Chapter 8

Current Electricity

(D) Electricity and Magnetism

SYLLABUS

(i) Ohm's law, concepts of e.m.f., potential difference, resistance; resistances in series and parallel; internal resistance.

Scope of syllabus : Concepts of p.d. (V), current (I) and resistance (R) and charge (Q). Ohm's law: statement, $V = IR$; SI units; experimental verification; graph of V vs I and resistance from slope; ohmic and non-ohmic resistors, factors affecting resistance (including specific resistance) and internal resistance, super conductors, electromotive force (e.m.f.); combination of resistances in series and parallel and derivations of expressions for equivalent resistance. Simple numerical problems using the above relations. (Simple network of resistors).

(ii) Electrical power and energy.

Scope of syllabus : Electrical energy; examples of heater, motor, lamp, loudspeaker *etc.*, electrical power, measurement of electrical energy; $W = QV = VIt$ from the definition of p.d., Combining with Ohm's law $W = VIt = I^2Rt = (V^2/R)t$ and electrical power $P = (W/t) = VI = I^2R = V^2/R$, Units : S.I. and commercial; power rating of common appliances, household consumption of electric energy; calculation of total energy consumed by electrical appliances; $W = Pt$ (kilowatt × hour = kWh), (simple numerical problems).

(A) CONCEPT OF CHARGE, CURRENT, POTENTIAL, POTENTIAL DIFFERENCE, AND RESISTANCE; OHM'S LAW

8.1 CONCEPT OF CHARGE

In class IX, we have read that when two bodies (such as glass and silk or ebonite and fur) are rubbed together, there is a transfer of electrons from one body to the other. The body which gains electrons becomes negatively charged and the body which loses electrons becomes positively charged. Thus there are *two* kind of charges : (1) positive charge, and (2) negative charge. Two like charges repel each other, while the two unlike charge attract each other. The charge on a bdoy is denoted by the symbol q (or Q).

Unit of charge : The S.I. unit of charge is **coulomb** (symbol C). The smaller units of charge are milli-coulomb (mC), micro-coulomb (μC) and nano-coulomb (nC) where

1 mC $= 10^{-3}$ C, 1 μC $= 10^{-6}$ C, and

1 nC $= 10^{-9}$ C

The quantity of charge on a body is determined by the number of electrons in deficit (if the body is positively charged) or the number of electrons in excess (if the body is negatively charged). Thus, charge on a body $q = \pm ne$ where n is the number of electrons in deficit for + sign and in excess for – sign while e is the charge on an electron. The charge on an electron is $-1{\cdot}6 \times 10^{-19}$ C, so 1 C charge means a deficit of $\frac{1}{1{\cdot}6\times10^{-19}} = 6{\cdot}25 \times 10^{18}$ electrons.

8.2 CONCEPT OF CURRENT

The charge in motion constitutes electric current. ***Current is defined as the rate of flow of charge.*** In other words, the current flowing in a conductor is the amount of charge flowing per second through it. If a charge Q flows through the cross section of a conductor in time t, then current I through it is given as :

$$\boxed{I = \frac{Q}{t}} \qquad ...(8.1)$$

> ***Note :*** The current in a circuit is measured by an ammeter by connecting it in *series* in that circuit, taking care that the +ve marked terminal of ammeter is towards the positive terminal of the source of current.

Unit of current : The S.I. unit of charge is coulomb and therefore current is measured in coulomb per second which has been given the name **ampere** (symbol A) in honour of the French physicst Andre Ampere. We define *one ampere as the current which flows when one coulomb of charge passes in one second. i.e.,*

$$\boxed{1\ \text{A} = \frac{1\ \text{C}}{1\ \text{s}} = 1\ \text{C s}^{-1}} \qquad ...(8.2)$$

To express a weak current, the smaller units of current are **milli-ampere** (mA) and **micro-ampere** (μA) which are related to ampere (A) as follows :

$$1\ \text{mA} = 10^{-3}\text{A} \quad \text{and} \quad 1\ \mu\text{A} = 10^{-6}\ \text{A}$$

Flow of current : In metals, the moving charges are free electrons which constitute the current, while in electrolytes and ionised gases, both the positively charged ions (cations) and the negatively charged ions (anions) are the moving charges which constitute current.

If n electrons pass through the cross section of a conductor in time t, then total charge passed through the conductor is given as

$$\boxed{Q = n \times e} \qquad ...(8.3)$$

and the current in conductor is

$$\boxed{I = \frac{Q}{t} = \frac{ne}{t}} \qquad ...(8.4)$$

Since 1 C charge is carried by $6{\cdot}25 \times 10^{18}$ electrons, so if 1 A current flows through a conductor, it implies that $6{\cdot}25 \times 10^{18}$ electrons pass in 1 second across the cross section of conductor.

> ***Note :*** Current is a *scalar* quantity. By stating the direction of current, we mean that the direction of motion of electrons is opposite to it.

8.3 CONCEPT OF POTENTIAL AND POTENTIAL DIFFERENCE (P.D.)

Potential : We have read that the like charges repel, while the unlike charges attract each other. If a charge A is brought near another like charge B, some work has to be done in moving the charge A against the repulsive force on it due to the other charge B. Similarly if a charge A is brought near another unlike charge B, work is done by the attractive force on the charge A due to the unlike charge B. Thus some work is always involved in moving a charge in the vicinity of another charge. Therefore, the potential at a point in a region of charges, is measured in terms of the work done in moving a test charge* from a point of zero potential to that point. Since force between the two charges at infinite separation is zero, therefore we consider the potential to be zero when the test charge is at infinite separation from the other charge. Then we define potential as under :

> *The potential at a point is defined as the amount of work done in bringing a unit positive charge from infinity to that point.*

It is denoted by the symbol V. It is a *scalar* quantity.

> ***Note :*** The potential is positive at a point in the vicinity of a positive charge since work has to be done on the positive test charge against the repulsive force due to the positive charge in bringing it from infinity, while it is negative at a point in the vicinity of a negative charge since work is done on the test charge by the attractive force itself.

In Fig. 8.1, a test charge Q is brought from infinity to a point P in the vicinity of a positively charged body.

* A test charge is a charge of known small value. It is considered such that its presence does not disturb the charges already present in that region.

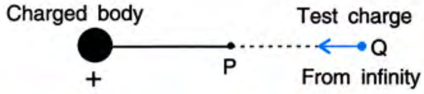


Fig. 8.1 Bringing a test charge Q from infinity to a point in the vicinity of a charged body

If W joule of work is done in bringing the test charge Q coulomb from infinity to the point P, then electric potential V at the point P is given as

$$\boxed{V = \frac{W}{Q}} \quad ....(8.5)$$

Obviously the work needed to move a charge Q from infinity to a point P where electric potential is V, will be

$$\boxed{W = QV} \quad .....(8.6)$$

Unit of electric potential

From eqn. (8.5),

$$\text{Unit of potential } V = \frac{\text{unit of work } W}{\text{unit of charge } Q}$$

The S.I. unit of work is joule and that of charge is coulomb, so the S.I. unit of potential is joule/coulomb (or J C^{-1}) which has been given the name **volt** (symbol V) in the honour of the scientist Volta. Hence, *the potential at a point is said to be* 1 volt *when* 1 *joule of work is done in bringing* 1 *coulomb charge from infinity to that point.* Thus,

$$\boxed{1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}} = 1 \text{ J C}^{-1}} \quad ...(8.7)$$

Potential difference (p.d.)

In practice when we consider the flow of current between two points A and B of an electric circuit, we consider only the flow of charge between the two points A and B, therefore it is not necessary to know the exact potential at each point A and B. It is sufficient to know the *potential difference* (abbreviated as p.d.) between the two points A and B. Using the definition of potential at a point, the potential difference between two points can be defined as follows :

The potential difference (p.d.) between two points is equal to the work done in moving a unit positive charge from one point to the other.

It is a *scalar* quantity.

If W joule of work is done in moving a test charge Q coulomb from a point A to the point B, the potential difference between the two points A and B is

$$\boxed{V_A - V_B = \frac{W}{Q}} \quad ....(8.8)$$

Note : The potential difference between two points in an electric circuit is measured by a voltmeter which is connected across those points *in parallel* with the circuit, taking care that the +ve marked terminal of voltmeter is connected to the higher potential point.

Unit of potential difference

Potential difference (p.d.) is also expressed in **volt** (V). *The potential difference between two points is said to be* 1 *volt if the work done in moving* 1 *coulomb charge from one point to other is* 1 *joule, i.e.,*

$$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}} = 1 \text{ J C}^{-1}$$

8.4 CONCEPT OF RESISTANCE

When current flows through a conductor (say, a metallic wire), the wire offers some obstruction to the flow of current *i.e.*, it offers some resistance. Thus,

The obstruction offered to the flow of current by the conductor (or wire) is called its resistance.

Cause of resistance : A metal has a large number of electrons and an equal number of positive ions (*i.e.*, the atoms which have given out electrons). The positive ions do not move, while the electrons move *almost freely* inside the metal.

These electrons are called the *free electrons*. They move at random, colliding among themselves and with the positive ions as shown in Fig. 8.2 (a).

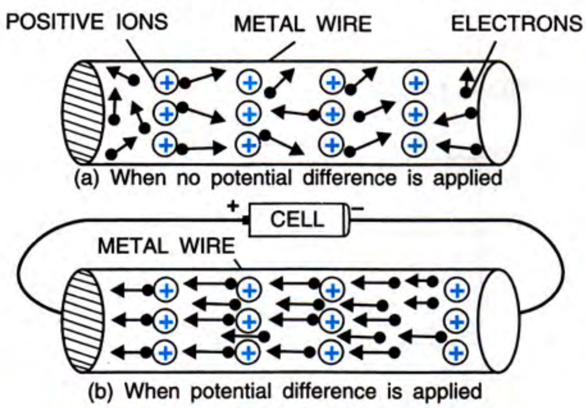


Fig. 8.2 Flow of current in a metal wire

When the ends of the metal wire are connected to a cell (or a source of current), *i.e.*, when a potential difference is applied across the ends of the metal wire, the electrons inside it (due to acceleration) start moving from the end at negative potential towards the end at positive potential [Fig. 8.2 (b)] during which their speed increases. But during the movement, they collide with the fixed positive ions and lose some of their kinetic energy due to which their speed decreases. After the collision, they are again accelerated towards the positive potential due to the existing potential difference so their speed again increases and then again in collision with the positive ions, their speed decreases. This process continues. As a result, *the electrons do not move in bulk with a continuously increasing speed, but there is a drift of electrons towards the positive terminal.* Thus a metal wire offers some resistance to the flow of electrons through it.

The resistance of a conductor depends on the number of collisions suffered by the electrons with the positive ions while moving from one end to the other end.

8.5 OHM'S LAW ($V = IR$)

We have read that for the continuous flow of current in a conductor, a constant potential difference has to be maintained across it. In 1826, a German scientist Georg Simon Ohm, by his experiments, found a relationship between the potential difference and current in a conductor. This relationship is stated in form of a law known as Ohm's law.

Statement of Ohm's law

According to Ohm's law, the current flowing in a conductor is directly proportional to the potential difference applied across its ends provided the physical conditions and the temperature of conductor remain constant.

The direct proportionality between the current and potential difference implies that if the potential difference across the ends of a conductor is doubled, the current flowing in it also gets doubled.

If a current I flows in a conductor when the potential difference across its ends is V, then according to Ohm's law

$$I \propto V$$

or $$\boxed{\frac{V}{I} = \text{constant}} \qquad ...(8.9)$$

In eqn. (8.9), we put the constant equal to R, the *resistance of conductor.* Then,

$$\boxed{V = IR} \qquad ...(8.10)$$

Here the resistance R is a constant at a given temperature for the given conductor.

If $I = 1$, then $V = R$

Thus the resistance of a conductor is numerically equal to the potential difference across its ends when unit current flows through it.

Unit of resistance : From relation (8.10),

$$\text{Unit of } R = \frac{\text{unit of } V}{\text{unit of } I}$$

The S.I. unit of potential difference is volt and that of current is ampere, so the unit of resistance is volt/ampere (or V A^{-1}) which is named after the scientist Ohm as **ohm**. It is denoted by the symbol Ω (omega). One ohm is defined as below :

The resistance of a conductor is said to be 1 ohm if 1 ampere current flows through it when a potential difference of 1 volt is applied across the ends of the conductor, *i.e.*,

$$1 \text{ ohm} = \frac{1 \text{ volt}}{1 \text{ ampere}}$$

High resistances are measured in units : kilo-ohm (kΩ) and mega-ohm (MΩ), where

$$1 \text{ kilo-ohm (or } 1 \text{ k}\Omega) = 10^3\ \Omega$$

and $$1 \text{ mega-ohm (or } 1 \text{ M}\Omega) = 10^6\ \Omega$$

Conductance : The reciprocal of resistance is called ***conductance.*** *i.e.*,

$$\text{Conductance} = \frac{1}{\text{Resistance}} \quad ....(8.11)$$

Its unit is $(\text{ohm})^{-1}$ or siemen (symbol Ω^{-1}).

Note : Now a days we do not write mho for $(\text{ohm})^{-1}$.

***I-V* graph :** For a metallic conductor, the ratio *V/I* is constant for all values of *V* and *I*. If a graph is plotted for current *I* against potential difference *V*, we get a straight line passing through origin as shown in Fig. 8.3.

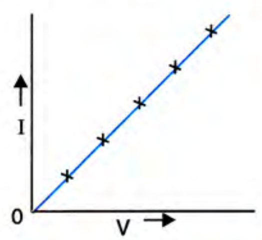


Fig. 8.3 I - V graph for a metallic conductor

Slope of *I-V* graph : The slope of *I-V* graph is $\frac{\Delta I}{\Delta V}$ which is the reciprocal of resistance of the conductor, *i.e.*,

$$\text{Slope} = \frac{\Delta I}{\Delta V} = \frac{1}{\text{resistance of the conductor}} \quad ..(8.12)$$

Limitation of Ohm's law : *Ohm's law is obeyed only when the temperature of conductor remains constant.*

8.6 EXPERIMENTAL VERIFICATION OF OHM'S LAW

Electric circuit

To verify Ohm's law, the electric circuit used is shown in Fig. 8.4.

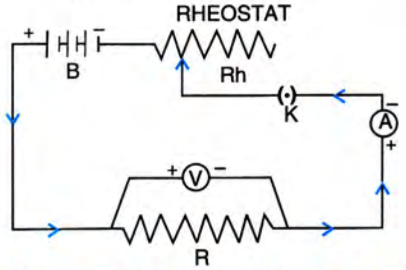


Fig. 8.4 Electric circuit for verification of Ohm's law

The rheostat Rh, key K, ammeter A and resistance wire R are connected in series with the battery B, taking care that the + ve marked terminal of ammeter A is towards the positive terminal of the battery. The voltmeter V is then connected in parallel across the resistance wire R keeping its + ve marked terminal towards the positive terminal of the battery.

The battery (B) sends current in the circuit. The current in the circuit is controlled by the rheostat (Rh) and the ammeter (A) measures the current. The key K is used to make and break the circuit. The wire R (say, a nichrome wire) is the unknown resistance. The voltmeter (V) measures the potential difference across the ends of the resistance wire R.

Procedure

As the key K is closed, current flows in the circuit. The rheostat Rh is adjusted to get the minimum (non-zero) reading in the ammeter A and voltmeter V. The ammeter reading *I* and the voltmeter reading *V* are noted. The sliding terminal of rheostat is then moved to increase the current gradually and each time the value of current *I* flowing in the circuit and the potential difference *V* across the resistance wire R are recorded by noting the readings of the ammeter A and voltmeter V respectively. In this way, different sets of the values of *I* and *V* are recorded in the table given below. Then for each set of values of I and V, the ratio V/I is calculated.

Observations

S.No.	Ammeter reading I (in ampere)	Voltmeter reading V (in volt)	Resistance $R = V/I$ (in ohm)
1			
2			
3			
4			
5			
6			

Average R = ... ohm

From the above table, it is noticed that for each observation, *the ratio V/I is almost constant* and so its average value gives the resistance R of the wire.

***V-I* graph :** A graph is plotted for V against I by taking V on Y-axis and I on X-axis which is found to be a straight line as shown in Fig. 8.5. This verifies the Ohm's law.

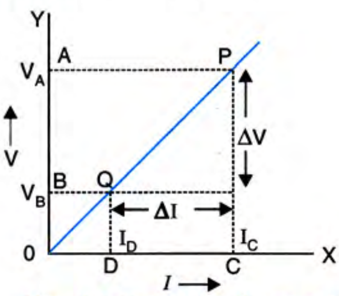


Fig. 8.5 Graph for V verses I

Slope of *V-I* graph : To find the slope of straight line obtained on $V–I$ graph, take two points P and Q on the straight line. From the points P and Q, draw normals PA and QB on the Y-axis; and PC and QD on the X-axis. Read the potential V_A at A and V_B at B and find the difference $V_A - V_B = \Delta V$. Similarly read the current I_C at C and I_D at D, and find the difference $I_C - I_D = \Delta I$. Then find the slope = $\Delta V/\Delta I$.

The slope of the straight line on $V–I$ graph *i.e.*, $(\Delta V/\Delta I)$ gives the resistance R of the conductor (or wire), *i.e.*,

$$\boxed{R = \frac{\Delta V}{\Delta I} = \text{slope of } V \text{ vs } I \text{ graph}} \quad ..(8.13)$$

Obviously, greater is the slope of V-I graph, greater is the resistance of conductor.

8.7 OHMIC AND NON-OHMIC RESISTORS

Ohmic resistors : The conductors which obey the Ohm's law are called the *ohmic resistors* (or *linear resistances*). Examples are : all metallic conductors (such as silver, aluminium, copper, iron, *etc.*), nichrome, copper sulphate solution with copper electrodes, and dil. sulphuric acid, *etc.* at a constant temperature.

