## Magnetic terms, magnetic material and properties of magnet

**Objectives:** At the end of this lesson you shall be able to
- **state the different kinds of magnets and state the classification of magnetic material**
- **state the classifications of magnets.**

**Magnetism and magnets:** Magnetism is a force that acts on some materials and not on other materials. Physical devices which possess this force are called magnets. Magnets attract iron and steel, and when free to rotate, they will move to a fixed position relative to the north pole.

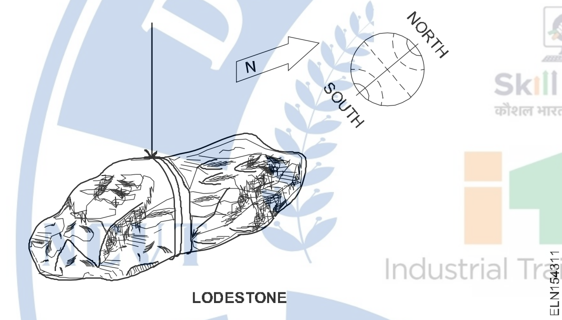
**Classification of magnets**

Magnets are classified into two groups.

- Natural magnets
- Artificial magnets

Lodestone (an iron compound) is a natural magnet which was discovered centuries ago. (Fig 1)

Fig 1




There are two types of artificial magnets. Temporary and permanent magnets.

**Temporary magnets or electromagnets:** If a piece of magnetic material, say, soft iron is placed in a strong magnetic field of a solenoid it becomes magnetised by induction. The soft iron itself becomes a temporary magnet as long as the current continues to flow in the solenoid. As soon as the source producing the magnetic field is removed, the soft iron piece will loose its magnetism.

**Permanent magnets:** If steel is substituted for soft iron in the same inducing field as in the previous case, due to the residual magnetism, the steel will become a permanent magnet even after the magnetising field is removed. This property of retention is termed retentiveness. Thus, permanent magnets are made from steel, nickel, alnico, tungsten all of which have higher retentiveness.

**Classification of magnetic substances**

Materials can be classified into three groups as follows.

**Ferromagnetic substances:** Those substances which are strongly attracted by a magnet are known as ferromagnetic substances. Some examples are iron, nickel, cobalt, steel and their alloys.

**Paramagnetic substances:** Those substances which are slightly attracted by a magnet of common strength are called paramagnetic substances. Their attraction can easily be observed with a powerful magnet. In short, paramagnetic substances are similar in behaviour to ferromagnetic materials. Some examples are aluminium, manganese, platinum, copper etc.

**Diamagnetic substances:** Those substances which are slightly repelled by a magnet of powerful strength only are known as diamagnetic substances. Some examples are bismuth, sulphur, graphite, glass, paper, wood, etc. Bismuth is the strongest of the diamagnetic substances.

**There is no substance which can be properly called non-magnetic. It may also be noted that water is a diamagnetic material, and air is a paramagnetic substance.**

## Magnetic terms and properties of magnet

**Objectives:** At the end of this lesson you shall be able to
- **define the terms magnetic field, magnetic line, magnetic axis, magnetic neutral axis and unit pole**
- **explain the properties of a magnet**
- **state the application, care and maintenance of a permanent magnet.**

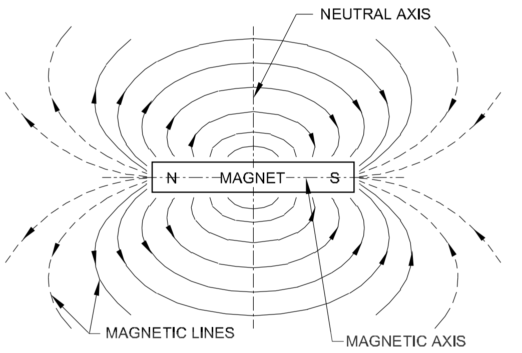
**Magnetic fields:** The force of magnetism is referred to as a magnetic field. This field extends out from the magnet in all directions, as illustrated in Fig 1. In this figure, the lines extending from the magnet represent the magnetic field.

The space around a magnet in which the influence of the magnet can be detected is called the magnetic field.

**Magnetic lines:** Magnetic lines of force (flux) are assumed to be continuous loops, the flux lines continuing on through the magnet. They do not stop at the poles.

The magnetic lines around a bar magnet are shown in Fig 1.

Fig 1




MAGNETIC FIELD OF A MAGNET. THE FLUX IS MOST DENSE AT THE POLES.

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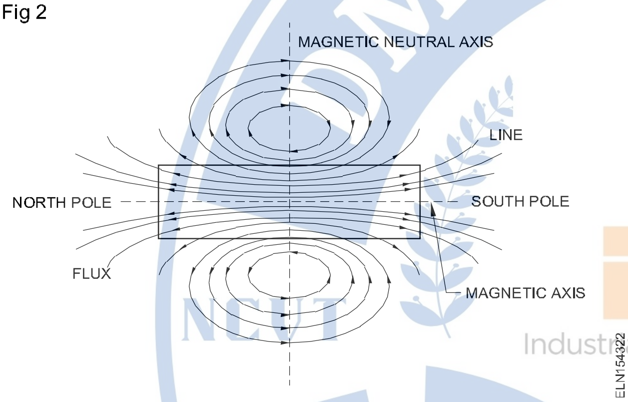
**Magnetic axis:** The imaginary line joining the two poles of a magnet are called the magnetic axis. It is also known as the magnetic equator.

**Magnetic neutral axis** (Fig 2): The imaginary lines which are perpendicular to the magnetic axis and pass through the centre of the magnet are called the magnetic neutral axis.

Fig 2

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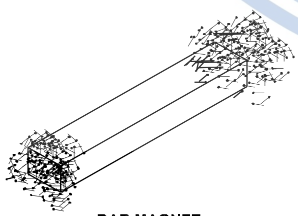
**Unit pole:** A unit pole may be defined as that pole which, when placed one metre apart from an equal and similar pole, repels it with a force of 10 newtons.

**Properties of a magnet**

The following are the properties of magnets.

