Objective Electrical Technology

[For the Students of UPSC (Engg. Services); IAS (Engg. Group); B.Sc. Engg.; Diploma and Other Competitive Courses

More than **4500** Objective Questions with Hints

V.K. MEHTA
ROHIT MEHTA

S. CHAND

1 BASIC CONCEPTS

Chapter Overview

1. Nature of Electricity

According to Modern electron theory of matter, all matter whether solid, liquid or gas is composed of very small particles called **molecules.** A molecule is in turn made up of **atoms.** An atom consists of a central part called **nucleus** and around the nucleus (called **extra-nucleus**), there are a number of **electrons** revolving in different paths or orbits. The size of the nucleus is very small as compared to the size of the atom. The nucleus contains **protons** and **neutrons**. A proton is a positively charged particle having mass 1837 times that of an electron. A neutron has the same mass as proton but no charge. Clearly, the nucleus of an atom bears a positive charge. An electron is a negatively charged particle having negative charge equal to the positive charge on a proton. Under normal conditions, the number of electrons is equal to the number of protons in an atom. Therefore, an atom is neutral as a whole, the negative charge on electrons cancelling the positive charge on protons.

The above discussion shows that matter is electrical in nature *i.e.* it contains particles of electricity *viz* protons and electrons. Whether a given body exhibits electricity (*i.e.* charge) or not depends upon the relative number of these particles of electricity.

(*i*) If the number of protons is equal to the number of electrons in a body, the resultant charge is zero and the body will be electrically neutral. Thus the paper of this book is electrically neutral (*i.e.* paper exhibits no charge) because it has the same number of protons and electrons.

(*ii*) If from a neutral body, some *electrons are removed, there occurs a deficit of electrons in the body. Consequently, the body attains a positive charge. *Hence a positively charged body has deficit of electrons from the normal due share.*

(*iii*) If a neutral body is supplied with electrons, there occurs an excess of electrons. Consequently, the body attains a negative charge. *Hence a negatively charged body has an excess of electrons from the normal due share.*

---

* Electrons have very small mass and, therefore, are much more mobile than protons. On the other hand, protons are powerfully held in the nucleus and cannot be removed or detached.

2. Unit of Charge

The charge on an electron is so small that it is not convenient to select it as the unit of charge. In practice, coulomb is used as the unit of charge. One coulomb of charge is equal to the charge on 625×10^{16} electrons *i.e.*

$$1 \text{ coulomb} = \text{Charge on } 625 \times 10^{16} \text{ electrons}$$

Thus when we say that a body has a positive charge of 1 coulomb (1C), it means that it has a deficit of 625×10^{16} electrons from the normal due share.

3. Free Electrons

We know that electrons move around the nucleus of an atom in different orbits. The electrons in the last orbit are called **valence electrons.** In certain substances, especially metals (*e.g.* copper, aluminium *etc*), the valence electrons are so *weakly attached to their nuclei that they can be easily removed or detached. Such electrons are called **free electrons.** It may be noted here that all valence electrons in a metal are not free electrons. It has been found that one atom of metal can provide at the most one free electron. Since a small piece of metal has billions of atoms, one can expect a very large number of free electrons in metals. For example, 1 cm^3 of copper has about 8.5×10^{22} free electrons at room temperature.

4. Electric Current

The flow of free electrons (or charge) in a definite direction is called **electric current**. The flow of electric current is shown in Fig. 1.1. The copper strip has a large number of free electrons. When electric pressure or voltage is applied, the free electrons being negatively charged start moving towards the positive terminal around the circuit as shown in Fig. 1.1. This directed flow of electrons is called electric current.

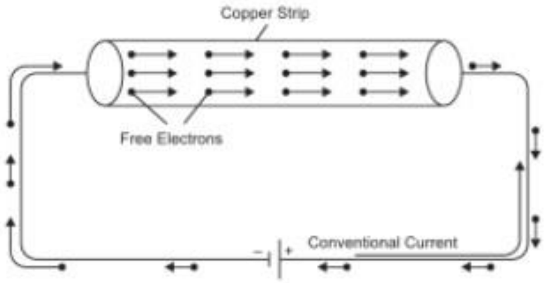

Fig. 1.1

Conventionally, the direction of electric current is taken along the direction of motion of positive charges. When current is caused by electrons (*e.g.* in metals), the direction of current is opposite to the direction of electron flow.

