CHAPTER-4

TOPICS TO BE COVERED

4.1 **Electrical Properties:**

Volume resistivity, surface resistance, dielectric loss, dielectric strength (breakdown voltage) dielectric constant

4.2 **Physical Properties:**

Hygroscopicity, tensile and compressive strength, abrasive resistance, brittleness

4.3 **Thermal Properties:**

Heat resistance, classification according to permissible temperature rise. Effect of overloading on the life of an electrical appliance, increase in rating with the use of insulating materials having higher thermal stability, Thermal conductivity, Electro-thermal breakdown in solid dielectrics

4.4 **Chemical Properties:**

Solubility, chemical resistance, weatherability

4.5 **Mechanical properties**, mechanical structure and tensile structure

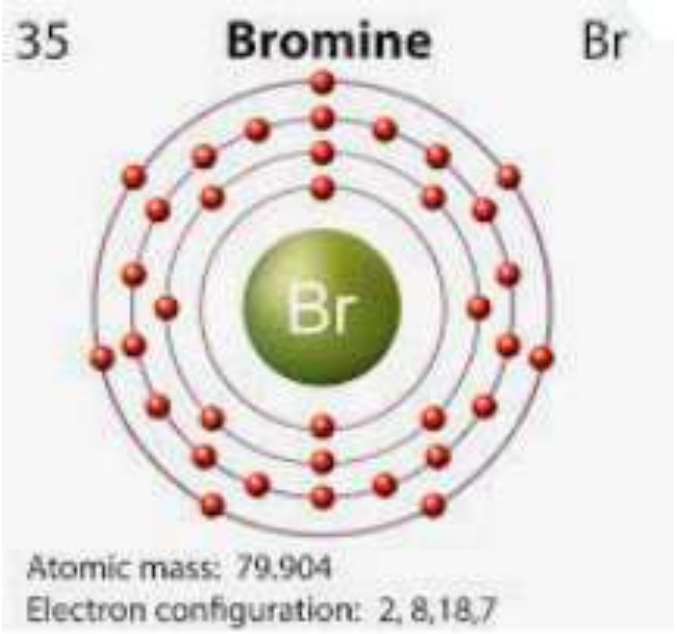
Insulating material

- Do not allow the passage of electric current
- Offers very high resistance to electric current
- The resistivity of these materials is very high,
- its values lies between 10^12 -10^18 Ω-m.
- Example :Rubber, wood, glass ceramic, mica etc
- Most insulators are compounds of several elements.
- Dielectric materials-which can store electrical energy. Ex-air, mica, ceramic

Insulating materials

- Electrons are firmly held to their atom
- Electron can’t be detached from outermost shell
- It is not easy to pass the electric current through them
- Ex- bromine, selenium,Arsenic

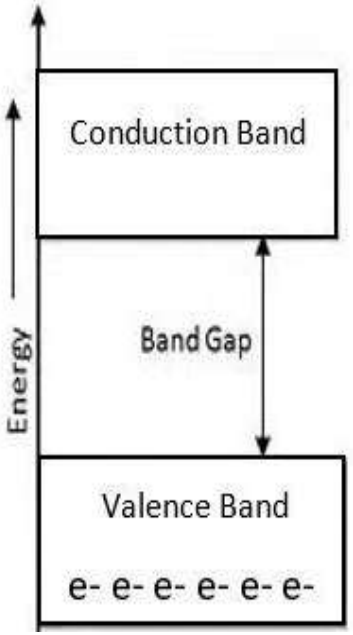
Atomic structure of Insulators



Insulators

- The energy gap in the insulator is very high up to 7eV.
- The material cannot conduct because the movement of the electrons from the valence band to the conduction band

  is not possible.
- Glass and wood



Why Insulation is required??

- In domestic wiring, underground transmission lines, insulating materials covering the conducting wires (carrying current) serve as protector against the electrical shock
- Also prevents the leakage of current in Overhead transmission lines.

FACTORS AFFECTING SELECTION OF AN INSULATING MATERIAL

1. Operating condition : Selection should be made on the basis of operating temperature, pressure and magnitude of voltage and current.
2. Easy in shaping : It can be fabricated to desired shape and size.
3. Availability of material : easily available.
4. Cost : Cost is also an important factor.

Characteristics of Good insulating material

- High insulation resistance
- High dielectric strength
- High mechanical strength
- High thermal conductivity
- Low permittivity
- Low dissipation factor
- Least thermal expansion