**Attractive property :** A magnet has the property of attracting magnetic substances (such as iron, nickel and cobalt) and its power of attraction is greatest at its poles. (Fig 3)

Fig 3



BAR MAGNET

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**Directive property:** If a magnet is freely suspended, its poles will always tend to set themselves in the direction of north and south. (Fig 4)

**Induction property:** A magnet has the property of producing magnetism in a nearby magnetic substance by induction. (Fig 5)

Fig 4

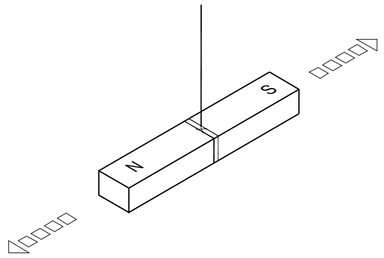


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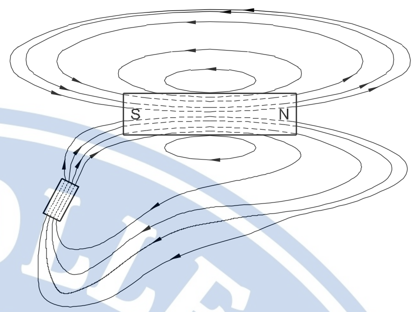
Fig 5




SOFT IRON PROVIDES A PATH FOR MAGNETIC LINES OF FORCE.

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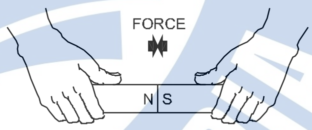
**Demagnetising property:** If a magnet is handled roughly by heating, hammering, etc. it will lose its magnetism.

**Property of strength:** Every magnet has two poles. The two poles of a magnet have equal pole strength.

**Saturation property:** If a magnet of higher strength is further subjected to magnetization, it will never acquire more magnetization due to its being already saturated.

**Property of attraction and repulsion**: Unlike poles (i.e. north and south) attract each other, (Fig 6) while like poles (north/north and south/south) repel each other. (Fig 7)

Fig 6




ATTRACTION

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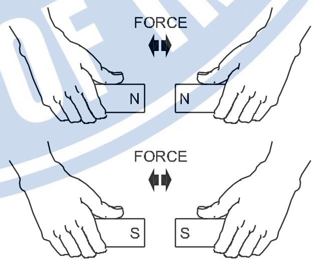
Fig 7




REPULSION

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**Shapes of magnets**: Magnets are available in various shapes, with the magnetism concentrated at their ends known as poles. The common shapes are listed here.

- Bar magnet
- Horseshoe magnet
- Ring magnet

– Cylindrical type magnet

– Specially shaped magnets

**Methods of magnetizing:** There are three principal methods of magnetizing a material.

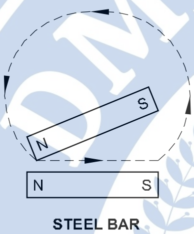
- Touch method
- By means of electric current
- Induction method.

**Touch method**: This method can be further divided into:

- single touch method
- double touch method, and

**Single touch method:** In the single touch method, the steel bar to be magnetized is rubbed with either of the poles of a magnet, keeping the other pole away from it. Rubbing is done only in one direction as shown in Fig 8. The process should be repeated many times for inducing magnetization of the bar.

Fig 8

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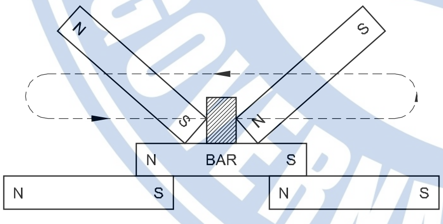
**Double touch method**: In this method the steel bar to be magnetized is placed over the two opposite pole ends of a magnet, and the rubbing magnets are placed together over the centre of the bar with a small wooden piece in between, as shown in Fig 9. They are never lifted off the surface of the steel bar, but rubbed again and again from end to end, finally ending at the centre where the rubbing was started.

Fig 9




DOUBLE-TOUCH METHOD

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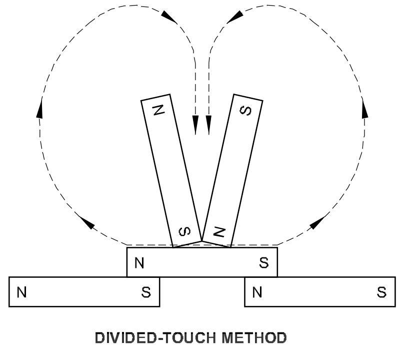
**Divided touch method:** Here the two different poles of the rubbing magnets are placed as in the previous case. They are then moved along the surface of the steel bar to the opposite ends. The rubbing magnets are then lifted off the surface of the steel bar and placed back in the centre of the bar. The whole process is repeated again and again as shown in Fig 10.

The steel bar thus magnetized becomes a permanent magnet but the degree of magnetization is very low.

Fig 10




DIVIDED-TOUCH METHOD

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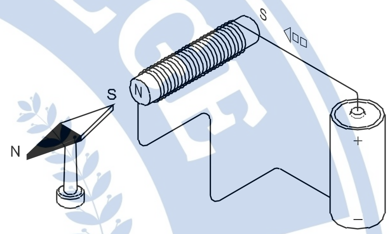
**By electric current**: The bar to be magnetized is wound with an insulated copper wire, and then a strong electric current (DC) from a battery is passed through the wire for some time. The steel bar then becomes highly magnetized. The magnet made by such an arrangement is called an electromagnet and is generally used in laboratories. (Fig 11)

Fig 11

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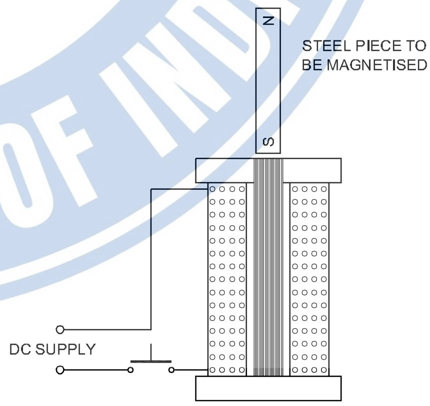
**Induction method:** This is a commercial method of making permanent magnets. In this method a pole charger is used which has a coil of many turns and an iron core inside it as shown in Fig 12. The direct current supply is fed to the coil through a push-button switch.

