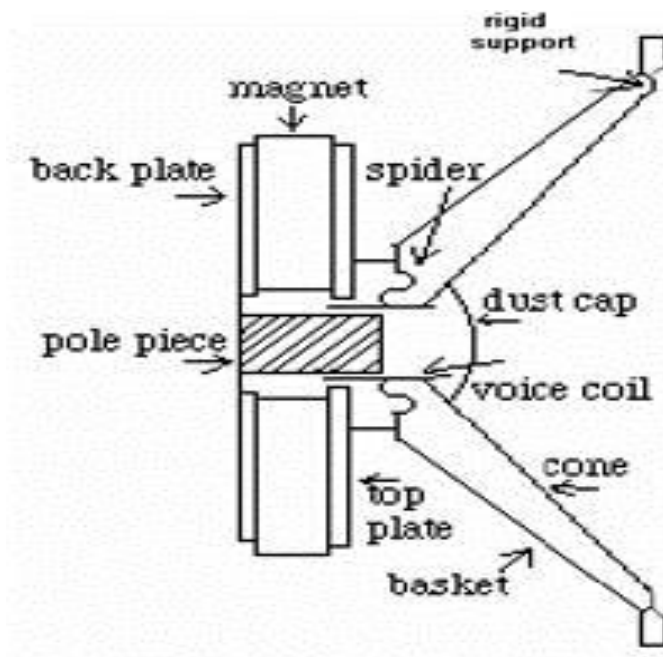


Fig. LOUD SPEAKER

The magnetic circuit comprises of a permanent magnet and soft iron pole pieces so that a strong magnetic field is available in the short cylindrical air gap. A moving coil, called the voice or speech coil, is suspended from the end of paper or plastic cone so that it lies in the gap. When the electric current flows through the coil it produces a force which tends to move the cone backwards and forwards according to the direction of the current. The cone acts as a piston, transferring this force to the air, and producing the required sound waves.

TRAINING:	BASIC	PREPARED BY; OCHEPA MOSES
COURSE:	ELECTRONICS	
MODULE:	ENGINEERING SCIENCE AND PRINCIPLES	DATE;
COURSE UNIT:	ELECTROMAGNETIC INDUCTION	TIME; 6HOURS

ELECTROMAGNETIC INDUCTION.

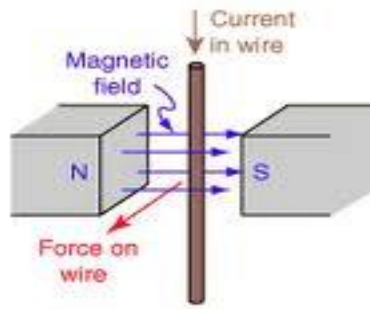
We have now seen that if electrical current is flowing in a conductor, there is an associated magnetic field created around the wire. In a similar manner, if we move a wire inside a magnetic field there will be an electrical current that will be generated in the wire.

INTRODUCTION

Current is produced in a conductor when it is moved through a magnetic field because the magnetic lines of force are applying a force on the free electrons in the conductor and causing them to move. This process of generating current in a conductor by placing the conductor in a changing magnetic field is called **induction**. This is called induction because there is no physical connection between the conductor and the magnet. The current is said to be induced in the conductor by the magnetic field.

One requirement for this electromagnetic induction to take place is that the conductor, which is often a piece of wire, must be perpendicular to the magnetic lines of force in order to produce the maximum force on the free electrons. The direction that the induced current flows is determined by the direction of the lines of force and by the direction the wire is moving in the field. In the animation above the ammeter (the instrument used to measure current) indicates when there is current in the conductor.

(When a conductor is moved across a magnetic field so as to cut through the lines of force (flux), an electromotive force (emf) is produced in the conductor. If the conductor forms a closed circuit then the emf produced causes an electric current to flow round the circuit. This effect is known as electromagnetic induction.)