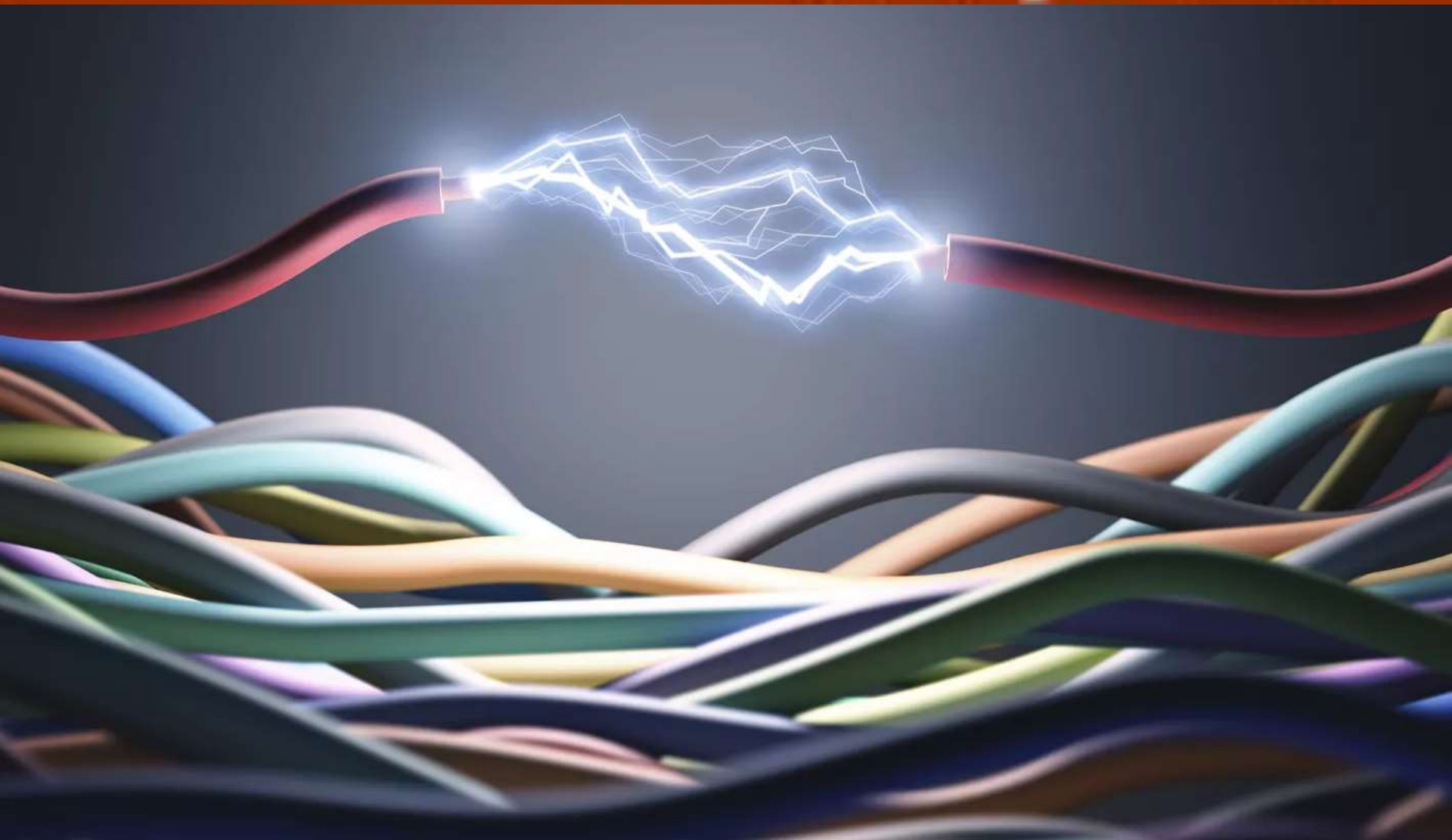
Classification of Insulating materials

Gaseous Insulating Materials	Liquid insulating Material	Solid insulating Material
Air, vacuum, hydrogen, nitogen, Co2, SF6	Mineral oils, natural oils, vegetable oils, synthetic oils, varnish, enamel,silicon liquids etc	Rubber, PVC, Dry wood, paper, impregnated paper, mica, cotton, silk, glass, asbestos, porcelain, bakelite

Properties of Insulating material

1. Electrical properties
2. Physical properties
3. Thermal Properties
4. Chemical properties
5. Mechanical properties

Electrical Properties



Electrical properties

1. INSULATION RESISTANCE OR RESISTIVITY
2. DIELECTRIC STRENGTH (BREAKDOWN VOLTAGE)
3. DIELECTRIC CONSTANT
4. DIELECTRIC LOSS

1. INSULATION RESISTANCE

- It is the property of a material by virtue of which a material resists flow of electric current
- It should be as high as possible
- It is of two types –

1. Volume Insulation resistance
2. Surface Insulation resistance

1. INSULATION RESISTANCE

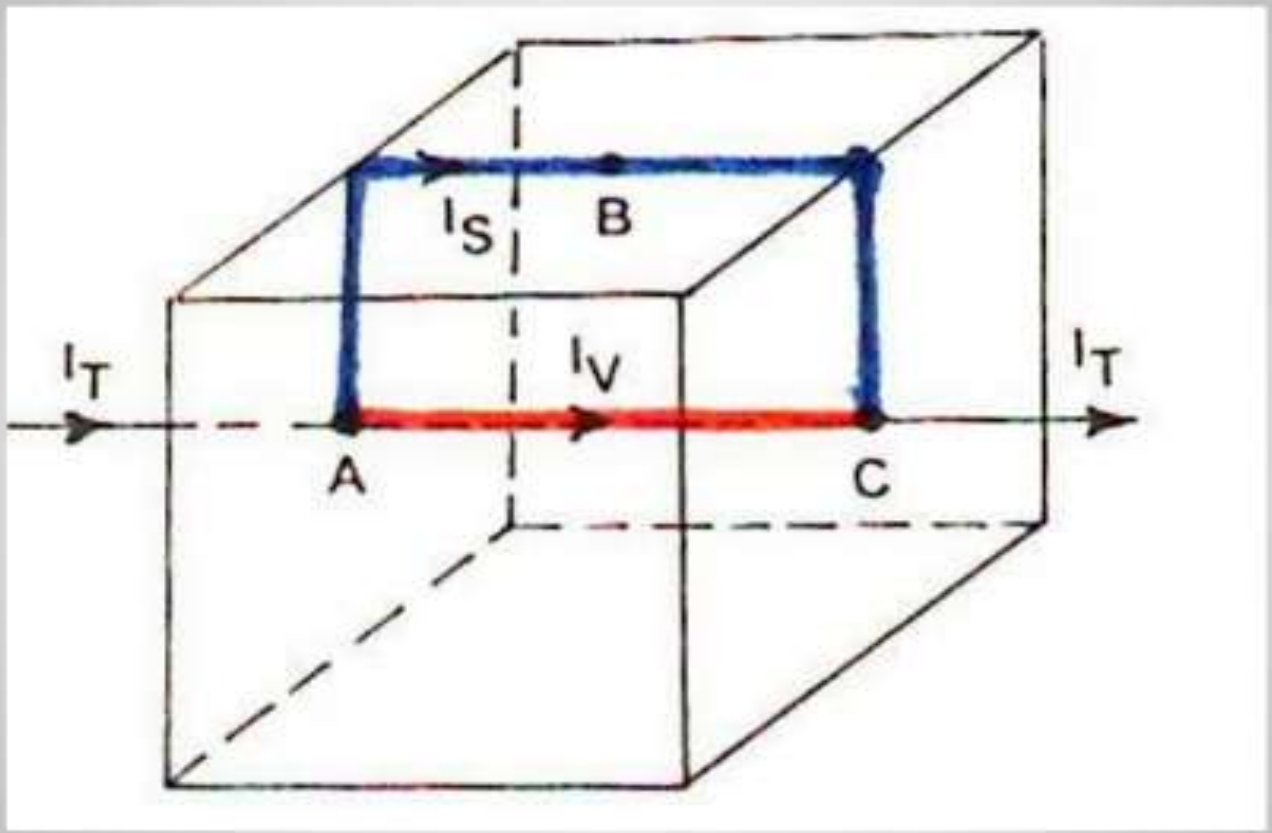
- Ideally it should be infinite
- Practically there is always leakage current which flows through the material when voltage is applied to insulator.
- It is of two types –