For such resistors, a graph plotted for the potential difference V against current I is a straight line passing through the origin as shown in Fig. 8.5 and the *resistance R is same irrespective of the value of* V or I (*i.e.*, the ratio V/I is constant for all values of V or I).

Non-ohmic resistors : The conductors which do not obey the Ohm's law are called the *non-ohmic resistors* (or *non-linear resistances*). Examples are : LED, solar cell, junction diode, transistor, filament of a bulb, *etc.*

For these conductors, the graph plotted for the potential difference V against current I is not a straight line, but it is a curve. Fig. 8.6 shows a $V–I$ graph in case of a junction diode.

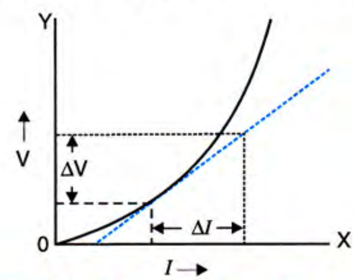


Fig. 8.6 Graph for V vs I for non-ohmic conductors

> ***Note :*** For the Ohmic resistor, it is necessary that the straight line on $V–I$ graph passes through the origin; but for a non-ohmic resistor, it is not necessary that the curve on $V–I$ graph must pass through the origin.

The resistance of such a conductor (*i.e.*, the ratio V/I) is different for different values of V or I. The resistance at a particular value of V or I is obtained by finding the slope of the tangent drawn at the corresponding point on the $V–I$ graph. The value $\Delta V/\Delta I$ is called the *dynamic resistance* since its value is different for the different values of V or I.

Distinction between the ohmic and non-ohmic resistors

Ohmic resistor	Non-ohmic resistor
1. It obeys the Ohm's law. *i.e.,* V/I is constant for all values of V or I.	1. It does not obey the Ohm's law *i.e.,* V/I is not same for all values V or I.
2. The graph for potential difference V versus current I is a straight line.	2. The graph for potential difference V versus current I is not a straight line.
3. The slope of $V–I$ graph is same at all values of V or I at a given temperature	3. The slope of $V–I$ graph is different at different values of V or I even at a given temperature.
Examples : All metallic conductors such as silver, iron, copper, nichrome, electrolyte with suitable electrodes, etc.	*Examples* : Junction diode, LED, transistor, filament of a bulb, etc.

Factors affecting the resistance of a conductor

The resistance of a conductor depends on the following *four* factors :

(1) nature of conductor,

(2) length of conductor,

(3) thickness of conductor, and

(4) temperature of conductor.

(1) *Dependence on the material of conductor :* Different substances have different concentration of free electrons and therefore *the resistance of a conductor depends on its material.* Substances such as silver, copper, lead, aluminium, etc. have high concentration of free electrons, so they offer less resistance and are, therefore, called the *good conductors* of electricity. But the substances such as rubber, glass, wood, etc. have negligible concentraton of free electrons, so they offer very high resistance and are called the *insulators* of electricity.

(2) *Dependence on the length of conductor :* In a long conductor, the number of collisions of free electrons with the positive ions will be more as compared to a shorter one. Therefore, *a longer conductor offers more resistance.* In fact, the resistance of a conductor is directly proportional to the length l of the conductor *i.e.,*

$$\boxed{R \propto l} \qquad ....(8.14)$$

If the length of wire of same radius is doubled, the resistance of the wire gets doubled.

(3) *Dependence on the thickness of conductor :* In a thick conductor, electrons get a larger area of cross section to flow as compared to a thin conductor, therefore *a thick conductor offers a less resistance.* The resistance of a conductor is inversely proportional to its area of cross section a normal to the direction of flow of current *i.e.,*

$$\boxed{R \propto \frac{1}{a}} \qquad ....(8.15)$$

If the radius of wire of same length is doubled (or area of cross section becomes four times), its resistance becomes *one-fourth;* if the radius is *tripled* (or area of cross section becomes nine times), the resistance becomes *one-ninth* and so on.

(4) *Dependence on the temperature of conductor:* With the increase in temperature of a conductor, the random motion of electrons increases. As a result, the number of collisions of electrons with the positive ions increases. Hence, *the resistance of conductor increases with an increase in its temperature.* The resistance of filament of a bulb is more when it is glowing (*i.e*, when it is at a high temperature) as compared to that when it is not glowing (*i.e.*, when it is cold).

***V-I* graph for a conductor at two temperatures :** Fig. 8.7 shows two straight lines A and B on the *V-I* graph for a conductor at two different temperatures T_1 and T_2 ($T_1 > T_2$) respectively. The straight line A is more steeper

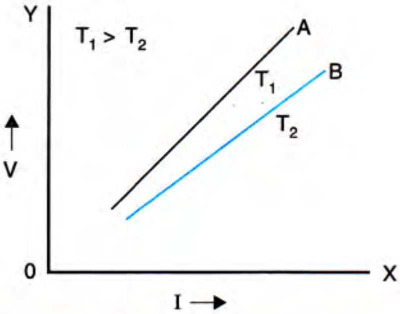


Fig. 8.7 V-I graph of a conductor at two temperatures T_1 and T_2

than the line B because the resistance of conductor is more at high temperature T_1 than at low temperature T_2.

8.9 SPECIFIC RESISTANCE (OR RESISTIVITY)

Experimentally it has been observed that

(1) *The resistance of a wire is directly proportional to its length. i.e.,*

$$\boxed{R \propto l} \quad \text{........ (i)}$$

(2) *The resistance of a wire varies inversely as the area of cross section of the wire. i.e.,*

$$\boxed{R \propto \frac{1}{a} \text{ or } R \propto \frac{1}{\pi r^2}} \quad \text{........ (ii)}$$

where r is the radius of wire.

Combining the above eqns. (i) and (ii),

$$\boxed{R \propto \frac{l}{a} \quad \text{or} \quad R = \rho\frac{l}{a} = \rho\frac{l}{\pi r^2}} \quad \text{....(8.16)}$$

Here ρ is a constant which is called the ***specific resistance*** (or ***resistivity***) of the material of the wire.

From the above relation (8.16),

Specific resistance $\rho = \frac{Ra}{l}$

If $l = 1$, $a = 1$, then $\rho = R$. Thus,

Specific resistance of a material is the resistance of a wire of that material of unit length and unit area of cross section.

Unit of specific resistance : From relation $\rho = \frac{Ra}{l}$

$$\text{Unit of } \rho = \frac{\text{unit of } R \times \text{unit of } a}{\text{unit of } l}$$

$$= \frac{\text{ohm} \times \text{metre}^2}{\text{metre}} = \text{ohm} \times \text{metre (or } \Omega \text{ m)}$$

Thus the unit of specifici resistances is ohm × metre (or Ω m).

Specific resistance of some substances at 20°C

Substance	Specific reistance (Ω m)	Substance	Specific reistance (Ω m)
Metals		**Semiconductors**	
Silver	$1{\cdot}63 \times 10^{-8}$	Graphite	$0{\cdot}2 \times 10^{-5}$
Copper	$1{\cdot}73 \times 10^{-8}$	Germanium	$0{\cdot}6 \times 10^{-5}$
Aluminium	$2{\cdot}63 \times 10^{-8}$	Silicon	$2{\cdot}3 \times 10^{-5}$
Lead	$2{\cdot}8 \times 10^{-8}$	Carbon	$3{\cdot}5 \times 10^{-5}$
Tungsten	$5{\cdot}5 \times 10^{-8}$		
Iron	$9{\cdot}8 \times 10^{-8}$		
Tin	$11{\cdot}3 \times 10^{-8}$	**Insulators**	
Steel	20×10^{-8}	Wood	$10^{8} - 10^{11}$
Alloys		Glass	$10^{10} - 10^{14}$
Brass	$6{\cdot}6 \times 10^{-8}$	Diamond	nearly 10^{12}
Manganin	44×10^{-8}	Amber	5×10^{14}
Constantan	49×10^{-8}	Mica	$10^{11} - 10^{15}$
Nichrome	100×10^{-8}	Polythene	nearly 10^{16}

Factors affecting the specific resistance

(1) The specific resistance of a substance is its charactertic. It is different for different substances. It is very low for metals ($\approx 10^{-8}$ Ω m), low for semiconductor ($\approx 10^{-5}$ Ω m), but very high for insulators ($\approx 10^{13}$ Ω m).

(2) The specific resistance of a substance depends on its temperature. It increases with the increase in temperature for metals, but it decreases with the increase in temperature for semiconductors. For some alloys e.g. constantant, manganin, it remains practically constant with change in temperature.

Note : The specific resistance of material of a conductor is constant at a given temperature and it does not depend on the shape and size of the conductor. From eqn. (8.16), it is evident that if a given wire is *stretched* such that its length gets doubled, then its area of cross section will get halved (since the volume remains unchanged). Now the resistance will *increase to four times* of its previous value (twice because of the increase in length and then twice because of the decrease in the area of cross section). Similarly, if the length is increased to *three times by stretching* the wire, its resistance becomes *nine times* of its previous value. On the other hand, if a wire is *doubled on itself,* its length is halved and area of cross section is doubled, so the the resistance becomes *one-fourth* of its previous value. But in each case, specific resistance is unchanged.

Conductivity

The reciprocal of specific resistance is known as *conductivity.* It is represented by the symbol σ (sigma). Thus conductivity

$$\boxed{\sigma = \frac{1}{\rho} = \frac{l}{Ra}} \qquad ....(8.17)$$

Its S.I. unit is $\frac{1}{\text{ohm} \times \text{metre}}$ or ohm^{-1} metre^{-1} (symbol Ω^{-1} m^{-1}) or siemen metre^{-1}.

8.10 CHOICE OF MATERIAL OF A WIRE

The choice of material of a wire depends on the purpose for which the wire is to be used.

(1) **The wires used for electrical connections and for power transmission :** Such wires should possess negligible resistance. Due to low (or negligible) resistance of connection wires, the current in circuit remains unaffected, and the loss of energy due to heating is prevented. Hence they are made of materials such as *copper* or *aluminium*, whose specific resistance is very small. Further they are made thick so that their resistance becomes low.

Note : Though specific resistance of silver is less than that of copper, but because of its high cost, silver is not used.

(2) **The resistance wires (or standard resistors) :** Such wires are of high resistance and their resistance almost does not change due to change in temperature. They are made from alloys such as *manganin, constantan, etc.* for which the specific resistance is high and the effect of change in temperature on their resistance is negligible.

(3) **A fuse wire* :** It is made from an *alloy of lead and tin* because its melting point is low and its specific resistance is more than that of copper or aluminium so that the resistance of a short and thin fuse wire is high to the extent that it permits current up to its safe limit to pass through it. An excessive current melts it so that it blows off.

(4) **The filament of an electric bulb :** A *tungsten* wire is used because it has a high melting point.

(5) **The heating element in appliances such as heater, toaster, oven, etc. :** A *nichrome* wire is used because the specific resistance of nichrome is high and its resistance increases to a great extent with the increase in temperature.

8.11 SUPERCONDUCTORS

Experimentally it is observed that the resistance of some substances like tin, lead, *etc.* decreases tremendously with the decrease in temperature and becomes almost zero in the low temperature range near absolute zero. Such substances are called the *superconductors.* Zero resistance of a superconductor means its infinite conductivity (*i.e.*, once a current starts flowing in a superconductor, it persists even when there is no potential difference across it). Thus

A superconductor is a substance of zero resistance (or infinite conductance) at a very low temperature.

Examples : Mercury below 4·2 K, lead below 7·25 K and niobium below 9·2 K are the superconductors.

The superconductors are not in common use since it is very difficult to achieve such a low temperature. However they can be very useful if it is possible to obtain them at room temperature. The size of computers could then be reduced to a few centimetre and power lines could then be made as thin as a single wire.

* Refer chapter 9, article 9.4.

EXAMPLES

1. Fig. 8.8 shown I–V graph for two conductors A and B.

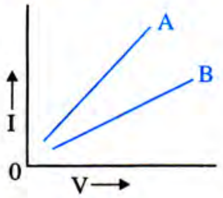


Fig. 8.8

(i) Which of the conductor is ohmic ?

(ii) Which conductor has more resistance ? Give reason to you ranswer.

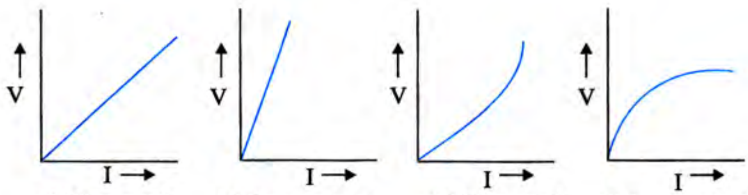
(i) Both conductors **A and B are ohmic.**

(ii) The resistance of **conductor B is more.**

Reason : Resistance = $\dfrac{1}{\text{Slope of } I\text{-}V \text{ graph}}$

Since straight line for conductor B is less steeper than that of conductor A, so the resistance of conductor B is more than that of A.

2. Fig. 8.9 shows V–I graphs experimentally obtained in different cases. Select the graphs for ohmic and non-ohmic resistors.



(a) Pure metal (b) Copper sulphate solution with copper electrodes (c) Filament of a bulb (d) Junction diode

Fig. 8.9

The V–I graphs shown in Fig. 8.9 (a) and (b) are for the ohmic resistors, while in Fig. 8.9 (c) and (d) are for the non-ohmic resistors.

3. Calculate the potential difference required across a conductor of resistance 5 Ω to pass a current of 1·5 A through it .

Given : $R = 5\ \Omega$, $I = 1{\cdot}5$ A, V = ?

From Ohm's law, $V = IR$

∴ Potential difference $V = 1{\cdot}5 \times 5 =$ **7·5 V**

4. An electric gadget draws a current 200 mA from a battery of 12 V. Find its resistance.

Given : $I = 200$ mA $= 200 \times 10^{-3}$ A, $V = 12$ V

$$\text{Resistance } R = \frac{V}{I} = \frac{12\text{ V}}{200 \times 10^{-3}\text{ A}} = 60\ \Omega$$

5. A torch bulb when cold has a resistance 1 Ω. It draws a current 300 mA, when glowing from a source of 3 V. Calculate the resistance of the bulb when glowing and explain the reason for the difference in resistance.

While glowing, $I = 300$ mA $= 0{\cdot}3$ A, $V = 3$ V

$$\therefore \text{Resistance of bulb } R = \frac{V}{I} = \frac{3}{0{\cdot}3} = 10\ \Omega$$

Reason : The difference in resistance of bulb when cold ($R = 1\ \Omega$) and when it glows ($R = 10\ \Omega$), is that the resistance of filament of bulb increases with the increase in temperature.

6. Calculate the resistance of 1 km long copper wire of radius 1 mm.

(Specific resistance of copper is $1{\cdot}72 \times 10^{-8}\ \Omega$ m).

Given : $l = 1$ km $= 1000$ m, $r = 1$ mm $= 10^{-3}$ m,

$a = \pi r^2 = 3{\cdot}14 \times (10^{-3})^2 = 3{\cdot}14 \times 10^{-6}$ m^2,

Specific resistance $\rho = 1{\cdot}72 \times 10^{-8}\ \Omega$ m

$$\text{Resistance } R = \rho\frac{l}{a} = \frac{(1{\cdot}72 \times 10^{-8}) \times 1000}{3{\cdot}14 \times 10^{-6}} = 5{\cdot}5\ \Omega$$

7. When a potential difference of 2 volt is applied across the ends of a wire of 5 m length, a current of 1 A flows through it. Calculate :

(i) the resistance per unit length of the wire,

(ii) the resistance of 2 m length of the wire,

(iii) the resistance across the ends of the wire if it is doubled on itself.

(i) Given $V = 2$ volt, $I = 1$ A

Resistance of 5 m length of wire

$$R = \frac{V}{I} = \frac{2}{1} = 2\ \Omega$$

Resistance per unit length of the wire

$$= \frac{R}{l} = \frac{2}{5} = 0{\cdot}4\ \Omega\ \text{m}^{-1}$$

(ii) Resistance of 2 m length of the wire

= Resistance per unit length × length

$= 0{\cdot}4 \times 2 =$ **0·8 Ω**

(iii) When the wire is doubled on itself, its area of cross section becomes twice and the length becomes half. Let a be the initial area of cross section and ρ be the specific resistance of the material of wire. Then

$$l = 5 \text{ m}, R = 2\ \Omega, l' = 2{\cdot}5 \text{ m}, a' = 2a.$$

From relation $R = \rho \frac{l}{a}$, we have

Initial resistance $2 = \rho \frac{5}{a}$ .... (i)

New resistance $R' = \rho \frac{2{\cdot}5}{2a}$ .... (ii)

On dividing eqn. (ii) by eqn. (i),

$$\frac{R'}{2} = \frac{2{\cdot}5\rho}{2a} \Big/ \frac{5\rho}{a} = \frac{1}{4}$$

$$\therefore \quad R' = \frac{2}{4} = 0{\cdot}5\ \Omega$$

Thus on doubling the wire on itself, its resistance become one-fourth.

EXERCISE–8(A)

1. Define the term current and state its S.I. unit.
2. Define the term electric potential. State its S.I. unit.
3. How is the electric potential difference between the two points defined ? State its S.I. unit.
4. Explain the statement 'the potential difference between two points is 1 volt'.
5. (a) State whether the current is a scalar or vector ? What does the direction of current convey ?
   (b) State whether the prtential is a scalar or vector ? What does the positive and negative sign of potential convey ?
6. Define the term resistance. State its S.I. unit.
7. (a) Name the particles which are responsible for the flow of current in a metal.
   (b) Explain the flow of current in a metal on the basis of movement of the particles named by you above in part (a).
8. State Ohm's law and draw a neat labelled circuit diagram containing a battery, a key, a voltmeter, an ammeter, a rheostat and an unknown resistance to verify it.
9. (a) Name and state the law which relates the potential difference and current in a conductor.
   (b) What is the necessary condition for a conductor to obey the law named above in part (a) ?
10. (a) Draw a V-I graph for a conductor obeying Ohm's law. (b) What does the slope of V-I graph for a conductor represent ? **Ans.** (b) resistance
11. Draw a I–V graph for a linear resistor. What does its slope represent ?
12. What is an ohmic resistor ? Give *one* example of an ohmic resistor. Draw a graph to show its current-voltage relationship. How is the resistance of the resistor determined from this graph ?
13. What are non-ohmic resistors ? Give *one* example and draw a graph to show its current-voltage relationship.
14. Give *two* differences between an ohmic and non-ohmic resistor.
15. Fig. 8.10 below shows the I–V curves for two resistors. Identify the ohmic and non-ohmic resistors. Give a reason for your answer.

