Class X : Physics

Chapter: Electricity

Topics

Topics
Ohm's Law
Resistance of a System of Resistors
Electrical Energy and Power

[ ]

Ohm's Law

1. What is the difference between static and current electricity?
Static electricity consists of immobile charges. It is produced on non-conducting material or on a conductor insulated from outside. Current electricity consists of charges in motion. Actually, current is defined as charge flowing per unit time.

2. What is the origin of static electricity?
Static electricity is produced due to transfer of electrons from one body to another due to friction. The body which loses electrons becomes positively charged and the body which gains electrons becomes negatively charged. So it is not creation of charge but is redistribution of charges.

3. What is the difference between conductors and insulators?
Electrons in the conductors are free to move inside the volume of the body. So by applying external energy we can force these electrons to move from one point to another. In this way the current is produced in conductors. On the other hand, insulators do not have free electrons. Electrons cannot move freely inside the body of insulators.

4. Give three examples each of conductors and insulators.

Conductors	Insulators
Copper	Rubber
Graphite	Glass
Silver	Plastic

5. Give one example of a source of current. Does it produce charge?

A cell is a simple device which is source of electric current. It does not produce charge. It only causes the motion of electrons which are already present in the wire.

6. What is the difference between the direction of conventional current and the flow of electrons in a circuit?
Electrons flow from a negatively charged plate towards the positively charged plate. Conventionally, the direction of electric current corresponds to the direction of flow of positive charge, i.e, from positively charged plate to negatively charged plate.

7. Define electric current.
Electric current is defined as the rate of flow of electric charge i.e. the quantity of charge flowing per unit time.

$I = \frac{Q}{t}$

8. Define the unit of electric current.
Current through a wire is said to be 1 ampere if a charge of 1 coulomb flows through the wire in 1 second.

9. What is the charge on an electron in coulombs?
Charge on an electron = 1.6×10^{-19} coulombs.

10. How many electrons will make one coulomb of charge?
Since one electron has a charge equal to 1.6×10^{-19} coulombs, number of electrons making one coulomb will be $\frac{1}{1.6 \times 10^{-19}} = \frac{1}{1.6} \times 10^{19} = 6 \times 10^{18}$ number of electrons, approximately.

11. The filament of an electric toaster draws a current of 40 A which heats for 30 minutes. Determine the amount of charge that flows through the filament.
Current I = 40 A
Time t = 30 min = 30×60 = 1800 s
Charge Q = I x t = $40 \times 1800 = 72000 = 72 \times 10^3$ C

12. Define electric potential difference.
Electric potential difference between any two points A and B on a conductor carrying current is the work done to move a unit charge from A to B. $V = \frac{W}{Q}$

13. Define the unit of electric potential difference.
One volt is the potential difference when 1 joule of work is done to move a charge of 1 coulomb.

$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$

14. Why is potential difference necessary to maintain current?
As water flows from a greater height to lower height and air flows from higher

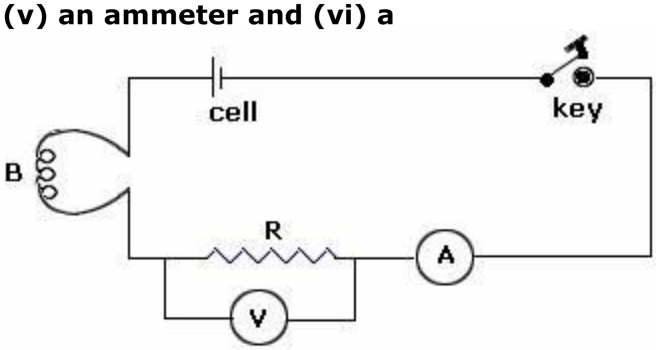
pressure to lower pressure, similarly current flows from higher potential to lower potential. So if there is no potential difference there will be no current.

15. Give two conditions needed for the flow of current.
Flow of current in a wire is produced and maintained only if - potential difference is applied across the ends of a wire. - a constant potential difference is maintained across the two ends of a wire.

16. How does a cell maintain the potential difference across the conductor?
The chemical reactions inside the cell generate a difference in potential between the electrodes.

17. Differentiate between a cell and a battery.
A cell is a single unit of source of electric current. A battery consists of number of cells connected in series.