* On a relative scale, the spacing between the nucleus and valence electrons is vast. If a copper atom could be magnified until the electrons were as large as coins, the valence electrons would be several kilometres away from the nucleus. This relatively large distance dictates that valence electron is only weakly attached to the nucleus.

If the two bodies are joined through a conductor [See Fig. 1.2 (*ii*)], then *electrons will flow from body *B* to body *A*. When the two bodies attain the same potential, the flow of current stops. Therefore, we arrive at a very important conclusion that current will flow in a circuit if potential difference exists. No potential difference, no current flow. It may be noted that potential difference is sometimes called voltage.

Unit. Since the unit of electric potential is volt, one can expect that the unit of potential difference will also be volt. It is defined as :

The potential difference between two points is **1 volt** *if one joule of work is done in transferring 1C of charge from the point of lower potential to the point of higher potential.*

8. Concept of E.M.F. and Potential Difference

There is a distinct difference between e.m.f. and potential difference. The e.m.f. of a device, say a battery, is a measure of the energy the battery gives to each coulomb of charge. Thus if a battery supplies 4 joules of energy per coulomb, we say that it has an e.m.f. of 4 volts. The energy given to each coulomb in a battery is due to the chemical action.

The potential difference between two points, say *A* and *B*, is a measure of the energy used by one coulomb in moving from *A* to *B*. Thus if potential difference between points *A* and *B* is 2 volts, it means that each coulomb will give up an energy of 2 joules in moving from *A* to *B*.

9. Drift Velocity of Free Electrons

When potential difference (or voltage) is applied across the ends of a metallic wire, the free electrons start drifting towards the positive terminal of the source. *The average velocity with which free electrons get drifted in a metallic conductor under the influence of potential difference is called* **drift-velocity** (v_d) of the free electrons. The drift velocity of free electrons is very small, of the order of 10^{-5} ms^{-1}.

Note. The reader may wonder that if electrons drift so slowly, how room light turns on quickly when switch is closed ? The answer is that propagation of electric field takes place with the speed of light. When we apply electric field (*i.e.*, potential difference) to a wire, the free electrons everywhere in the wire begin drifting almost at once.

10. Relation between Current and Drift Velocity

Consider a portion of a copper wire through which current *I* is flowing as shown in Fig. 1.3. Clearly, copper wire is under the influence of electric field.

Let A = area of *X*-section of the wire

n = electron density, *i.e.*, number of free electrons per unit volume

e = charge on each electron

v_d = drift velocity of free electrons

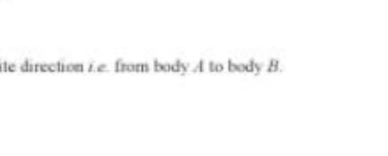

Fig. 1.3

In one second, all those free electrons within a distance v_d to the right of cross-section at *P* (*i.e.*, in a volume $A\ v_d$) will flow through the cross-section at *P* as shown in Fig. 1.3. This volume contains $n\ A\ v_d$ electrons and, hence, a charge $(n\ A\ v_d)e$. Therefore, a charge of $n\ e\ A\ v_d$ per second passes the cross-section at *P*.

$$\therefore \qquad I = neAv_d$$

* The conventional current flow will be in the opposite direction *i.e.* from body *A* to body *B*.

Since A, n and e are constant, $I \propto v_d$

Hence, current flowing through a conductor is directly proportional to the drift velocity of free electrons.

