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ELECTRIC CURRENT 1

TOPIC 1

WHAT IS ELECTRIC CURRENT?

Electricity is essentially the phenomenon contributed to electrons or charges. This is broadly divided into two types: Static and Dynamic.

In this chapter, we will study about dynamic electricity or current electricity which is the study of charges in motion.

Hence, we may now define electric current as the flow of electric charge through a medium.

Such currents might also occur naturally in many situations. Lightning is one such phenomenon in which, charges flow from the clouds to the earth through the atmosphere, sometimes with disastrous results. The flow of charges in lightning is not steady, but in our everyday life we see many electronic devices around us in which charges flow in a steady manner, like water flowing smoothly in a river. A torch and a cell-driven clock are examples of such devices.

In the present chapter, we shall study some of the basic laws concerning steady electric currents.

It is the most versatile form of energy we know and can be easily converted into various useful forms. Ever since the advent of batteries, in the 17^{th} century, and later generators towards the end of the 19^{th} century, current electricity has been the mainstay of the civilized world. From something as ubiquitous as lighting up the light bulb to running the International Space Station going around the earth we all need electricity. Let us look at some interesting aspects of this useful form of energy in this chapter.

Electric current is defined as the rate of flow of charges through a specific location in a conductor.

Mathematically, $I = \frac{dq}{dt}$ where q denotes charge.

Its S.I. unit is Ampere (A).

TOPIC 2

ELECTRIC CURRENT IN CONDUCTORS

You already know about the atomic structure wherein the positively charged protons lie with the neutral neutrons inside the nucleus while the negatively charged electrons go around the nucleus in various orbits. In atoms, as in molecules, the electrons are bound to the nucleus and forms a stable atom. But the outer layers of the orbit containing what we call as valence or free electrons have a force of attraction not very binding in materials known as Conductors. So in conductors the electrons, the valence ones, are kind of free to move around. This means that given an electric field the electrons can be made to move in a particular directions instead of randomly moving around. This application of electric field makes the electrons move in a given direction per unit time giving rise to Electric Current (I). But though these electrons are relatively free to move they cannot keep gaining speeds due to the applied electric fields. The process is a lot similar to the Brownian motion.

TOPIC 3

OHM'S LAW

George Simon Ohm discovered that when the physical conditions, such as temperature, pressure, humidity *etc.*, along a conductor are kept constant the potential difference across the conductor vary proportionally to the current flowing through the conductor.

$$V \propto I$$

$$\Rightarrow \quad V = IR$$

Where, R is the proportionality constant known as resistance of the conductor.

The resistance also depends on the length of the conductor, its area of cross-section and its material as

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

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

where, ρ denotes the resistivity of the material.

Combining both the equations,

we get,

$$V = \rho \frac{l}{A} I = j\rho l$$

where, j is known as current density which is the current passing per unit area of cross-section.

Furthermore the equation can be restructured as

$$J = \frac{I}{A}$$

$$\frac{V}{l} = j$$

$$\Rightarrow \quad E = j\rho$$

where, E is the electric field. This directly leads us to a much useful term known as conductivity.

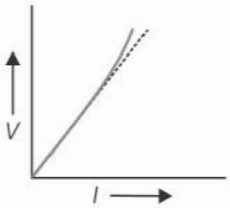
$$j = \sigma E$$

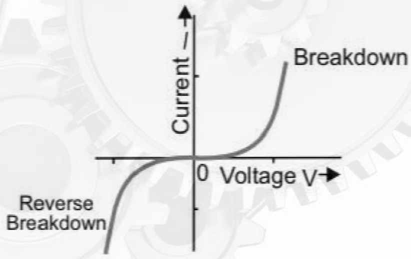
Where, σ denotes conductivity which is the reverse of resistivity.

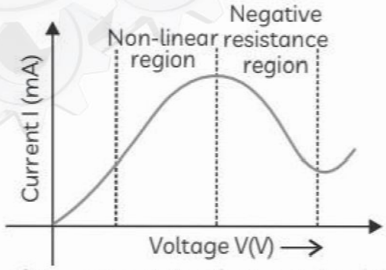
TOPIC 4

V–I CHARACTERISTICS

As mentioned earlier, the Ohm's law requires the physical conditions of the materials to remain constant. This means that the proportional relation between V and I are not unique and tend to change depending on the type of material we are using. Ionic materials, Electrolytes, Semi-conductors etc., are certain materials where Ohm's law is not valid. Similarly as we will see a little later even in conductors the validity of Ohm's law is subjected to certain stringent conditions which cannot be met always.