The steel piece to be magnetized is placed on the iron core kept inside the coil, and direct current is passed through the coil. The iron core now becomes a powerful magnet.

Fig 12

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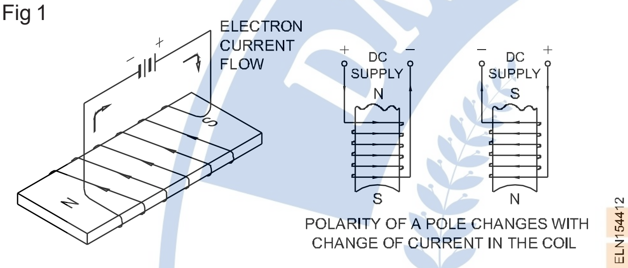
## Principles and laws of electro magnetism

**Objectives:** At the end of this lesson you shall be able to
- **explain what is meant by electromagnetism**
- **state right Hand Grip rule, Corkscrew rule and Right Hand palm rule.**

**Electromagnetism**: On passing a current through a coil of wire, a magnetic field is set up around the coil. If a soft iron bar is placed in the coil of wire carrying the current, the iron bar becomes magnetized. This process is known as `electromagnetism'. The soft iron bar remains as a magnet as long as the current is flowing in the circuit. It loses its magnetism when the current is switched off from the coil.

The polarity of this electromagnet depends upon the direction of the current flowing through it. If the direction of the current is altered, the polarity of the magnetic field will also be changed as shown in Fig 1.

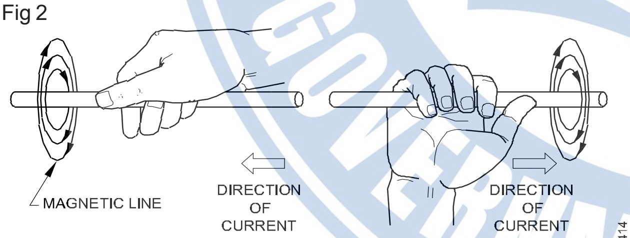
Fig 1




POLARITY OF A POLE CHANGES WITH CHANGE OF CURRENT IN THE COIL

**The right hand grip rule** can be used to determine the direction of the magnetic field. If you wrap your fingers around the wire with your thumb pointing in the direction of current flow, your fingers will point in the direction of the magnetic field as shown in Fig 2.

Fig 2



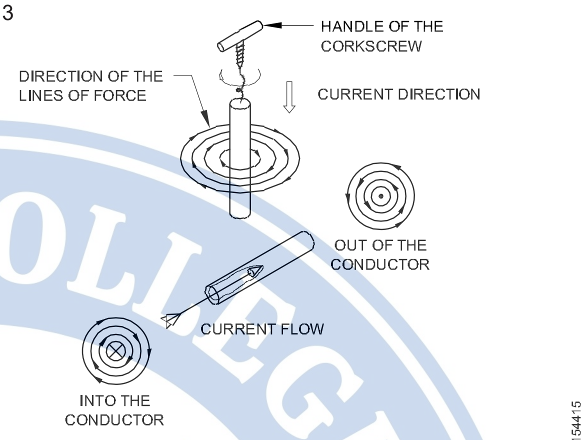

RIGHT HAND GRIP RULE SHOWING THE DIRECTION OF CURRENT AND DIRECTION OF MAGNETIC LINES

Assume a **right handed corkscrew** to be along the wire so as to advance in the direction of the current. The motion of the handle gives the direction of magnetic lines of force around the conductor (Fig 3)

The direction of the magnetic field can be found from right hand palm rule (Fig 4)

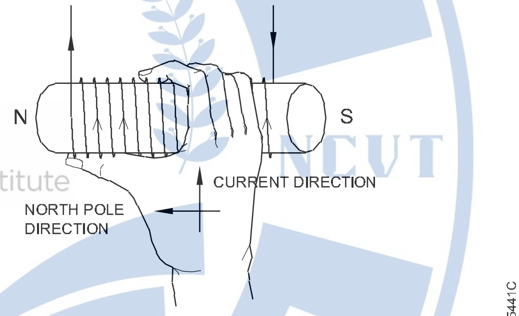
**The Right Hand Palm Rule** : Hold the right hand palm over the solenoid in such a way the fingers point in the direction of current in the solenoid conductors then the thumb indicates the direction of magnetic field (North Pole) of the solenoid.

Fig 3




CORKSCREW RULE

Fig 4




RIGHT HAND PALM RULE

**Magnetic materials for temporary magnets:** Electromagnets are generally known as temporary magnets. The magnetic strength of such magnets can be varied by varying the current passing through them. Soft iron is used in electromagnets as a magnetic core. Silicon steel is very much used in bigger magnets (steel with 2.4% silicon). Nowadays other metals like permalloy, mumetal are also used for some applications.

Permalloy is an alloy of iron and nickel which can be magnetized by a very weak magnetic field and is useful for telephones.

Mumetal is an alloy of nickel, copper, chromium and iron. It has very high permeability and resistivity. Eddy current loss is very low. It is used in instrument transformers and for screening magnetic fields.

## The magnetic circuits - self and mutually induced emfs

**Objectives:** At the end of this lesson you shall be able to
- **define the magnetic terms in a magnetic circuit (like M.M.F., reluctance, flux, field strength, flux density, permeability, relative permeability)**
- **state hysterisis.**

**MagnetoMotive Force (MMF)**: The amount of flux density set up in the core is dependent upon five factors - the current, number of turns, material of the magnetic core, length of core and the cross-sectional area of the core. More current and the more turns of wire we use, the greater will be the magnetising effect. We call this product of the turns and current the magnetomotive force (mmf), similar to the electromotive force (emf).

MMF = NI ampere-turns

where mmf - is the magnetomotive force in ampere turns

N - is the number of turns wrapped on the core

I - is the current in the coil, in amperes, A.

If one ampere current is flowing through a coil having 200 turns then the mmf is 200 ampere turns.

**Reluctance:** In the magnetic circuit there is something analogous to electrical resistance, and is called reluctance, (symbol S). The total flux is inversely proportional to the reluctance and so if we denote mmf by ampere turns. we can write

$$\phi = \frac{NI}{S}$$ Where $\phi$ is flux and reluctances $$S = \frac{\ell}{\mu_o \mu_r a}$$

where S - reluctance

l - length of the magnetic path in metres

$\mu_o$ - permeability of free space

$\mu_r$ - relative permeability

a - cross-sectional area of the magnetic path in sq.mm.