11. Resistance

The opposition offered by a substance to the flow of electric current is called its **resistance.**

Since current is the flow of free electrons, resistance is the opposition offered by the substance to the flow of free electrons. This opposition occurs because atoms and molecules of the substance obstruct the flow of these electrons. Certain substances (*e.g.*, metals such as silver, copper, aluminium *etc.*) offer very little opposition to the flow of electric current and are called conductors. On the other hand, those substances which offer high opposition to the flow of electric current (*i.e.*, flow of free electrons) are called insulators *e.g.*, glass, rubber, mica, dry wood *etc.*

It may be noted here that resistance is the electric friction offered by the substance and causes production of heat with the flow of electric current. The moving electrons collide with atoms or molecules of the substance ; each collision resulting in the liberation of minute quantity of heat.

Unit of resistance. The practical unit of resistance is ohm and is represented by the symbol Ω. It is defined as under :

A wire is said to have a resistance of **1 ohm** *if a p.d. of 1 volt across its ends causes 1 ampere to flow through it.*

12. Calculating Resistance

The resistance R of a material of length l and area of cross-section A is given by ;

$$R = \rho \frac{l}{A}$$

where ρ (Greek letter 'Rho') is called resistivity or specific resistance of the material. Its value depends upon the nature of the material and temperature.

13. Resistivity or Specific Resistance

$$R = \rho \frac{l}{A}$$

If $l = 1$ m ; $A = 1$ m^2, then $R = \rho$.

Hence **specific resistance** (*or* **resistivity**) *of a material is the resistance offered by 1 m length of wire material having area of cross-section of 1 m*^{2} (See Fig. 1.4).

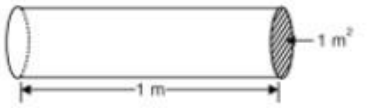

Fig. 1.4

The SI unit of resistivity is ohm-m (Ω m). Different materials have different resistivities. For example, the resistivity of copper is 1.7×10^{-8} Ω m. It means that if you take a copper wire 1 m long and having an area of X-section of 1 m^2, then resistance of this piece of copper wire will be $1.7 \times 10^{-8}\Omega$.

14. Conductance

The reciprocal of resistance of a conductor is called its **conductance** (G). If a conductor has a resistance R, then its conductance G is given by ;

$$G = \frac{1}{R}$$

A circuit with high conductance has low resistance, and a circuit with low conductance has high resistance. The SI unit of conductance is **siemen**. It is denoted by the symbol S. Suppose a wire has a resistance of 0.5 Ω. Then its **conductance** is given by ;

$$G = \frac{1}{R} = \frac{1}{0.5} = 2 \text{ S}$$

Conductivity. *The reciprocal of resistivity of a conductor is called its* **conductivity**. It is denoted by the symbol σ. If a conductor has resistivity ρ, then its conductivity is given by ;

$$\sigma = \frac{1}{\rho}$$

Now,
$$G = \frac{1}{R} = \frac{A}{\rho l}$$

∴
$$G = \sigma \frac{A}{l}$$

Clearly, SI unit of conductivity is siemen per metre (Sm^{-1}).

15. Carbon Resistors

A component whose function in a circuit is to provide a specified value of resistance is called a **resistor**. The most commonly used resistors in electrical and electronic circuits are the carbon resistors. A carbon resistor is made from powdered carbon mixed with a binding material and baked into a small tube with a wire attached to each end. These small-sized resistors are manufactured in values from a fraction of an ohm to several million ohms. Note that the power rating of a carbon resistor depends upon the physical size of the resistor. A larger resistor is able to throw off (dissipate) more heat than a smaller one.

Colour code for carbon resistors. Since a carbon resistor is physically quite small, it is more convenient to use a *colour code* indicating the resistance value than to imprint the numerical value on the case. In this scheme, there are generally four colour bands *A*, *B*, *C* and *D* printed on the body of the resistor as shown in Fig. 1.5. The first three colour bands (*A*, *B* and *C*) give the value of the resistance while the fourth band (*D*) tells about the *tolerance in percentage. The table below shows the colour code for resistance values and colour code for tolerance.