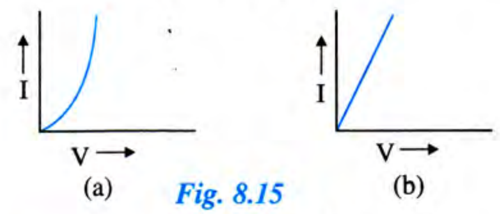


Fig. 8.15

Ans. ohmic – (b); non-ohmic – (a)

Reason : For (b), I–V graph is a straight line, while for (a), the graph is a curve.

16. Draw a V-I graph for a conductor at two different temperatures. What conclusion do you draw from your graph for the variation of resistance of conductor with temperature ?
17. (a) How does the resistance of a wire depend on its radius ? Explain your answer.
    (b) Two copper wires are of same length, but one is thicker than the other. Which will have more resistance ? **Ans.** thin wire
18. How does the resistance of a wire depend on its length ? Give a reason for your answer.
19. How does the resistance of a metallic wire depend on its temperature ? Explain with reason.
20. Two wires, one of copper and other of iron, are of the same length and same radius. Which will have more resistance ? Give reason. **Ans.** iron wire.

    Reason : specific resistance of iron is more than that of copper.

21. Name *three* factors on which resistance of a given wire depends and state how is it affected by the factors stated by you.

22. Define the term specific resistance and state its S.I. unit.

23. Write an expression connecting the resistance of a wire and specific resistance of its material. State the meaning of symbols used.

24. State the order of specific resistance of (i) a metal, (ii) a semiconductor, and (iii) an insulator.

25. (a) Name *two* factors on which the specific resistance of a wire depends ?
    (b) Two wires A and B are made of copper. The wire A is long and thin, while the wire B is short and thick. Which will have more specific resistance ?
    Ans. Both will have same specific resistance

26. Name a substance of which the specific resistance remains almost unchanged by the increase in temperature. **Ans.** manganin

27. How does specific resistance of a semi-conductor change with the increase in temperature ?

28. How does (a) resistance, and (b) specific resistance of a wire depend on its (i) length, and (ii) radius ?

29. (a) Name the material used for making the connection wires. Give a reason for your answer.
    (b) Why should a connection wire be thick ?

30. Name a material which is used for making the standard resistor. Give a reason for your answer.

31. Name the material used for making a fuse wire. Give a reason.

32. Name the material used for (i) filament of an electric bulb, and (ii) heating element of a room heater.

33. What is a superconductor ? Give *one* example of it.

34. A substance has zero resistance below 1 K. What is such a substance called ? **Ans.** superconductor

MULTIPLE CHOICE TYPE

1. Which of the following is an ohmic resistance ?
   (a) LED (b) junction diode
   (c) filament of a bulb (d) nichrome.
   Ans. (d) nichrome

2. For which of the following substances, resistance decreases with increase in temperature ?
   (a) copper (b) mercury
   (c) carbon (d) platinum. **Ans.** (c) carbon

NUMERICALS

1. In a conductor, $6{\cdot}25 \times 10^{16}$ electrons flow from its end A to B in 2 s. Find the current flowing through the conductor. ($e = 1{\cdot}6 \times 10^{-19}$ C)
   Ans. 5 mA from B to A

2. A current of 1·6 mA flows through a conductor. If charge on an electron is $-1{\cdot}6 \times 10^{-19}$ coulomb, find the number of electrons that will pass each second through the cross section of that conductor.
   Ans. 10^{16}

3. Find the potential difference required to flow a current of 200 mA in a wire of resistance 20 Ω.
   Ans. 4 V

4. An electric bulb draws 1·2 A current at 6·0 V. Find the resistance of filament of bulb while glowing.
   Ans. 5 Ω

5. A car bulb connected to a 12 volt battery draws 2 A current when glowing . What is the resistance of the filament of the bulb ? Will the resistance be more, same or less when the bulb is not glowing ?
   Ans. 6 Ω, resistance will be less when the bulb is not glowing

6. Calculate the current flowing through a wire of resistance 5 Ω connected to a battery of potential difference 3 V. **Ans.** 0·6 A

7. In an experiment of verification of Ohm's law, following observations are obtained.

Potential difference V (in volt)	0·5	1·0	1·5	2·0	2·5
Current I (in ampere)	0·2	0·4	0·6	0·8	1·0

   Draw a V–I graph and use this graph to find :
   (a) the potential difference V when the current I is 0·5 A,
   (b) the current I when the potential difference V is 0·75 V,
   (c) the resistance in circuit.
   Ans. (a) 1·25 V (b) 0·3 A (c) 2·5 Ω

8. Two wires of the same material and same length have radii r_1 and r_2 respectively. Compare : (i) their resistances, (ii) their specific resistance.
   Ans. (i) $r_2^2 : r_1^2$ (ii) 1 : 1

9. A given wire of resistance 1 Ω is stretched to double its length. What will be its new resistance ?
   Ans. 4 Ω

10. A wire of resistance 3 ohm and length 10 cm is stretched to length 30 cm. Assuming that it has a uniform cross section, what will be its new resistance ? **Ans.** 27 Ω

11. A wire of resistance 9 ohm having length 30 cm is tripled on itself. What is its new resistance ?
Ans. 1 Ω

12. What length of copper wire of specific resistance $1 \cdot 7 \times 10^{-8}$ Ω m and radius 1 mm is required so that its resistance is 1 Ω ?
Ans. 184·7 m

13. The filament of a bulb takes a current 100 mA when potential difference across it is 0·2 V. When the potential difference across it becomes 1·0 V, the current becomes 400 mA. Calculate the resistance of filament in each case and account for the difference.
Ans. 2·0 Ω, 2·5 Ω, resistance of filament increases with the increase in temperature

(B) ELECTRO-MOTIVE FORCE, TERMINAL VOLTAGE AND INTERNAL RESISTANCE OF A CELL; COMBINATION OF RESISTORS

8.12 ELECTRO-MOTIVE FORCE (E.M.F.) OF A CELL

We have read that an electric cell has *two* conductors of suitable material kept in an appropriate electrolyte taken in a vessel.

The electric cell maintains a constant difference in potential between the two conductors (called the electrodes or terminals) by a chemical reaction to obtain a continuous flow of charge between them. Thus a cell stores the chemical energy and it can be used as a *source of current (or electrons).* The chemical energy changes into the electrical energy when the cell is in use.

Fig. 8.11 shows an electric cell having two electrodes one of zinc and other of copper, placed in an electrolyte (*i.e.*, dil. sulphuric acid).

The electrolyte (e.g. H_2SO_4) in water dissociates into the positive ions (H^+) and negative ions (SO_4^{2-}). These ions move towards the electrodes. The negative ions (SO_4^{2-}) impart electrons to the zinc electrode and positive ions gain electrons from the copper electrode. This chemical action creates a difference in concentration of electrons between the two electrodes of the cell. As a result, the zinc electrode acquires a negative potential (so it is called the cathode) and the copper electrode acquires a positive potential (so it is called the anode) *i.e.*, a potential difference called the *electro-motive force* (e.m.f.) is created between the two electodes (or terminads) of the cell. When some electrical component (such as bulb etc.) is joined to the terminals of the cell, electrons flow in the external circuit from the zinc electrode to the copper electode (or current flows in the external circuit from the copper electrode to the zinc electrode).

When no current is drawn from a cell i.e., when the cell is in open circuit (Fig. 8.11), the potential difference between the terminals of the cell is called its electro-motive force (or *e.m.f.*).

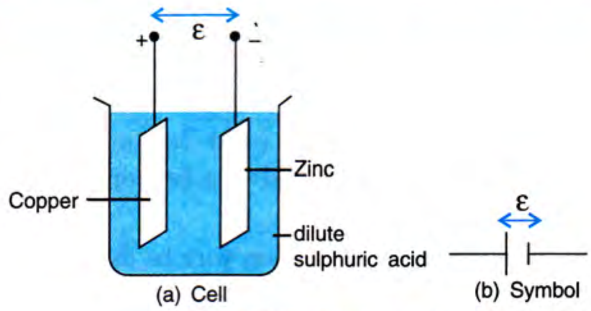


Fig. 8.11 Cell in open circuit

The e.m.f. of a cell is generally denoted by the symbol ε (epsilon). Its unit is volt (symbol V). It can be measured by connecting a voltmeter of high resistance across the cell.

When a cell is connected in a circuit containing various electrical components, a current flows in the external circuit because the e.m.f. between the terminals provide energy for the charge to flow through the components joined in the circuit. Therefore,

The e.m.f. of a cell is defined as the energy spent (or the work done) per unit charge in taking a positive test charge around the complete circuit of the cell (i.e., in the circuit outside the cell as well as in the electrolyte inside the cell).

If W work is done in taking a test charge q around the complete circuit of the cell, then e.m.f. of the cell is

$$\boxed{\varepsilon = \frac{W}{q}} \quad ...(8.18)$$

Factors affecting the e.m.f. of a cell

The e.m.f. of a cell depends on : (1) the material of the electrodes, and (2) the electrolyte used in the cell. However, it is independent of (a) the shape of electrodes, (b) the distance between the electrodes, and (c) the amount of electrolyte.

Thus the e.m.f. of a cell is its characteristic property. It is different for different kind of cells. For example, the e.m.f. of a *voltaic cell* is 1·08 volt, that of a *Leclanche cell* is 1·5 volt and of a *Daniel cell* is 1·08 volt.

8.13 TERMINAL VOLTAGE OF A CELL

When current is drawn from a cell i.e., when the cell is in closed circuit (Fig. 8.12), the potential difference between the electrodes of the cell is known as its terminal voltage.

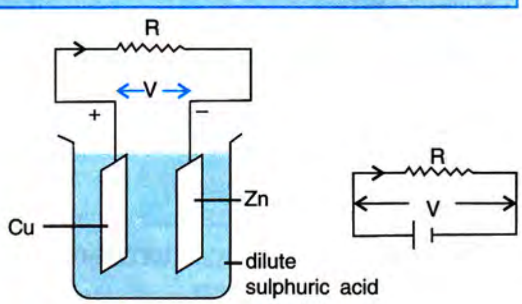


Fig. 8.12 Cell in closed circuit

The terminal voltage of a cell is generally denoted by the letter V. *It is also expressed in volt* (symbol V).

The terminal voltage of a cell is defined as the work done per unit charge in carrying a positive test charge around the circuit connected across the terminals of cell.

If W' is the work done in carrying a test charge q around the circuit connected across the terminals of a cell (*i.e.*, only outside the cell and not inside the cell), then the terminal voltage of the cell is

$$\boxed{V = \frac{W'}{q}} \quad ...(8.19)$$

Voltage drop in a cell

From the definitions of e.m.f. and terminal voltage of a cell, it is clear that the terminal voltage V of a cell is less* than its e.m.f. ε by the amount of energy spent in the flow of charge through the electrolyte inside the cell. If w is the work done (or energy spent) in carrying a test charge q through the electrolyte inside the cell, then the quantity $\frac{w}{q}$ is called the voltage drop in the cell which is denoted as v, *i.e.*

$$\boxed{\text{Voltage drop in the cell } v = \frac{w}{q}} \quad ....(8.20)$$

Thus, *the work done in carrying a unit charge through the electrolyte is called the voltage drop in the cell.* It is so called because this voltage is not available to us for use.

Relationship between e.m.f. and terminal voltage of a cell.

By the law of conservation of energy,

$$W = W' + w \quad ....(i)$$

Dividing the above eqn. (i) by q on both the sides, we get

$$\frac{W}{q} = \frac{W'}{q} + \frac{w}{q} \quad .....(ii)$$

But from eqns. (8.18), (8.19) and (8.20),

$$\frac{W}{q} = \varepsilon \; ; \; \frac{W'}{q} = V \text{ and } \frac{w}{q} = v.$$

Therefore from eqn (ii),

$$\boxed{\varepsilon = V + v \text{ or } V = \varepsilon - v} \quad ..(8.21)$$

Thus when current is drawn from a cell, its terminal voltage V is less than its e.m.f. ε by an amount equal to the voltage drop v inside the cell. When a heavy current is drawn from

* The terminal voltage V is more than the e.m.f. ε only when the cell is charged by passing current through it.

the cell, a large number of charge carriers flow through the electrolyte and hence more work is done. This results in more voltage drop v and hence less terminal voltage V. Thus, the terminal voltage V of a cell depends on the amount of current I drawn from it.

Distinction between e.m.f. and terminal voltage of a cell

E.m.f. of cell	Terminal voltage of cell
1. It is measured by the amount of work done in moving a unit positve charge in the complete circuit inside and outside the cell.	1. It is measured by the amount of work done in moving a unit postive charge in the circuit outside the cell.
2. It is the characteristic of the cell, *i.e.*, it does not depend on the amount of current drawn from the cell.	2. It depends on the amount of current drawn from the cell. More the current drawn from the cell, less is the terminal voltage.
3. It is equal to the terminal voltage when cell is not in use, while greater than the terminal voltage when cell is in use.	3. It is equal to the e.m.f. of cell when cell is not in use, while less than the e.m.f. when cell is in use.

8.14 INTERNAL RESISTANCE OF A CELL

When a cell is in a closed circuit, the current flows inside the cell through its electrolyte due to the flow of ions (both cations and anions), while outside the cell through the external circuit, due to the flow of free electrons. It flows from anode to cathode in the external circuit and from cathode to anode inside the cell through the electrolyte so as to maintain a continuous flow. *The resistance offered by the electrolyte inside the cell, to the flow of current, is called the internal resistance of cell.* It is the internal resistance of cell due to which its voltage drops on drawing current from it. It is denoted by the symbol r. Its unit is ohm (symbol Ω).

If current I is drawn from the cell of which internal resistance is r, the voltage drop is

$$\boxed{v = Ir} \quad ....(8.22)$$

Note : For circuit analysis, the internal resistance r of a cell is considered to be connected in series with the cell as shown in Fig 8.13.

A cell with its internal resistance is represented as shown in Fig. 8.13.

Fig. 8.13 Representation of a cell with its internal resistance

Relationship between the e.m.f., terminal voltage and internal resistance

Let a cell of e.m.f. ε and internal resistance r be used to send current in an external resistance R connected across the cell as shown in Fig. 8.14.

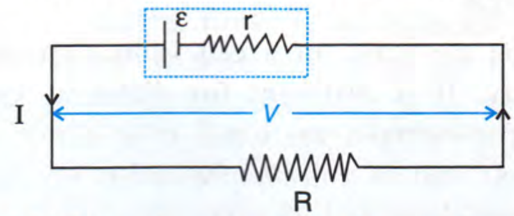


Fig. 8.14 Current in an external resistance from a cell

$$\boxed{\text{Total resistance of circuit} = R + r} \quad ...(8.23)$$

Current drawn from the cell

$$\boxed{I = \frac{\text{e.m.f. of cell}}{\text{total resistance}} = \frac{\varepsilon}{R+r}} \quad ..(8.24)$$

$$\boxed{\text{E.m.f. of cell} \quad \varepsilon = I\,(R + r)} \quad ...(8.25)$$

The terminal voltage of the cell is then

$$\boxed{V = IR} \quad ...(8.26)$$

and voltage drop due to internal resistance is

$$\boxed{v = Ir} \quad ...(8.27)$$

From eqns. (8.25), (8.26) and (8.27),

$$\varepsilon = V + v \text{ or } v = \varepsilon - V$$

Then from eqns. (8.26) and (8.27), internal resistance is

$$\boxed{r = \frac{v}{I} = \frac{\varepsilon - V}{I} = \frac{\varepsilon - V}{V/R} = \left(\frac{\varepsilon}{V} - 1\right)R} \quad ...(8.28)$$

Factors affecting the internal resistance of a cell

The internal resistance of a cell depends on the following *four* factors :

(1) ***The surface area of the electrodes*** – larger the surface area of electrodes, less is the internal resistance.

(2) ***The distance between the electrodes*** – more the distance between the electrodes, greater is the internal resistance.

(3) ***The nature and concentration of the electrolyte*** – less ionic the electrolyte or higher the concentration of electrolyte, greater is the internal resistance.

(4) ***The temperature of the electrolyte*** – higher the temperature of the electrolyte, less is the internal resistance.

8.15 COMBINATION OF RESISTORS

In order to have a desired resistance in a circuit, sometimes we have to connect two or more resistors together. They can be combined in *three* ways : (1) ***in series,*** (2) ***in parallel,*** and (3) ***both in series and parallel.***

> *Note* : When the resistance of the combination is to be increased, they are combined in series and when the resistance of the combination is to be decreased, in order to pass a heavy current in the circuit, they are combined in parallel.

(1) Combination of resistors in series

In the series combination, the resistors are joined one after the other. In Fig. 8.15, three resistors R_1, R_2 and R_3 are connected in series between the points A and D such that one end of resistor R_1 is connected to the point A and its other end to the resistor R_2. The other end of the resistor R_2 is connected to one end of the resistor R_3 and the other end of resistor R_3 to the point D. The ends A and D of the combination are then connected to the terminals of the battery through a key K.