The unit of reluctance is ampere turns/Wb.

**Magnetic flux**: The magnetic flux in a magnetic circuit is equal to the total number of lines existing on the cross-section of the magnetic core at right angle to the direction of the flux. Its symbol is Ø and the SI unit is weber.

$$\phi = \frac{NI}{S}$$

$$= \frac{NIa\mu_o\mu_r}{\ell}$$

where

$\phi$ - total flux

N - number of turns

I - current in amperes

S - reluctance

$\mu_o$ - permeability of free space

$\mu_r$ - relative permeability

a - magnetic path cross-sectional area in $m^2$

$\ell$ - length of magnetic path in metres.

**Flux density** (B): The total number of lines of force per square metre of the cross- sectional area of the magnetic core is called flux density, and is represented by the symbol B. Its SI unit (in the MKS system) is tesla (weber per metre square).

$$B - \frac{\phi}{A} \text{ Weber/ } m^2$$

where $\phi$ - total flux in webers

A - area of the core in square metres

B - flux density in weber/metre square.

**Permeability**: The permeability of a magnetic material is defined as the ratio of flux created in that material to the flux created in air, provided that mmf and dimensions of the magnetic circuit remain the same. It's symbol is μ and

$$\mu = B/H$$

where B is the flux density

H is the magnetising force.

Being a ratio it has no unit and it is expressed as a mere number. The permeability of air μ air = unity. The relative permeability μr of iron and steel ranges from 50 to 2000. The permeability of a given material varies with its flux density.

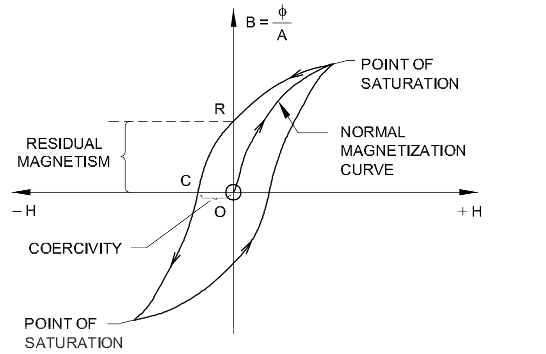
**Hysteresis**: Consider the graphical relation between B and H for a magnetic material. Since μ = B/H, the graphical relationship shows how the permeability of a material varies with the magnetizing intensity H.

Assume that the magnetic core is initially completely demagnetised. As we increase the current, $H = \frac{NI}{\ell}$ increases and there will be an increase in the flux density, B. Since the number of turns and the length of core of a coil are fixed, H is directly proportional to the current or ammeter reading. The flux density can be measured by inserting the probe of a flux meter into a small hole drilled in the core.

A plot of the values of B and H gives the normal magnetization curve, as shown in Fig 1.There is evidently a linear portion where B is relatively proportional to H. But then a condition of saturation occurs when a very large increase in H is required to significantly increase B. This point in the curve is called as **saturation point.**

If the current is now gradually reduced towards zero, H returns to zero, but B does not. The core exhibits retentiveness and retains some residual magnetism. The **retentiveness** is represented by the distance OR.

Fig 1




HYSTERESIS LOOP FOR MATERIAL USED IN AN AC CIRCUIT

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If the connections to the coil are reversed, and the current is again increased, it is found that a certain amount of H is required to bring the magnetism in the core down to zero. This is called the **coercivity** and is represented by the distance OC.

Further, any increase in the current in the opposite direction increases the magnetism in the core as before in the opposite direction, until once again saturation occurs.

## Electromagnet applications - Electromagnetic induction

**Objectives:** At the end of this lesson you shall be able to
- **compare the magnetic circuit and electric circuit**
- **state the applications of an electromagnet (Bell & Buzzer tubelight choke)**
- **state the principle and laws of electromagnetic induction**
- **explain about the counter EMF-induced reactance-time constant.**

### Comparison between magnetic and electric circuits

**Similarities (Fig 1a & 1b)**

| | Magnetic Current | Electrical Current |
|---|---|---|
| 1 | Flux = $\frac{\text{mmf}}{\text{reluctance}}$ | Current = $\frac{\text{emf}}{\text{resistance}}$ |
| 2 | M.M.F. (Ampere-turns) | E.M.F. (Volts) |
| 3 | Flux $\phi$ (Webers) | Current I (amperes) |
| 4 | Flux density B (Wb/m²) | Current density (A/m²) |
| 5 | Reluctance $S = \frac{\ell}{\mu A}$ or $S = \frac{\ell}{\mu_0 \mu_r a}$ | Resistance $R = \frac{\rho L}{A}$ |
| 6 | Permeance = (1/reluctance) | Conductance (= 1/resistance) |
| 7 | Reluctivity $\mu_o \mu_r A$ | Resistivity |
| 8 | Permeability (=1/reluctivity) | Conductivity(=1/resistivity) |

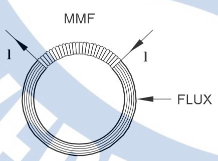



Fig 1a

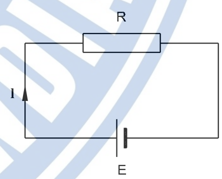



Fig 1b

**Practical applications of electromagnets**: Electromagnets are used in the manufacture of all types of electrical machines, such as motors, generators, transformers, convertors, some electrical measuring instruments, protective relays, for medical purposes (like removing iron pieces from eyes) and in many other electrical devices like bells, buzzers, circuit-breakers, relays, telegraphic circuits, lifts and other industrial uses.

a Bells

b Buzzers

c Circuit-breakers

d Relays

e Telegraphic circuits

f Lifts

g Industrial uses

**Principles and laws of electromagnetic induction**

Faraday's Laws of Electromagnetic Induction are also applicable for conductors carrying alternating current.

**Faradays' Laws of Electromagnetic Induction**

**Faraday's First Law** states that whenever the magnetic flux is linked with a circuit changes, an emf is always induced in it.