Variation of V vs I For: A Conductor, A Semi-Conductor Diode, Ga-As.

TOPIC 5

DRIFT OF ELECTRONS AND ORIGINS OF RESISTIVITY

Let us go back to our discussion on how electrons tend to move inside a conductor. Imagine an electron in the conductor subjected to an electric field. This field will give rise to a force which will then result in the electron accelerating as per the relation.

$$a = -\frac{eE}{m}$$

This will lead to an increase in the speed of the electron as given in

$$v = u + at = u + \frac{eE}{m}\tau \qquad \text{.... (i)}$$

Here we may safely drop the negative sign from equation with the simple understanding that the negative sign means the electron will be moving opposite to the applied field.

Now let us assume that this electron starts from rest and acquires some velocity under the influence of the electric field. By the time it has acquired some velocity it will run into another electron and collide with it thereby losing its speed all the way down to zero. Hence, it will start to move again from rest and the cycle will continue. Hence, the initial velocity can be taken to be zero. Also since we are dealing with one electron here and it is not possible to calculate the trajectory of all electrons in the conductor hence we will generalize the equation so that all electrons are taken into account.

Hence, equation (i) will get modified as.

$$v = \frac{eE}{m} t$$

$$v_d = (v_l)_{avg}$$

$$v_d = \left(\frac{eE}{m}(t)\right)_{avg} = \frac{eE}{m}\tau \qquad \text{.... (ii)}$$

here, v_d is known as the drift speed, which is the average speed of all electrons taken together. τ is known as relaxation time, which is the average time between two successive collisions. The main point to be taken care of is that the relaxation time is much shorter than the individual time of movement of the electrons. Hence in a way the drift speed can be thought to be independent of the time taken for the electrons to gain speed.

Let us assume n as the number of electrons per unit volume in a given conductor. As the electric field is applied, the electrons tend to move opposite to the applied field with a velocity v_d. Hence in a certain time t the electron would have covered a distance $d = v_d t$. If the area of cross–section of the conductor is A then the total number of electrons passing through the given length is given by $nAv_d t$. Hence, the total charge flowing through the area of cross-section is $neAv_d t$. Hence we may now describe the equation as

$$q = It = neAv_d t$$

Now substituting the eqn (ii) in above eqn. we get

$$I = ne^2 E \frac{A}{m}\tau \qquad \left(\because v_d = \frac{eE}{m}\tau\right)$$

Since, $I = jA$

Hence,

$$j = \frac{ne^2 E\tau}{m}$$

On comparing with the equation $j = \sigma E$, we get,

$$\sigma = \frac{ne^2\tau}{m}$$

Since, $\sigma = \frac{1}{\rho}$ hence

$$\rho = \frac{m}{ne^2\tau}$$

which gives us the origin of resistivity of any material.

Example 1.1: Case Based:

In atoms and molecules, the negatively charged electrons and the positively charged nuclei are bound to each other and thus are not free to move. Bulk matter is made up of many molecules, a gram of water, for example, contains approximately 10^{22} molecules. These molecules are so closely packed that the electrons are no longer attached to individual nuclei. In some materials, the electrons will still be bound, i.e., they will not accelerate even if an electric field is applied. In other materials, notably metals, some of the electrons are practically free to move within the bulk material. These materials, generally called conductors, develop electric currents in them when an electric field is applied. If we consider solid conductors, then of course the atoms are tightly bound to each other so that the current is carried by the negatively charged electrons. There are, however, other types of conductors like electrolytic solutions where positive and negative charges both can move.

(A) What is the net charge on a current carrying conducting wire?

(B) What is the electric field outside the surface of a current carrying wire?

(C) A proton and an electron are moving in uniform electric field, they experience:

(a) same force and same acceleration

(b) same force different acceleration

(c) different force different acceleration

(d) no force and no acceleration.

(D) Which of the characteristics of electrons determines the current in a conductor?

(a) Drift velocity alone

(b) Thermal velocity alone

(c) Both drift velocity and thermal velocity

(d) Neither drift nor thermal velocity

Ans. (A) Zero (neutral)

(B) Zero

(C) *(b) same force different acceleration*

Explanation: This is because the magnitude of the acceleration will be the ratio of the magnitude of the force to the mass. Since the masses of the electron and proton are different, so even though the magnitudes of the forces on them are equal, the magnitudes of their accelerations will not be equal.