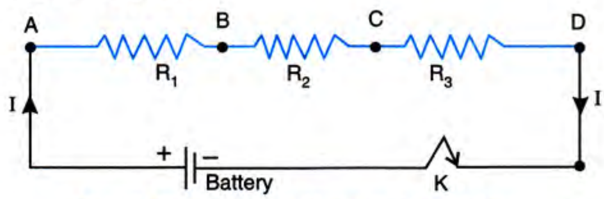


Fig. 8.18 Series combination of resistors

The end A of the resistor R_1 connected at the positive terminal of the battery is at a higher potential. The potential decreases in steps across each resistor and at the end D of the last resistor R_3, the potential is minimum. If V_A, V_B, V_C and V_D are the potentials at the points A, B, C and D respectively, then $V_A > V_B > V_C > V_D$. The potential difference across the resistor R_1 is $V_1 = V_A - V_B$, across the resistor R_2 is $V_2 = V_B - V_C$ and across the resistor R_3 is $V_3 = V_C - V_D$.

The following *two* facts are to be noted about the series combination.

(a) *The current has a single path for its flow. Hence same current passes through each resistor, so the potential difference across any resistor is directly proportional to its resistance.*

(b) *The potential difference across the entire circuit is equal to the sum of the potential differences across the individual resistor. i.e.,*

$$V = V_1 + V_2 + V_3 + ...$$

Expression for the equivalent resistance

If current I is drawn from the battery, the current through each resistor will also be I.

By Ohm's law,

p.d. between A and B is $V_1 = V_A - V_B = IR_1$

p.d. between B and C is $V_2 = V_B - V_C = IR_2$

and p.d. between C and D is $V_3 = V_C - V_D = IR_3$

Adding these, we get

$$V = V_1 + V_2 + V_3 = V_A - V_D = I(R_1 + R_2 + R_3) \quad ... (i)$$

If the equivalent resistance between the points A and D is R_s, then the potential difference between the points A and D is

$$V = V_A - V_D = I R_s \quad .... (ii)$$

∴ From eqns. (i) and (ii),

$$I R_s = I(R_1 + R_2 + R_3)$$

or $$\boxed{R_s = R_1 + R_2 + R_3} \quad ....(8.29)$$

Thus, in the series combination, the equivalent resistance is equal to the sum of the individual resistances.

In general, if n resistances joined in series are R_1, R_2, ..., R_n, the equivalent resistance is given as :

$$\boxed{R_s = R_1 + R_2 + ... + R_n} \quad ....(8.30)$$

If there are n equal resistances, each of value R, connected in series, the equivalent resistance is

$$\boxed{R_s = R + R + ... n \text{ times} = nR} \quad ....(8.31)$$

Example : If we connect three resistors of resistances 2 Ω, 3 Ω and 5 Ω in series, the equivalent resistance R_s of the combination is

$$R_s = R_1 + R_2 + R_3 = 2 + 3 + 5 = 10\ \Omega$$

(2) Combination of resistors in parallel

In the parallel combination, one end of each resistor is connected at one point (say, A) and the other end of each resistor is connected at the other point (say, B). The battery alongwith a key K is then connected in between the points A and B as shown in Fig. 8.16.

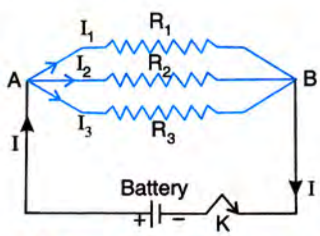


Fig. 8.16 Parallel combination of resistors

Let V_A and V_B be the potentials at the points A and B respectively. The point A connected to the positive terminal of the battery is at a higher potential than the point B connected to the negative terminal of the battery (*i.e.*, $V_A > V_B$). The potential difference across each resistor is $V = V_A - V_B$.

The following *two* points are to be noted about the parallel combination.

(a) *The potential difference across each resistor is same* (= $V_A - V_B = V$, say) *which is equal to the potential difference across the terminals of the battery (or source).*

(b) The main current I from the battery divides itself in different arms at the point A. The low resistance arm allows more current and the high resistance arm allows less current, *i.e., the current in a resistor is inversely proportional to its resistance. The sum of currents* I_1, I_2, I_3, ... *in the separate branches of the parallel circuit is equal to the total current I drawn from the source. i.e.,*

$$I = I_1 + I_2 + I_3 + ...$$

Expression for the equivalent resistance

Let I_1, I_2 and I_3 be the currents through the resistances R_1, R_2 and R_3 respectively, then total current drawn from the battery is

$$I = I_1 + I_2 + I_3 \quad ....(i)$$

If potential difference between the two ends A and B is V, then by Ohm's law

$$\text{current in } R_1 \text{ is } I_1 = \frac{V}{R_1}$$

$$\text{current in } R_2 \text{ is } I_2 = \frac{V}{R_2}$$

and $$\text{current in } R_3 \text{ is } I_3 = \frac{V}{R_3}$$

On adding these,

$$I_1 + I_2 + I_3 = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \quad ..... (ii)$$

If the equivalent resistance of the combination between the points A and B is R_p, then total current drawn from the source is

$$I = \frac{V}{R_p} \quad ...... (iii)$$

Substituting the values of I and $I_1 + I_2 + I_3$ from eqns. (iii) and (ii) in eqn. (i), we get

$$\frac{V}{R_p} = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

or $$\boxed{\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} \quad ....(8.32)$$

Thus, *in the parallel combination, the reciprocal of the equivalent resistance is equal to the sum of the reciprocals of the individual resistances.*

In general, if n resistances R_1, R_2, R_3, ..., R_n be joined in parallel, the equivalent resistance R_p is given as :

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ... + \frac{1}{R_n} \quad ....(8.33)$$

If there are n equal resistances, each of value R, connected in parallel, the equivalent resistance R_p is given by

$$\frac{1}{R_p} = \frac{1}{R} + \frac{1}{R} + ... \; n \text{ terms} = \frac{n}{R}$$

or $$R_p = \frac{R}{n} \quad .... (8.34)$$

For two resistances R_1 and R_2 connected in parallel, the equivalent resistance R_p is given as

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} \quad \text{or} \quad \frac{1}{R_p} = \frac{R_2 + R_1}{R_1 R_2}$$

or $$R_p = \frac{R_1 R_2}{R_1 + R_2} \quad .....(8.35)$$

> ***Note :*** In the parallel combination, the equivalent resistance R_p is less than even the smallest resistance connected.

Example : If we connect three resistances 1 Ω, 10 Ω and 100 Ω in parallel, the equivalent resistance R_p is given as :

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{1} + \frac{1}{10} + \frac{1}{100} = \frac{111}{100}$$

or $$R_p = \frac{100}{111} = 0{\cdot}9009\ \Omega \approx 0{\cdot}9\ \Omega$$

i.e., R_p is less than 1 Ω.

(3) Combination of resistors both in series and parallel

Sometimes to obtain a desired value of resistance from the given resistors, we connect some resistors in parallel and then this parallel combination of resistors is connected in series with some more resistors. A branch of parallel combination may also have two or more resistors in series combination. Similarly, there can be more than one parallel combinations in series also. In such a case, we first determine the resistance of each branch of parallel combination. Then we determine the equivalent resistance of each parallel combination. After this, we find the total resistance by adding the resistances of series combination and the equivalent resistance of the parallel combination.

Example : To obtain an equivalent resistance 1·5 Ω using three resistors each of 1 Ω, we connect a parallel combination of two resistors, in series with the third resistor as shown in Fig. 8.17.

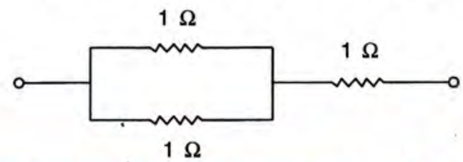


Fig. 8.17 Combination of three resistors each of 1 Ω for equivalent resistance 1·5 Ω

> ***Note :*** **(1)** For the two resistors joined in series, the equivalent resistance is more than when they are joined in parallel. Therefore on *V–I* graph, the straight line obtained for series combination will have more slope than that for the parallel combination as shown in Fig. 8.18. In Fig. 8.18, the straight line A corresponds to the series combination of resistors, while the straight line B corresponds to the parallel combination of resistors.
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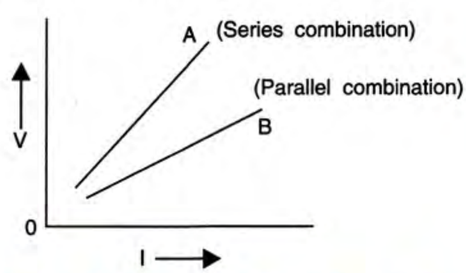
> 
>
>
> *Fig. 8.18 V–I graphs for series and parallel combinations*
>
> **(2)** If current I is divided into two resistances R_1 and R_2 connected in parallel

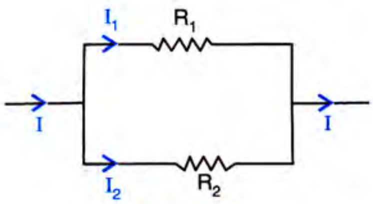


Fig. 8.19

as shown in Fig. 8.19, then $I = I_1 + I_2$ and $I_1R_1 = I_2R_2$. Hence the current in resistance R_1 is $I_1 = \frac{IR_2}{R_1 + R_2}$ and current in resistance R_2 is $I_2 = \frac{IR_1}{R_1 + R_2}$.

(3) If voltage V is divided in two resistances R_1 and R_2 connected in series as shown in

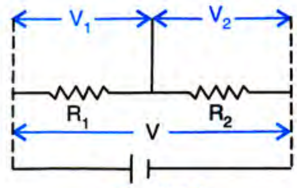


Fig. 8.20

Fig. 8.20, then current drawn from the cell is $I = \frac{V}{R_1 + R_2}$.

∴ Potential difference across R_1 is

$$V_1 = IR_1 = \frac{VR_1}{R_1 + R_2}$$

and potential difference across R_2 is

$$V_2 = IR_2 = \frac{VR_2}{R_1 + R_2}.$$

EXAMPLES

1. A high resistance voltmeter measures the potential difference across a battery to be 9·0 V. On connecting a 24 Ω resistor across the terminals of the battery, the voltmeter reads 7·2 V. Calculate the internal resistance of the battery.

Since the voltmeter has a high resistance, it is supposed to draw no current. Therefore, 9 V is the e.m.f. of the cell.

Thus ε = 9 volt, V = 7·2 volt, R = 24 Ω, r = ?

From relations $\varepsilon = I(R + r)$ and $V = IR$,

$$r = \left(\frac{\varepsilon}{V} - 1\right) \times R = \left(\frac{9}{7 \cdot 2} - 1\right) \times 24 = 6\ \Omega$$

2. A battery of voltage 12 V sends current 400 mA to an appliance. After a long contineous use, the current drops to 320 mA and the appliance does not operate. Find : (i) the resistance of appliance, (ii) the terminal voltage of the battery when the appliance stops operating, (iii) the voltage drop, and (iv) the internal resistance of the battery.

Given : ε = 12 V, I = 400 mA = 400 × 10^{-3} A = 0·4 A

(i) Resistance of appliance $R = \frac{\varepsilon}{I} = \frac{12\text{ V}}{0 \cdot 4\text{ A}} = 30\ \Omega$

(ii) After long use, when current drops to I' = 320 mA = 0·32 A, the terminal voltage of the battery

$V = I'R$ = (0·32 A) × (30 Ω) = **9·6 V**

(iii) Voltage drop $v = \varepsilon - V$ = 12 V − 9·6 V = **2·4 V**

(iv) Internal resistance of the battery

$$r = \frac{v}{I'} = \frac{2 \cdot 4\text{ V}}{0 \cdot 32\text{ A}} = 7 \cdot 5\ \Omega$$

3. A cell supplies a current of 2 A when it is connected to a 5 Ω resistance and supplies a current of 1·2 A, if it is connected to a resistance of 9 Ω. Find the e.m.f and internal resistance of the cell.

Given : I_1 = 2 A when R_1 = 5 Ω

From relation $\varepsilon = I(R + r)$

$$\varepsilon = 2(5 + r) \qquad \text{.... (i)}$$

Now I_2 = 1·2 A when R_2 = 9 Ω

$$\therefore \quad \varepsilon = 1 \cdot 2\ (9 + r) \qquad \text{.... (ii)}$$

From eqns. (i) and (ii),

$$2(5 + r) = 1 \cdot 2\ (9 + r)$$

or $10 + 2r = 10 \cdot 8 + 1 \cdot 2r$

or $2r - 1 \cdot 2r = 10 \cdot 8 - 10$ or $0 \cdot 8r = 0 \cdot 8$

$$\therefore \quad r = \frac{0 \cdot 8}{0 \cdot 8} = 1\ \Omega.$$

From eqns. (i), ε = 2 (5 + 1) = 2 × 6 = **12 volt.**

Thus, e.m.f. = **12 V** and internal resistance = **1 Ω.**

4. Three resistors of 2 Ω, 3 Ω and 4 Ω are connected in (a) series, (b) parallel. Draw the arrangment and find the equivalent resistance in each case.

Given : R_1 = 2 Ω, R_2 = 3 Ω, R_3 = 4 Ω

The series and parallel arrangments of resistors are shown in Fig. 8.21.

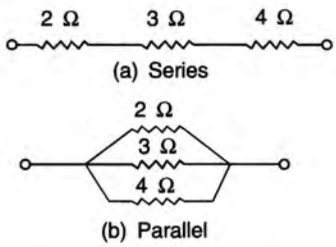


Fig. 8.21

(a) In series, the equivalent resistance is

$$R_s = R_1 + R_2 + R_3$$
$$= 2 + 3 + 4 = 9\ \Omega$$

(b) In parallel, if the equivalent resistance is R_p, then

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

or $$\frac{1}{R_p} = \frac{1}{2} + \frac{1}{3} + \frac{1}{4} = \frac{13}{12}$$

or $$R_p = \frac{12}{13} = 0{\cdot}92\ \Omega$$

5. What resistance must be connected to a 15 Ω resistance to provide an effective resistance of 6 Ω ?

Given, $R_1 = 15\ \Omega$, $R_2 = ?$,

effective resistance $R = 6\ \Omega$

Since the effective resistance has decreased, so R_2 must be connected in *parallel* with R_1.

$\therefore R_p = 6\ \Omega$

In parallel combination,

$$R_p = \frac{R_1 R_2}{R_1 + R_2} \text{ or } 6 = \frac{15 \times R_2}{15 + R_2}$$

or $6 \times (15 + R_2) = 15\ R_2$

or $90 + 6\ R_2 = 15\ R_2$

or $15\ R_2 - 6\ R_2 = 90$

or $9\ R_2 = 90$ or $R_2 = 10\ \Omega$

6. Three resistors of 6 Ω, 3 Ω and 2 Ω are connected together so that the total resistance is greater than 6 Ω, but less than 8 Ω. Draw a diagram to show this arrangement and calculate its total resistance.

Since total resistance is to be greater than 6 Ω, therefore 6 Ω resistor should be in series with the other resistors, the equivalent resistance of which is less than 2 Ω so that the total resistance is less than 8 Ω. Now to have a resistance less than 2 Ω, remaining 3 Ω and 2 Ω resistors should be combined in parallel. The arrangement is shown in Fig. 8.22.

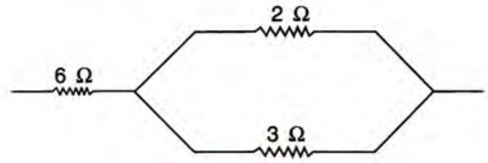


Fig. 8.22

For resistors of 2 Ω and 3 Ω in parallel, the equivalent resistance R_p is given as

$$\frac{1}{R_p} = \frac{1}{2} + \frac{1}{3} = \frac{5}{6}$$

$$\therefore \quad R_p = \frac{6}{5} = 1{\cdot}2\ \Omega$$

The arrangement in Fig. 8.22 takes the form as shown in Fig. 8.23.

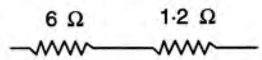


Fig. 8.23

In Fig. 8.23, the resistors of 6 Ω and 1·2 Ω are in series.

∴ Total resistance of arrangement = 6 +1·2 = 7·2 Ω

(which is less than 8 Ω, but greater than 6 Ω).

7. Calculate the equivalent resistance between the points A and B in the circuit shown in Fig. 8.24.

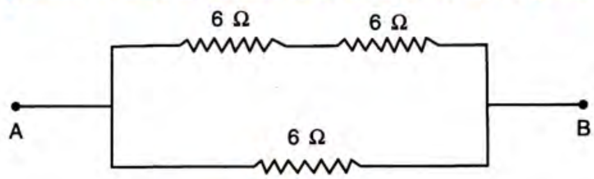


Fig. 8.24

In the circuit, two resistors 6 Ω and 6 Ω are connected in series. The equivalent resistance of this series combination is $R_s = 6 + 6 = 12\ \Omega$.

The equivalent resistance R_s (= 12 Ω) is now connected in parallel with a resistor 6 Ω between the points A and B as shown is Fig.8.25.