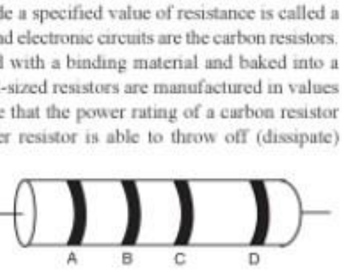

Fig. 1.5

Colour Code for Resistance Values

Black	0	Green	5
Brown	1	Blue	6
Red	2	Violet	7
Orange	3	Grey	8
Yellow	4	White	9

Colour Code for Tolerance

Gold	± 5%
Silver	± 10%
No colour	± 20%

(*i*) To read the resistance value, we refer to the first three colour bands (*A*, *B* and *C*). The first two colour bands (*A*, *B*) specify the first two digits of the resistance value and the third colour band (*C*) gives the number of zeros that follow the first two digits. Suppose the first three colour bands (*A*, *B* , *C*) on the resistor are red, brown, orange respectively. Then value of the resistance is 21,000 Ω.

* Due to manufacturing variations, the resistance value may not be the same as indicated by colour code. Thus, a resistor marked 100 Ω ; ± 10% tolerance means that resistance value is between 90 Ω and 110 Ω.

Red : 2

Brown : 1 $\qquad \therefore$ Value = 21,000 Ω

Orange : 000

(*ii*) The fourth band *D* gives the value of tolerance in percentage. If colour of the fourth band is gold, tolerance is ± 5 percent and if silver, then tolerance is ± 10 per cent. If the fourth band is omitted, the tolerance is assumed to be ± 20 per cent.

Note. In order to remember the colour code, the above sentence (BB ROY Great Britain Very Good Wife.) may be helpful.

16. Effect of Temperature on Resistance

It has been found that in the normal range of temperatures, the resistance of a metallic conductor increases linearly with the rise in temperature. Therefore, resistance/temperature graph is a straight line as shown in Fig. 1.6.

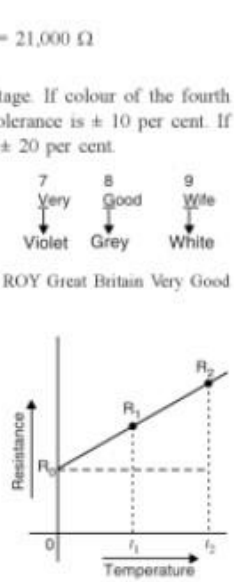

Fig. 1.6

Consider a metallic conductor having resistance R_0 at 0°C and R_1 at t_1°C. Then in the normal range of temperatures, the increase in resistance (*i.e.*, $R_1 - R_0$)

(*i*) is directly proportional to the initial resistance, *i.e.*,

$$R_1 - R_0 \propto R_0$$

(*ii*) is directly proportional to the rise in temperature, *i.e.*,

$$R_1 - R_0 \propto t_1$$

(*iii*) depends upon the nature of the material.

Combining the first two, we get,

$$R_1 - R_0 \propto R_0\, t_1$$

or $$R_1 - R_0 = \alpha_0 R_0\, t_1 \qquad \ldots(i)$$

where α_0 is a constant and is called temperature co-efficient of resistance at 0°C. Its value depends upon the nature of material and temperature.

Rearranging eq. (*i*), we get, $R_1 = R_0\,(1 + \alpha_0\, t_1)$ $\qquad \ldots(ii)$

Definition of α_0. From eq. (*i*), we get,

$$\alpha_0 = \frac{R_1 - R_0}{R_0 \times t_1}$$

= Increase in resistance/ohm original resistance/°C rise in temperature

Hence **temperature co-efficient of resistance** *of a conductor is the increase in resistance per ohm original resistance per °C rise in temperature.*

(*a*) Temperature coefficient α_1 at t_1°C is given by ; $\alpha_1 = \dfrac{\alpha_0}{1+\alpha_0 t_1}$

Similarly, temperature coefficient α_2 at t_2°C is given by ;

$$\alpha_2 = \frac{\alpha_0}{1+\alpha_0 t_2}$$

The relation between α_1 and α_2 is given by ;

$$\alpha_2 = \frac{1}{\frac{1}{\alpha_1} + (t_2 - t_1)}$$

(*b*) If the resistance of a conductor is R_2 at t_2°C and R_1 at t_1°C ($t_2 > t_1$), then, (α_1 = temp. coefficient at t_1°C)

$$R_2 = R_1 [1 + \alpha_1(t_2 - t_1)]$$

17. Ohmic and Non-Ohmic Conductors

There are two types of conductors *viz* (*i*) ohmic conductors and (*ii*) non-ohmic conductors.