**The Second Law** states that the magnitude of the induced emf is equal to the rate of change of flux linkage.

**Dyanamically Induced EMF**

Accordingly induced emf can be produced either by moving the conductor in a stationery magnetic field or by changing magnetic flux over a stationery conductor. When conductor moves and produces emf, the emf is called as dynamically induced emf Ex. generators.

**Statically Induced EMF**

When changing flux produces emf the emf is called as statically induced emf as explained below. Ex: Transformer.

**Statically induced emf**: When the induced emf is produced in a stationery conductor due to changing magnetic field, obeying Faraday's laws of electro magnetism, the induced emf is called as statically induced emf.

There are two types of statically induced emf as stated below:-

1 **Self induced emf** produced with in the same coil

2 **mutually induced emf** produced in the neighbouring coil

**Self-induction**: The production of an electromotive force in a circuit, when the magnetic flux linked with the circuit changes as a result of the change in a current inducing in the same circuit.

According to Faraday's Laws, an emf is induced in the conductor. Similarly, when the magnetic field collapses, the flux lines cut through the conductor again, and an emf is induced once again. This is called self-induction.

**Mutual Inductance:** When two or more coils one magnetically linked together by a common magnetic flux, they are said to have the property of mutual inductance. It is the basic operating principal of the transformer, motor generaters and any other electrical component that interacts with another magnetic field. It can define mutual induction on the current flowing in one coil that induces a voltage in an adjacement coil.

**Inductance**: Inductance (L) is the electrical property of an electrical circuit or device to oppose any change in the magnitude of current flow in a circuit.

Devices which are used to provide inductance in a circuit are called inductors. Inductors are also known as chokes, coils, and reactors. Inductors are usually coils of wire.

**Factors determining inductance**: The inductance of an inductor is primarily determined by four factors.

- Type of core permeability of the core $m_r$.
- Number of turns of wire in the coil 'N'.
- Spacing between turns of wire (Spacing factor).
- Cross-sectional area (diameter of the coil core) 'a' or 'd'.

**Henry**: A conductor or coil has an inductance of one henry if a current that changes at the rate of one ampere per second produces a induced voltage (cemf) of 1 volt.

## Counter emf - inductive reactance

**Objectives:** At the end of this lesson you shall be able to
- **explain the term Counter EMF (CEMF)**
- **explain about the inductive reactance**
- **state the reasons for the difference between ohmic resistance and impedance of a coil.**

**Counter EMF and LENZ's law**: The voltage induced in a conductor or coil by its own magnetic field is called a counter electromotive force (cemf). Since the induced emf (voltage) is always opposing, or countering, the action of the source voltage, it is known as cemf. Counter electromotive force is sometimes referred to as back electromotive force (bemf).

In any type of inductive circuit there is an important relationship between the direction of the current change and the induced voltage. **Lenz's law** states that a cemf always has a polarity which opposes the force that created it.

The inductance rating of an inductor refers to its ability to generate a counter voltage to a change in current flow. One henry (1H - the SI unit) represents the inductance of a coil in which a current change of one ampere per second (1 A/s) will produce a cemf of one volt (1V).

**Inductive reactance**:The opposition offered to an AC current flow by the inductive effect is called inductive reactance. Inductive reactance is the result of the cemf of the inductor.

**Eddy currents** are caused by voltages induced into the conductors and other surrounding metal parts. They are directly proportional to the frequency of the supply. The heat produced by these currents tends to increase the effective resistance of the circuit.

**Effect of inductance present in a AC circuit:** Coils have various uses in electrical engineering such as

- excitation coils in electric machines or magnets
- relay coils in switching devices
- choke coils for limiting current etc.

# Capacitors - types - functions, grouping and uses

**Objectives:** At the end of this lesson you shall be able to
- **describe capacitor its construction and charging**
- **explain capacitance and the factors determining**
- **state the different types and application of capacitors.**

Scan the QR Code to view the video for this exercise

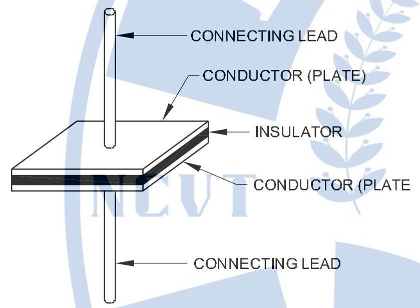
## Capacitor

Capacitor is a passive two terminal electrical/electronic component that stores potential energy in the form of electrostatic field

The effect of capacitor is called as capacitance. It consists of two conducting plates separated by an insulating material called as dielectric. In simple, capacitor is a device designed to store electric charge.

**Construction:** A capacitor is an electrical device consisting of two parallel conductive plates, separated by an insulating material called the dielectric. Connecting leads are attached to the parallel plates. (Fig 1)

Fig 1




SIMPLE CAPACITOR. THE PLATES OF A CAPACITOR ARE ALWAYS INSULATED FROM EACH OTHER

**Function:** In a capacitor the electric charge is stored in the form of an electrostatic field between the two conductors or plates, due to the ability of dielectric material to distort and store energy while it is charged and keep that charge for a long period or till it is discharged through a resistor or wire. The unit of charge is coulomb and it is denoted by the letter `C'.

**Capacitance :** The ability or capacity to store energy in the form of electric charge is called capacitance. The symbol used to represent capacitance is C.

**Unit of capacitance:** The base unit of capacitance is the **Farad.** The abbreviation for **Farad** is **F**. One farad is that amount of capacitance which stores 1 coulomb of charge when the capacitor is charged to 1 V. In other words, a Farad is a coulomb per volt (C/V).

## Farad

A farad is the unit of capacitance (C), and a coulomb is the unit of charge(Q), and a volt is the unit of voltage(V). Therefore, capacitance can be mathematically expressed as $C = \frac{Q}{V}$

## Capacitive reactance

Similar to resistors and inductors, a capacitor also offers opposition to the flow of AC current. This opposition offered to the flow of current by a capacitor is called **capacitive reactance** abbreviated as $X_C$.

Capacitive reactance, $X_C$ can be mathematically represented as;

$$X_c = \frac{1}{2\pi fc}$$

**Factors determining capacitance:** The capacitance of a capacitor is determined by four factors.

- Area of the plates ($C \alpha A$)
- Distance between the plates ($C \alpha d$)
- Type of dielectric material
- Temperature
- Resistance of the plates

**Types of capacitors:** Capacitors are manufactured in a wide variety of types, sizes and values. Some are fixed in value, in others the value is variable.