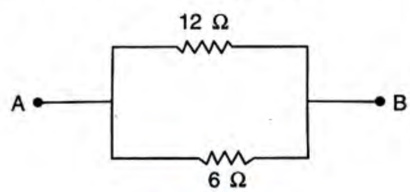


Fig. 8.25

If the equivalent resistance between A and B in Fig. 8.25 is R_p, then

$$\frac{1}{R_p} = \frac{1}{12} + \frac{1}{6} = \frac{3}{12}$$

or $$R_p = \frac{12}{3} = 4\ \Omega$$

8. In the circuit shown in Fig. 8.26, calculate the equivalent resistance between the points A and B.

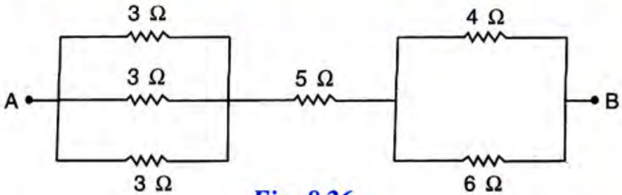


Fig. 8.26

In the circuit, there are *three* parts. In one part, three resistors each of 3 Ω are connected in parallel. If the equivalent resistance of this part is R'_p, then

$$\frac{1}{R'_p} = \frac{1}{3} + \frac{1}{3} + \frac{1}{3} = \frac{3}{3} = 1$$

or $$R'_p = 1\ \Omega$$

In second part, two resistors 4 Ω and 6 Ω are connected in parallel. If the equivalent resistance is R''_p, then

$$\frac{1}{R''_p} = \frac{1}{4} + \frac{1}{6} = \frac{3+2}{12} = \frac{5}{12} \text{ or } R''_p = \frac{12}{5} = 2{\cdot}4\ \Omega.$$

The two parts of resistance $R'_p = 1\ \Omega$ and $R''_p = 2{\cdot}4\ \Omega$ are connected in series with the resistance 5 Ω between the points A and B as shown in Fig. 8.27.

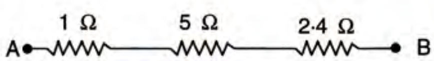


Fig. 8.27

The equivalent resistance between the points A and B in Fig. 8.27 is

$$R_s = 1 + 5 + 2{\cdot}4 = \mathbf{8{\cdot}4\ \Omega}$$

9. Four resistors each of resistance 2·0 Ω are joined end to end to form a square ABCD. Calculate the equivalent resistance of the combination between any two adjacent corners.

Fig. 8.28 shows four resistors each of resistance 2·0 Ω joined end to end to form a square ABCD. We are to find the equivalent resistance of the combination between the adjacant corners A and B.

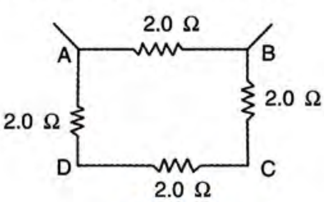


Fig. 8.28

Between A and B, there are three resistors in the arms AD, DC and CB in series in one branch. The equivalent resistance of this branch is $R_s = 2{\cdot}0 + 2{\cdot}0 + 2{\cdot}0 = 6{\cdot}0\ \Omega$.

Now one resistor (= 2·0 Ω) in arm AB is in parallel combination with the equivalent resistance R_s (= 6 Ω) as shown in Fig. 8.29.

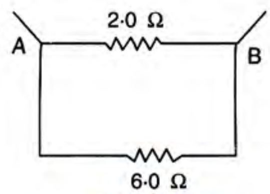


Fig. 8.29

If the equivalent resistance between the points A and B in Fig. 8.29 is R_p, then

$$\frac{1}{R_p} = \frac{1}{6} + \frac{1}{2} = \frac{1+3}{6} = \frac{4}{6}$$

or $$R_p = \frac{6}{4} = \mathbf{1{\cdot}5\ \Omega}$$

10. For the combination of resistors shown in Fig. 8.30, find the equivalent resistance between the point (a) C and D, and (b) A and B.

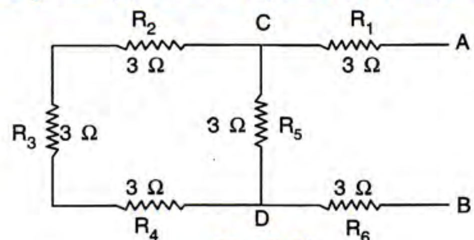


Fig. 8.30

(a) Between the points C and D : The resistors R_2, R_3 and R_4 are in series. They can be replaced by an equivalent resistance R_s where

$$R_s = R_2 + R_3 + R_4 = 3 + 3 + 3 = 9\ \Omega.$$

The resistance R_5 (= 3 Ω) and R_s (= 9 Ω) are in parallel between the points C and D as shown in Fig. 8.31.

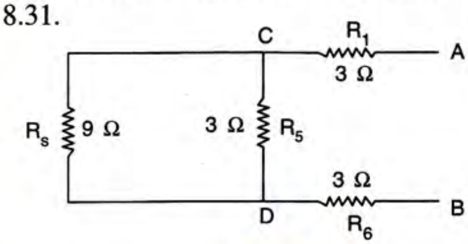


Fig. 8.31

If the equivalent resistance between C and D in Fig. 8.31 is R_p, then

$$\frac{1}{R_p} = \frac{1}{3} + \frac{1}{9} \text{ or } \frac{1}{R_p} = \frac{3+1}{9} = \frac{4}{9}$$

or $$R_p = \frac{9}{4} = 2{\cdot}25\ \Omega$$

Thus the equivalent resistance between C and D is **2·25 Ω.**

(b) Between A and B : Now the resistors R_1 (= 3 Ω), R_p (=2·25 Ω) and R_6 (= 3 Ω) are in series between the points A and B as shown in Fig. 8.32.

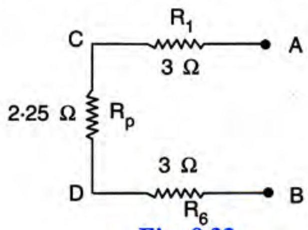


Fig. 8.32

The equivalent resistance between A and B in Fig. 8.32 is

$$R_{AB} = R_1 + R_p + R_6 = 3 + 2{\cdot}25 + 3 = \mathbf{8{\cdot}25\ \Omega}$$

11. Two resistors of 4 Ω and 6 Ω are connected in parallel. The combination is connected across a 6 V battery of negligible resistance. Calculate : (a) the total resistance of circuit, (b) the current through the battery, (c) the current through each resistor. Draw a circuit diagram.

The circuit diagram is shown in Fig. 8.33.

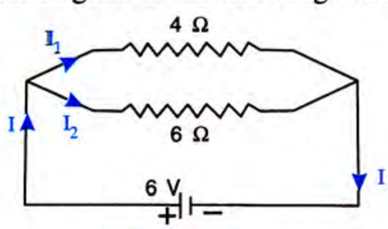


Fig. 8.33

(a) If the resistance of the parallel combination is R_p, then

$$\frac{1}{R_p} = \frac{1}{4} + \frac{1}{6} = \frac{3+2}{12} = \frac{5}{12}$$

or $$R_p = \frac{12}{5}\ \Omega = 2{\cdot}4\ \Omega$$

(b) Let current through the battery be I, then

$$I = \frac{V}{R_p} = \frac{6}{2{\cdot}4} = \mathbf{2{\cdot}5\ A}$$

(c) The potential difference across each resistor is V= 6 volt (same as of the battery) since they are in parallel.

Current through 4 Ω resistor

$$I_1 = \frac{V}{R_1} = \frac{6}{4} = \mathbf{1{\cdot}5\ A}$$

Current through 6 Ω resistor

$$I_2 = \frac{V}{R_2} = \frac{6}{6} = \mathbf{1{\cdot}0\ A}$$

Note that $I = I_1 + I_2$.

12. The circuit diagram shown in Fig. 8.34 includes a 6 V battery, an ammeter A, a fixed resistor R_1 of 2 Ω and a resistance wire R_2 connected between the terminals A and B. The resistance of the battery and ammeter may be neglected. Calculate the ammeter readings when the wire R_2 is of

(a) 0·20 m length and of resistance 4 Ω.

(b) 0·40 m length and of same thickness and material as in case (a).

(c) 0·20 m length and of area of cross section double than in case (a).

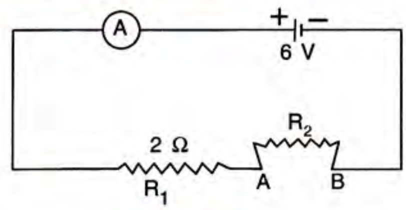


Fig. 8.34

(a) Given : resistance R_2 = 4 Ω.

Total resistance of the circuit

$$R_s = R_1 + R_2 = 2 + 4 = 6\ \Omega$$

By Ohm's law,

$$\text{Current } I = \frac{V}{R_s} = \frac{6}{6} = \mathbf{1\ A}$$

(b) On doubling the length (*i.e.*, 0·40 m), the resistance of wire R_2 is doubled, *i.e.*, it becomes 8 Ω.

∴ Total resistance $R_s = 2 + 8 = 10\ \Omega$

$$\text{Current } I = \frac{6}{10} = \mathbf{0{\cdot}6\ A}$$

(c) On doubling the area of cross section, the resistance of wire R_2 is reduced to half, *i.e.*, it becomes $\frac{1}{2} \times 4\ \Omega = 2\ \Omega$.

∴ Total resistance $R_s = 2 + 2 = 4\ \Omega$.

$$\text{Current } I = \frac{6}{4} = \mathbf{1{\cdot}5\ A}$$

13. Three resistors 8 Ω, 12 Ω and 6 Ω are connected to a 12 V battary as shown in Fig. 8.35 below.

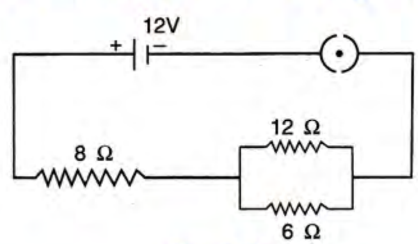


Fig. 8.35

Find :

(a) the current through the 8 Ω resistor,

(b) the potential difference across the parallel combination of 6 Ω and 12 Ω resistors, and

(c) the current through the 6 Ω resistor.

(a) If R_p is the equivalent resistance of resistors 12 Ω and 6 Ω connected in parallel, then

$$\frac{1}{R_p}=\frac{1}{12}+\frac{1}{6}=\frac{1+2}{12}=\frac{3}{12} \text{ or } R_p=\frac{12}{3}=4\ \Omega$$

Now total resistance of circuit will be the equivalent resistance of series combination of resistors 8 Ω and R_p (= 4 Ω) *i.e.*, total resistance $R_s = 8 + 4 = 12\ \Omega$.

Current in 8 Ω resistor = Current drawn from battery

$$\therefore\quad I=\frac{\text{e.m.f. of battery}}{\text{total resistance}}=\frac{12\text{ V}}{12\ \Omega}=\mathbf{1\ A}$$

(b) The potential difference across the parallel combination of 6 Ω and 12 Ω resistors

$$V = I \times R_p = 1 \times 4 = \mathbf{4\ V}$$

(c) If current through the 6 Ω resistor is I_1, then

$$V = I_1 \times 6 \quad\text{or}\quad 4 = I_1 \times 6$$

$$\therefore\quad I_1 = \frac{4}{6} = \mathbf{0{\cdot}67\ A}$$

14. A cell of e.m.f. 1·5 V, internal resistance 1 Ω is connected to the resistors of 4 Ω and 20 Ω in series. Draw a circuit diagram and calculate :

(a) the current in the circuit,

(b) the p.d. across each resistor,

(c) the p.d. across the cell, and

(d) the voltage drop when the current is flowing.

The circuit diagram of the arrangement is shown in Fig. 8.36.

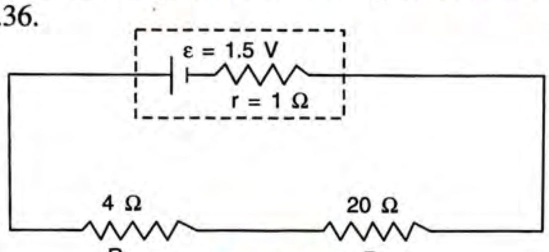


Fig. 8.36

Total resistance of the circuit

$$R = R_1 + R_2 + r = 4 + 20 + 1 = 25\ \Omega$$

(a) Current in the circuit

$$I=\frac{\text{e.m.f.}}{\text{total resistance}}=\frac{1{\cdot}5}{25}=\mathbf{0{\cdot}06\ A}$$

(b) p.d. across the resistor R_1 (= 4 Ω) is

$$V_1 = IR_1 = 0{\cdot}06 \times 4 = \mathbf{0{\cdot}24\ V}$$

p.d. across the resistor R_2 (= 20 Ω)

$$V_2 = IR_2 = 0{\cdot}06 \times 20 = \mathbf{1{\cdot}20\ V}$$

(c) p.d. across the cell is the total p.d. in the external circuit = $V_1 + V_2 = 0{\cdot}24 + 1{\cdot}20 =$ **1·44 V**

(d) Voltage drop $v = Ir = 0{\cdot}06 \times 1 =$ **0·06 V.**

or $v = \varepsilon - V = 1{\cdot}5 - 1{\cdot}44 = 0{\cdot}06$ V

15. Fig. 8.37 below shows a battery of e.m.f. 9 V and internal resistance 0·6 Ω, connected to three resistors A, B and C. Calculate : (a) the combined resistance of B and C, (b) the total resistance of A, B and C, (c) the total resistance of circuit, (d) the current in each resistor A, B and C, (e) the potential drop across the internal resistance, (f) the potential difference across the resistor B, and (g) the terminal voltage of the cell.

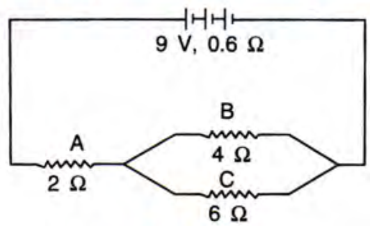


Fig. 8.37

Given : $\varepsilon = 9$ V, $r = 0{\cdot}6\ \Omega$

Resistance of resistor A = 2 Ω,

Resistance of resistor B = 4 Ω,

Resistance of resistor C = 6 Ω.

(a) The resistors B and C are in parallel. If the equivalent resistance is R_p, then

$$\frac{1}{R_p}=\frac{1}{4}+\frac{1}{6}=\frac{5}{12} \text{ or } R_p=\frac{12}{5}=\mathbf{2{\cdot}4\ \Omega}$$

(b) The resistor A is in series with the resistance R_p as shown in Fig. 8.38.

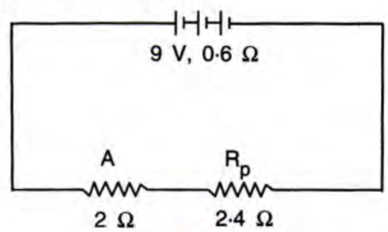


Fig. 8.38

∴ Total resistance of A and R_p in series is

$$R_s = 2 + 2{\cdot}4 = \mathbf{4{\cdot}4\ \Omega}.$$

(c) Total resistance of circuit = $R_s + r$

$$= 4{\cdot}4 + 0{\cdot}6 = \mathbf{5\ \Omega}$$

(d) Current drawn from the battery

$$I=\frac{\text{e.m.f.}}{\text{total resistance}}=\frac{9}{5}=\mathbf{1{\cdot}8\ A}$$

Current in resistor A is I = **1·8 A**

Now the current I divides in two parts. Let the current in resistor B be I_1 and in resistor C be I_2, then

$$I = I_1 + I_2$$

and $$I_1 \times 4 = I_2 \times 6$$

On solving, $$I_1 = \frac{6}{4+6} \times I = \frac{3}{5} \times 1{\cdot}8 = 1{\cdot}08 \text{ A}$$

and $$I_2 = \frac{4}{4+6} \times I = \frac{2}{5} \times 1{\cdot}8 = 0{\cdot}72 \text{ A}$$

Thus, current in resistor B is I_1 = **1·08 A**

current in resistor C is I_2 = **0·72 A**

(e) Potential drop across the internal resistance

$v = Ir = 1{\cdot}8 \times 0{\cdot}6 =$ **1·08 V**

(f) Potential difference across the resistor B

$= I_1 \times 4 = 1{\cdot}08 \times 4 =$ **4·32 V**

(g) Terminal voltage of the cell $V = IR_s$

$= 1{\cdot}8 \times 4{\cdot}4 =$ **7·92 V**

Alternative : $V = \varepsilon - v = 9 - 1{\cdot}08 = 7{\cdot}92$ V

16. In the diagram given below in Fig. 8.39, A, B and C are three ammeters each of negligible resistance. The ammeter B reads 0·5 A. Calculate:
(a) the readings of the ammeters A and C,
(b) the total resistance of the circuit, and
(c) the e.m.f. of the cell.

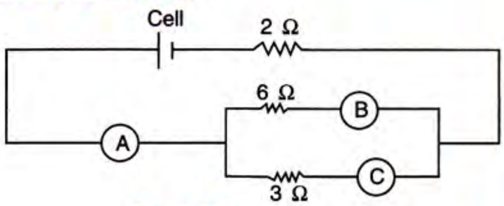


Fig. 8.39

(a) Given : current in 6 Ω resistor I_1 = 0·5 A (*i.e.*, the reading of ammeter B).

∴ p.d. across 6 Ω resistor = 0·5 × 6 = 3 V

The same will be the p.d. across the 3 Ω resistor connected in parallel with the 6 Ω resistor. Therefore current in 3 Ω resistor is

$$I_2 = \frac{3\text{ V}}{3\,\Omega} = 1 \text{ A}$$

Hence reading of ammeter C will be **1 A.**

The ammeter A will read the total current

$I = I_1 + I_2 = 0{\cdot}5 + 1 =$ **1·5 A**

(b) If R_p is the equivalent resistance of resistors 6 Ω and 3 Ω connected in parallel, then

$$\frac{1}{R_p} = \frac{1}{6} + \frac{1}{3} = \frac{1+2}{6} = \frac{3}{6}$$

or $$R_p = \frac{6}{3} = 2\,\Omega$$

Now total resistance of circuit will be the equivalent resistance of series combination of resistors 2 Ω and R_p (= 2 Ω). *i.e.*,

Total resistance R_s = 2 + 2 = **4 Ω**

(c) E.m.f. of cell = total current drawn × total resistance of circuit

= 1·5 × 4 = **6 V**

EXERCISE–8(B)

1. Explain the meaning of the terms e.m.f., terminal voltage, and internal resistance of a cell.

2. State *two* differences between the e.m.f. and terminal voltage of a cell.

3. Name *two* factors on which the internal resistance of a cell depends and state how does it depend on the factors stated by you.