18. Represent by means of a schematic diagram a circuit containing following elements: (i) a cell (ii) plug key (iii) an electric bulb (iv) a resistance (v) an ammeter and (vi) a

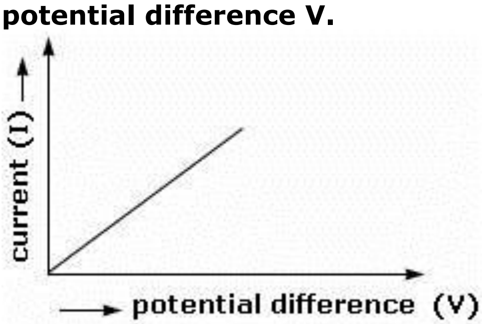


voltmeter.

19. State Ohm's law.
The current through a conductor is proportional to the potential difference applied across its ends, at constant temperature.

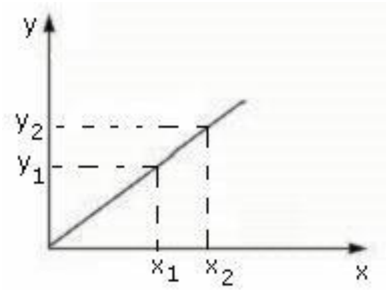
$i \propto V$
where R is a constant called resistance]

20. Represent graphically, the variation of current I as a function of potential difference V.



21. How is slope of the graph represented? Which physical quantity is represented by the inverse of the slope of V - I graph?
Slope of a graph is represented as

$= \frac{y_2 - y_1}{x_2 - x_1}$



Inverse of slope of V - I graph = $\left(\frac{\Delta I}{\Delta V}\right)^{-1} = \frac{\Delta V}{\Delta I}$ = Resistance of the conductor

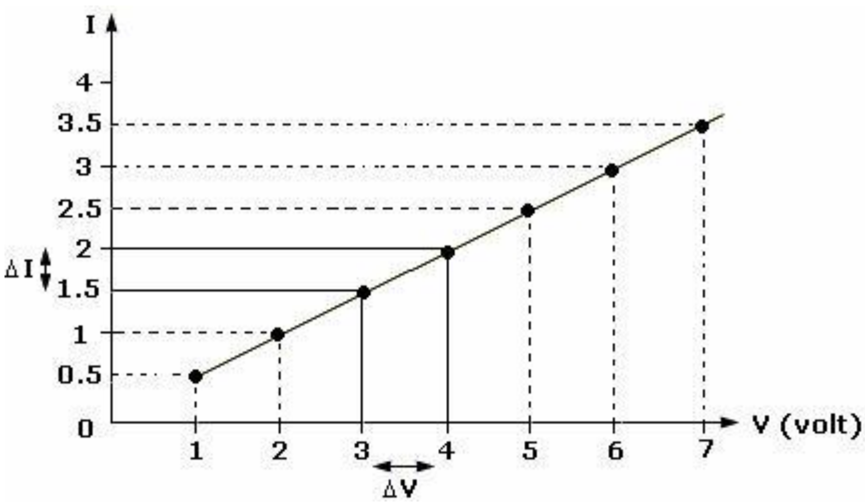
22. The values of current I flowing through a given resistor for the various values of potential difference applied are given as below:

Voltage (V)	Current (I)
1	0.5
2	1
3	1.5
4	2
5	2.5
6	3
7	3.5

Plot the graph between V and I. Determine resistance of the conductor from the graph.

Resistance of conductor = Inverse of slope of graph $R = \left(\frac{\Delta I}{\Delta V}\right)^{-1} = \left(\frac{0.5}{1}\right)^{-1}$

$R = \frac{1}{0.5} = 2\ \Omega$



1. What is resistance of a conductor due to?
Resistance of a conductor is due to the obstruction to the flow of electrons due to the collisions with atoms and other electrons.

2. Define the unit of resistance.
Resistance of a conductor is said to be 1 ohm ($1\,\Omega$), when a potential difference of 1 volt (1 V) applied across the ends of a conductor produces a current of 1 ampere (A).

$$1\Omega = \frac{1\,V}{1\,A}$$

3. State three factors on which the resistance of a wire depends upon.
(i) Nature of material of the wire (ii) Length of the wire (iii) Cross-sectional area of the wire

4. Express mathematically, the resistance of a conductor in terms of the factors on which it depends upon.
Resistance is directly proportional to the length of the wire and inversely proportional to the area cross section of the wire, under constant temperature

$$R \propto \frac{\ell}{A}$$

$$R = \frac{\rho \ell}{A}$$ where ρ is the resistivity of the material of the wire.

conditions.