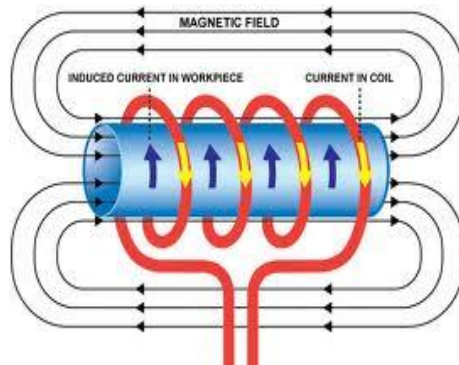
In the above diagrams,

- i) When the magnet is moved at constant speed towards the coil (fig. a), a deflection is noted on the galvanometer showing the current is produced in the coil.
- ii) When the magnet is held stationary, even within the coil, no deflection is recorded.
- iii) When the relative speed is say, doubled, the galvanometer deflection is doubled.
- iv) When a stronger magnet is used, a greater galvanometer deflection is noted
- v) When a number of turns of wire of the coil is increased, a greater galvanometer deflection is noted.

LAWS OF ELECTROMAGNETIC INDUCTION.

FARADAY'S LAWS:

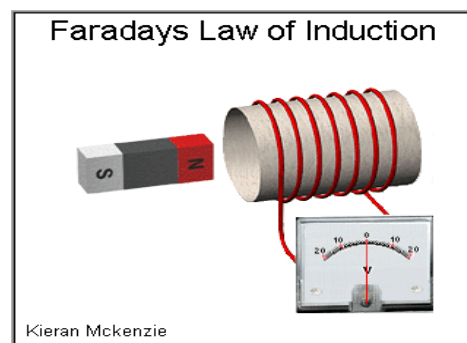
- i) First Law of Faraday's Electromagnetic Induction state that whenever a conductor are placed in a varying magnetic field emf are induced which is called induced emf, if the conductor circuit are closed current are also induced which is called induced current. (An induced emf is set up whenever the magnetic field linking that circuit changes)



- ii) Second Law of Faraday's Electromagnetic Induction states that the induced emf is equal to the rate of change of flux linkages (flux linkages is the product of turns, n of the coil and the flux associated with it).

OR

The magnitude of the induced emf in any circuit is proportional to the rate of change of the magnetic flux linking the circuit.



LENZ'S LAW:

The direction of an induced emf is always such that it tends to set up a current opposing the motion or the change of flux responsible for inducing the emf.

An alternative method to Lenz's law of determining relative direction is given by Fleming's right hand rule which states:

Let the thumb, first finger and second finger of the right hand be extended such that they are all at right angles.

If the **first** finger points in the direction of the *magnetic field*,
the **thumb** points in the direction of *motion* of the conductor relative to the magnetic field,
then the **second** finger will point in the direction of the *induced emf*.

Summarizing:

F irst finger	-	Field
th u M b	-	Motion
s e C ond finger	-	Emf

OR



In a generator; conductors forming an electric circuit and an emf is induced in them and thus a source of emf is created. The generator converts mechanical energy into electrical energy. The emf induced set up between the ends of the conductor is given by;

$$E = Blv \text{ volts}$$

Where v = is the conductor velocity

If the conductor moves at an angle θ° to the magnetic field, then;

$$E = Blv \sin\theta \text{ volts}$$

INDUCTANCE

This is the name given to the property of a circuit whereby there is an emf induced into the circuit by the change of flux linkages produced by a current change.

SELF INDUCTANCE (L)

This is when the emf is induced in the same circuit as that in which the current is changing.

MUTUAL INDUCTANCE (M)

This is when the emf is induced in the circuit by a change of flux due to current changing in the adjacent circuit. The unit for inductance is the henrys (H).

A circuit has an inductance of one henrys when an emf of one volt is induced in it by a current changing at the rate of one ampere per second.

Induced emf in a circuit of N turns $E = N \left[\frac{\Delta\Phi}{t} \right] \text{ volt}$

where $\Delta\Phi$ is the change in flux, in webers

t is the time taken for the flux to change, in seconds.