(*i*) **Ohmic conductors.** Those conductors which obey Ohm's law ($I \propto V$) are called ohmic conductors *e.g.* metals. The V–I graph for such a conductor is a straight line passing through the origin. Fig. 1.7 (*i*) shows V-I graph for two ohmic conductors namely 1 kΩ and 2 kΩ resistors. The 1-kΩ resistor conducts 5 mA at 5 V, 10 mA at 10 V. The 2 kΩ resistor conducts 2·5 mA at 5 V and 5 mA at 10 V.

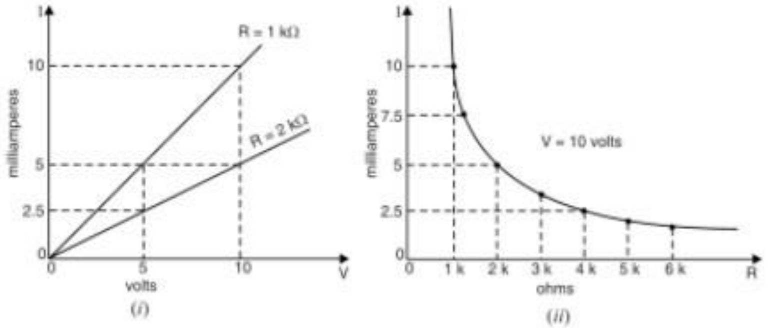

Fig. 1.7

(*ii*) **Non-ohmic conductors.** Those conductors which do not obey ohm's law ($I \propto V$) are called non-ohmic conductors *e.g.* vacuum tubes, transistors, electrolytes etc. The V-I graph for such a conductor is non-linear. Fig. 1.7 (*ii*) shows ohm-ampere graph of a non-ohmic conductor for a fixed p.d. of 10 V. A 1 kΩ conductor conducts 10 mA, a 2 kΩ conductor conducts 5 mA and a 4 kΩ conductor conducts 2·5 m A. Note that relationship between resistance and current is non-linear.

18. Ohm's Law

The relationship between voltage across and current through a conductor was first discovered by German scientist George Simon Ohm. This relationship is called Ohm's law and may be stated as under :

The current (I) flowing through a conductor is directly proportional to the potential difference (V) across its ends provided the physical conditions (temperature, strain, etc.) do not change i.e.,

$$I \propto V$$

or $$\frac{V}{I} = \text{Constant} = R$$

where R is a constant of proportionality and is called *resistance* of the conductor.

If a *graph is drawn between applied potential difference (V) and current (I) flowing through the conductor, it will be a straight line passing through the origin. Note that slope of the graph gives the resistance of the conductor ($\tan\theta = V/I = R$).

19. Electric Power

The **power of an electric appliance** *is the rate at which electrical energy is converted into other forms of energy* (*e.g.* heat, *etc.*). For example, a 60 W bulb converts 60 J of electrical energy into heat and light each second.

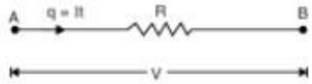

Fig. 1.8

Thus referring to Fig. 1.8, as the charge q (= It) moves from point A to B, it loses electric potential energy = qV. In other words, qV joules of electrical energy is converted into heat in t seconds.

$$\therefore \quad \text{Electric Power} = \frac{qV}{t} = \frac{(It)V}{t} \text{ J/s or watts}$$

$$\therefore \quad \text{Electric Power} = V\,I \text{ watts} \qquad \ldots(i)$$

$$= I^2 R \text{ watts} \quad (\because V = I\,R) \qquad \ldots(ii)$$

$$= V^2/R \text{ watts} \qquad \ldots(iii)$$

Any one of the three formulas can be used to calculate electric power, depending upon the problem in hand.