5. Give three differences between ammeter and voltmeter.

Parameter	Ammeter	Voltmeter
Usage	To measure current	To measure potential difference
Connectivity in the circuit	Always connected in series	Always connected in parallel
Resistance	The resistance of ammeter is low	The resistance of voltmeter is high

6. There are two wires, thick and thin. Which one will have greater resistance?
Thin wire will offer larger resistance as resistance of wire is inversely proportional to cross sectional area.

7. A metallic wire of length 1 m is stretched to double its length. Calculate the ratio of its initial and final resistance assuming that there is no change in its density on stretching.
Given $\ell_1 = 1\text{m}$ $\ell_2 = 2\text{m}$ as $R_1 \propto \ell_1$ $R_2 \propto \ell_2$

No change in density,

$$\Rightarrow \ell_1 A_1 = \ell_2 A_2$$

$$\Rightarrow \frac{\ell_1}{\ell_2} = \frac{A_2}{A_1}$$

$$\frac{R_1}{R_2} = \frac{\ell_1}{\ell_2}\frac{A_2}{A_1} = \left(\frac{\ell_1}{\ell_2}\right)^2 = \left(\frac{1}{2}\right)^2$$

$$\frac{R_1}{R_2} = \frac{1}{4}$$

8. Justify that a good conductor offers less resistance.
A good conductor contains large number of loosely held electrons. The free electrons available for free flow are large and hence conductivity is high. The obstruction to the flow of electrons is less as the attractive force between the atoms and electrons is small. Resistance to the electron flow is less.

9. Define resistivity.
Resistivity is defined as the resistance offered by a cube of a material of side 1 m, when current flows perpendicular to the opposite faces.

$\rho = \frac{R\,A}{\ell}$, for A = 1 m^2 and ℓ = 1 m,

$\rho = R$

10. State the unit of resistivity.

$$\text{Resistivity}, \rho = \frac{R\,A}{\ell} \equiv \text{ohm} - \text{metre}$$

11. Give one example each of the materials of low and high resistivity.
Low resistivity: Metals and alloys.
High resistivity: Insulators.

12. A copper wire has a diameter of 0.5 mm and a resistivity of 1.6 x 10^{-6} Ω cm. How much of this wire would be required to make a 10 Ω coil?

From, $A = \pi r^2 = 3.14 \times (0.25 \times 10^{-3})^2 = 1.96 \times 10^{-7}\,m^2$

$\rho = 1.6 \times 10^{-6}\,\Omega - cm = 1.6 \times 10^{-8}\,\Omega - m$ $R = 10\,\Omega$

$$\Rightarrow \ell = \frac{R\,A}{\rho} = \frac{10 \times 1.96 \times 10^{-7}}{1.6 \times 10^{-8}} = 122.5\,m$$

13. How does the increase in temperature affect the resistance of a wire?

If a wire is a conductor, rise in temperature will increase its resistance.
If it is an insulator, change in temperature will have no effect, and if it is semi conductor, the resistance will decrease with the increase in temperature.

14. Why are alloys preferred over metals in electric heating devices? Give two reasons.
Resistivity of an alloy is in general higher than that of pure metals, which helps in producing greater amount of heating. Also the variation of resistivity with temperature is least in alloys and hence do not burn readily at high temperatures. Therefore, alloys are commonly used in heating devices.

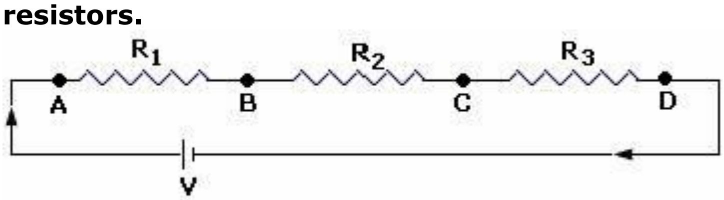
15. Metals like tungsten are preferred in incandescent lamps whereas metals like copper and aluminum are preferred for electrical transmission lines. Why?
Tungsten has very high resistivity and hence preferred for incandescent lamps. Metals like copper and aluminum are very good conductors and of very low resistivity, which are ideally suited for transmission lines.

