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STANDARDS CLUB

BUREAU OF INDIAN STANDARDS

Learning Science via Standards

मानकः पथप्रदर्शकः

Cables

IS 694

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Lesson 13

May 2023

Nurturing Young Minds as
Ambassadors of Quality and Standards

Foreword

Everything around us, whether natural phenomena or manmade products can be explained through science. The product which are used in our daily life are outcome of conscious efforts by the mankind to fulfil and exceed the needs of the present and demands of the future. Students are taught science as part of their school curriculum, to enable them to understand the various scientific laws and principles and also to inculcate the habit of exploring the world through the lens of science. Quality characteristics of any product or service are decided based on the stated and implied needs and are generally described in a document called 'Standard'. Science and standards are inseparable and integral aspect of any product.

Bureau of Indian Standards (BIS), the national standards body of India, is mandated for establishment and promotion of standards and creating a quality ecosystem in the country. This is achieved through developing Indian Standards on products and services through the active involvement of relevant stakeholders and dissemination of information of such standards for their use and implementation across all sectors of economy. Academia, as an important stakeholder of BIS, has been contributing towards development of standards through research activities and providing inputs related to technological advancements in product development, their characteristics and use as well as methods of tests. BIS, on its part has also been promoting standards in academia through a variety of programmes. This has since been institutionalized in the form of "Standards Clubs" which are being established in educational institutions across India to nurture the young minds as ambassadors of quality and standards and prepare them for dealing with these aspects in future.

In this initiative of BIS, called "Learning Science via Standards", a series of Lesson Plans are made elaborating the various scientific concepts, laws and principles to help students understand their practical applications via standards. The series comprises of a variety of subjects for insights into the scientific laws and principles and relating them to the quality characteristics of products used in day-to-day life. First 10 Lesson Plans in the series are released on the occasion of World Consumer Rights Day on 15 Mar 2023.

The Lesson Plans are expected to serve as a useful tool for the teaching fraternity for imparting knowledge on scientific laws and principles through their practical applications in activities and products around us and facilitate an interactive learning experience for the students.

Electric Cable

An electrical cable is an assembly of one or more wires running side by side or bundled, which is used to carry electric current. The conductors can be made of various metals such as copper or aluminum and the insulating materials can be made of rubber, plastic, or other materials. The specific design and materials used determine the cable's electrical characteristics, such as resistance, capacitance, and inductance, which affect its performance in a particular application.

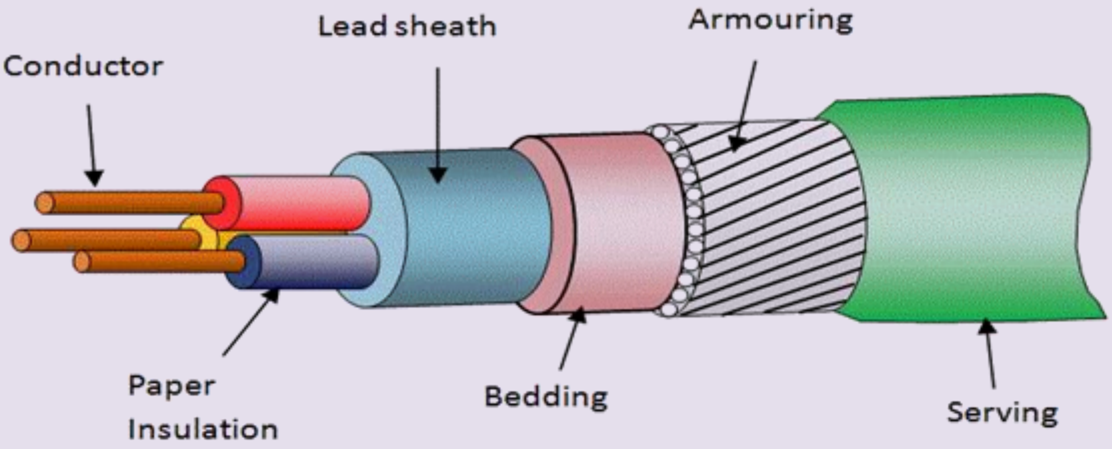


Fig 1 Different Layers of Cable

1. Conductors

Electric conductors are generally made of copper and aluminum materials used for conducting electricity. The flow of charges in a conductor is defined as electricity. A good electricity conductor has good conductivity properties.

a) What is Conductivity?

Electrical conductivity is a measure of the ability of a substance to allow the flow of an electric current.

The conductivity of a conductor depends on the total number of charged particles present and how far they can move from one place to another. Following are some points about how conductors work:

- A conductor has free-moving electrons, which allow electricity to pass through smoothly.
- When an electric charge is transferred through a conductor, it gets distributed across its entire body due to the movement of electrons.
- Electric charges continue to spread over a conductor’s surface until the force of repulsion between the electrons in areas of surplus electrons is reduced to the minimum.
- When a conductor is brought in contact with another conductor, electric charges get transferred from the first object to the other until the charges are minimized.