(D) *(a) Drift velocity alone*

Explanation: $I = neAv_d$

As we can see from the above equation that drift velocity is only responsible for current in a conductor.

Mobility

Mobility of electrons is defined as the drift velocity acquired per unit change in the applied electric field.

$$\mu = \frac{v_d}{E}$$

which means,

$$\mu = \frac{e\tau}{m}$$

Example 1.2:

Assertion (A): The resistivity of a conductor increases on increasing temperature.

Reason (R): The time between electron collisions reduce on increasing temperature.

(a) If both Assertion and Reason are true and Reason is correct explanation of Assertion.

(b) If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.

(c) If Assertion is true but Reason is false.

(d) If both Assertion and Reason are false.

Ans. *(a) If both Assertion and Reason are true and Reason is correct explanation of Assertion.*

Explanation: On increasing the temperature of conductors the average kinetic energy of the electrons also increases. The increase in electron kinetic energy leads to increase in electrons speed thereby increasing the collision frequency and decreasing the time between collisions (τ). The decrease in τ leads to increase in resistivity.

Example 1.3: What is the drift velocity of electrons in a copper conducting wire of area of cross-section $2 \times 10^{-7} m^2$ and carrying a current of 2 A? The number density is $9 \times 10^{28} m^{-3}$.

Ans. We know that,

$$I = neAv_d$$

which gives us the equation for drift speed as:

$$v_d = \frac{I}{neA}$$

Given, $n = 9 \times 10^{28}$, $A = 2 \times 10^{-7}$ and I = 2 A

we get,

$$v_d = \frac{2}{9 \times 10^{28} \times 1.6 \times 10^{-19} \times 2 \times 10^{-7}}$$

$$= \frac{1}{9 \times 1.6 \times 10^2}$$

$$= 7 \times 10^{-4} m/s$$

TOPIC 6

TEMPERATURE DEPENDENCE OF RESISTIVITY

As the temperature of a resistor increases so does the kinetic energy of the free electrons which leads to higher mean velocities and hence lower mean collision time. As the collision time decreases the resistivity increases. This is not the only reason. Resistivity also has to do with the number density but that is beyond the scope. Hence, resistivity also changes with temperature.

$$\rho_T = \rho_o [1 + \alpha (T - T_o)]$$

Here, α is the temperature coefficient of resistivity.

Important

➥ *The temperature coefficient for a conductor is positive showing that an increase in temperature will lead to an increase in resistivity but for a semi-conductor this value is negative showing that an increase in temperature decreases resistivity.*

TOPIC 7

ELECTRICAL ENERGY AND POWER

From the definition of potential

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

We can say, $W = qV$.

Since, $q = It$ and $V = IR$

Hence, $W = (It)(IR) = I^2Rt$

This equation is also known as Joule's law of heating equation.

Therefore work can be written as:

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

Since, power is described as rate of doing work.

Hence, $P = \frac{W}{t}$

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

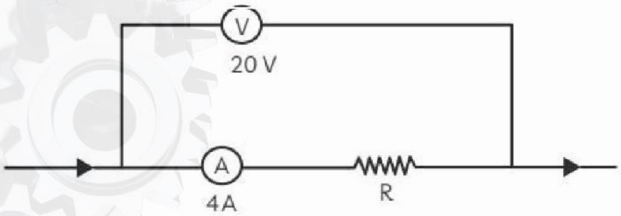
Since resistance of transmission wires cannot be made zero hence some power is dissipated during transmission. To lower transmission losses we transfer electricity at very high voltages. [You will study about this in later chapters.]

OBJECTIVE Type Questions

[1 mark]

Multiple Choice Questions

1. In the diagram shown, the reading of voltmeter is 20 V and that of ammeter is 4 A. The value of R should be:
(Consider given ammeter and voltmeter are not ideal)



(a) equal to 5 Ω
(b) greater than 5 Ω

(c) less than 5 Ω

(d) greater or less than 5 Ω

[Diksha]

Ans. *(c) less than 5 Ω*

Explanation: According to the ohm's law,

$$V = IR$$

$$20\ V = 4\ A \times R$$

$$\Rightarrow \quad R = 5\ \Omega$$

But here the ammeter is not ideal so the resistance will be less than 5 Ω.

2. The specific resistance of a rod of copper as compared to that of thin wire of copper is:

(a) less

(b) more

(c) same

(d) depends upon the length and area of cross-section of the wire

[Delhi Gov. SQP 2022]

Ans. *(c) same*

Explanation: Specific resistance of a conductor depends on the nature of material but is independent of the dimension of the conductor. Thus, specific resistance of rod of copper as compared to that of thin wire of copper is same.