16. What is the constitution of the alloy nichrome? What is its use?
Nichrome is an alloy of nickel, chromium, manganese and iron. It has very high resistivity so it is used in heating elements of electric irons, toasters etc.

17. An electric heater has a coil of resistance 100 Ω.
How much current will the electric heater draw from a 210 V line?
Given V = 210 volt, R = 100 Ω
From Ohm's law: V = I R
Hence, $I = \frac{210}{100}$ = 2.1 ampere

Resistance of a System of Resistors

1. Derive the formula for equivalent resistance in a series combination of resistors.



Applying Ohm's law to the three resistors,
$V_A - V_B = iR_1$ - (1)
$V_B - V_C = iR_2$ - (2)
$V_C - V_D = iR_3$ - (3)
Adding we get $V_A - V_D = i (R_1 + R_2 + R_3)$ - (4)
Let R_{eq} be the equivalent resistance between A & D.

So $V_A - V_D = iR_{eq}$ - (5)
From (4) and (5)
$i R_{eq} = i (R_1 + R_2 + R_3)$
$\Rightarrow R_{eq} = R_1 + R_2 + R_3$

2. Derive the formula for equivalent resistance in a parallel combination of resistors.
Applying Ohm's law to the three resistors,
$V_A - V_B = i_1R_1$
$V_A - V_B = i_2R_2$
$V_A - V_B = i_3R_3$
Let R_{eq} be the equivalent resistance between A and B.
So $V_A - V_B = iR$
Now $i = i_1 + i_2 + i_3$

$$\frac{V_A - V_B}{R} = \frac{V_A - V_B}{R_1} + \frac{V_A - V_B}{R_2} + \frac{V_A - V_B}{R_3} \Rightarrow \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

3. What are the differences between series and parallel combination of resistors?

Parameter	Series Combination	Parallel Combination
Value of equivalent resistance, R_{eq}	R_{eq} is more than the largest of the constituent resistors, as $R = R_1 + R_2 + R_3$	Req is smaller than the smallest of the constituent resistors, as $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$
Distribution of current	Current through each of the resistors in series is the same.	Current through each of the resistors is different.
Distribution of voltage	Potential difference across each of the resistors in series is different	Potential difference across each of the resistors in parallel is the same.

4. Why is series arrangement not used for domestic circuits?
In a series arrangement of appliances, in case of faulty operations, if any one of the appliances gets out of operation, the entire circuit gets broken. In a parallel arrangement of appliances, each appliance is connected independently across the mains supply. Each appliance or component of the circuit functions independent of each other. Hence parallel arrangement is preferred in domestic circuits.

5. Resistors R_1, R_2 and R_3 are connected in a particular combination in a circuit. Current I through each resistor is the same.
(i) Identify the nature of combination of the resistors.
(ii) Express the equivalent resistance of the combination.
(iii) What is the voltage across each resistor, if voltage applied across the combination is V?
(i) Series combination
(ii) $R_{eq} = R_1 + R_2 + R_3$
(iii) $V = V_1 + V_2 + V_3$
where potential difference across R_1 is $V_1 = I R_1$,
potential difference across R_2, $V_2 = I R_2$,

potential difference across R_3 , $V_3 = I R_3$.

6. Resistors R_1, R_2 and R_3 are connected in a particular combination such that potential difference across each resistor is V.
(i) Identify the nature of combination.
(ii) Write the expression for current in each of the resistors.
(iii) Express the equivalent resistance of the combination.
(i) Parallel combination

(ii) Current through R_1, $I_1 = \frac{V}{R_1}$;

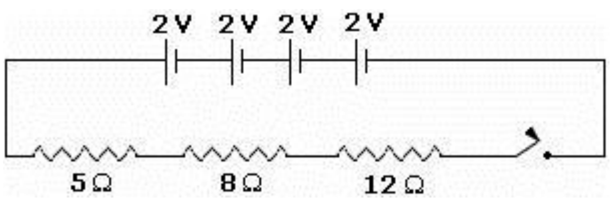
Current through R_2 , $I_2 = \frac{V}{R_2}$;

Current through R_3, $I_3 = \frac{V}{R_3}$.