1. Volume Insulation resistance
2. Surface Insulation resistance

(a) Volume insulation resistance

- It is the resistance offered to the leakage current Iv flowing through the insulating material.
- Volume resistivity is the resistance between opposite faces of a cube of unit dimensions.
- Resistivity is affected by the working temperature.
- Unit is M Ω-cm
- In pic , it is from A to C

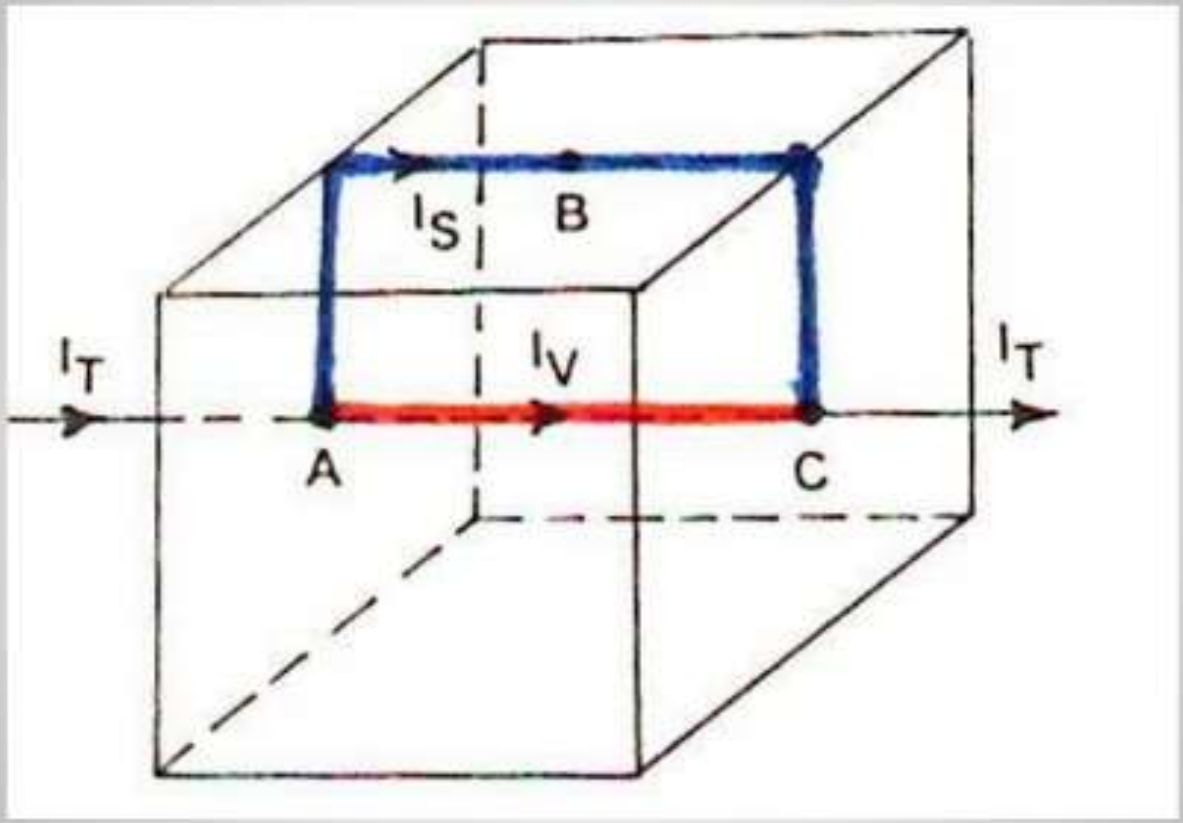
VOLUME RESISTANCE



(b) Surface Resistance

- It is the resistance offered to the leakage current Is which flows over the surface of insulating material.
- Surface resistivity is the resistance offered between opposite sides of a square of unit dimensions.
- It depends on humidity.
- Unit is M Ω-cm^2
- In pic , it is from A to B then from B to C

SURFACE RESISTANCE



Factors affecting Insulation resistance

1. Temperature

   It decreases with increase in temp

2. Moisture

   It decreases if material absorb moisture, main reason for insulation breakdown, non hygroscopic