## Fixed capacitors

**Ceramic capacitors:** Ceramic dielectrics provide very high dielectric constants (1200 is typical). As a result, comparatively high capacitance values can be achieved in a small physical size.

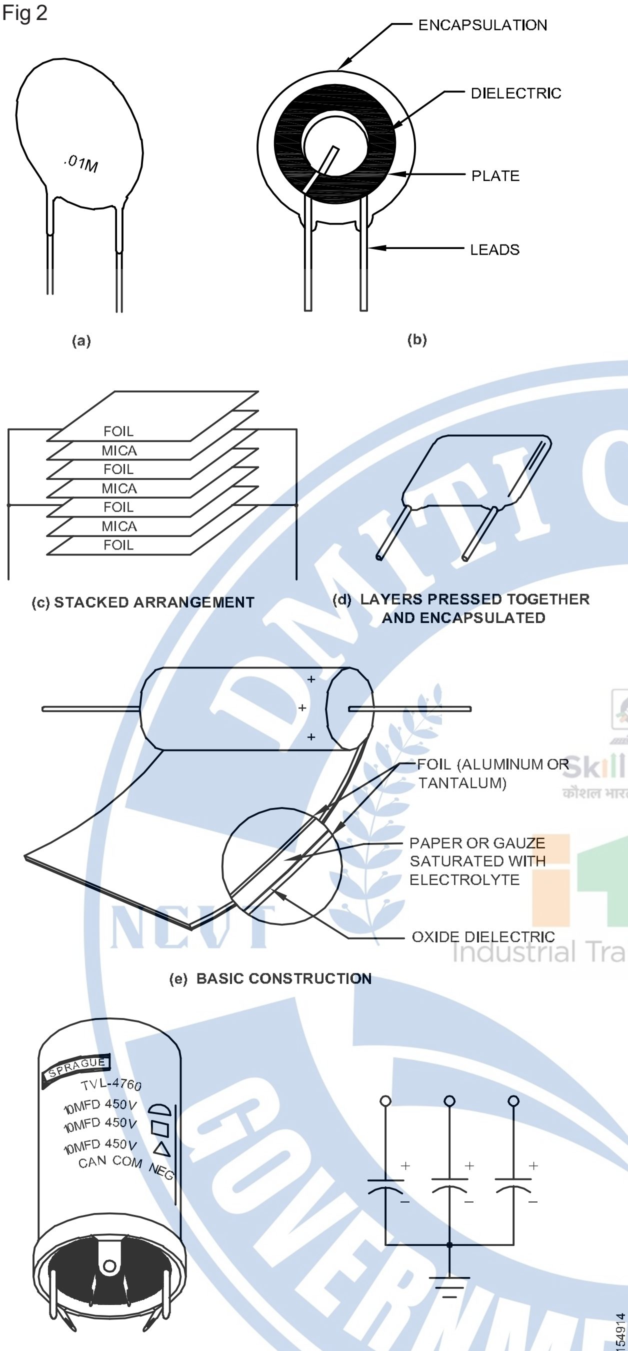
Ceramic capacitors are illustrated in Figs 2a) and (b). These discs are made by using ceramic as an insulator with a silver deposit on each side of the plates. These are used for small values of capacitance and an ordinary TV set might contain several dozens in its circuitry.

Ceramic capacitors are typically available in capacitance values ranging from 1µF to 2.2µ F with voltage ratings up to 6 KV.

**Mica capacitors:** There are two types of mica capacitors, stacked foil as shown in Fig 2(c). It consists of alternate layers of metal foil and thin sheets of mica. The metal foil forms the plate, with alternate foil sheets connected together to increase the plate area, thus increasing the capacitance.

The mica foil-stack is encapsulated in an insulating material such as bakelite, as shown in Fig 2d of the figure.

Fig 2




(c) STACKED ARRANGEMENT

(d) LAYERS PRESSED TOGETHER AND ENCAPSULATED

(e) BASIC CONSTRUCTION

(f) ELECTROLYTIC CAPACITOR AND SYMBOL

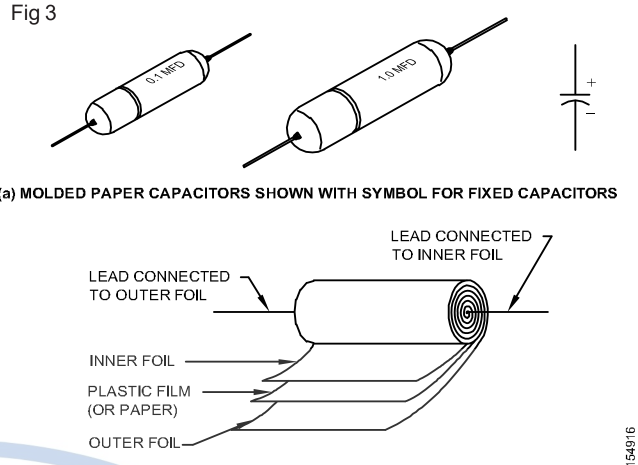
Mica capacitors are available with capacitance values ranging from 1 pF to 0.1 pF and voltgage ratings from 100 to 2500 V DC.

**Electrolytic capacitors:** Electrolytic capacitors are polarised so that one plate is positive and the other negative.

These capacitors are used for high capacitance values up to over 200,000μ F, but they have relatively low breakdown voltages (350 V is a typical maximum) and high amounts of leakage.

Electrolytic capacitors are available in two types: aluminium and tantalum. The basic construction of an electrolytic capacitor is shown in Figs 2(e) and (f).

Fig 3




(a) MOLDED PAPER CAPACITORS SHOWN WITH SYMBOL FOR FIXED CAPACITORS

(b) BASIC CONSTRUCTION OF PAPER CAPACITOR

**Paper/plastic capacitors:** There are several types of plastic-film capacitors and the older paper dielectric capacitors. Polycarbonate, parylene, polyester, polystyrene, polypropylene, mylar, and paper are some of the more common dielectric materials used. Some of these types have capacitance values up to 100μF.