(iii) $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

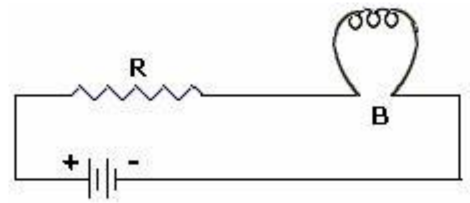
<u>Numericals Based on Ohm's Law</u>

1. (a) Draw a schematic diagram of a circuit consisting of a battery of four 2 V cells, a 5 ohm resistor, a 8 ohm resistor and a 12 ohm resistor and a plug key all connected in series.
(b) In the above diagram, an ammeter is put to measure the current through the resistors and a voltmeter to measure the voltage across the 12 Ω resistor.
What would be the readings in the ammeter and the voltmeter?
(a)



(b) Ammeter here would measure the total current through the circuit.
Equivalent resistance = 5 + 8 + 12 = 25 Ω
Total potential difference = 2 + 2 + 2 + 2 = 8 V
From ohm's law V = I R
$I = \frac{V}{R} = \frac{8}{25} = 0.32\ A$
So the ammeter would read the current as 0.32 A
Voltmeter across 12 Ω resistor would measure potential difference across it
i.e. V = I R
V = 0.32 $\times$ 12 = 3.84 volt.

2. In the circuit given below, resistor R = 10 Ω and the bulb offers a resistance of 2 Ω. The battery in the circuit is of 6 V.
Determine the current through the resistor R.



Resistor R and Bulb B are in series.
Equivalent resistance in the circuit,
R_{eq} = R + B = 10 + 2 = 12 Ω.
Potential difference across R_{eq} is 6 V.
Ohm's Law, V = I R

$$\Rightarrow \quad I = \frac{V}{R_{eq}} = \frac{6}{12} = \frac{1}{2}$$

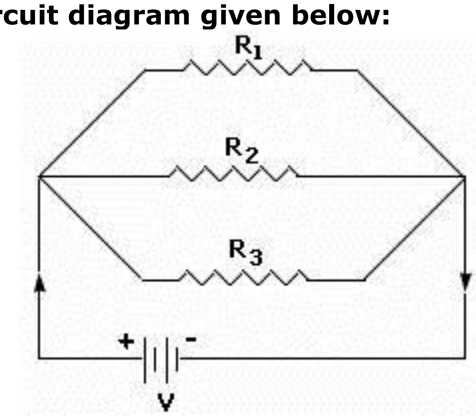
Current through R and B is the same as they are in series.
I = 0.5 ampere.

3. Study the circuit diagram given below.
Determine:
(i) the current through each of the resistors.
(ii) the potential difference across each of the resistors.
In the circuit diagram, the three resistors are in series.
Hence, R_{eq} = 2 + 3 + 5 = 10 Ω.
(i) In a series combination, the current through each resistor is the same. Hence, from Ohm's Law, V = I R_{eq}
$\Rightarrow$ Current through each resistor,

$$I = \frac{V}{R_{eq}} = \frac{6}{10} = 0.6 \text{ A}$$

(ii) In a series combination, the potential difference applied across combination = sum of potential differences across each resistor.
$V = V_1 + V_2 + V_3$
Here, Potential difference across R_1 : V_1 = I R_1 = 0.6 $\times$ 2 = 1.2 volt.
Potential difference across R_2 : V_2 = I R_2 = 0.6 $\times$ 3 = 1.8 volt
Potential difference across R_3 : V_3 = I R_3 = 0.6 $\times$ 5 = 3 volt.

3. In the circuit diagram given below:



Given that R_1 = 4 Ω; R_2 = 6 Ω, R_3 = 10 Ω and V = 1.5 volt.
Determine: (i) current through each resistor (ii) equivalent resistance of the combination (iii) the total current through the circuit.
The resistors R_1, R_2 and R_3 are in parallel combination.
(i) The potential difference across each resistor is same in parallel combination. i.e. V

= 1.5 volt.