- Examples of conductors: copper, silver, iron, brass, steel, gold, aluminum, etc. Even human and animal bodies are examples of conductors.

b) Importance of conductors in our life

- Silver is known as the best conductor of electricity as it contains a large number of movable free electrons. It is used in various specialized tools like satellites, solder and electric circuit boards.
- Copper is commonly used in household appliances and electrical equipment.
- Aluminum is often used in long-distance power lines and electrical appliances.
- Nickel is widely used in electric vehicle batteries and power generation facilities.
- Graphite is the only non-metal that can conduct electricity. It is used in making electrodes and in car batteries**.**

Q1. As we know silver is the best conductor of electricity but why don't we use it as a conductor?

Q2. What is the relation between conductivity and resistivity properties of a conductor material?

2. Ohm's Law

The amount of current flowing through a circuit is directly proportional to the voltage applied to the circuit and inversely proportional to the resistance of the circuit. A pictorial representation of Ohm's Law is shown in figure below,

- ***Voltage*** *is the difference in charge between two points.*
- ***Current*** *is the rate at which charge is flowing.*
- ***Resistance*** *is a material's tendency to resist the flow of charge (current).*

V = I x R

Where,
V= Voltage applied to the circuit
I = Current passing thorough the circuit
R = Resistance of the circuit

This law is particularly useful in cables as it allows engineers to determine the current that will flow through the cable for a given voltage and resistance. For example, in electrical power transmission, the voltage is typically kept constant and the resistance of the cables is carefully controlled to ensure that the current does not exceed a safe limit and cause damage to the cable or the equipment it is connected to.

Conductor of the cable should have minimum resistance so that for a given voltage applied, maximum current can be passed through the cable.

Similarly, Resistance of Insulation should be maximum so that current should not pass/ leak through the insulation.

Q3. What can be the properties of a good conductor and a bad conductor?

Q4. Through which experiments the qualities of a good conductor can be ensured?

Q5. Why are Copper and Aluminium used as conductors?

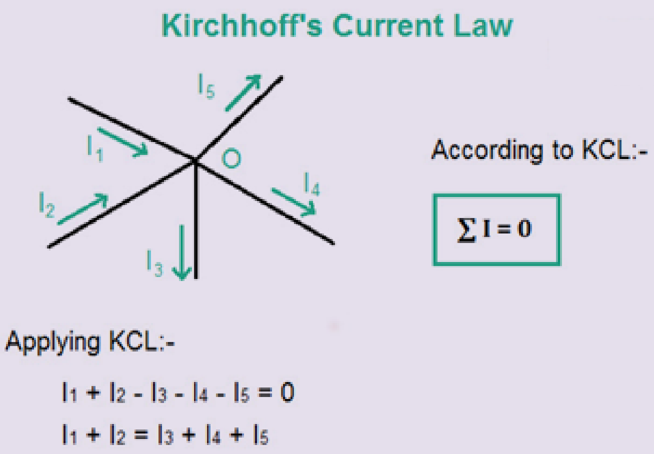
3. Kirchhoff's Circuit Laws

Kirchhoff's Circuit Laws are two fundamental principles of electrical circuits that describe the behavior of voltages and currents in a closed loop.

These laws provide a set of mathematical tools that allow electrical engineers to analyze complex circuits and determine the behavior of voltages and currents in different parts of the circuit. They are widely used in the design and analysis of electrical systems, including electric cables.

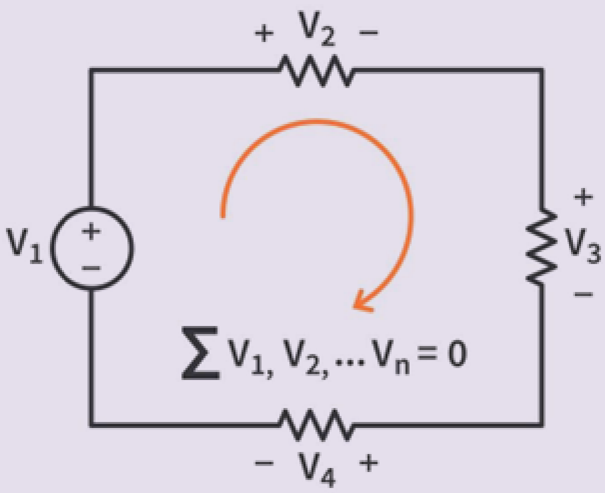
a) **Kirchhoff's Current Law (KCL):**

This law states that the total current entering a junction in a circuit must equal the total current leaving the junction. Mathematically, it can be expressed as the sum of all currents flowing into a node (junction) must equal zero. A pictorial representation is given below,



b) Kirchhoff's Voltage Law (KVL):

This law states that the total voltage around any closed loop in a circuit must equal zero. Mathematically, it can be expressed as the sum of all voltages around a closed loop must equal zero. Pictorial representation of the KVL is given below.



4. Semiconductors

Semiconductors are known as the 'Brains of Modern Electronics'. Semiconductors are elements with a conductivity value between conductors and insulators.