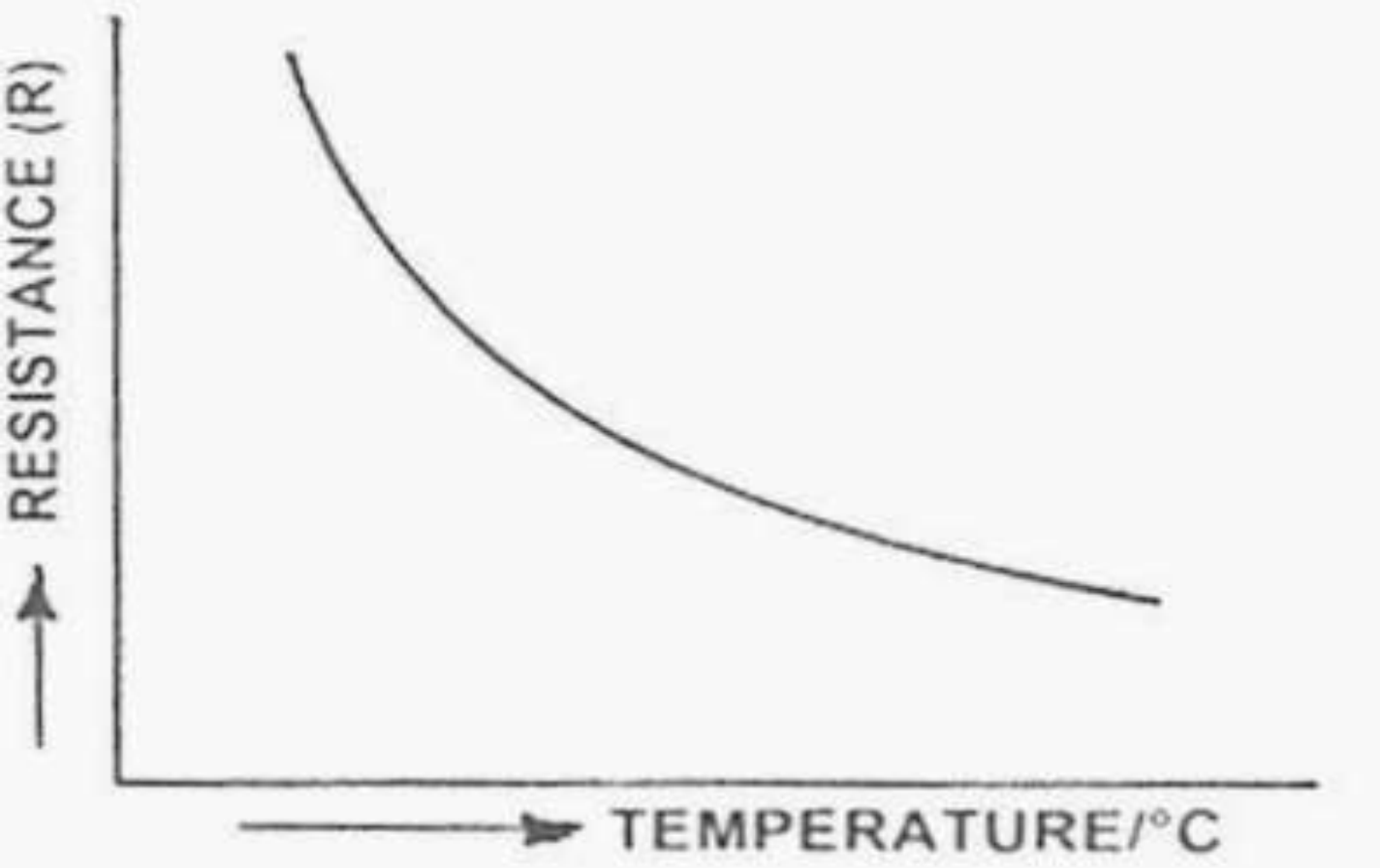
3. Voltage

   It decreases by the voltage applied and direction in which voltage is applied

4. Ageing

   It decreases and decides the life of apparatus

Effect of Temp on R



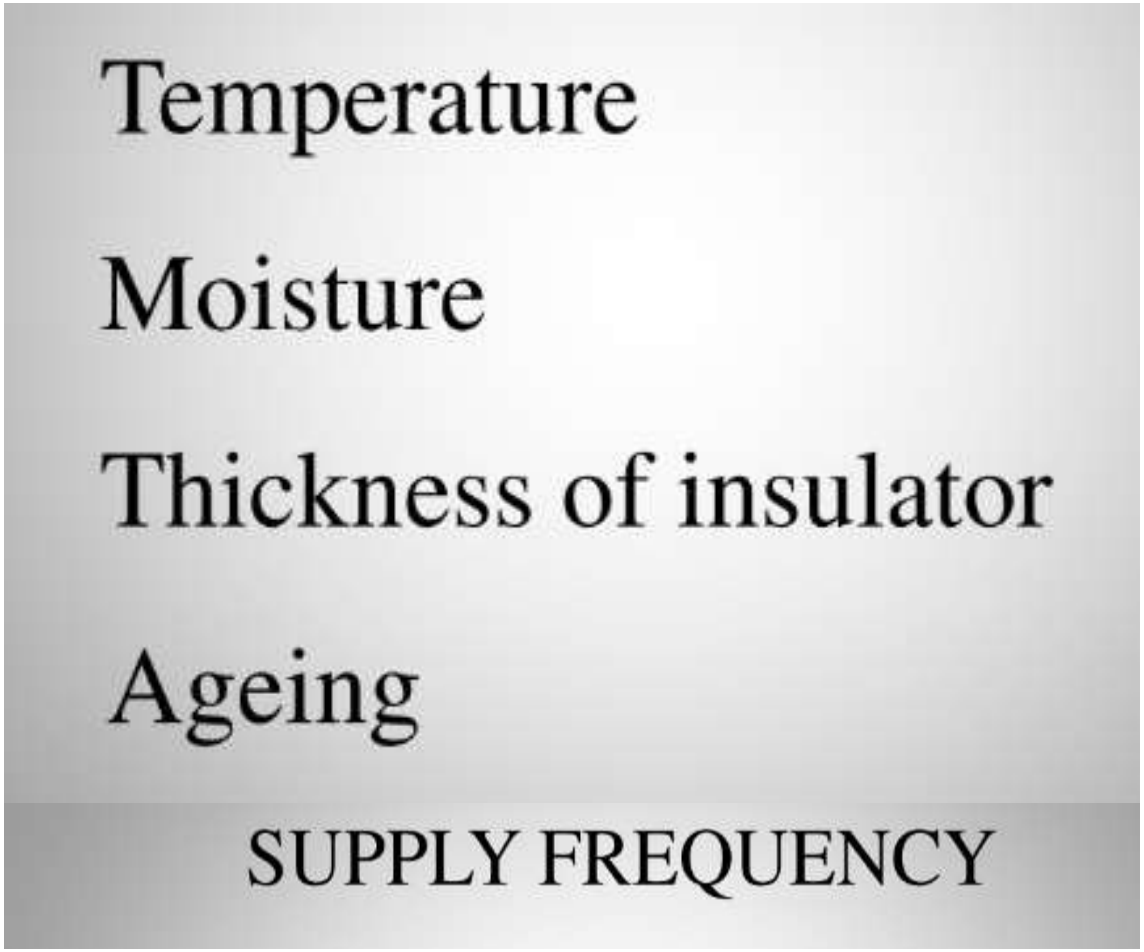
2. DIELECTRIC STRENGTH

- It is the minimum voltage which when applied to an insulating material will result in the destruction of its insulating properties.
- Electrical appliances/apparatus is designed to operate within a defined range of voltage.
- If the operating voltage is increased gradually at some value of voltage, the breakdown of the insulating materials will occur.
- The property which attributes to such type of break down is called the dielectric strength.

e.g. dielectric strength of mica is 80kV/mm.

- If the V>80kV is applied across 1mm thick sheet of mica, mica will lose its insulating properties and current will start passing through mica sheet.
- In other words dielectric strength of an insulating material is the maximum potential gradient that the material can withstand without rupture

Factors affecting Dielectric strength



Factors affecting Dielectric strength

1. Temperature

   It decreases with increase in temp

2. Moisture

   It decreases if material absorb moisture, main reason for insulation breakdown, non hygroscopic

3. Thickness of insulators

   It increases with the increase in the thickness of insulator

4. Ageing