I_1 = Current through R_1 = $\frac{V}{R_1} = \frac{1.5}{4} = 0.375$ ampere

I_2 = Current through R_2 = $\frac{V}{R_2} = \frac{1.5}{6} = 0.25$ ampere

I_3 = Current through R_3 = $\frac{V}{R_3} = \frac{1.5}{10} = 0.15$ ampere

(ii) Equivalent resistance of the combination:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_{eq}} = \frac{1}{4} + \frac{1}{6} + \frac{1}{10} = \frac{15 + 10 + 6}{60} = \frac{31}{60}$$

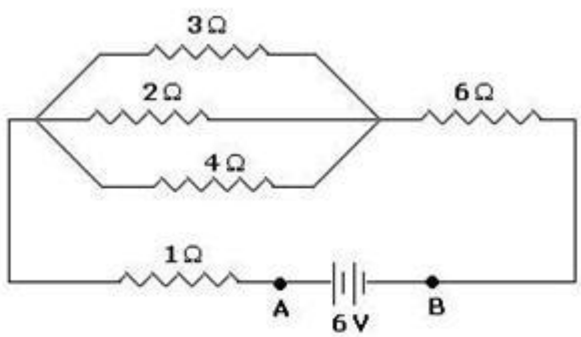
$$R_{eq} = \frac{60}{31} = 1.935\ \Omega$$

(iii) Total current in the circuit

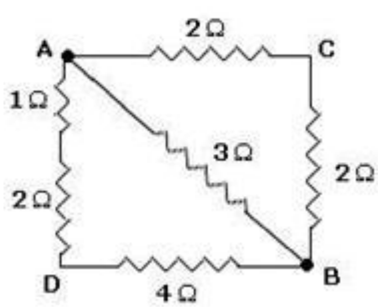
$$I = \frac{V}{R_{eq}} = \frac{1.5}{1.935} = 0.775 \text{ ampere}$$

Or $I = I_1 + I_2 + I_3 = 0.375 + 0.25 + 0.15 = 0.775$ ampere.

4. Find the equivalent resistance between the points A and B in each of the following networks.



(i)



(ii)

(i) 3 Ω, 2 Ω and 4 Ω are in parallel

$$\Rightarrow \frac{1}{R_1} = \frac{1}{3} + \frac{1}{2} + \frac{1}{4} = \frac{4 + 6 + 3}{12} = \frac{13}{12}$$

$\Rightarrow$ $R_1 = \frac{12}{13}\Omega$ $\frac{12}{13}\Omega$, 1 Ω and 6 Ω are in series

$\Rightarrow$ R_{eq} between A and B $= 1 + \frac{12}{13} + 6$

$$= 7 + \frac{12}{13} = \frac{91+12}{13} = \frac{103}{13} = 7.92\ \Omega$$

(ii) Resistance arms ACB; AB and ADB are parallel to each other.
Resistance of the arm ACB = 2 + 2 = 4 Ω
Resistance of the arm AB = 3 Ω
Resistance of the arm ADB = 1 + 2 + 4 = 7 Ω

Equivalent resistance between A and B: $\frac{1}{R_{eq}} = \frac{1}{4} + \frac{1}{3} + \frac{1}{7} = \frac{21+28+12}{84} = \frac{61}{84}$

$\Rightarrow$ $R_{eq} = \frac{84}{61} = 1.37\,\Omega$

5. If you connect three resistors having values 2 Ω, 3 Ω and 5 Ω in parallel, then, will the value of the total resistance be less than 2 Ω or greater than 5 Ω or lie between 2 Ω and 5 Ω? Explain.

Equivalent resistance of resistors connected in parallel is smaller than the smallest of the component resistors. $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{2} + \frac{1}{3} + \frac{1}{5} = \frac{15+10+6}{30}$

$\frac{1}{R_{eq}} = \frac{31}{30}$ $\Rightarrow$ $R_{eq} = \frac{30}{31} = 0.96\ \Omega$

Smallest component resistor is 2 Ω

$\Rightarrow$ $R_{eq} < 2\Omega$

Electrical Energy and Power

1. Why heat is produced in a resistance when current is passed through it?

All materials offer resistance to the flow of current through them. So some external energy is required to make the current flow. This energy is provided by the battery. Some of this energy gets dissipated as heat energy, so the resistor becomes hot.

2. What are the three factors on which total amount of heat produced in a wire depends upon?

Total amount of heat produced in a wire depends upon
(i) Current through the wire (ii) Resistance of the wire (iii) Time duration for which current is passed through the wire.

3. If we increase the value of current to twice the value, how does heat produced change in a resistor?

We know that, heat produced = i^2Rt i.e, heat produced $\propto$ i^2 so, if we increase the value of current to twice its value, heat produced will becomes four times.