Example: Silicon, Germanium, Arsenide, and the elements near the 'metalloid-staircase' on the periodic table.

Importance of semiconductors in our life

- Semiconductors are used in temperature sensors of air conditioners.
- Semiconductors are used in designing logic gates, digital circuits, and analogue circuits like oscillators and amplifiers.
- Semiconductors are used in solar plates.
- Semiconductors are used in 3D printers and microchips.
- Semiconductor devices are used in computers, calculators, mobile phones and other electronic gadgets.

5. Insulators

Insulators are non-metal elements that have high resistance to the transmission of electricity. These materials stop electrons from moving freely from one element to another.

Examples: glass, plastics, wool, cotton, rubber, pure water etc.

Importance of insulators in our life

- Ceramic materials (insulators) are often used in wire holders and coating in high voltage power systems to restrict wires from conducting electricity.
- Dry cotton is a frequently used material in cloth tapes that insulates electrical wires and keeps people safe and secure.

- Fiberglass wire is an excellent insulator used in high voltage power systems like ovens or furnaces.
- Glass is typically used as an insulator in power lines.
- Rubber is an excellent insulator. Electricians use rubber gloves and shoes to protect themselves against electric shocks. Rubber is also used in switchboards and electrical sheathing.

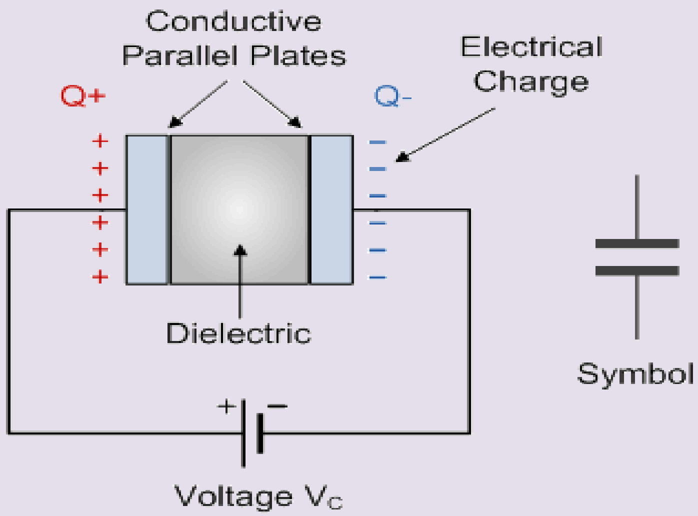
a) Insulation

Insulation is the act of separating two conducting materials by using a non-conducting material to stop the flow of the electricity conductor to another or a material that can be used to insulate.

Wire or cable insulation to stop electricity conducting outside a wire or cable.

6. Capacitance

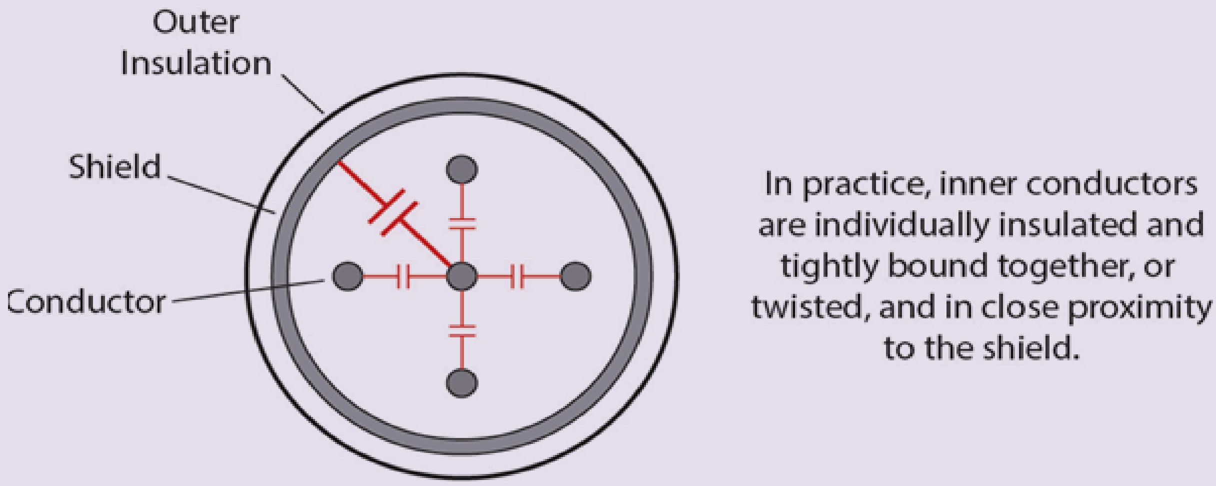
A capacitor is a system of two conductors separated by an insulator. The conductors have charges, say Q1 and Q2, and potentials V1 and V2. Usually, in practice, the two conductors have charges Q and – Q, with potential difference V = V1 – V2 between them. We shall consider only this kind of charge configuration of the capacitor. (Even a single conductor can be used as a capacitor by assuming the other at infinity.) A pictorial representation of parallel plate capacitor is given below,



The electric field in the region between the conductors is proportional to the charge Q. That is, if the charge on the capacitor is, say doubled, the electric field will also be doubled at every point. This follows from the direct proportionality between field and charge implied by Coulomb's law and the superposition principle.