   It decreases with ageing and decides the life of apparatus

5. Supply frequency

   It increases with the increase in the supply frequency of the applied voltage.

Dielectric strength of some commonly used Insulators

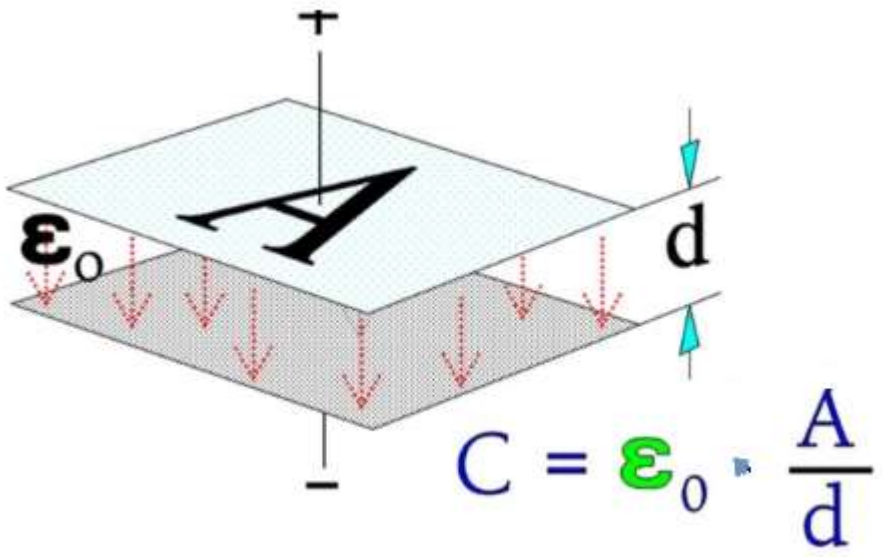
S.No	Insulating material	Dielectric strength
1	Natural Rubber	24 KV/mm
2	Synthetic rubber	4-44 KV/mm
3	Asbestos	3.5-4 KV/mm
4	Mica	80 KV/mm
5	Porcelain	1.5-16 KV/mm

3. DIELECTRIC CONSTANT (Permittivity)

- The ratio of capacity of storing the electric charge by an insulating material to that of air is called dielectric constant of the material.

Every insulating material has the property of storing electric charge 'Q' , when a voltage V is applied across it. The charge is proportional to the voltage applied i.e.

$Q \propto V$ and we get $Q=CV$



- Where C is the capacitance of the capacitor which was formed by placing the material between the conductors across which voltage is applied.

The capacitance of the capacitor will change if the air between the plates of a capacitor is replaced by an insulating material acting as a dielectric.

The property of insulating materials that causes the difference in the value of capacitance, physical dimensions remaining same, is called the dielectric constant or permittivity

4. DIELECTRIC LOSS

- When an alternating voltage is applied across the insulating material, Electrical energy is absorbed by it and dissipated in the form of heat is called dielectric loss.