⚠ Caution

➥ *Students often confused and start calculating the answer. First read the question. Here, specific resistance is constant. So, its value will remain same.*

3. By increasing the temperature, the specific resistance of a conductor and a semiconductor:

(a) increases for both.

(b) decreases for both.

(c) increases for a conductor and decreases for a semiconductor.

(d) decreases for a conductor and increases for a semiconductor.

[CBSE Term-1 SQP 2021]

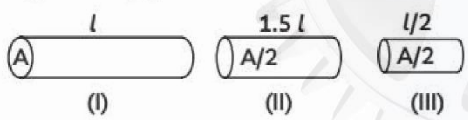
Ans. *(c) increases for a conductor and decreases for a semiconductor.*

Explanation: Specific resistance of a conductor increases and for a semiconductor decreases with increase in temperature because for a conductor, a temperature coefficient of resistivity $\alpha = +$ ve

and for a semiconductor, $\alpha = -$ ve

[CBSE Marking Scheme Term-1 SQP 2021]

4. The figure shows three cylindrical copper conductors along with their face areas and lengths. Rank them according to the current through them, greatest first:



(a) $I_1 = I_2 = I_3$

(b) $I_1 > I_2 > I_3$

(c) $I_1 < I_2 < I_3$

(d) $(I_1 = I_3) > I_2$

[Diksha]

Ans. *(d)* $(I_1 = I_3) > I_2$

Explanation: Resistance of (I) $= \rho\dfrac{l}{A} = R_1$

$$\text{Resistance of (II)} = \rho\frac{1.5l}{A/2} = 3\rho\frac{l}{A} = 3R_1$$

$$\text{Resistance of (III)} = \rho\frac{l/2}{A/2} = \rho\frac{l}{A} = R_1$$

Since, $\quad I = \dfrac{V}{R}$

Hence, $\quad I_1 = I_3 = \dfrac{V}{R_1}$

$$I_2 = \frac{V}{3R_1} = \frac{I_1}{3} = \frac{I_3}{3}$$

$$\therefore \quad (I_1 = I_3) > I_2$$

5. An electric current is passed through a circuit containing two wires of same material, connected in parallel. If the lengths and radii of the wires are in the ratio of 3 : 2 and 2 : 3, then the ratio of the current passing through the wire will be:

(a) 2 : 3

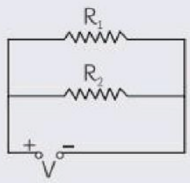
(b) 3 : 2

(c) 8 : 27

(d) 27 : 8

[CBSE Term-1 SQP 2021]

Ans. *(c) 8 : 27*



$$l_1 : l_2 = 3 : 2$$

$$r_1 : r_2 = 2 : 3$$

$$I_1 : I_2 = ?$$

$$R_1 = \rho\frac{l_1}{\pi r_1^2}$$

$$R_2 = \rho\frac{l_2}{\pi r_2^2}$$

$$\frac{R_1}{R_2} = \frac{l_1}{l_2}\frac{\pi r_2^2}{\pi r_1^2}$$

$$= \frac{l_1}{l_2} \times \frac{r_2^2}{r_1^2}$$

$$= \frac{3}{2} \times \left(\frac{3}{2}\right)^2$$

$$= \frac{(3)^3}{(2)^3} = \frac{27}{8}$$

$$\therefore \quad \frac{I_1}{I_2} = \frac{\frac{V}{R_1}}{\frac{V}{R_2}} = \frac{R_2}{R_1} = \frac{8}{27}$$

[CBSE Marking Scheme Term-1 SQP 2021]

6. **The temperature (T) dependence of resistivity of material A and material B is represented by fig (i) and fig (ii) respectively.**

Identify material A and material B.

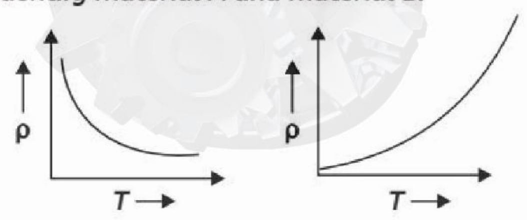


Fig. (i) *Fig. (ii)*

(a) material A is copper and material B is germanium.

(b) material A is germanium and material B is copper.

(c) material A is nichrome and material B is germanium.