Now, potential difference V is the work done per unit positive charge in taking a small test charge from the conductor 2 to 1 against the field. Consequently, V is also proportional to Q, and the ratio Q/V is a constant C is called the capacitance of the capacitor. C is independent of Q or V, as stated above.

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



Capacitance in Conductors

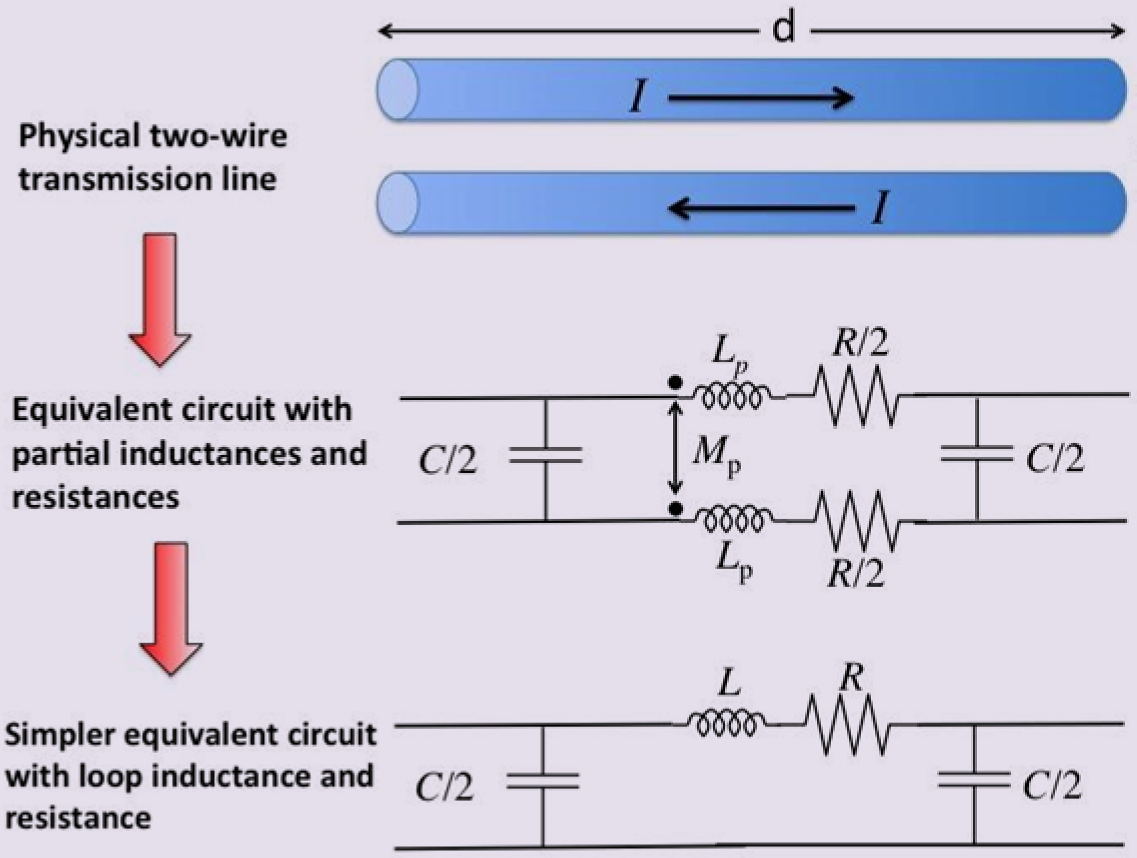
7. Inductance

When a current flows through a conductor it produces a magnetic field around the conductor. If this induced magnetic field changes with a changing current it produces an electromotive force (EMF) of 1 Volt which opposes the change. Any sudden change is opposed by the induced current. This is known as self -induction.

Mutual induction is the effect of inducing this EMF upon another conductor in the same magnetic field. An electrical transformer works on this principle of induction, the primary coil windings inducing voltage in the secondary coil windings

The symbol representing Inductance is L.

The SI unit of inductance is the henry and is defined as '1 henry induces an electromotive force of 1 volt in a closed circuit with a uniform change of current of one amp per second'.



Capacitance, Inductance and Resistance of Cable

8. Metallic sheath

A metallic sheath of lead or aluminum is provided over the insulation of cable for protecting the cable from moisture, gases or other liquids (like) acids or alkalies in the soil and atmosphere. The metallic sheath is shown in Fig 1.

9. Bedding

Bedding is a layer in between metallic sheath and armoring. It consists of fibrous materials like jute or hessian tape. It protects the metallic sheath against corrosion and from mechanical injury due to armoring.

10. Armouring

Steel wire armoured cable has a strong steel wire conductor assembled with a layer of insulation.