4. A cell of e.m.f. ε and internal resistance r is used to send current to an external resistance R. Write expressions for (a) the total resistance of circuit, (b) the current drawn from the cell, (c) the p.d. across the cell, and (d) voltage drop inside the cell.

Ans. (a) $R + r$ (b) $\dfrac{\varepsilon}{(R+r)}$ (c) $\dfrac{\varepsilon}{(R+r)} \times R$ (d) $\dfrac{\varepsilon}{R+r} \times r$

5. A cell is used to send current to an external circuit. (a) How does the voltage across its terminals compare with its e.m.f. ? (b) Under what condition is the e.m.f. of the cell equal to its terminal voltage?

Ans. (a) terminal voltage < e.m.f.; (b) e.m.f. is equal to terminal voltage when no current is drawn.

6. Explain why is the p.d. across the terminals of a cell more in an open circuit and reduced in a closed circuit.

7. Write the expressions for the equivalent resistance R of three resistors R_1, R_2 and R_3 joined in (a) parallel, and (b) series.

8. How would you connect two resistors in series ? Draw a diagram. Calculate the total equivalent resistance.

9. Show by a diagram how two resistors R_1 and R_2 are joined in parallel. Obtain an expression for the total resistance of combination.

10. State how are the *two* resistors joined with a battery in each of the following cases when :

(a) same current flows in each resistor,

(b) potential difference is same across each resistor,

(c) equivalent resistance is less than either of the two resistances, and

(d) equivalent resistance is more than either of the two resistances.

Ans. (a) series (b) parallel (c) parallel (d) series.

11. The *V-I* graph for a series combination and for a parallel combination of two resistors is shown in Fig. 8.40. Which of the two, A or B, represents the parallel combination ? Give a reason for your answer.

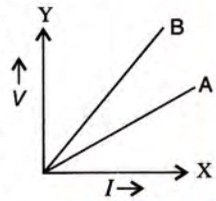


Fig. 8.40

Ans. A

Reason : Since the straight line A is less steeper than B, so the straight line A represents small resistance. In parallel combination, the equivalent resistance is less than in series combination so A represents the parallel combination.

MULTIPLE CHOICE TYPE

1. In series combination of resistances :

(a) p.d. is same across each resistance

(b) total resistance is reduced

(c) current is same in each resistance

(d) all above are true.

Ans. (c) current is same in each resistance.

2. In parallel combination of resistances :

(a) p.d. is same across each resistance

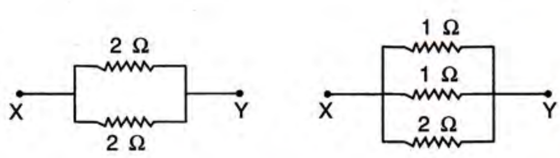
(b) total resistance is increased

(c) current is same in each resistance

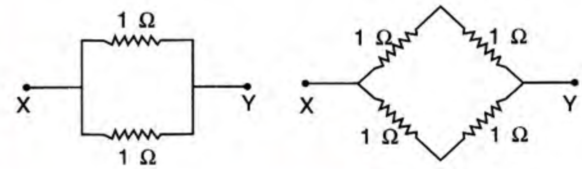
(d) all above are true.

Ans. (a) p.d. is same across each resistance.

3. Which of the following combinations have the same equivalent resistance between X and Y ?



(a) (b)



(c) (d)

Fig. 8.41

Ans. (a) and (d)

NUMERICALS

1. The diagram in Fig. 8.42 shows a cell of e.m.f. ε = 2 volt and internal resistance r = 1 ohm connected to an external resistance R = 4 ohm. The ammeter A measures the current in the circuit and the voltmeter V measures the terminal voltage across the cell. What will be the readings of the ammeter and voltmeter when (i) the key K is open, and (ii) the key K is closed.

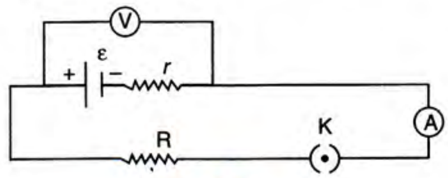


Fig. 8.42

Ans. (i) ammeter reading = 0, voltmeter reading = 2 volt
(ii) ammeter reading = 0·4 ampere,
voltmeter reading = 1·6 volt

2. A battery of e.m.f. 3·0 V supplies current through a circuit in which the resistance can be changed. A high resistance voltmeter is connected across the battery. When the current is 1·5 A, the voltmeter reads 2·7 V. Find the internal resistance of the battery.

Ans. 0·2 Ω

3. A cell of e.m.f. 1·8 V and internal resistance 2 Ω is connected in series with an ammeter of resistance 0·7 Ω and a resistor of 4·5 Ω as shown in Fig. 8.43.

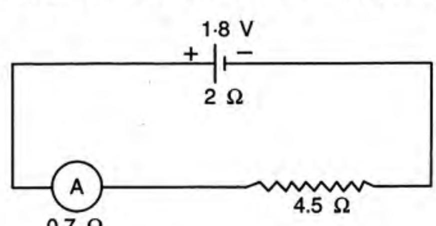


Fig. 8.43

(a) What would be the reading of the ammeter ?

(b) What is the potential difference across the terminals of the cell ?

Ans. (a) 0·25 A (b) 1·3 V

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4. A battery of e.m.f. 15 V and internal resistance 3 ohm is connected to two resistors of resistances 3 ohm and 6 ohm in series. Find :

(a) the current through the battery,

(b) the p.d. between the terminals of the battery.

Ans. (a) 1·25 A (b) 11·25 V

5. A cell of e.m.f. ε and internal resistance r sends current 1·0 A when it is connected to an external resistance 1·9 Ω. But it sends current 0·5 A when it is connected to an external resistance 3·9 Ω. Calculate the values of ε and r.

Ans. ε = 2·0 V, r = 0·1 Ω

6. Two resistors having resistance 4 Ω and 6 Ω are connected in parallel. Find their equivalent resistance. **Ans.** 2·4 Ω

7. Four resistors each of resistance 2 Ω are connected in parallel. What is the effective resistance ?

Ans. 0·5 Ω

8. You have three resistors of values 2 Ω, 3 Ω, and 5 Ω. How will you join them so that the total resistance is less than 1 Ω ? Draw diagram and find the total resistance. **Ans.** In parallel, 0·97 Ω

9. Three resistors each of 2 Ω are connected together so that their total resistance is 3 Ω. Draw a diagram to show this arrangement and check it by calculation.

Ans. a parallel combination of two resistors, in series with one resistor.

10. Calculate the equivalent resistance between the points A and B in Fig. 8.44 if each resistance is 2·0 Ω.

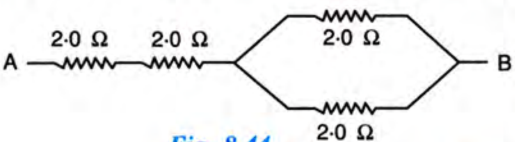

Fig. 8.44

Ans. 5·0 Ω

11. A combination consists of three resistors in series. Four similar sets are connected in parallel. If the resistance of each resistor is 2 ohm, find the resistance of the combination. **Ans.** 1·5 Ω

12. In the circuit shown below in Fig. 8.45, calculate the value of x if the equivalent resistance between the points A and B is 4 Ω.

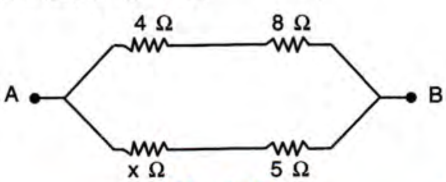

Fig. 8.45

Ans. 1 Ω

13. Calculate the effective resistance between the points A and B in the circuit shown in Fig. 8.46.

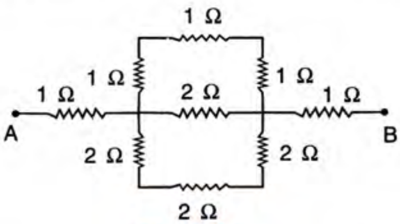

Fig. 8.46

Ans. 3 Ω

14. A uniform wire with a resistance of 27 Ω is divided into three equal pieces and they are joined in parallel. Find the equivalent resistance of the parallel combination. **Ans.** 3 Ω

15. A circuit consists of a resistor of 1 ohm in series with a parallel arrangement of resistors of 6 ohm and 3 ohm. Calculate the total resistance of the circuit. Draw a diagram of the arrangment. **Ans.** 3 ohm

16. Calculate the effective resistance between the points A and B in the network shown below in Fig. 8.47.

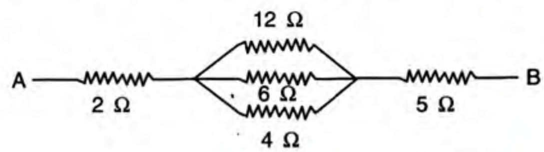

Fig. 8.47

Ans. 9 Ω

17. Calculate the equivalent resistance between the points A and B in Fig. 8.48.

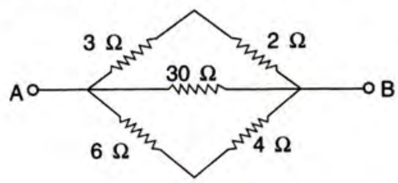

Fig. 8.48

Ans. 3 Ω

18. In the network shown in Fig. 8.49, calculate the equivalent resistance between the points (a) A and B, and (b) A and C.

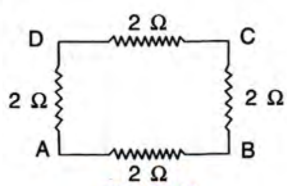

Fig. 8.49

Ans. (a) 1·5 Ω, (b) 2 Ω

19. Five resistors, each of 3 Ω, are connected as shown in Fig 8.50. Calculate the resistance (a) between the points P and Q, and (b) between the points X and Y.

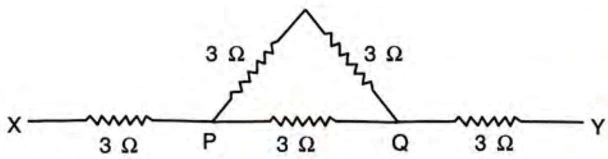

Fig. 8.50

Ans. (a) 2 Ω (b) 8 Ω

20. Two resistors of 2·0 Ω and 3·0 Ω are connected (a) in series, (b) in parallel, with a battery of 6·0 V and negligible internal resistance. For each case draw a circuit diagram and calculate the current through the battery.

Ans. (a) in series : 1·2 A (b) in parallel : 5 A

21. A resistor of 6 Ω is connected in series with another resistor of 4 Ω. A potential difference of 20 V is applied across the combination. Calculate : (a) the current in the circuit, and (b) the potential difference across the 6 Ω resistor. **Ans.** (a) 2 A (b) 12 V

22. Two resistors of resistance 4 Ω and 6 Ω are connected in parallel to a cell to draw current 0·5 A from the cell.

(a) Draw a labelled diagram of the arrangment.

(b) Calculate the current in each resistor.

Ans. 0·3 A in 4 Ω and 0·2 A in 6 Ω

23. Calculate the current flowing through each of the resistors A and B in the circuit shown in Fig. 8.51.

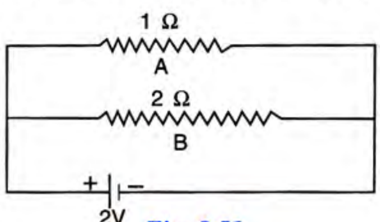

Fig. 8.51

Ans. in resistor A, current = 2 A, in resistor B, current = 1 A

24. In Fig 8.52, calculate :

(a) the total resistance of the circuit,

(b) the value of *R*, and

(c) the current flowing in *R*.

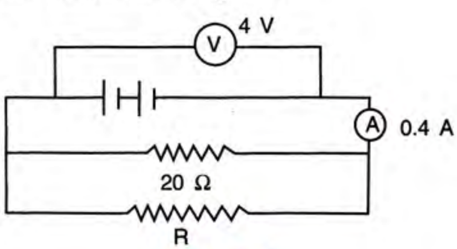

Fig. 8.52

Ans. (a) 10 Ω (b) 20 Ω (c) 0·2 A

25. A particular resistance wire has a resistance of 3·0 ohm per metre. Find :

(a) The total resistance of three lengths of this wire each 1·5 m long, joined in parallel.

(b) The potential difference of the battery which gives a current of 2·0 A in each of the 1·5 m length when connected in parallel to the battery (assume that the resistance of battery is negligible).

(c) The resistance of 5 m length of a wire of the same material, but with twice the area of cross section.

Ans. (a) 1·5 Ω (b) 9 V (c) 7·5 Ω

26. A cell supplies a current of 1·2 A through two resistors each of 2 Ω connected in parallel. When the resistors are connected in series, it supplies a current of 0·4 A. Calculate : (i) the internal resistance, and (ii) e.m.f. of the cell.

Ans. (i) 0·5 Ω, (ii) 1·8 V

27. A battery of e.m.f. 15 V and internal resistance 3 Ω is connected to two resistors 3 Ω and 6 Ω connected in parallel. Find : (a) the current through the battery, (b) the p.d. between the terminals of the battery, (c) the current in 3 Ω resistor, (d) the current in 6 Ω resistor.

Ans. (a) 3 A (b) 6 V (c) 2 A (d) 1 A

28. The circuit diagram in Fig. 8.53 shows three resistors 2 Ω, 4 Ω, and *R* Ω connected to a battery of e.m.f. 2 V and internal resistance 3 Ω. If main current of 0·25 A flows through the circuit, find :

(a) the p.d. across the 4 Ω resistor,

(b) the p.d. across the internal resistance of the cell,

(c) the p.d. across the *R* Ω or 2 Ω resistor, and

(d) the value of *R*.

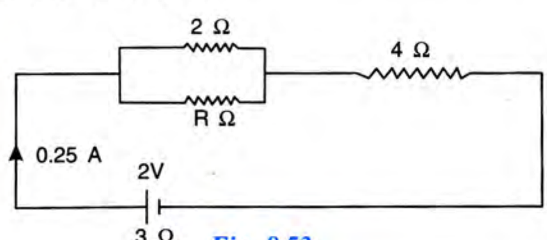

Fig. 8.53

Ans. (a) 1 V (b) 0·75 V (c) 0·25 V (d) 2 Ω

29. Three resistors of 6·0 Ω, 2·0 Ω and 4·0 Ω are joined to an ammeter A and a cell of e.m.f. 6·0 V as shown in Fig. 8.54. Calculate :

(a) the effective resistance of the circuit, and

(b) the reading of ammeter.

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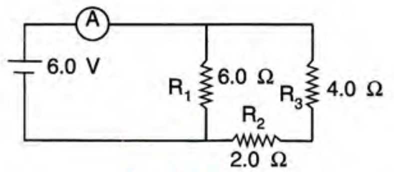

Fig. 8.54

Ans. (a) 3·0 Ω (b) 2 A

30. The diagram below in Fig. 8.55 shows the arrangement of five different resistances connected to a battery of e.m.f. 1·8 V. Calculate :

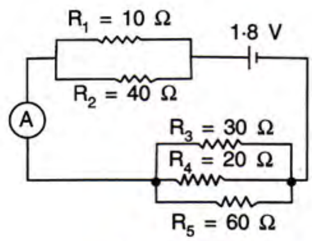

Fig. 8.55

(a) the total resistance of the circuit, and

(b) the reading of ammeter A.

Ans. (a) 18 Ω (b) 0·1 A

31. A cell of e.m.f. 2 V and internal resistance 1·2 Ω is connected to an ammeter of resitance 0·8 Ω and two resistors of 4·5 Ω and 9 Ω as shown in Fig. 8.56.

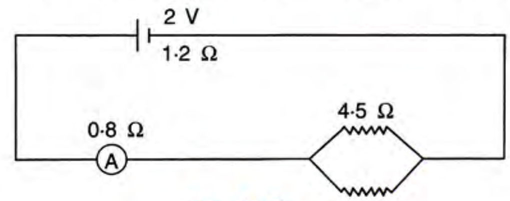

Fig. 8.56

Find :

(a) the reading of the ammeter,

(b) the potential difference across the terminals of the cell, and

(c) the potential difference across the 4·5 Ω resistor.

Ans. (a) 0·4 A (b) 1·52 V (c) 1·2 V

(C) ELECTRICAL ENERGY AND POWER

8.16 ELECTRICAL ENERGY

We have read that the energy exists in various forms such as mechanical energy, heat energy, chemical energy, electrical energy, light energy, nuclear energy, *etc*. According to the law of conservation of energy, energy can be transformed from one form to the other, but it can neither be created nor destroyed. In our daily life, we use many devices where electrical energy is used by converting it into the other forms such as heat energy, light energy, mechanical energy, chemical energy, sound energy, and magnetic energy.

Examples : **(1)** On passing electric current through the heating element (e.g. a wire of an alloy) of an *electric heater*, *oven* or *geyser*, it gets heated up due to its resistance, and the electrical energy gets converted into the heat energy which is used for the heating purposes.

(2) On passing electric current through an *electric lamp*, the filament of the bulb gets heated to an extent that it *glows*. The electrical energy thus changes into the heat energy and light energy.

(3) On passing electric current through an *electric motor used in fan, mixer, juicer, etc.*, its coil and the attachment with the axle of coil begin to rotate and simultaneously the coil gets slightly heated up. The electrical energy thus changes mostly into the mechanical energy and a small part into the heat energy.

(4) On passing electric current through the *electrolyte* (e.g. dilute sulphuric acid) while charging a lead accumulator, a chemical reaction takes place and the electrical energy gets converted into the chemical energy.

(5) On passing the electrical pulses from a microphone to a *loudspeaker,* the electrical energy gets converted into the sound energy.

(6) On passing electric current in a coil wound around a soft iron bar, the bar gets magnetised and becomes an electromagnet. Thus the electrical energy gets converted into the magnetic energy.