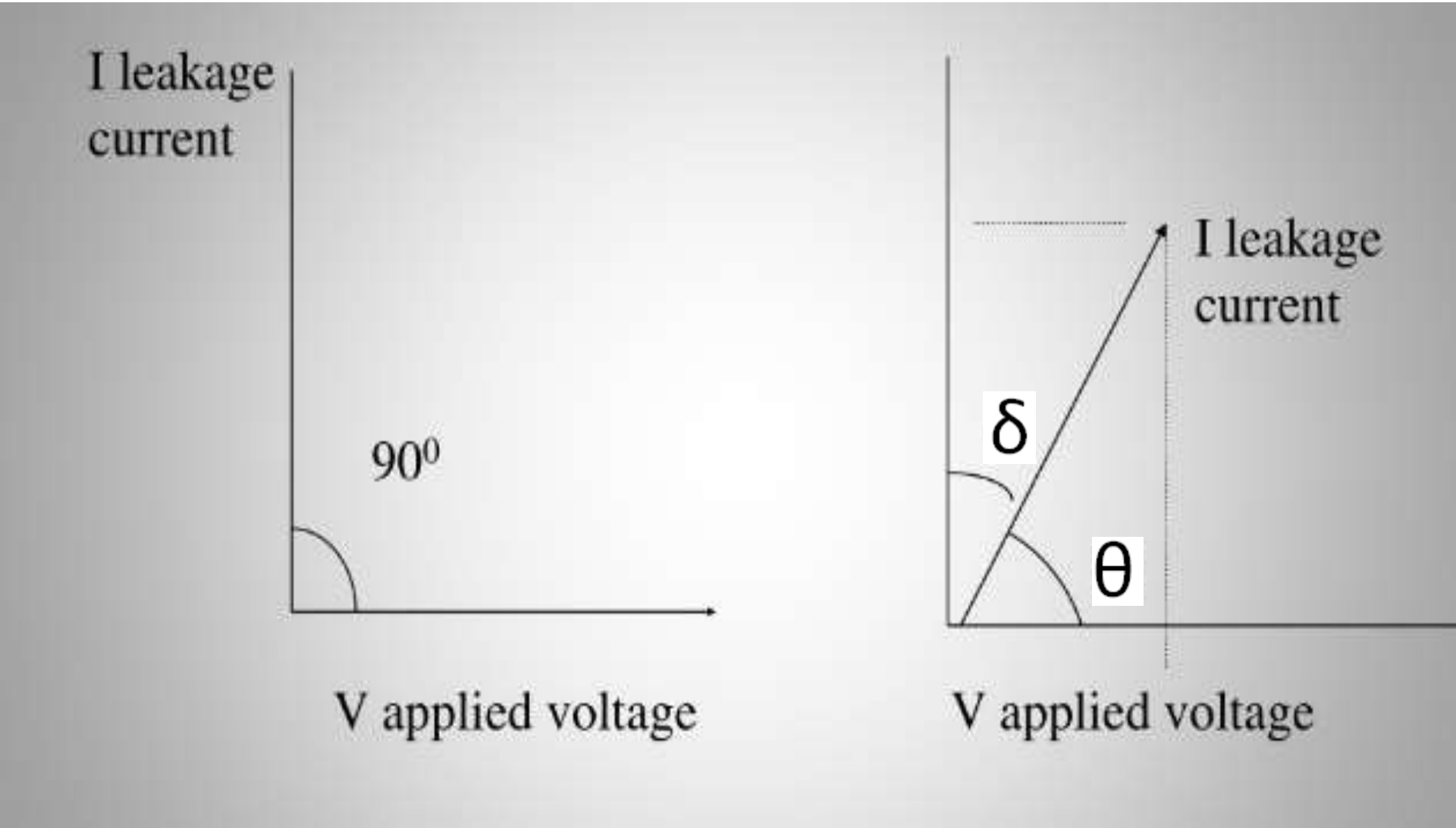
In Ideal Insulator (no dielectric loss)

- When a perfect insulation is subjected to alternating voltage, it is like applying like alternating voltage to a perfect capacitor. In such a case there is no consumption of power.
- Charging current lead the applied voltage by 90 degree exactly.
- No power loss in the insulation.
- Only vacuum and purified gases approach this perfection.

In Practical Insulator

- When an insulator is subjected to alternating voltage, some amount of dissipation of energy
- This dissipation of energy is called dielectric loss .
- The leakage current does not lead applied voltage by exactly 90 degree.
- The phase angle is always less than 90 degree.

The complementary angle δ=90- θ is called dielectric loss angle.



FACTORS AFFECTING DIELECTRIC LOSS

- Temperature.
- Moisture.
- Voltage applied.

TEMPERATURE

With rise in temperature the dielectric loss also increases.

MOISTURE

Presence of moisture in the insulator increases the dielectric loss in the insulator.

APPLIED VOLTAGE

Dielectric loss rises with rise in the applied voltage. This loss is one factor in limiting the operating voltage of underground cables generally to 100 kV.

PHYSICAL PROPERTIES

1. HYGROSCOPICITY

- The property of insulating material of absorbing moisture from the surroundings and let water to pass through it.
- Undesirable
- The insulating material should be non-hygroscopic.
- The absorption of moisture affect the electrical properties of insulating material
- Plastic and polythene are examples

2. Mechanical strength

- The insulating material should have high mechanical strength to bear the mechanical stresses and strains during operation.
- Tensile & Compressive strength must be good so that the mechanical breakdown or insulation failure will not occur when put in use.

3. Abrasive Resistance

- Another name surface Hardness
- It should resist surface scratching and abrasion (wear & tear)
- This ability helps to keep the material's original structure and look.

4. Brittleness

- The insulating material should not be brittle
- It must be able to bear the stresses due to dynamic forces in addition to static stress.
- Otherwise insulators may fracture easily due to stresses.

Thermal Properties

1. HEAT RESISTANCE

- This is general property of insulating material to withstand temperature variation within desirable limits, without damaging its other important properties.
- If an insulator has favorable properties at some temperature but, not able to retain at some higher temp, it is not a good insulator.
- Such insulators having high heat resistance are desirable

Permissible Temperature rise

A thumb rule

- Life of insulator is halved for 10 degree centigrade rise above the recommended operating temperature for a given apparatus.