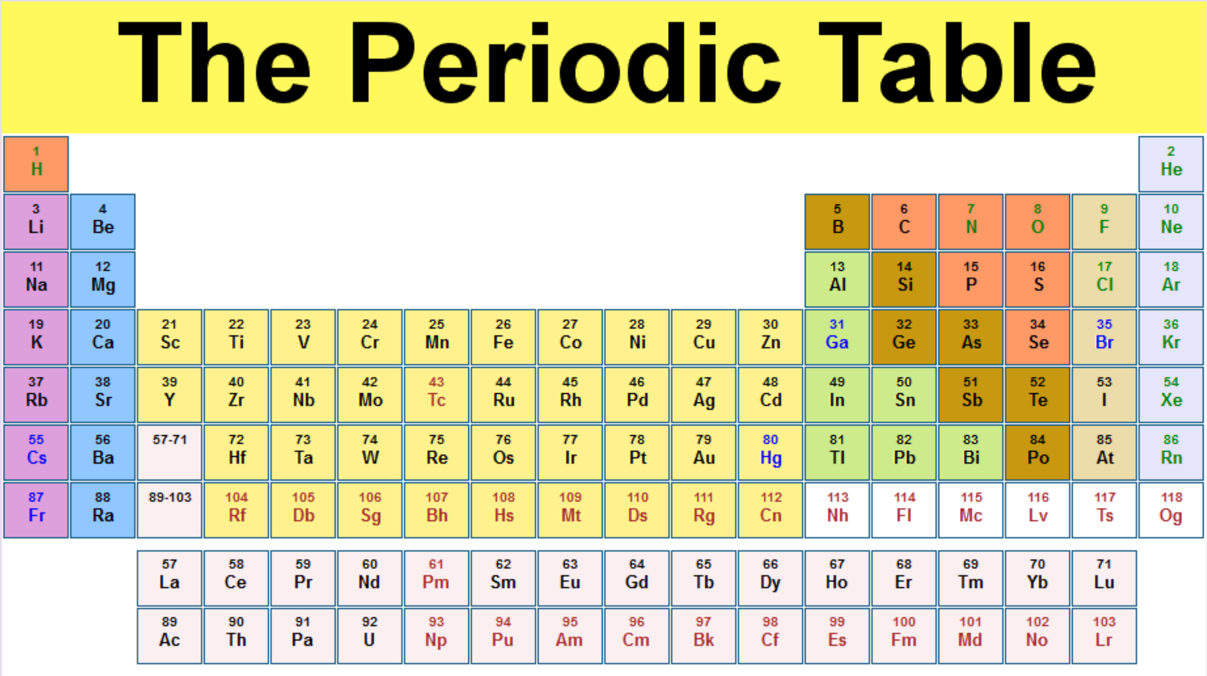
The main purpose of the shielded layer steel wire armoured cable is to improve the tensile strength and compressive strength. It also provides mechanical protection. Further, It also lengthens the service life and improves the anti-interference of the cable through shielding protection. Armouring of cable is shown in Fig 1.

11. Serving

A layer of fibrous materials is provided over the armouring to protect the armouring. This layer is known as the serving of the cable. Serving of cable is shown in Fig 1.

Q6. Why galvanized steel used for armouring in the cable?

Q7. Find out the at least 5 atoms for each conductor, semiconductor and insulator in the below periodic table?



12. Properties of Insulated Materials

PVC became the most commonly used material for cable insulation and sheathing due to its low cost, durability, and good electrical properties.

Insulation materials used in manufacturing of cable should have good tensile & elongation properties along with Heat Shock, Hot Deformation, Shrinkage, Thermal Stability, Flammability Resistance, anti-smoke properties etc.

13. Concept of Tensile Strength and Elongation

Tensile strength and elongation are important properties for insulating materials used in cables because these properties determine the ability of the insulation to withstand mechanical stress and deformation during cable installation and use.

Elongation is the ability of a material to stretch or deform under tension before breaking. In cables, the insulation material must be able to elongate and recover its original shape without cracking or tearing. If the insulation material has low elongation, it may become brittle and crack or tear under stress, which could lead to electrical failures or safety hazards.

a) **Tensile test:** It is a test in which a sample is subjected to a controlled tensile force until failure. Properties that are directly measured via a tensile test are ultimate tensile strength, breaking strength, maximum elongation and reduction in area. From these measurements the following properties can also be determined:

- Young's modulus,
- Poisson's ratio,
- Yield strength, and
- Strain-hardening characteristics.

In the tensile test, a material sample with standardized geometry (tensile test specimen) is subjected to a tensile load.

b) **Tensile strength:** Tensile strength is the amount of load or stress that can be handled by a material before it stretches and breaks.