8.17 MEASUREMENT OF ELECTRICAL ENERGY (EXPRESSION $W = QV = VIt$)

In Fig. 8.57, let a current I be flowing through a conductor of resistance R for time t, when a source of potential difference V is connected across its ends. We are to find the amount of electrical energy supplied by the source.

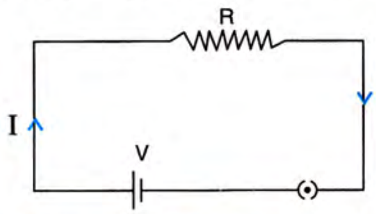

Fig 8.57 Current flowing in a resistance

By the definition of potential difference, work needed to move a charge Q through a potential difference V is

$$\boxed{W = QV} \quad ...(8.36)$$

But $\quad Q = I \times t$

$$\therefore \quad \boxed{W = VIt} \quad ...(8.37)$$

Thus eqn. (8.37) gives the electrical energy W supplied by the source (battery or mains) in providing the current I for time t in the conductor under a potential difference V.

Other expressions for electrical energy by the use of Ohm's law

By Ohm's law, $V = IR$

$\therefore$ From eqn. (8.37), $\quad W = I^2Rt \quad ...(8.38)$

$$\text{or} \quad W = \left(\frac{V}{R}\right)^2 \times Rt = \frac{V^2 t}{R} \quad ...(8.39)$$

Thus, electrical energy supplied by the source

$$W = Q\,V = VIt = I^2Rt = \frac{V^2 t}{R}$$

S.I. unit : The S.I. unit of electrical energy is joule (symbol J).

8.18 ELECTRICAL POWER AND ITS EXPRESSION $P = \frac{W}{t} = VI$

In an electrical circuit, electric power is defined as *the rate at which the electrical energy is supplied by the source*. Thus,

$$\text{Power } P = \frac{\text{energy supplied } W}{\text{time } t} = \frac{QV}{t}$$

Since $\quad Q = It \quad$ (from eqn. 8.1)

$$\therefore \quad P = \frac{VIt}{t} = VI \quad ...(8.40)$$

By Ohm's law, $I = \frac{V}{R}$

$$\therefore \quad P = \frac{V^2}{R} \quad ...(8.41)$$

Since $V = IR$

$$\therefore \quad P = \frac{(IR)^2}{R} = I^2R \quad ...(8.42)$$

Thus,

$$\text{Electrical power } P = \frac{W}{t} = VI = \frac{V^2}{R} = I^2R$$

Units of electrical power : The S.I. unit of potential difference is volt, of current is ampere, so the S.I. unit of electrical power is volt × ampere (V A) or watt (W) or J s^{-1}.

In relation $P = VI$, if $V = 1$ volt and $I = 1$ ampere, then $P = 1$ watt. Thus,

One watt is the electric power consumed when a current of 1 ampere flows through a circuit having a potential difference of 1 volt.

Bigger units of electric power are kilowatt (kW), megawatt (MW) and gigawatt (GW). They are related as :

1 kilowatt (1 kW) = 1000 W or 10^3 W,

1 megawatt (1 MW) = 10^6 W, and

1 giga watt (1 GW) = 10^9 W

8.19 COMMERCIAL UNIT OF ELECTRICAL ENERGY

The S.I. unit of energy is joule (J). If an electrical appliance of power P watt is used for t second, the electrical energy consumed is

W = power × time

$$\boxed{W = P \times t \qquad \text{watt} \times \text{second}} \quad ..(8.43)$$

Thus, watt × second can be used as the unit of electrical energy.

In practice, the electrical energy is measured in bigger units *i.e.*, watt × hour (Wh) or kilowatt × hour (kWh). *These are the commercial units of electrical energy.* They are defined as follows :

Watt-hour : *One watt-hour* (Wh) *is the electrical energy consumed by an electrical appliance of power* 1 *watt when it is used for* 1 *hour.*

$$1 \text{ watt-hour} = 1 \text{ watt} \times 1 \text{ hour} = 1 \text{ W} \times (60 \times 60 \text{ s}) = 3600 \text{ J}$$

Thus, $$\boxed{1 \text{ Wh} = 3600 \text{ J}} \qquad ...(8.44)$$

Kilowatt-hour : *One kilowatt-hour* (kWh) *is the electrical energy consumed by an electrical appliance of power* 1 *kilowatt when it is used for* 1 *hour*.

1 kilowatt-hour (or 1 kWh)

$$= 1 \text{ kilowatt} \times 1 \text{ hour}$$
$$= 1000 \text{ watt} \times 1 \text{ hour}$$
$$= 1000 \text{ J s}^{-1} \times (60 \times 60 \text{ s})$$
$$= 3{\cdot}6 \times 10^6 \text{ J}$$

Thus, $$\boxed{1 \text{ kWh} = 3{\cdot}6 \times 10^6 \text{ J}} \qquad ...(8.45)$$

The electrical energy (or electricity) consumed by various appliances in our houses (or industries) is measured in the unit kWh and its cost is paid to the electric company accordingly.

8.20 POWER RATING OF COMMON ELECTRICAL APPLIANCES

Generally an electrical appliance such as electric bulb, geyser, heater, *etc.* is rated with its *power* and *voltage. For example*, an electric bulb is rated as 100 W –220 V. It means that if the bulb is lighted on a 220 V supply, the electric *power consumed by it is 100 W (i.e., 100 J of* electrical energy is consumed by the bulb in 1 s or in other words, 100 J of electrical energy is converted in the filament of bulb into the light and heat energy in 1 second).

From this rating, we can calculate the following *two* quantities :

(1) the resistance of the filament of bulb when it is glowing, and

(2) the safe limit of current which can flow through the bulb while in use.

From relation (8.41) $P = \frac{V^2}{R}$

∴ Resistance of filament of bulb while in use, is

$$R = \frac{V^2}{P}$$

or $$\boxed{R = \frac{(\text{voltage rating on the appliance})^2}{\text{power rating on the appliance}}} \qquad ..(8.46)$$

and the current through the filament of bulb when in use, is

$$I = \frac{P}{V}$$

If current exceeds this value, the power supplied at voltage V will exceed the rated power of the bulb and the bulb may get fused. So this value of current is called the *safe current* which can flow through the bulb at voltage V. Thus

$$\boxed{\text{Safe current } I = \frac{\text{power rating on the appliance}}{\text{voltage rating on the appliance}}} \qquad ..(8.47)$$

Example : If the bulb is rated '100 W – 220 V', the resistance of its filament while glowing, is

$$R = \frac{V^2}{P} = \frac{(220)^2}{100} = 484\ \Omega$$

> ***Note :*** The actual resistance of filament of a bulb when it is not glowing (*i.e.*, when it is cold) is appreciably less than this value because the resistance of filament increases when its temperature increases, on glowing.

The safe limit of current through the filament of bulb while glowing is

$$I = \frac{P}{V} = \frac{100}{220} = 0{\cdot}454 \text{ A} \approx 0{\cdot}5 \text{ A}$$

Thus the bulb can withstand a current of 0·5 A. If current exceeds 0·5 A, it may cause the bulb to fuse. At a voltage higher than the rated value, an excessive current will flow through the filament of bulb which will raise its temperature to the extent that it will melt and the bulb will get fused.

Note : The power consumed by a bulb will be equal to the power rating only when the bulb is connected exactly at the voltage rated on it. If the voltage at which the bulb is connected is slightly more, the bulb will glow more brightly *i.e.*, it will consume more power and if the voltage is low, the bulb will glow less and will give a faint dull red light because it will consume less power.

Example : If a bulb is rated 100 W, 220 V, it consumes 100 W power at 220 V and the resistance of its filament while glowing is $\frac{(220)^2}{100}\,\Omega$ $= 484\ \Omega$. Now if this bulb is lighted at 110 V, it will consume power equal to $\frac{(110)^2}{484}$ W = 25 W*. But if the same bulb is lighted at 250 V, it will consume power equal to $\frac{(250)^2}{484}$ W = 129·1 W*.

The table below gives the power rating of some common appliances.

Power rating of some common appliances

Appliance	Power (in watt)	Voltage (in volt)
Car (filament) bulb	20	12
Electric bulb	15–200	220
Fluorescent tube	40	220
Electric fan	60–100	220
Television set	120	220
Refrigerator	150	220
Electric iron	700	220
Electric mixer	750	220
Room heater	1000	220
Geyser	1500	220
Electric kettle	2000	220
Electric oven	3000	220

In our country, a.c. is supplied at voltage equal to 220 V.

8.21 HOUSEHOLD CONSUMPTION OF ELECTRICAL ENERGY

Every home using electricity has an electric meter which measures the amount of electrical energy consumed by the various appliances in that house over a given period of time. The electric meter is fixed at the mains board or just outside our house. The electrical energy is sold in units of kilowatt-hour (kWh). *Thus the unit in which the consumer pays the cost of electrical energy consumed is* kWh.

The electrical energy consumed by an appliance in a certain time can be calculated in kWh by the following relation :

$$\text{Energy (in kWh)} = \text{power (in kW)} \times \text{time (in h)} = \frac{\text{power (in watt)} \times \text{time (in hour)}}{1000} = \frac{V\,(\text{volt}) \times I\,(\text{ampere}) \times t\,(\text{hour})}{1000} \qquad ...(8.48)$$

From relation (8.48), it is clear that the total energy consumed by an electrical appliance in kWh can be calculated by multiplying its power rating in kW with the time duration in hour (h) for which it was in use. The cost of electricity will then be the product of energy consumed in kWh with the rate in rupees per kWh.

$$\text{Cost of electricity} = \text{electrical energy in kWh} \times \text{cost per kWh} \qquad ...(8.49)$$

Example : If an electric oven of power 3 kW is used for 2 h each day, the electrical energy consumed by the electric oven per day will be 3 kW × 2 h = 6 kWh, while the total electrical energy consumed in a month of 30 days will be 3 kW × (2 × 30 h) = 180 kWh. The cost of electricity at a rate of ₹ 4·50 per kWh will then be 180 kWh × ₹. 4·50 = ₹ 810.

Note : **(1)** If we use the appliances of different powers P_1, P_2, P_3, ... kW for *different* duration t_1, t_2, t_3, ... hour, the total energy consumed in kWh is the sum of product of power rating in kW and time duration in hour for each appliance. *i.e.*,

$$\text{Total energy consumed} = (P_1t_1 + P_2t_2 + P_3t_3 + ...)\ \text{kWh} \qquad ...(8.50)$$

* Here it has been assumed that (i) the resistance of the filament of bulb remains same when the bulb is used at 110 V and 250 V. In fact, this is not true because the resistance of filament changes with the temperature. At 110 V, the resistance will be less than 484 Ω and the power consumed will be more than 25 W, but less than 100 W. Similarly at 250 V, the resistance will be more than 484 Ω so the power consumed will be less than 129 W, but still more than 100 W. (ii) the current in the bulb remains less than its safe value.

(2) In a house, if we use several appliances of different powers P_1, P_2, P_3, ... kW for *same* duration t hour, the total energy consumed by all the appliances in that duration can be calculated by multiplying the sum of power rating of all appliances in kW with the time duration in hour. *i.e.,*

Total energy consumed in kWh

= total power rating in kW × time duration in hours

$$= (P_1 + P_2 + P_3 + ...) \times t \quad ....(8.51)$$

8.22 HEATING EFFECT OF CURRENT

The amount of heat produced in a wire on passing current through it, depends on the following *three* factors :

(1) The amount of current passing through the wire : The amount of heat H produced in a wire is directly proportional to the square of current I passing through the wire,

i.e., $\qquad H \propto I^2 \qquad$ .....(i)

(2) The resistance of wire : The amount of heat H produced in the wire is directly proportional to the resistance R of the wire,

i.e., $\qquad H \propto R \qquad$ .....(ii)

(3) The time for which current is passed in the wire : The amount of heat H produced in a wire is directly proportional to the time t for which current is passed in the wire

i.e., $\qquad H \propto t \qquad$ .....(iii)

Combining the eqns. (i), (ii) and (iii),

$$H \propto I^2Rt$$

or $\boxed{H = I^2Rt \text{ joule or } H = 0{\cdot}24\ I^2Rt \text{ cal}}$.(8.52)*

where I is in ampere, R in ohm and t in second. The relation (8.52) is also known as *Joule's law of heating*.

* 1 cal = 4·18 joule

EXAMPLES

1. A voltage source sends a current 2·5 A to a resistor of 20 Ω connected across it for 5 minutes. Calculate : (i) the p.d. of the source, (ii) the electrical energy supplied by the source, and (iii) the heat in cal, produced in the resistor.

Given : $I = 2{\cdot}5$ A, $R = 20\ \Omega$,

t = 5 minutes = 5 × 60 s = 300 s

(i) p.d. of the source $V = IR = 2{\cdot}5 \times 30 =$ **50 V**

(ii) Electrical energy supplied by the source

$= VIt = 50 \times 2{\cdot}5 \times 300 =$ **$3{\cdot}75 \times 10^4$ J**

(iii) Heat produced in the resistor = $3{\cdot}75 \times 10^4$ J

$$= \frac{3{\cdot}75 \times 10^4}{4{\cdot}18} \text{ cal} = \mathbf{9 \times 10^3 \text{ cal}} \text{ (nearly)}$$

Alternative : Heat produced = $0{\cdot}24\ I^2Rt$ cal

$= 0{\cdot}24 \times (2{\cdot}5)^2 \times 20 \times 300 =$ **9×10^3 cal**

2. The current through a 12 V tungsten filament lamp connected to a 12 V accumulator of negligible resistance is 3·0 A. Calculate :

(i) the resistance of the filament,

(ii) the power of the lamp, and

(iii) the electrical energy in kWh consumed in 5 hours

Given : V = 12 volt, I = 3·0 ampere, t = 5 h

(i) Resistance $R = \frac{V}{I} = \frac{12}{3} =$ **4 Ω**

(ii) Power $P = V \times I = 12 \times 3 =$ **36 W**

(iii) Electrical energy $W = VIt = 12 \times 3 \times 5$

= 180 Wh = **0·18 kWh**

Alternative method :

Electrical energy in kWh

$$= \frac{V(\text{in volt}) \times I(\text{in ampere}) \times t(\text{in hour})}{1000}$$

$$= \frac{12 \times 3 \times 5}{1000} = \mathbf{0{\cdot}18 \text{ kWh}}$$

3. An electric kettle is rated at 230 V, 1000 W. (a) What is the resistance of its element when in use ? (b) What is the safe value of current that can pass through its element ?

Given : P = 1000 W, V = 230 volt

(a) From relation $P = \frac{V^2}{R}$,

Resistance of element while in use

$$R = \frac{V^2}{P} = \frac{(230)^2}{1000} = 52{\cdot}9\ \Omega$$

(b) From relation $P = VI$,

$$\text{Safe current } I = \frac{P}{V} = \frac{1000}{230} = 4{\cdot}35 \text{ A}$$

4. A 6 V, 12 W lamp is connected in series with a resistor R and a source of voltage 12 V.

(a) What is the purpose of the resistor R ?

(b) Calculate the value of the resistor R, for the proper working of the lamp.

(c) What is the current flowing through the circuit ?

(a) The given lamp is meant to be used on supply of voltage 6 V. Since the source available is of voltage 12 V, so a resistor R is used in series with the lamp to reduce the current to its safe value for the lamp.

(b) Maximum current which the lamp rated 6 V, 12 W can withstand, is

$$I = \frac{P}{V} = \frac{12}{6} = 2 \text{ A}$$

Resistance of the filament of lamp while in use

$$R' = \frac{V^2}{P} = \frac{(6)^2}{12} = 3\ \Omega$$

On connecting a resistor R in series with the lamp, total resistance of circuit $= R + R' = (R + 3)\ \Omega$

With supply of voltage 12 V, the current in the circuit should be $I = 2$ A.

By Ohm's law, $V = IR$

$\therefore \quad 12 = 2\,(R + 3)$

or $\quad 12 = 2R + 6$ or $R = 3\ \Omega$

(c) Current flowing through the circuit = 2 A

5. Two coils of resistances $R_1 = 3\ \Omega$ and $R_2 = 6\ \Omega$ are connected in series across a battery of p.d. 12 V. Draw the circuit diagram. Find : (i) the electrical energy consumed in 1 minute in each resistance, and (ii) the total electrical energy supplied by the battery in 1 minute.

The circuit is shown in Fig 8.58.

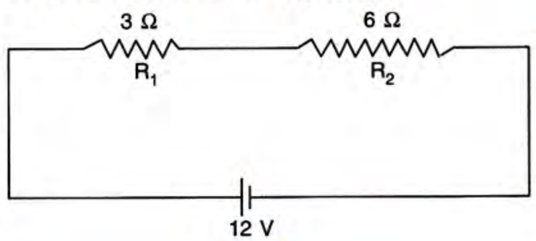

Fig 8.58

(i) Given : $R_1 = 3\ \Omega$, $R_2 = 6\ \Omega$, $V = 12$ volt, $t = 1$ minute $= 60$ s

Total resistance of circuit $R = R_1 + R_2$

$= 3 + 6 = 9\ \Omega$

$$\text{Current in circuit } I = \frac{V}{R} = \frac{12}{9} = \frac{4}{3}\text{A}$$

Since the resistances are in series, so same current flows in each resistance.

Electrical energy consumed in R_1 will be

$$W_1 = I^2 R_1 t = \left(\frac{4}{3}\right)^2 \times 3 \times 60 = 320 \text{ J}$$

Electrical energy consumed in R_2 will be

$$W_2 = I^2 R_2 t = \left(\frac{4}{3}\right)^2 \times 6 \times 60 = 640 \text{ J}$$

(ii) Total electrical energy supplied by the battery in 1 minute

$$W = W_1 + W_2 = 320 \text{ J} + 640 \text{ J} = 960 \text{ J}$$

Alternative method : Total electrical energy supplied by the battery in time t (= 1 minute or 60 s) to the total resistance R (= 9 ohm) is

$$W = \frac{V^2 t}{R} = \frac{(12)^2 \times 60}{9} = 960 \text{ J}$$

6. Two resistors R_1 and R_2 of resistance 3 Ω and 6 Ω respectively are connected in parallel across a battery of p.d. 12 V. Draw the circuit diagram. Calculate the electrical energy consumed in 1 minute in each resistance.