Induced emf in a coil of inductance L henrys $E = L \frac{[\Delta I]}{t}$ volt

where ΔI is the change in current, in amperes

t is time taken for current to change, in seconds

The above equation for emf E is often stated as $E = -N \frac{[\Delta \Phi]}{t}$ and $E = -L \frac{[\Delta I]}{t}$,

the minus sign reminding of the reverse direction given by Lenz's law.

Example I

Determine the emf induced in a coil of 200 turns when there is a change of flux of 25 mWb linking with it.

$$\text{Induced emf } E = -N \frac{[\Delta \Phi]}{t} = -200 \frac{[25 \times 10^{-3}]}{50 \times 10^{-3}} = -100 \text{ volts}$$

Example II

A flux of 400 μWb passing through a 150 turns coil is reversed in 40ms. Find the average emf induced.

Since flux reverses, the flux changing from +400 μWb to -400 μWb , totals to 800 μWb .

$$\text{Flux} = 800 \mu\text{Wb} = 800 \times 10^{-6} \text{ Wb}, \quad t = 40\text{ms} = 40 \times 10^{-3} \text{ s}$$

$$\text{Induced emf } E = -N \frac{[\Delta \Phi]}{t} = -150 \times \frac{[800 \times 10^{-6}]}{40 \times 10^{-3}} = -3 \text{ volts}$$

Example III

An emf of 1.5KV is induced in a coil when a current of 4A collapses uniformly to zero in 8ms. Determine the inductance of the coil.

$$\text{Change in current, } \Delta I = (4 - 0) = 4\text{A}, \quad t = 8\text{ms} = 8 \times 10^{-3} \text{ s}, \\ E = 1.5\text{KV} = 1.5 \times 10^3 \text{ V}$$

$$\frac{\Delta I}{t} = \frac{4}{8 \times 10^{-3}} = \frac{4 \times 10^3}{8} = \frac{4000}{8} = 500 \text{ A/s}$$

$$\text{Since } E = -L \frac{[\Delta I]}{t}$$

$$\text{Then } L = \frac{E}{\Delta I / t} = \frac{1.5 \times 10^3}{500} = \frac{1500}{500} = 3 \text{ Henrys}$$

Example III

An emf of 1.5KV is induced in a coil when a current of 4A collapses uniformly to zero in 8ms. Determine the inductance of the coil.

$$\text{Change in current, } \Delta I = (4 - 0) = 4A, \quad t = 8\text{ms} = 8 \times 10^{-3} \text{ s}, \\ E = 1.5\text{KV} = 1.5 \times 10^3 \text{ V}$$

$$\frac{\Delta I}{t} = \frac{4}{8 \times 10^{-3}} = \frac{4 \times 10^3}{8} = \frac{4000}{8} = \mathbf{500 \text{ A/s}}$$

$$\text{Since } E = -L \left[\frac{\Delta I}{t} \right]$$

$$\text{Then } L = \frac{E}{\Delta I / t} = \frac{1.5 \times 10^3}{500} = \frac{1500}{500} = \mathbf{3\text{Henrys}}$$

Example IV

An average emf of 40V is induced in a coil of inductance 150mH when a current of 6A is reversed. Calculate the time taken for the current to reverse.

$$E = 40\text{V}, \quad L = 150\text{mH} = 150 \times 10^{-3} \text{ H} \\ \text{Change in current } I = 6 - (-6) = 12\text{A} \text{ (since the current is reversed)}$$

$$\text{Since } E = L \left[\frac{\Delta I}{t} \right]$$

$$\text{time, } t = \frac{L \Delta I}{E} = \frac{150 \times 10^{-3} \times 12}{40} = \mathbf{0.045 \text{ s} = 45\text{ms}}$$

INDUCTORS

A component called an inductor is used when the property of inductance is required in a circuit. An inductor is simply a coil of wire. Factors which affect the inductance of an inductor include;

- i) **The number of turns of wire:** – The more the turns the higher the inductance.
- ii) **The cross sectional area of the coil:**– The greater the cross-sectional area the higher the inductance
- iii) **The presence of a magnetic cone:**– When the coil is wound on an iron core the same current sets up a more concentrated field and the Inductance is increased.
- iv) **The way the turns are arranged:**– A short thick coil of wire has a higher inductance than along thin one.