CLASSIFICATION ON THE BASIS OPERATING TEMPERATURE

CLASS ‘Y’ INSULATION - 90 ºC

CLASS ‘A’ INSULATION - 105 ºC

CLASS ‘E’ INSULATION - 120 ºC

CLASS ‘B’ INSULATION - 130 ºC

CLASS ‘F’ INSULATION - 155 ºC

CLASS ‘H’ INSULATION - 180 ºC

CLASS ‘C’ INSULATION - >180 ºC

Class	Insulating materials included	Assigned limiting insulating temperature
Y	Cotton, silk, paper, cellulose, wood, etc., neither impregnated nor immersed in oil. Materals of Y class are unsuitable for electrical machines and apparatus as they deteriorate rapidly and are extremely hygroscopic.	90°C
A	Materials of class Y impregnated with natural resin, cellulose esters, insulating oils etc. Also included in this list are laminated wool, varnished paper.	105°C
E	Synthetic resin enamels, cotton and paper laminates with formaldehyde bonding etc.	120°C
B	Mica, glass fibres, asbestos with suitable bonding substance, built up mica, glass fibre and asbestos laminates.	130°C
F	Materials of class B with bonding materials of higher thermal stability.	155°C
H	Glass fibre and asbestos materials, and built up mica, with silicon resins.	180°C
C	Mica, ceramics, glass, quartz without binders or with silicon resins of higher thermal stablity.	above 180°C

Effect of overloading on the life of an electrical appliance

Electrical Overloading

- When current higher than its rated value is made to flow →large **I^2R (heat loss)** →temp rise above normal value → thermal expansion → if cooling then thermal contraction →thermal & Mechanical stresses → bring brittleness and ageing → finally breakdown or insulation failure → damage the equipment

Increase in rating with the use of insulating material

- Having higher thermal stability

  it increases the working temperature, so apparatus can be electrically overloaded to work upto a higher temperature.
- It increases life of apparatus

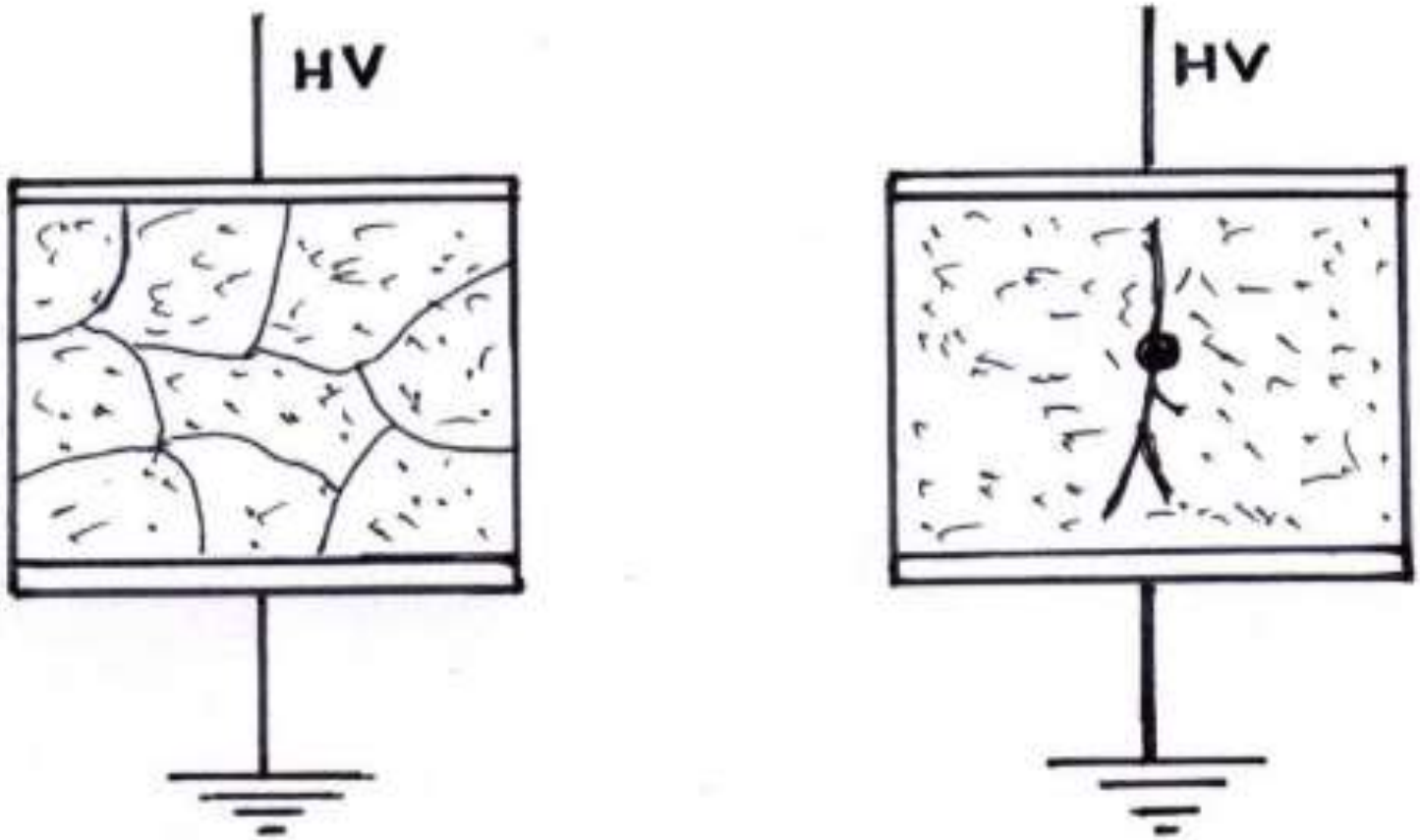
THERMAL CONDUCTIVITY

- It is the property of insulating material which will not allow temperature rise because of effective heat transfer to the atmosphere
- It plays significant role in high voltage apparatus where thickness of insulation is more.
- Heat generated due to **I^2R (heat loss) and dielectric loss is dissipated** through the insulator itself.