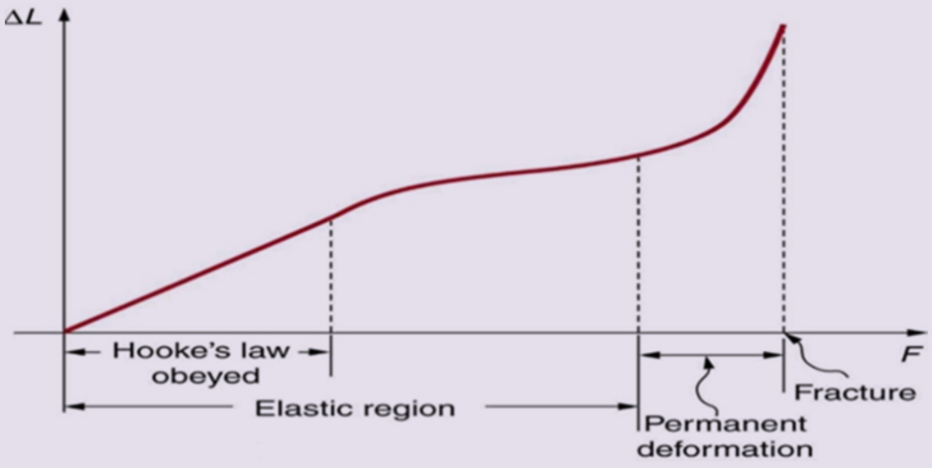
c) **Yield strength:** When a force is applied to an object, the object experiences elastic deformation at first. The object will return to its original size and shape when the force is removed as long as the resulting stress does not exceed the yield stress.

d) **Hooke’s Law and study of deformation**

A change in shape due to the application of a force is a deformation. Even very small forces are known to cause some deformation. For small deformations, two important characteristics are observed. First, the object returns to its original shape when the force is removed i.e., the deformation is elastic for small deformations. Second, the size of the deformation is proportional to the force i.e., for small deformations, **Hooke’s law** is obeyed. It states that “when an object has a relatively small deformation the size of the deformation is directly proportional to the deforming load or force".

Where,

ΔL is the amount of deformation produced by the force F, and k is a proportionality constant.

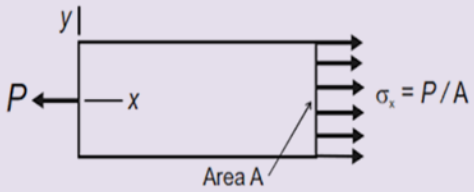


A graph of deformation ΔL versus applied force F.

e) **What is stress?**

Stress is defined as force per unit area within materials that arises from externally applied forces, uneven heating, or permanent deformation. Stress is given by the following formula:

$$\sigma = F/A$$



where, σ is the stress applied, **F** is the force applied and **A** is the area of the force application. The unit of stress is N/m2.

f) **What is Strain?**

Strain is the amount of deformation experienced by the body in the direction of force applied, divided by the initial dimensions of the body.

The following equation gives the relation for deformation in terms of the length of a solid:

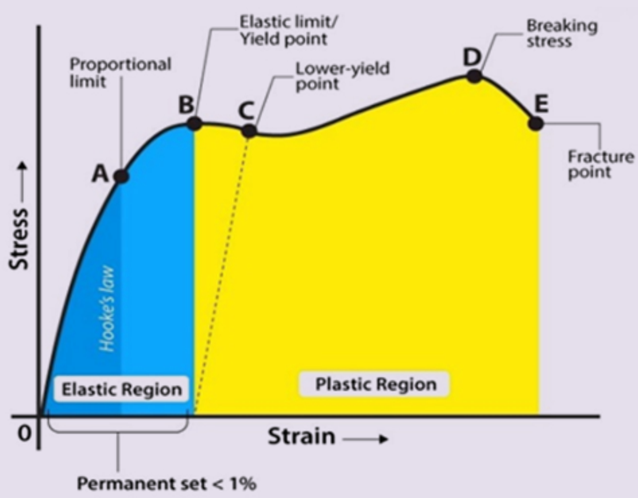
$$\epsilon = \delta l / L$$

Where,

Epsilon, ϵ is the strain due to the stress applied, δl is the change in length and L is the original length of the material.

The strain is a dimensionless quantity as it just defines the relative change in shape. The different regions in the stress-strain diagram are indicated in the figure.

g) **Proportional Limit:** It is the region in the stress-strain curve that obeys Hooke's Law. In this limit, the stress-strain ratio gives us a proportionality constant known as Young's modulus. The point OA in the graph represents the proportional limit.



h) **Elastic Limit:** It is the point in the graph up to which the material returns to its original position when the load acting on it is completely removed. Beyond this limit, the material doesn't return to its original position, and a plastic deformation starts to appear in it.

i) **Yield Point:** The yield point is defined as the point at which the material starts to deform plastically. After the yield point is passed, permanent plastic deformation occurs. There are two yield points (i) upper yield point (point B) (ii) lower yield point (point C).

j) **Ultimate Stress Point:** It is a point that represents the maximum stress that a material can endure before failure. Beyond this point, failure occurs.

k) **Fracture or Breaking Point:** It is the point in the stress-strain curve at which the failure of the material takes place.

l) **Young's modulus E:** Young's modulus E or the modulus of elasticity in tension or compression (i.e., negative tension), is a mechanical property that measures the tensile or compressive stiffness of a solid material when the force is applied lengthwise (L):

$$E = \sigma/\varepsilon$$

Where, **σ** = uniaxial stress, or uniaxial force per unit surface area, pressure units.