Fig 3a show a common basic construction used in many plastic-film and paper capacitors. Fig 3b shows a construction view for one type of plastic-film capacitor.

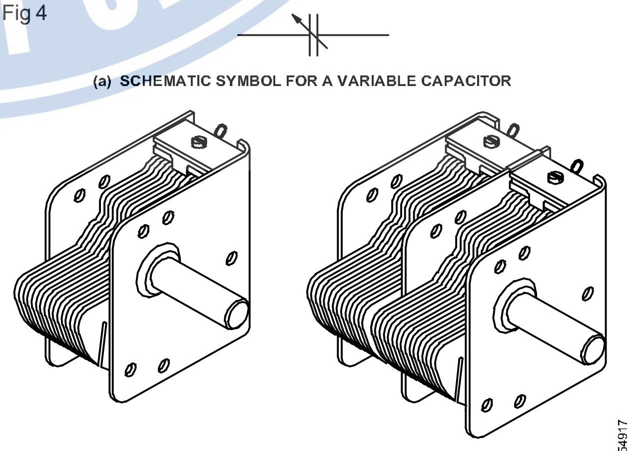
## Variable capacitors

Variable capacitors are used in a circuit when there is a need to adjust the capacitance value either manually or automatically. For example, in radio or TV tuners. The major types of variable or adjustable capacitors are now discussed.

**Air capacitor:** Variable capacitors with air dielectrics, such as the one shown in Fig 4(b), are sometimes used as tuning capacitors in applications requiring frequency selection. This type of capapcitor is constructed with several plates that mesh together. One set of plates can be moved relative to the other, thus changing the effective plate area and the capacitance. The movable plates are linked together mechanically so that they move when a shaft is rotated.

The schematic symbol for a variable capacitor is shown in Fig 4(a).

Fig 4




(a) SCHEMATIC SYMBOL FOR A VARIABLE CAPACITOR

(b) SINGLE AND TWO-GANG VARIABLE CAPACITORS WITH AIR DIELECTRIC

**Application of capacitors with type and ratings - Chart I**

| Type | Capacitance | Voltage WVDC (Working voltage DC) | Applications |
|---|---|---|---|
| Disc and tube ceramics | 1pF - 1µF | 50-500 | General, VHF. |
| Paper | 0.001-1µF | 200-1600 | Motors, power supplies. |
| Polyester | 0.001-1µF | 100-600 | Enetertainment- electronics. |
| Electrolytic-aluminum | 1-500,000µF | 5-500 | Power supplies, filters. |
| Electrolytic-tantalum | 0.1-1000µF | 3-125 | Small space requirement, high reliability, low leakage. |
| Mica | 330pF-0.05µF | 50-100 | High frequency. |
| Silver-mica | 5-820pF | 50-500 | High frequency. |
| Variable-ceramic | 1-5 to 16-100pF | 200 | Radio, TV, communications. |
| Air | 10-365pF | 50 | Broadcast receivers. |

## Grouping of capacitors

**Objectives:** At the end of this lesson you shall be able to
- **state the necessity of grouping capacitors and method of connection**
- **state the conditions for connecting capacitors in parallel and in series**
- **explain the values of capacitance and voltage in parallel and series combination**

**Necessity of grouping of capacitors:** In certain instances, we may not be able to get a required value of capacitance and a required voltage rating. In such instances, to get the required capacitances from the available capacitors and to give only the safe voltage across capacitor, the capacitors have to be grouped in different fashions. Such grouping of capacitors is very essential.

**Methods of grouping:** There are two methods of grouping.

- Parallel grouping
- Series grouping

**Parallel grouping**

**Conditions for parallel grouping**

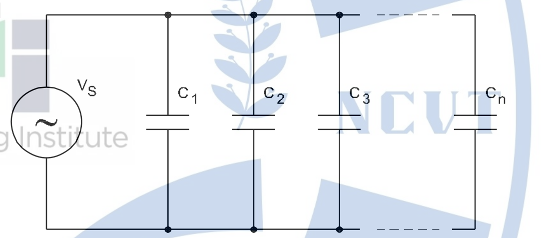
- Voltage rating of capacitors should be higher than the supply voltage Vs.
- Polarity should be maintained in the case of polarised capacitors (electrolytic capacitors).

**Necessity of parallel grouping:** Capacitors are connected in parallel to achieve a higher capacitance than what is available in one unit.

**Connection of parallel grouping:** Parallel grouping of capacitors is shown in Fig 1 and is analogous to the connection of resistance in parallel or cells in parallel.

**Total capacitance:** When capacitors are connected in parallel, the total capacitance is the sum of the individual capacitances, because the effective plate area increases. The calculation of total parallel capacitance is analogous to the calculation of total resistance of a series circuit.

Fig 1




CAPACITORS IN PARALLEL

**General formula for parallel capacitance:** The total capacitance of parallel capacitors is found by adding the individual capacitances.

$C_T = C_1 + C_2 + C_3 + ............ + C_n$

where $C_T$ is the total capacitance,

$C_1, C_2, C_3$ etc. are the parallel capacitors.

The voltage applied to a parallel group must not exceed the lowest breakdown voltage for all the capacitors in the parallel group.

**Example**: Suppose three capacitors are connected in parallel, where two have a breakdown voltage of 250 V and one has a breakdown voltage of 200 V, then the maximum voltage that can be applied to the parallel group without damaging any capacitor is 200 volts.

The voltage across each capacitor will be equal to the applied voltage.

**Charge stored in parallel grouping:** Since the voltage across parallel-grouped capacitors is the same, the larger capacitor stores more charge. If the capacitors are equal in value, they store an equal amount of charge. The charge stored by the capacitors together equals the total charge that was delivered from the source.

$Q_T = Q_1 + Q_2 + Q_3 + ..... + Q_n$

where $Q_T$ is the total charge

$Q_1, Q_2, Q_3$.....etc. are the individual charges of the capacitors in parallel.

Using the equation Q = CV,

the total charge $Q_T = C_T V_S$

where $V_S$ is the supply voltage.