Electro -Thermal breakdown in Solid dielectrics

- When electric field is applied to solid dielectric, heat is produced due to dielectric losses, which is dissipated through conduction and radiation.
- Practically solid dielectric is heterogeneous and different domains attain different temperatures due to this some domain burn due to high heat and some receive less heat. Burning causes more heat and losses .This process continues leading to thermal breakdown

Electro -thermal breakdown in Solid dielectrics



Chemical Properties

SOLUBILITY

CHEMICAL RESISTANCE

WEATHER ABILITY

1. SOLUBILITY

- Not soluble in water or other chemicals available in nature
- Must be free from the chemical effects of oils, liquids, gases, fumes
- Must be free from oxidation and hydrolysis
- If soluble in water, then moisture from atmosphere causes insulation failure

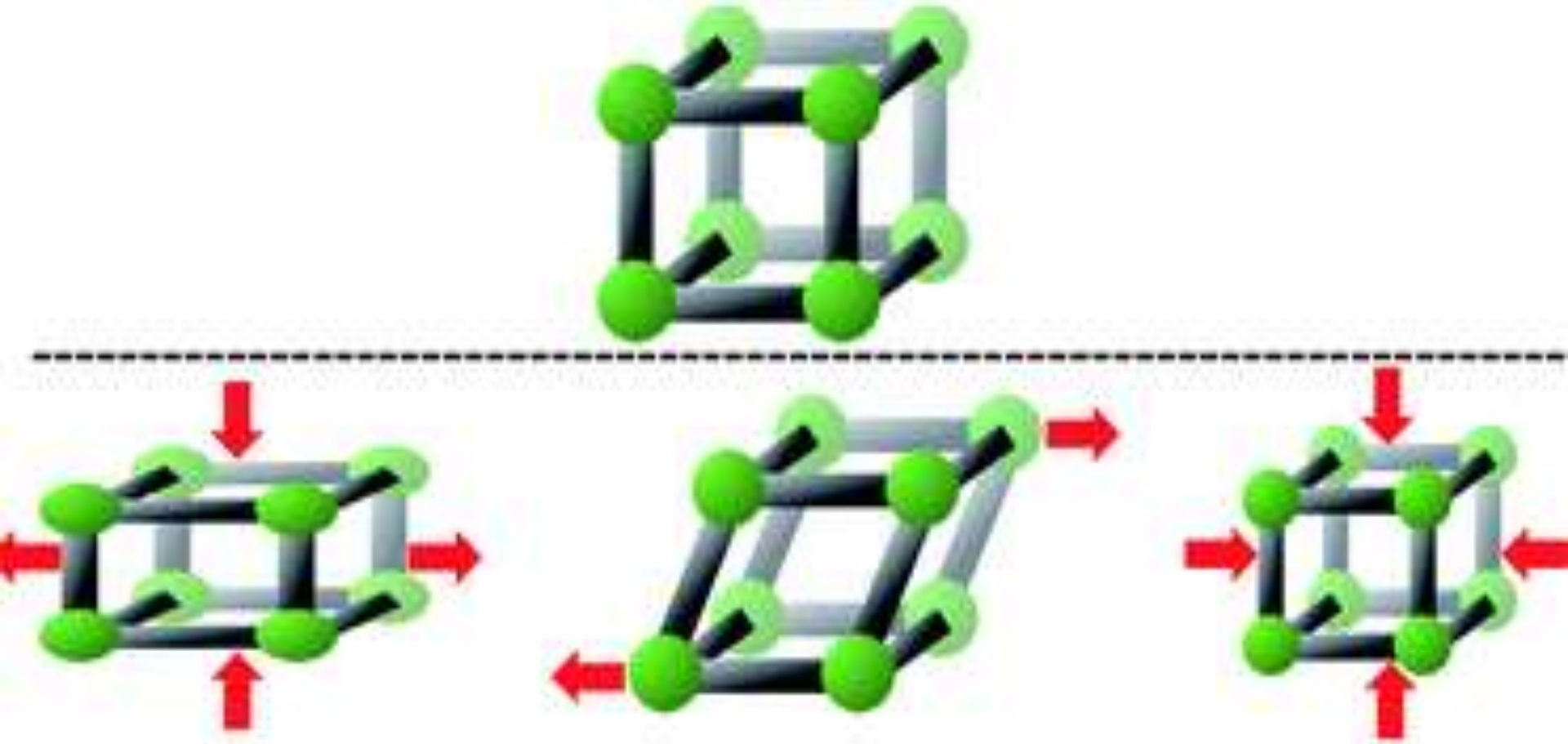
2. CHEMICAL RESISTANCE

- It should be able to resistant to chemicals available in the environment it is used.
- Ex -If used in Underground cables, then soil and chemicals available in soil must not react with it.

3. WEATHER ABILITY

- It must be weatherproof.
- Insulators come in contact with atmosphere both during manufacture or operation.
- They are subjected to weather conditions like heat , dust, humidity etc which affects electrical properties etc

Mechanical Properties



MECHANICAL STRENGTH

- It should have high mechanical strength to bear the mechanical stresses and strains during operation.
- Temperature and humidity are the main factors which reduce the mechanical strength of insulating materials.

Low density

- The insulating material should have low density to reduce the weight of equipment in which insulating material is being used.

Machinability & Mouldability

- This property of insulating material helps us to give the desired shapes to the insulating materials.

Porosity

- A material having very small holes in it is called a porous material.
- Insulator absorbs moisture if it is porous, which reduces its resistivity as will as mechanical strength. It also affects the electrical properties like dielectric strength, insulation resistance etc
- Porous material are impregnated with varnishes or resins to fill their pores which makes them non-porous thus better insulating materials.

Reference link

- https://www.slideserve.com/robertcollins/insulating-materials-subject-electrical-and-electronics-engg-materials-powerpoint-ppt-presentation