(d) material A is copper and material B is nichrome. [CBSE SQP 2022]

Ans. *(b) material A is germanium and material B is copper.*

[CBSE Marking Scheme SQP 2022]

Explanation: Relation for resistivity is $\rho = \frac{m}{ne^2\tau}$

For conductor, when temperature increases relaxation time decreases and hence resistivity increases. For semiconductor, resistivity decreases with increase in temperature. So, Fig. (i) represent semiconductor (germanium) and Fig. (ii) represent conductor (copper).

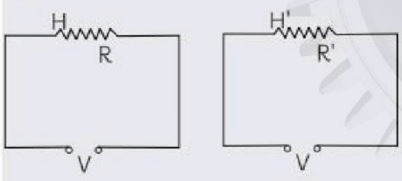
7. **A constant voltage is applied between the two ends of a uniform metallic wire, heat 'H' is developed in it. If another wire of the same material, double the radius and twice the length as compared to original wire is used then the heat developed in it will be:**

(a) $\frac{H}{2}$ **(b) H**

(c) 2H **(d) 4H**

[CBSE Term-1 SQP 2021]

Ans. *(c) 2H*



$$R = \rho\frac{l}{A} \qquad R' = \rho\frac{2l}{\pi(2r)^2}$$

$$R = \rho\frac{l}{\pi r^2} \qquad R' = \rho\frac{2l}{\pi 4r^2}$$

$$H = \frac{V^2}{R}t \ \ \& \ \ H' = \frac{V^2}{R'}t$$

$\because$ V = constant

$$\frac{H'}{H} = \frac{V^2}{R'}\frac{R}{V^2}\frac{t}{t}$$

$$= \frac{R}{R'} = \rho\frac{l}{\pi r^2}\frac{2\pi r^2}{\rho l}$$

$$\frac{H'}{H} = \frac{2}{1}$$

$$H' = 2H$$

[CBSE Marking Scheme Term-1 SQP 2021]

8. **Two wires of same material having radii in the ratio 1:2, carry currents in the ratio 4:1. The ratio of drift velocities of electrons in them is:**

(a) 2 : 1 **(b) 1 : 1**

(c) 1 : 4 **(d) 16 : 1**

9. **If the potential difference V applied across a conductor is increased to 2 V with its temperature kept constant, the drift velocity of the free electrons in a conductor will:**

(a) remain the same

(b) become half of its previous value

(c) be double of its initial value

(d) become zero

[CBSE Term-1 SQP 2021]

Ans. *(c) be double of its initial value*

Explanation: We know,

$$v_d = \frac{eE}{m}\tau$$

$$v_d = e\frac{V}{ml}\tau$$

If temperature is kept constant, relaxation time τ-will remain constant, and *e*, *m* are also constants.

$$v_d \propto V$$

$$2v_d \propto 2V$$

Thus, Correct option is (c).

[CBSE Marking Scheme Term-1 SQP 2021]

10. **A steady current of 8 mA flows through a wire. The number of electrons passing through a cross-section of the wire in 10 s is:**

(a) 4.0×10^{16} **(b)** 5.0×10^{17}

(c) 1.6×10^{16} **(d)** 1.0×10^{17}

[CBSE 2023]

Ans. *(b) 5.0×10^{17}*

Explanation: The amount of charge passing through a cross-section of a wire in a given time is given by the expression:

$$Q = i \times t$$

where Q is the charge, i is the current, and t is the time.

In this case, the current is 8 mA = 8×10^{-3} A, and the time is 10 s. Therefore, the charge passing through the cross-section in 10 s is:

$$Q = (8 \times 10^{-3}) \times (10 \text{ s}) = 8 \times 10^{-2} \text{ C}$$

The amount of charge on one electron is 1.6×10^{-19} C. Therefore, the number of electrons passing through the cross-section in 10 s is:

$$\text{number of electrons} = \frac{Q}{(\text{charge on one electron})}$$

$$= \frac{8 \times 10^{-2}\text{C}}{1.6 \times 10^{-19}\text{C}} = 5 \times 10^{-17}$$

11. **Calculate the number of units of electricity used if a bulb of 100 W is kept on for 5 hours.**

(a) 1 unit **(b) 0.1 unit**
(c) 5 unit **(d) 0.5 unit**

Ans. *(d) 0.5 unit*

Explanation: The number of units of electricity consumed is

$$n = \frac{(\text{total wattage} \times \text{time in hour})}{1000}$$

Total wattage = 100 W
Time in hour = 5 hour

Therefore $n = \frac{100 \times 5}{1000}$

$= 0.5$ units

So, the number of units of electricity consumed is 0.5 units.