The circuit diagram is shown in Fig. 8.59.

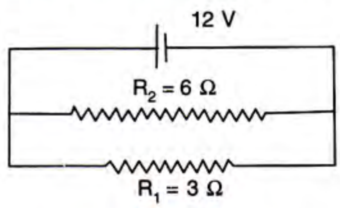

Fig 8.59

Given : $R_1 = 3\ \Omega$, $R_2 = 6\ \Omega$, $V = 12$ volt, $t = 1$ minute $= 60$ s

The resistors R_1 and R_2 are connected in parallel, so the voltage V across each resistor is equal to 12 volt.

Electrical energy spent in R_1 resistor

$$W_1 = \frac{V^2 t}{R_1} = \frac{(12)^2 \times 60}{3} = 2880 \text{ J}$$

Electrical energy spent in R_2 resistor

$$W_2 = \frac{V^2 t}{R_2} = \frac{(12)^2 \times 60}{6} = 1440 \text{ J}$$

7. Fig. 8.60 shows two resistors A of 4 Ω and B of 6 Ω joined in series to a battery of e.m.f. 12 V and internal resistance 2 Ω. Calculate : (i) the current in circuit, (ii) the terminal voltage of the battery, (iii) the p.d. across the resistor B, and (iv) the electrical energy spent in 1 minute in resistor A.

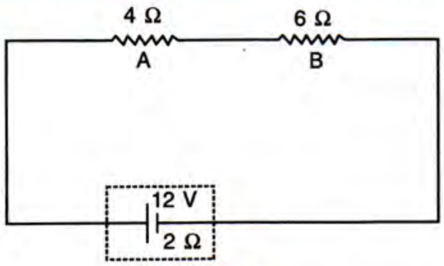

Fig 8.60

Given : $R_A = 4\ \Omega$, $R_B = 6\ \Omega$, $\varepsilon = 12$ V, $r = 2\ \Omega$, $t = 1$ minute = 60 s

(i) Total resistane of circuit

$$R = R_A + R_B + r = 4 + 6 + 2 = 12\ \Omega$$

Current in circuit $I = \dfrac{\varepsilon}{R} = \dfrac{12\text{ V}}{12\,\Omega} = 1{\cdot}0$ **A**

(ii) Terminal voltage of the battery $V = \varepsilon - Ir$

$$= 12 - (1{\cdot}0 \times 2) = 10\text{ V}$$

(iii) p.d. across the resistor B = $I R_B$

$$= 1{\cdot}0 \times 6 = 6{\cdot}0\text{ V}$$

(iv) Electrical energy spent in resistor A

$$= I^2R_At = (1{\cdot}0)^2 \times 4 \times 60$$
$$= 240\text{ J}$$

8. Two bulbs A and B are rated 100 W, 120 V and 10 W, 120 V respectively. They are connected across a 120 V source in series.

(a) Calculate the current through each bulb.

(b) Which bulb will consume more power ?

(a) Resistance of bulb A (rating 100 W, 120 V) is

$$R_A = \frac{V^2}{P_A} = \frac{(120)^2}{100} = 144\ \Omega$$

Resistance of bulb B (rating 10 W, 120 V) is

$$R_B = \frac{V^2}{P_B} = \frac{(120)^2}{10} = 1440\ \Omega$$

The bulbs are connected in series across a source of voltage $V = 120$ volt,

Total resistance $R_s = R_A + R_B$

$$= 144 + 1440 = 1584\ \Omega$$

Current in circuit $I = \dfrac{V}{R_s} = \dfrac{120}{1584} = 0{\cdot}08$ **A**

Same current (= **0·08 A**) passes through each bulb.

(b) Power consumed in the bulb A is $P_A = I^2R_A$

Power consumed in the bulb B is $P_B = I^2R_B$

Since $R_A < R_B$ $\quad\therefore\ P_A < P_B$

Hence the **bulb B** (rated 10 W, 120 V) consumes more power than the bulb A (rated 100 W, 120 V) when they are connected in series.

9. Two bulbs A and B are rated 100 W, 120 V and 10 W, 120 V respectively. They are connected in parallel across a 120 V source.

(a) Find the current in each bulb.

(b) Which bulb will consume more power ?

(a) Resistance of bulb A (rating 100 W, 120 V) is

$$R_A = \frac{V^2}{P_A} = \frac{(120)^2}{100} = 144\ \Omega$$

Resistance of bulb B (rating 10 W, 120 V) is

$$R_B = \frac{V^2}{P_B} = \frac{(120)^2}{10} = 1440\ \Omega$$

As the bulbs are connected in parallel across a 120 V source, the voltage is the same (= 120 V) across each bulb.

Current in the bulb A

$$I_A = \frac{V}{R_A} = \frac{120}{144} = 0{\cdot}84\text{ A}$$

Current in the bulb B

$$I_B = \frac{V}{R_B} = \frac{120}{1440} = 0{\cdot}084\text{ A}$$

(b) Power consumed by the bulb A will be 100 W and by the bulb B will be 10 W as per their specifications since both the bulbs operate at their rated voltage (= 120 V). Obviously, the **bulb A** (with rating 100 W, 120 V) consumes more power than the bulb B (with rating 10 W, 120 V).

10. An electric iron is rated '220 V, 1 kW'. Under normal working conditions, find :

(i) the resistance of its heating element,

(ii) the amount of current that will flow through the element,

(iii) the amount of heat that will be produced in 5 minutes, and

(iv) the power consumed if the line voltage falls to 180 V.

Given : $V = 220$ volt, and $P = 1$ kW = 1000 W

(i) Since $P = \dfrac{V^2}{R}$

∴ Resistance of the heating element

$$R = \frac{V^2}{P} = \frac{(220)^2}{1000} = 48{\cdot}4\ \Omega$$

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(ii) Current through the element

$$I = \frac{P}{V} = \frac{1000}{220} = \mathbf{4{\cdot}54\ A.}$$

(iii) Heat produced in time t (= 5 min or 300 s)

= power × time

= 1000 × 300

= 300000 J = **300 kJ.**

(iv) If the line voltage falls to 180 V, power consumed is given by

$$P = \frac{V^2}{R} = \frac{(180)^2}{48{\cdot}4} = \mathbf{675\ W}$$

Here we have assumed that the resistance of the element does not change on fall of voltage.

11. A geyser has a rating 2 kVA, 240 V. (a) What is the electrical energy consumed by it in (i) kWh, and (ii) joule if it is used for 90 minutes. (b) If the cost of electricity is ₹ 4.50 per commercial unit, find the cost.

Given, P = 2 kVA = 2 kW, t = 90 minute = 1·5 h

(a) (i) Electrical energy consumed = power × time

= 2 kW × 1·5 h

= 3 kWh (or 3 commercial unit)

(ii) Since 1 kWh = $3{\cdot}6 \times 10^6$ J

∴ Electrical energy consumed = $3 \times 3{\cdot}6 \times 10^6$ J

= $1{\cdot}08 \times 10^7$ J

(b) Cost of electricity = 3 × ₹ 4.50 = ₹ **13.50.**

12. An electrical appliance is rated 1500 W, 250 V. This appliance is connected to mains of voltage 250 V. Calculate : (i) the current drawn, (ii) the electrical energy consumed in 60 hours, and (iii) the cost of electrical energy consumed at a rate of ₹ 4.50 per kWh.

Given : rating of the appliance = 1500 W, 250 V *i.e.*, P = 1500 W, V = 250 volt, time t = 60 h.

(i) Current drawn $I = \frac{P}{V} = \frac{1500}{250}$ = **6 A**

(ii) Electrical energy consumed = power × time

= 1500 W × 60 h = 90000 Wh = **90 kWh**

(iii) Cost of electrical energy

= electrical energy consumed in kWh × rate per kWh

= 90 × ₹ 4.50 = ₹ **405.0**

13. (a) Calculate the electrical energy in kWh consumed in a month, in a house using 2 bulbs of 100 W each and 2 fans of 60 W each, if the bulbs and fans are used for an average of 10 hours each day.

(b) If the cost per unit is ₹ 4.50, calculate in part (a) the amount of electric bill to be paid per month.

Given, power of each bulb = 100 W, power of each fan = 60 W, time t = 10 h each day.

(a) Power of 2 bulbs = 2 × 100 = 200 W

Power of 2 fans = 2 × 60 = 120 W

∴ Total power = 200 + 120 = 320 W

$$= \frac{320}{1000}\ \text{kW} = 0{\cdot}32\ \text{kW}$$

Time duration of consumption for a month at a rate of 10 h per day = 10 h × 30 = 300 h

∴ Total energy consumed

= total power × time duration

= 0·32 kW × 300 h = **96 kWh**

(b) Total cost = 96 × ₹ 4.50 = ₹ **432.0**

14.* A heating coil is immersed in a calorimeter of heat capacity 50 J °C⁻¹ containing 1·0 kg of a liquid of specific heat capacity 450 J kg⁻¹ °C⁻¹. The temperature of liquid rises by 10°C when 2·0 A current is passed for 10 minutes. Find : (i) the resistance of the coil, (ii) the potential difference across the coil. State the assumption used in your calculations.

Given : heat capacity of calorimeter mc = 50 J °C^{-1}

Mass of liquid M = 1·0 kg

Specific heat capacity of liquid

c' = 450 J kg^{-1} °C^{-1}

Rise in temperature $(T_2 - T_1)$ = 10 °C

Current I = 2·0 A

Time t = 10 min = 10 × 60 s = 600 s

Total heat energy required = heat energy required by the calorimeter + heat energy required by the liquid = $mc\,(T_2 - T_1) + Mc'\,(T_2 - T_1)$

$= (mc + Mc')\,(T_2 - T_1)$

$= [50 + (1{\cdot}0 \times 450)] \times (10)$ = 5000 joule

(i) If R is the resistance of coil, heat energy produced in the coil = $I^2 Rt = (2)^2 \times R \times 600$

= 2400 R joule

If there is no loss of heat,

heat energy required = Heat energy produced

5000 = 2400 R

or $R = \frac{5000}{2400}$ = **2·08 Ω**

(ii) Potential difference across the coil

$V = IR$ = 2 × 2·08 = **4·16 V**

Assumption : In the above calculations, we have assumed that there is **no loss** of heat.

* Solve this example after reading the chapter 11.

EXERCISE–8(C)

1. Write an expression for the electrical energy spent in flow of current through an electrical appliance in terms of current, resistance and time.
Ans. I^2Rt

2. Write an expression for the electrical power spent in flow of current through a conductor in terms of (a) resistance and potential difference, (b) current and resistance. **Ans.** (a) V^2/R (b) I^2R

3. Electrical power P is given by the expression $P = (Q \times V) \div$ time.
   (a) What do the symbols Q and V represent ?
   (b) Express the power P in terms of current and resistance explaining the meaning of symbols used there in.

4. Name the S.I. unit of electrical energy. How is it related to Wh ?

5. Explain the meaning of the statement 'the power of an appliance is 100 W'.

6. State the S.I. unit of electrical power.

7. (i) State and define the household unit of electricity.
   (ii) What is the voltage of the electricity that is generally supplied to a house ?
   (iii) What is consumed while using different electrical appliances, for which electricity bills are paid ?

8. Name the physical quantity which is measured in (i) kW, (ii) kWh.

9. Define the term kilowatt-hour and state its value in S.I. unit.

10. Distinguish between kilowatt and kilowatt-hour.

11. Complete the following :
    (a) $1 \text{ kWh} = \dfrac{1 \text{ volt} \times 1 \text{ ampere} \times ....}{1000}$
    (b) 1 kWh = ... J
    Ans. (a) 1 hour (b) $3{\cdot}6 \times 10^6$

12. What do you mean by power rating of an electrical appliance ? How do you use it to calculate (a) the resistance of the appliance, and (b) the safe limit of current in it, while in use ?

13. An electric bulb is rated '100 W, 250 V'. What information does this convey ?

14. List the names of *three* electrical gadgets used in your house. Write their power, voltage rating and approximate time for which each one is used in a day. Hence find the electrical energy consumed by each in a day.

15. Two lamps, one rated 220 V, 50 W and the other rated 220 V, 100 W, are connected in series with mains of voltage 220 V. Explain why does the 50 W lamp consume more power.

16. Name the factors on which the heat produced in a wire depends when current is passed in it, and state how does it depend on the factors stated by you.

MULTIPLE CHOICE TYPE

1. When a current I flows through a resistance R for time t, the electrical energy spent is given by :
   (a) IRt (b) I^2Rt
   (c) IR^2t (d) I^2R / t **Ans.** (b) I^2Rt

2. An electrical appliance has a rating 100 W, 120 V. The resistance of element of appliance when in use is :
   (a) 1·2 Ω (b) 144 Ω
   (c) 120 Ω (d) 100 Ω **Ans.** (b) 144 Ω

NUMERICALS

1. A current of 2 A is passed through a coil of resistance 75 Ω for 2 minutes. (a) How much heat energy is produced ? (b) How much charge is passed through the resistance ?
Ans. (a) 36000 J (b) 240 C

2. Calculate the current through a 60 W lamp rated for 250 V. If the line voltage falls to 200 V, how is the power consumed by the bulb affected ?
Ans. 0·24 A, power consumed reduces to 38·4 W

3. An electric bulb is rated '100 W, 250 V'. How much current will the bulb draw if connected to a 250 V supply ? **Ans.** 0·4 A

4. An electric bulb is rated '220 V, 100 W'. (a) What is its resistance ? (b) What safe current can be passed through it ? **Ans.** (a) 484 Ω, (b) 0·45 A

5. A bulb of power 40 W is used for 12·5 h each day for 30 days. Calculate the electrical energy consumed. **Ans.** 15 kWh

6. An electric iron is rated '750 W, 230 V'. Calculate the electrical energy consumed by the iron in 16 hours. **Ans.** 12 kWh

7. An electrical appliance having a resistance of 200 Ω is operated at 200 V. Calculate the energy consumed

by the appliance in 5 minutes (i) in joule, (ii) in kWh. **Ans.** (i) 60,000 J (ii) 0·0167 kWh

8. A bulb marked 12 V, 24 W operates on a 12 volt battery for 20 minutes. Calculate :
(i) the current flowing through it, and
(ii) the energy consumed.
Ans. (i) 2 A (ii) 28,800 J

9. A current of 0·2 A flows through a wire whose ends are at a potential difference of 15 V. Calculate :
(i) the resistance of the wire, and
(ii) the heat energy produced in 1 minute.
Ans. (i) 75 Ω (ii) 180 J

10. What is the resistance, under normal working conditions, of an electric lamp rated '240 V, 60 W' ? If two such lamps are connected in series across a 240 V mains supply, explain why each one appears less bright.

Ans. 960 Ω. When one lamp is connected across the mains, it draws 0·25 A current. If two such lamps are connected in series across the mains, current through each bulb becomes $\frac{240\text{ V}}{(960+960)\ \Omega}$ = 0·125 A (*i.e.*, current is halved). Hence heating (= I^2Rt) in each bulb becomes one-fourth, so each bulb appears less bright.

11. Two bulbs are rated '60 W, 220 V' and '60 W, 110 V' respectively. Calculate the ratio of their resistances.
Ans. 4 : 1

12. An electric bulb is rated '250 W, 230 V'. Calculate:
(i) the energy consumed in one hour, and
(ii) the time in which the bulb will consume 1·0 kWh energy when connected to 230 V mains. **Ans.** (i) 9×10^5 J (ii) 4 h

13. Three heaters each rated '250 W, 100 V' are connected in parallel to a 100 V supply. Calculate :
(i) the total current taken from the supply,
(ii) the resistance of each heater, and
(iii) the energy supplied in kWh to the three heaters in 5 hours.
Ans. (i) 7·5 A (ii) 40 ohm (iii) 3·75 kWh

14. A bulb is connected to a battery of p.d. 4 V and internal resistance 2·5 Ω. A steady current of 0·5 A flows through the circuit. Calculate :
(i) the total energy supplied by the battery in 10 minutes,
(ii) the resistance of the bulb, and
(iii) the energy dissipated in the bulb in 10 minutes.
Ans. (i) 1200 J (ii) 5·5 Ω (iii) 825 J

15. Two resistors A and B of resistance 4 Ω and 6 Ω respectively are connected in parallel. The combination is connected across a 6 volt battery of negligible resistance. Calculate : (i) the power supplied by the battery, and (ii) the power dissipated in each resistor.
Ans. (i) 15 W (ii) **A** – 9 W, **B** – 6 W

16. A battery of e.m.f. 15 V and internal resistance 2 Ω is connected to two resistors of resistances 4 ohm and 6 ohm joined in series. Find the electrical energy spent per minute in 6 ohm resistor.
Ans. 562·5 J

17. Water in an electric kettle connected to a 220 V supply takes 5 minutes to reach its boiling point. How long will it take if the supply voltage falls to 200 V ?
Ans. 6·05 minutes

18. An electric toaster draws current 8 A in a circuit with source of voltage 220 V. It is used for 2 h. Find the cost of operating the toaster if the cost of electrical energy is ₹ 4.50 per kWh.
Ans. ₹ 15.84

19. An electric kettle is rated '2·5 kW, 250 V'. Find the cost of running the kettle for two hours at ₹ 5.40 per unit. **Ans.** ₹ 27.00

20. A geyser is rated '1500 W, 250 V'. This geyser is connected to 250 V mains. Calculate :
(i) the current drawn,
(ii) the energy consumed in 50 hours, and
(iii) the cost of energy consumed at ₹ 4.20 per kWh.
Ans. (i) 6 A (ii) 75 kWh (iii) ₹ 315