ε = strain, or proportional deformation (change in length divided by original length), dimensionless.

14. Concept of Hot Deformation

As we know that Thermoplastics materials used as insulation tend to deform under high temperatures and small damage during movement or under installation to cable, can cause a puncture or cut of insulation. Hot Deformation test is conducted to check the properties of insulated materials resistance at elevated working conditions.

a) **Thermoplastic Materials**

Thermoplastic materials are a type of polymer that becomes pliable or moldable above a specific temperature and solidifies again upon cooling. They are widely used in various applications because of their high durability, flexibility, and ease of processing. Unlike thermosetting plastics, which become permanently rigid upon heating, thermoplastics can be melted and reformed multiple times without significant degradation of their properties. Some common examples of thermoplastic materials include polyethylene, polypropylene, polystyrene, PVC, nylon, and acrylics. They are used in a variety of applications, including packaging, automotive parts, construction materials, medical devices, and consumer goods etc.

b) **Properties of Thermoplastic Materials**

Thermoplastic materials have several unique properties that make them a popular choice for various applications. Some of the key properties of thermoplastic materials include:

- **High Durability:** Thermoplastics are known for their high durability and resistance to wear and tear.
- **Flexibility:** Thermoplastics can be easily molded or reshaped by heating them to their melting point and then cooling them down. This allows them to be molded into complex shapes and designs.
- **Chemical Resistance:** Thermoplastics are highly resistant to chemical corrosion, making them suitable for use in harsh environments where exposure to chemicals is likely.
- **Low Density:** Thermoplastics have a low density, making them lightweight and easy to handle.
- **Recyclable:** Thermoplastics can be recycled multiple times without significant degradation of their properties, making them an eco-friendly choice.
- **Transparency:** Many thermoplastics have excellent optical properties, allowing them to be used in applications where transparency is important, such as in packaging materials.
- **Good Electrical Insulation:** Thermoplastics have excellent electrical insulation properties, making them suitable for use in electronic components.

The combination of these properties makes thermoplastic materials highly versatile and useful in a wide range of applications.

c) **Thermosetting Materials**

Thermosetting materials are a class of polymer materials that, when heated, undergo a chemical reaction that permanently changes their structure and properties. This process is called crosslinking or curing, and it results in the formation of a three-dimensional network of covalent bonds that gives the material its rigidity and strength. Once a thermosetting material is cured, it cannot be melted or reshaped by heating, and it becomes a solid and durable material.

Examples of thermosetting materials include epoxy resins, phenolic resins, polyester resins, and polyurethane resins. These materials are used in a wide range of applications, including adhesives, coatings, composite materials, electrical insulation, and molded parts.

d) **Properties of Thermosetting Materials**

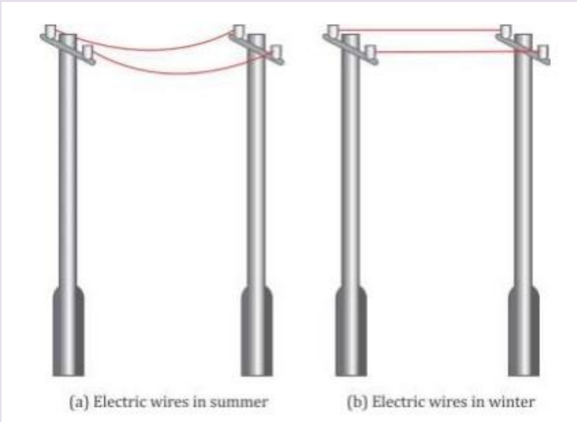
Thermosetting materials are a class of polymers that exhibit a unique set of properties due to their crosslinked structure, which is formed by a chemical reaction during the curing process. Some of the key properties of thermosetting materials include:

- **High heat resistance:** Thermosetting materials can withstand high temperatures without softening or degrading, making them ideal for use in high-temperature applications.
- **High chemical resistance:** Due to their crosslinked structure, thermosetting materials are highly resistant to chemical attack and corrosion.
- **High strength and stiffness:** The crosslinked structure gives thermosetting materials excellent mechanical properties, including high tensile strength, compression strength, and modulus of elasticity.
- **Dimensional stability:** Once cured, thermosetting materials maintain their shape and dimensions, even when exposed to changes in temperature or humidity.
- **Electrical insulation:** Thermosetting materials are often used as electrical insulators due to their high dielectric strength and resistance to electrical breakdown.
- **Resistance to creep:** Thermosetting materials exhibit minimal creep, meaning they resist deformation over time under constant load.
- **Low coefficient of thermal expansion:** Thermosetting materials have a low coefficient of thermal expansion, which means they resist dimensional changes with changes in temperature.
- **Difficult to recycle:** Due to their crosslinked structure, thermosetting materials are not easily recyclable, making them less environmentally friendly than thermoplastic materials.