12. **Which of the following has negative temperature coefficient of resistivity?**

(a) Metal
(b) Metal and semiconductor
(c) Semiconductor
(d) Metal and alloy **[CBSE Term-1 2021]**

Assertion-Reason Questions

For Questions 13 to 16, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given.

(a) If both Assertion and Reason are true and Reason is correct explanation of Assertion.
(b) If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.
(c) If Assertion is true but Reason is false.
(d) If both Assertion and Reason are false.

13. **Assertion (A):** **An electric bulb starts glowing instantly as it is switched on.**

Reason (R): **Drift velocity of electrons in a metallic wire is very large.**

[Delhi Gov. QB 2022]

Ans. *(c) If Assertion is true but Reason is false.*

Explanation: The current which is set up does not wait for the electrons flow from one end of the conductor to the another end. It is due to this reason, the electric bulb glows immediately when switch is on.

14. **Assertion (A): Ohm's law is applicable for all conducting elements.**

Reason (R): **Ohm's law is a fundamental law.**

15. **Assertion (A):** **Electric current has both magnitude and direction, yet it is a scalar quantity.**

Reason (R): **The laws of ordinary algebra are used to add electric currents and the laws of vector addition are not applicable to the addition of electric currents.**

Ans. *(a) If both Assertion and Reason are true and Reason is correct explanation of Assertion.*

Explanation: Electric current has direction as well as magnitude but does not follow laws of vector addition that's why it is scalar quantity.

16. **Assertion (A): As the temperature of a conducting wire increases, the drift velocity of the electrons also increases.**

Reason (R): **With an increase in temperature, the average time of collision increases.**

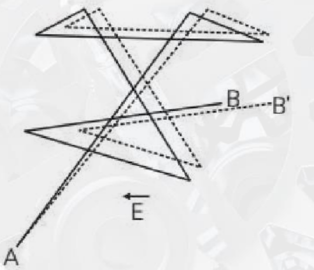
[CBSE Question Bank 2023]

CASE BASED Questions (CBQs)

[**4** & **5** marks]

Read the following passages and answer the questions that follow:

17. *When a potential difference V is applied across the two ends of a conductor, the free electrons in the conductor experience a force and are accelerated towards the positive end of conductor. On their way, they suffer frequent collisions with the ions or atoms of the conductor and lose their gained kinetic energy* *and again get accelerated due to electric field and lose the gained kinetic energy in the next collision and so on. The average velocity with which the free electrons get drifted towards the positive end of the conductor under the effect of applied electric field is called drift velocity.*



(A) How does the relaxation time of electron in the conductor change when temperature of the conductor decreases?

(B) Is the formula V = IR true for non-ohmic resistance also?

(C) The current I flows through a wire of radius r and the free electrons drift with velocity v_d. When a current 2I flows through the wire of same material but having double the radius, what will be the drift velocity of electrons in this wire.

[Delhi Gov. QB 2022]

Ans. (A) When temperature of the conductor decreases, ionic vibration in the conductor decreases, so relaxation time increases.

(B) Yes, it is true for non-ohmic resistance also.

(C)
$$v_d = \frac{I}{nAe} = \frac{I}{n.\pi r^2 e}$$

$$v_d' = \frac{2I}{n.\pi(2r)^2 e} = \frac{1}{2}\ v_d$$

18. *We can control the speed of the fans at our homes by moving the regulator to and fro. Here the current flowing through the fan is controlled by regulating the resistance through the regulator. A circular knob on the component can be related to achieve a variable resistance on the output terminals. For any specific value of the input, we can calculate the resistance, current and thus power flowing through Ohm's Law.*

(A) An electric heater is connected to the voltage supply, after few seconds, current gets its steady value then its initial current will be:

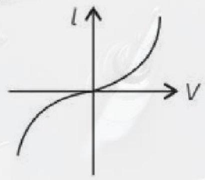
(a) equal to its steady current

(b) slightly higher than its steady current

(c) slightly less than its steady current

(d) zero

(B) The I-V characteristics shown in figure represents:



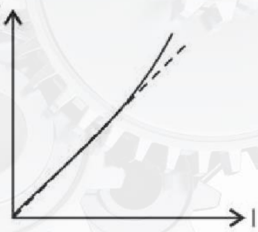
(a) ohmic conductors

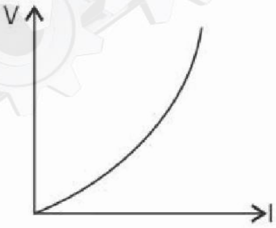
(b) non-ohmic conductors

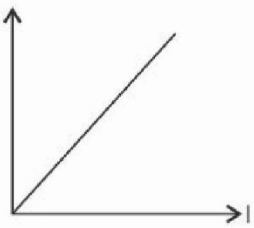
(c) insulators

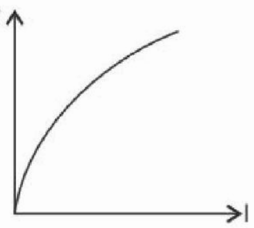
(d) superconductors

(C) Which of the following is correct for V-I graph of a good conductor?

(a)


(b)


(c)


(d)


(D) In the equation AB = C, A is the current density, C is the electric field, then B is:

(a) resistivity

(b) conductivity

(c) potential difference

(d) resistance

(E) In the absence of an electric field, the mean velocity of free electrons in a conductor at absolute temperature (T) is:

(a) zero

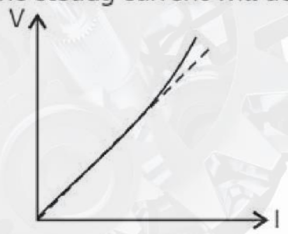
(b) independent of T

(c) proportional to T

(d) proportional to T^2

Ans. (A) *(b) slightly higher than its steady current*

Explanation: An electric heater is connected to the voltage supply. After a few seconds when the current gets its steady value then its initial current will be 'slightly higher than its steady current. This is because—the resistance will increase with increase in the temperature and hence the steady current will decrease.



(B) *(b) non-ohmic conductors*

Explanation:

The electric current is proportional to the voltage.

$$I \propto V$$

It gives linear relationship. The graph between the electric current and voltage is straight line passing through the origin.

The I – V characteristics shown in the figure is non-ohmic conductor.

(D) *(a) resistivity*

Explanation:

$$J = \sigma E$$

$$\Rightarrow \quad J\rho = E$$

J, is current density, E is electric field

So, $\quad B = \rho =$ resistivity.

(E) *(a) zero*

Explanation: In the absence of electric field, the electron moves in zig-zag direction as shown in figure. So net displacement is zero, hence mean velocity of free electrons in a conductor at absolute temperature is zero

Direction of electron (in the absence of electric field)

Net direction or movement (in presence of electric field)

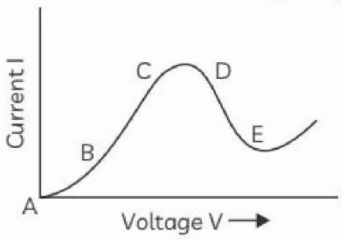
VERY SHORT ANSWER Type Questions (VSA)

[**1** mark]

19. Graph showing the variation of current versus voltage for a material GaAs is shown in the figure. Identify the region of:

(A) negative resistance

(B) where Ohm's law is obeyed. [CBSE 2015]



Ans. (A) DE is the region, of negative resistance because the slope of curve in this part is negative.

(B) BC is the region, where Ohm's law is obeyed as the current varies linearly with the voltage.

Caution

➥ *Students are often confused in the V-I graph. In V-I graph where the graph is linear it obeys Ohm's law.*

20. For wiring in the home, one uses Copper wires or Aluminium wires. What considerations are involved in this? [NCERT Exemplar]

Ans. For wiring in the home, Cu and Al wires are used due to its cost and good conductivity.

Caution

➥ *Students are often confused in choosing the wire for home. For the selection of metal for wiring, the main criterion are the availability, conductivity and the cost of the metal.*

21. Two wire one of copper and other of manganin have same resistance and equal length. Which wire is thicker? [Delhi Gov. QB 2022]

Ans.
$$R = \rho_c \frac{l_c}{A_C} = \rho_m \frac{l_m}{A_m}$$

$$\Rightarrow \quad \frac{\rho_c}{\rho_m} = \frac{A_c}{A_m} < 1$$

$\therefore$ Manganin is thicker.

22. Define the term 'mobility' of charge carriers in a conductor, write its S.I. unit. [CBSE 2014]

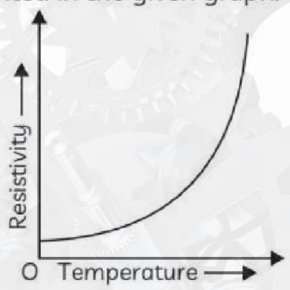
Ans. Mobility of charge carriers in a conductor is defined as the magnitude of their drift velocity per unit applied electric field.