ENERGY STORED IN A MAGNETIC FIELD

An inductor is a component that possesses an ability to store energy.

During the time, t seconds, the rate of increase of current is I/t amperes/second and emf E in the coil remains constant at $-LI/t$ volts and applied voltage to neutralize this is LI/t .

The power absorbed by the magnetic field increases uniformly from zero to LI^2/t watts.

$$\begin{aligned} \text{Hence average power absorbed by the magnetic field} &= \frac{LI^2/t}{2} \text{ watts} \\ &= \frac{1}{2} \frac{LI^2}{t} \text{ watts} \end{aligned}$$

Total energy absorbed by field = average power x time

$$\begin{aligned} &= \left[\frac{1}{2} \frac{LI^2}{t} \right] \times t \\ &= \frac{1}{2} LI^2 \text{ Joules} \end{aligned}$$

INDUCTANCE OF A COIL

If a current changing from 0 to I amperes produces a flux change from 0 to Φ webers; then $\Delta I = I$ and $\Delta \Phi = \Phi$. Then from induced emf $E = N \Phi/t = LI/t$

$$\text{Inductance of coil } L = \frac{N\Phi}{I} \text{ henrys.}$$

MUTUAL INDUCTANCE

If two coils A and C are placed relatively to each other and currently allowed to flow; some of the flux produced by the current in A becomes linked with C and the emf induced in C circulate a current.

When the switch is opened; the collapse of the flux induces an emf in the reverse direction in coil C.

Two coils are said to have mutual inductance when change of current and flux in one coil links with another coil and producing an emf in it (second coil). The SI units for mutual inductance is the same as for self inductance ie henrys.

If two coils, A and C, have a mutual inductance of M henrys and if the current in coil A increases from I_1 to I_2 amperes in t seconds;

$$\begin{aligned} \text{Average emf induced in C} &= -M \times \frac{[I_1 - I_2]}{t} = -M \times \left(\frac{\Delta I}{t} \right) \text{ volts} \\ &= -M \times \text{average rate of change of current in coil A.} \end{aligned}$$

The minus sign indicates that the emf induced in coil C circulates a current in such a direction as to oppose the increase of flux due to the growth of current in coil A.

If Φ_1 and Φ_2 represent flux linked with coil C due to current I_1 and I_2 in coil A and N_2 represents turns on coil C;

$$\text{Average emf induced in coil C} = - \frac{\Phi_2 - \Phi_1}{t} \times N_2$$

$$\text{Equating the two expressions } M \frac{[I_2 - I_1]}{t} = \frac{\Phi_2 - \Phi_1}{t} \times N_2$$

$$\begin{aligned} M &= \frac{\Phi_2 - \Phi_1}{I_2 - I_1} \times N_2 \text{ Henrys} \\ &= \frac{\text{change of flux linkages with C}}{\text{Change of current in coil A}} \end{aligned}$$

$$\text{OR } \text{Emf} = \frac{M}{\sqrt{L_1 L_2}} = \text{coupling coefficient}$$

Example

Two coils have a mutual inductance of 0.3H. If the current in one coil is varied from 5 to 2 in 0.4s, calculate:

- the average emf induced in the other coil
- the change of flux linkage of the later.

$$\begin{aligned} \text{a) Average rate of change of current in one coil} &= \frac{2-5}{0.4} = -7.5\text{A/s} \\ \text{Average emf in other coil} &= -0.3\text{H} \times -7.5\text{A/s} = 2.25 \text{ volts} \end{aligned}$$

- If Φ be the change of flux, in webers linked with the second coil,

$$\text{Average emf induced in that coil} = \frac{\Phi \times \text{number of turns}}{\text{time in seconds}}$$

$$2.25 = \Phi \times 200 \times 0.4$$

$$\Phi = 0.0045 \text{ Wb}$$