Overall, thermosetting materials offer a unique set of properties that make them highly useful in a wide range of applications, including aerospace, automotive, construction, electronics, and more.

15. Concept of Shrinkage

The shrinkage test is an important method for evaluating the dimensional stability of cables and wires. The test provides valuable information on the behavior of the cable under high temperature conditions, which is essential for ensuring the quality and reliability of the cable in various applications. At high elevated conditions if cable shrinkages more than permissible limits which may cause cracks in the insulation materials result in electrical shock.



Q8. Why is there a gap between railway tracks?

Q9. In the summer electric wires are loose while in the winter they are tight. Why?

17. Thermal Stability

Thermal stability properties are important in polyvinyl chloride (PVC) cables, which are widely used in electrical applications due to their low cost, durability, and good electrical properties. PVC cables are exposed to various temperature conditions during their lifetime, and it is essential to ensure that they maintain their structural integrity and performance under these conditions.

PVC cables are designed to have good thermal stability, meaning they can withstand high temperatures without degrading or losing their properties. The thermal stability of PVC cables can be characterized by several parameters, such as the temperature at which they begin to degrade, the rate of degradation, and the degree of weight loss.

18. Flammability Resistance Properties

The flammability resistance properties of electrical cables are an important consideration when designing and selecting cables for use in various applications. Electrical cables are often used in environments where the risk of fire is high, such as in buildings, aircraft, and vehicles. Therefore, it is important to ensure that the cables used in these environments are resistant to flames and do not propagate fires.

Cables can be designed to be flame retardant, meaning they resist the spread of flames, or fire resistant, meaning they can withstand exposure to flames without igniting. Flame retardant cables typically use additives such as halogenated compounds or mineral fillers to suppress the formation and spread of flames. Fire resistant cables, on the other hand, are often constructed with insulating materials that can withstand high temperatures without breaking down or igniting.

In addition to flame resistance, electrical cables may also be required to have other properties related to fire safety, such as low smoke emission, low toxicity, and low acidity. These properties are important to prevent the spread of smoke and toxic gases in the event of a fire, which can be just as dangerous as the flames themselves.

19. Interesting facts about electric cables

a) The first electric cable was invented by William Sturgeon in 1825.
b) The first underground cable was laid in New York City in 1882.
c) The longest undersea cable is the NorNed cable, which runs between Norway and the Netherlands and is 580 km long.
d) The longest underground cable is the Murraylink, which runs between Victoria and South Australia in Australia and is 180 km long.
e) The highest voltage power line in the world is located in China and has a voltage of 1,100 kV.

Lesson Plan Subjects

Published

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5.	Geyser	**15.**	Rear View Mirrors
6.	Helmet	**16.**	Headphones
7.	LED Bulb	**17.**	Milk Powder
8.	LPG Cylinders	**18.**	Pressure Cooker
9.	Cement Ash Brick	**19.**	Plywood
10.	Paints	**20.**	Multipurpose dry batteries

Forthcoming…

21.	Drinking Water	**37.**	PVC Pipes
22.	Electric Iron	**38.**	Bicycle
23.	Electric Mixer	**39.**	Refrigerator
24.	Family Sized Biogas Plant	**40.**	Solar Flat Plate Collector
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31.	Pasteurized Milk	**47.**	Vacuum Flask
32.	Hearing Aids	**48.**	Water Meter
33.	Paving Block	**49.**	Water Storage Tank
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36.	Plugs and Socket	**52.**	Geosynthetics

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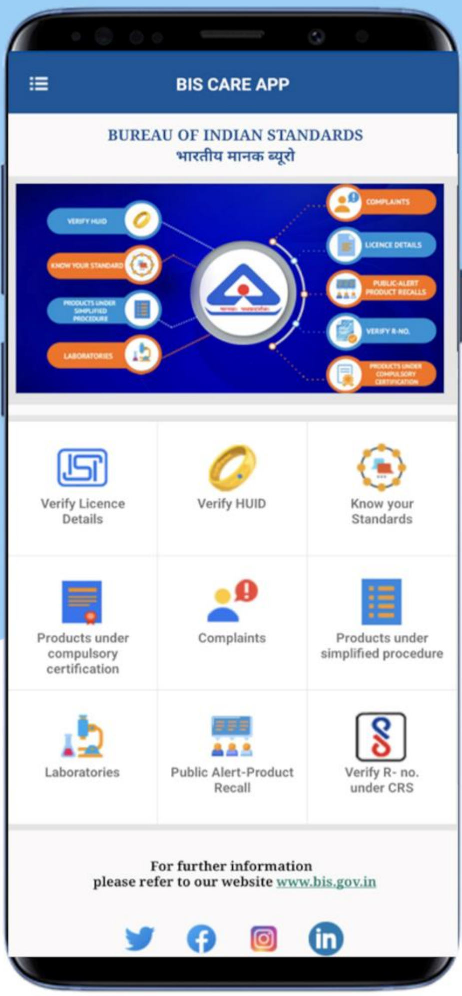

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