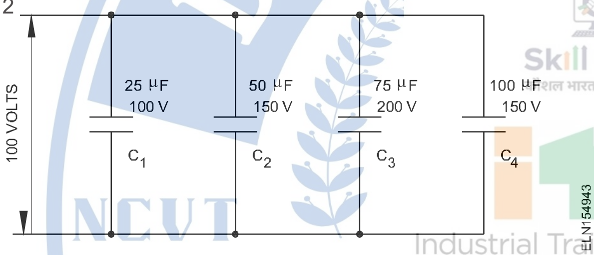
Again $C_T V_S = C_1 V_S + C_2 V_S + C_3 V_S$

Because all the $V_S$ terms are equal, they can be cancelled.

Therefore, $C_T = C_1 + C_2 + C_3$

**Question 1:** Calculate the total capacitance, individual charges and the total charge of the circuit given in Fig 2.

Fig 2




**Solution**

Total capacitance = $C_T$

$C_T = C_1 + C_2 + C_3 + C_4$

$C_T$ = 250 micro farads.

Individual charge = Q = CV

$Q_1 = C_1 V$

$= 25 \times 100 \times 10^{-6}$

$= 2500 \times 10^{-6}$

$= 2.5 \times 10^{-3}$ coulombs.

$Q_2 = C_2 V$

$= 50 \times 100 \times 10^{-6}$

$= 5000 \times 10^{-6}$

$= 5 \times 10^{-3}$ coulombs.

$Q3 = C_3 V$

$= 75 \times 100 \times 10^{-6}$

$= 7500 \times 10^{-6}$

$= 7.5 \times 10^{-3}$ coulombs.

$Q_4 = C_4 V$

$= 100 \times 100 \times 10^{-6}$

$= 10000 \times 10^{-6}$

$= 10 \times 10^{-3}$ coulombs.

Total charge $= Q_t = Q_1 + Q_2 + Q_3 + Q_4$

$= (2.5 \times 10^{-3}) + (5 \times 10^{-3}) + (7.5 \times 10^{-3}) + (10 \times 10^{-3})$

$= (2.5+5+7.5+10) \times 10^{-3}$

$= 25 \times 10^{-3}$ coulombs.

or $Q_T = C_T V$

$= 250 \times 10^{-6} \times 100$

$= 25 \times 10^{-3}$ coulombs.

**Series grouping**

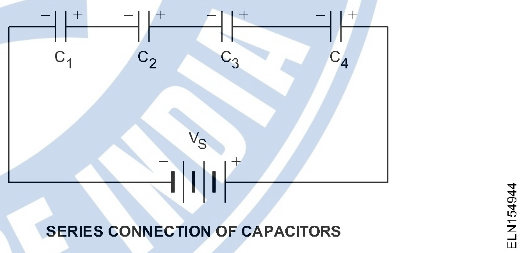
**Necessity of grouping of capacitors in series:** The necessity of grouping capacitors in series is to reduce the total capacitance in the circuit. Another reason is that two or more capacitors in series can withstand a higher potential difference than an individual capacitor.

**Conditions for series grouping**

- If different voltage rating capacitors have to be connected in series, take care to see that the voltage drop across each capacitor is less than its voltage rating.
- Polarity should be maintained in the case of polarised capacitors.

**Connection in series grouping:** Series grouping of capacitors, as shown in Fig 3 is analogous to the connection of resistances in series or cells in series.

Fig 3




**Total capacitance:** When capacitors are connected in series, the total capacitance is less than the smallest capacitance value, because

- the effective plate separation thickness increases
- and the effective plate area is limited by the smaller plate.

The calcualtion of total series capacitance is analogous to the calculation of total resistance of parallel resistors.

**General formula for series capacitance:** The total capacitance of the series capacitors can be calculated by using the formula

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ....... + \frac{1}{C_n}}$$

or

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ....... + \frac{1}{C_n}$$

If there are two capacitors in series

$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

If there are three capacitors in series

$$C_T = \frac{C_1 C_2 C_3}{(C_1 C_2) + (C_2 C_3) + (C_3 C_1)}$$

If there are `n' equal capacitors in series

$$C_T = \frac{C}{n}$$

**Maximum voltage across each capacitor:** In series grouping, the division of the applied voltage among the capacitors depends on the individual capacitance value according to the formula

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

The largest value capacitor will have the smallest voltage because of the reciprocal relationship.

Likewise, the smallest capacitance value will have the largest voltage.

The voltage across any individual capacitor in a series connection can be determined using the following formula.

$$V_X = \frac{C_T}{C_X} \times V_S$$

where $V_x$ - individual voltage of each capacitor

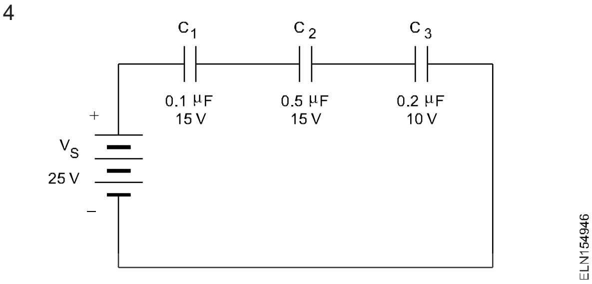
$C_x$ - individual capacitance of each capacitor

$V_s$ - supply voltage.

The potential difference does not divide equally if the capacitances are unequal. If the capacitances are unequal you must be careful not to exceed the breakdown voltage of any capacitor.

**Question 2**: Find the voltage across each capacitor in Fig 4.

Fig 4




Total capacitance: $C_T$

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\frac{1}{C_T} = \frac{1}{0.1} + \frac{1}{0.5} + \frac{1}{0.2} \text{ macro farad}$$

$$\frac{1}{C_T} = \frac{10}{1} + \frac{2}{1} + \frac{5}{1}$$

$$\frac{1}{C_T} = \frac{17}{1} \text{ and CT = 0.0588 micro farad}$$

$$V_1 = \frac{C_T}{C_1} \times V_S$$

$V_1 = 14.71\ V_S$

$$V_2 = \frac{C_T}{C_2} \times V_S$$

$$V_2 = \frac{0.0588}{0.5} \times 25$$

$V_2 = 2.94$ volts

$$V_3 = \frac{C_T}{C_3} \times V_S$$

$$V_3 = \frac{0.0588}{0.2} \times 25$$

$V_3 = 7.35$ volts