Unit of Electric Power. $P = V\,I$

The SI unit of p.d. is 1 V and that of current is 1 A so that SI unit of power = 1 V × 1 A = 1 VA or 1 watt (1W).

Hence electric power of a circuit or device is **one watt** *if a current of 1 A flows through it when a p.d. of 1 V is maintained across it.*

The bigger units of electric power are kilowatt (kW) and megawatt (MW).

$$1 \text{ kW} = 1000 \text{ W}\,; \qquad 1\text{MW} = 10^3 \text{ kW} = 10^6 \text{ W}$$

Note. Electric appliances are rated in terms of electric power. The faster the appliance converts electrical energy into some other from of energy, the greater the electric power it has. Thus, in 1 second, a 100 W bulb converts more electrical energy into heat and light than a 60 W bulb.

20. Electrical Energy

The loss of electrical potential energy in maintaining current in a circuit is called **electrical energy** *consumed in the circuit.*

Thus in Fig. 1.8 above, as the charge q (= $I\,t$) moves from point A to B, it loses electric potential energy = $q\,V = V\,I\,t$ joules. This loss of electric potential energy is converted into heat.

We say that electrical energy consumed in t seconds is VIt joules.

$$\therefore \quad \text{Electrical energy consumed, } W = V\,I\,t = I^2 R\,t = \frac{V^2}{R}\,t \text{ joules}$$

---

* Taking V along Y-axis and I along X-axis.

Unit of Electrical Energy. $W = V\,I\,t$ = power × time

The SI unit of power is 1W and that of time is 1s so that SI unit of electrical energy = 1 W × 1 s = 1 Ws or 1 J.

1 J (or 1Ws) energy is consumed when a device (e.g., bulb, heater, etc.) converts electrical energy to other forms at a rate of 1 W for a time of 1 second.

Commercial Unit. In practice, electrical energy is measured in kilowatt-hour (kWh).

1 kWh energy is consumed when a device converts electrical energy to other forms at a rate of 1 kW for a time of 1 hour.

Electrical energy in kWh = Power in kW × Time in hours

The electricity bills are made on the basis of total electrical energy consumed by the consumer. The unit for billing of electrical energy is 1 kWh. Thus when we say that a consumer has consumed 100 units, it means that electrical energy consumption is 100 kWh.

21. Use of Power and Energy Formulas

It has already been discussed that electric power as well as electrical energy consumed can be expressed by three formulas. While using these formulas, the following points may be kept in mind :

(*i*) Electric Power, $P = I^2R = \dfrac{V^2}{R}$ watts

Electrical energy consumed, $W = I^2Rt = \dfrac{V^2}{R}t$ joules

The above formulas apply *only* to resistors and to devices (*e.g.*, electric bulb, heater, electric kettle etc.) where all electrical energy consumed is converted into heat.

(*ii*) Electric power, $P = V\,I$ watts

Electrical energy consumed, $W = V\,I\,t$ joules

These formulas apply to any type of load including the one mentioned in para (*i*).

22. Electrical Materials

The materials used in electricity and electronics can be broadly divided into three major types *viz*

1. Conductors **2.** Semiconductors **3.** Insulators

Conductors (*e.g.* copper, aluminium etc.) conduct current very easily while insulators (*e.g.* glass, mica, paper) practically conduct no current. In other words, conductors have small resistivity and insulators have high value of resistivity. The resistivity of semiconductors (*e.g.* germanium, silicon etc.) lies between conductors and insulators.

1. Conductors

(*i*) Conductors are formed by metallic bonds. These bonds are based on a structure of positive metal ions surrounded by a cloud of electrons.

(*ii*) *Conductors have positive temperature coefficient of resistance i.e* their resistance increases with the rise in temperature and vice-versa [See Fig. 1.9].

(*iii*) Conductors are used to carry current in electric circuits.