4. Obtain an expression for the amount of work done by current I flowing through a wire of resistance R.

Work done in carrying a charge Q through a potential difference V is given as

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

$$\Rightarrow W = VQ$$

Also, $Q = I \times t$

$$\Rightarrow W = VIt$$

Using Ohm's law, $V = I R$

$W = I^2 Rt$

This work done in carrying the charge through the wire appears as the heat produced. i.e., $H = VI t = I^2 Rt$.

5. Give four examples where heating effect of current is desirable.

Toasters, electric irons, electric stoves and incandescent lamps.

6. Give examples where heating effect of current is undesirable.

Electric Motors, Generators and Transformers

7. Give an example where the electrical energy is converted into both heat and light energy.

Incandescent lamp.

8. Define electric power.

Electric power is the rate at which electrical energy is dissipated or consumed.

$$P = \frac{\text{energy dissipated}}{\text{time taken}}$$

$$P = \frac{E}{t}$$

9. Express electric power in terms of V and I .

$$P = \frac{E}{t} = \frac{I^2Rt}{t} = I^2R$$

From Ohm's law: $V = I R$

$$P = I^2 \frac{V}{I} = VI$$

Also, $P = \frac{V^2}{R^2}.R = \frac{V^2}{R}$

10. Define unit of electrical power.

Power consumed is said to be 1 watt, if 1 A of current flows through a potential difference of 1 V.

11. Which physical quantity is measured by the unit kWh or kilowatt-hour? Define kilowatt-hour.

Kilowatt-hour measures energy consumed or work done by the electrical appliances in our home.

When we use 1000 watt appliance for one hour or 10 bulbs of 100 watt each for one hour, electrical energy consumed will be 1 kWh, which is also called one electrical unit.

1. Show that 1 kWh = 3.6 $\times$ 10^6 J

1 kilowatt-hour = Unit of electrical energy

1 kWhr = 1000 W $\times$ 1 h = 1000 W $\times$ 3600 s

= 36 $\times$ 10^5 W - s

1 kWh = 3.6 $\times$ 10^6 J

2. An electric bulb is rated at 40 W, 220 V.
Determine:
(i) Current drawn by the bulb from the power supply 220 V.
(ii) Resistance of the filament of the bulb.

(i) As P = V I

40 = 220 I

$$\Rightarrow \quad I = \frac{40}{220} = 0.18\ A$$

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

$$40 = \frac{220 \times 220}{R}$$

$$R = \frac{220 \times 220}{40} = 1210\ \Omega$$

3. A bulb is rated at 2 V, 100 mA.
Determine its:
(i) Power (ii) Resistance of the filament.

(i) Power P = V I = 2 x 100 x 10^{-3} = 200 x 10^{-3} = 0.2 W

(ii) From $R = \frac{V^2}{P} = \frac{2 \times 2}{0.2} = 20\ \Omega$

4. A 60 W bulb is lighted for 8 hours daily and four 40 W tube lights are lighted for 2 hours every day. Calculate the energy consumed (in kWh) in 30 days.

Energy consumed by 60 W bulb in 1 day

$$= \left(\frac{60}{1000}\right) kW \times 8\ h = \frac{48}{100} kWh$$

Energy consumed by four 40 W tube lights in 1 day.

$$= 4 \times \left(\frac{40}{1000}\right) kW \times 2h = \frac{32}{100} kWh$$

Energy consumed in 1 day $= \frac{48}{100} + \frac{32}{100} = \frac{80}{100} = \frac{8}{10} kWh$

Energy consumed in 30 days $= \frac{8}{10} \times 30 = 24\ kWh$ = 24 electrical units

5. Which of the two will have greater resistance?
(i) 1000 W, 220 V heater (ii) 100 W, 220 V bulb.

100 W bulb will have greater resistance.

It is calculated as follows:

$$\text{Power} = V \times I = \frac{V^2}{R}$$

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

So Resistance of 1000 W heater

Resistance of 100 W bulb $= \frac{220 \times 220}{100} = 484\ \Omega$

6. The rate of electricity in a town is Rs 3.00 per unit.

Calculate the cost of running a 80 W fan for ten hours a day for the whole month of June.

Total number of hours involved = 10 x 30 = 300 h

Power consumed = 80 W x 300 h

= 24000 Wh $= \frac{24000}{1000}$ kWh = 24 kWh or 24 units

Cost of power = 24 x 3 = Rs 72.