Mobility, $\quad \mu = \frac{v_d}{E}$

S.I. unit of mobility is $m^2V^{-1}\,s^{-1}$.

23. Show variation of resistivity of copper as a function of temperature in a graph. [CBSE 2014]

Ans. The variation of resistivity of copper with temperature is parabolic in nature as represented in the given graph.



24. You are given three constants wires P, Q and R of length and area of cross-section (L, A), $\left(2L, \frac{A}{2}\right)$, $\left(\frac{L}{2}, 2A\right)$ respectively of same material. Which has highest resistance? **[Delhi Gov. QB 2022]**

25. The relaxation time τ is nearly independent of applied electric field (E), whereas it changes significantly with temperature T. First fact is (in part) responsible for Ohm's law whereas the second fact leads to variation of ρ with temperature. Elaborate why? **[NCERT Exemplar]**

SHORT ANSWER Type-I Questions (SA-I)

[**2** marks]

26. What happens to the drift velocity (v_d) of electrons and to the resistance (R) , if length of a conductor is doubled (keeping potential difference unchanged)? [CBSE 2002]

Ans. Drift velocity, $v_d = \frac{eE\tau}{m}$

Now, $E = \frac{V}{l}$,

where V is potential difference. If the length of the conductor is doubled then drift velocity will be halved.

Resistance of conductor is directly proportional to the length, therefore on doubling the length, resistance will become two times.

Related Theory

Drift velocity is inversely proportional to the length of the conductor.

27. A potential difference V is applied across the ends of copper wire of length l and diameter D. What is the effect on drift velocity of electrons if:

(A) V is halved?

(B) l is doubled?

(C) D is halved? [CBSE 2015]

Ans. Drift velocity,

$$v_d = \frac{I}{neA}$$

$$v_d = \frac{\frac{V}{R}}{neA} = \frac{V}{neA\left(\frac{\rho l}{A}\right)}$$

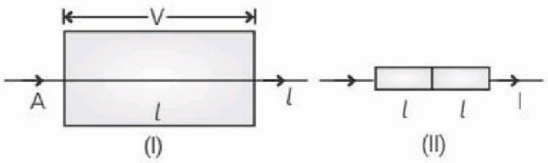
$$= \frac{V}{ne\rho l}$$

(A) As, $v_d \propto V$, when V is halved the drift velocity is halved.

(B) As, $v_d \propto \frac{1}{l}$, when l is doubled the drift velocity is halved.

(C) As, v_d is independent of D, when D is halved drift velocity remains unchanged.

28. A metal rod of square cross-sectional area A having length l has current I flowing through it when a potential difference of V volt is applied across its ends (figure I). Now, the rod is cut parallel to its length into two identical pieces and joined as shown in Figure II. What potential difference must be maintained across the length of $2l$, so that the current in the rod is still I?



Ans. From Ohm's law, we have V = IR

$$\Rightarrow \quad V = I\rho\frac{l}{A} \quad \left[\because R = \rho\frac{l}{A}\right] \quad ...(i)$$

When the rod is cut parallel and rejoined, the length of the conductor becomes $2l$, whereas the area decrease to $\frac{A}{2}$. If the current remains the same, then the potential changes as

$$V = I\rho\frac{2l}{\frac{A}{2}}$$

$$= 4 \times I\rho\frac{l}{A} = 4\,V$$

[using Eq. (i)]

The new potential applied across the metal rod will be four times the original potential (V).

29. **A heating element using nichrome connected to a 230 V supply draws an initial current of 3.2 A, which settles after a few seconds to a steady value of 2.8 A. What is the steady temperature of the heating element if the room temperature is 27.0 °C and the temperature coefficient of resistance of nichrome is $1.70 \times 10^{-4}\ °C^{-1}$?**

[CBSE SQP 2023]

Ans. Given: $V = 230$ V, $I_0 = 3.2$ A, $I = 2.8$ A,

$T_0 = 27$ °C, $\alpha = 1.70 \times 10^{-4}\ °C^{-1}$.

Using equation, $R = R_0(1 + \alpha\Delta T)$

i.e., $$\frac{V}{I} = \left(\frac{V}{I_0}\right)[1 + \alpha\Delta T]$$

and solving $\Delta T = 840$

i.e., $T = 840 + 27$

$= 867$ °C

[CBSE Marking Scheme SQP 2023]

30. **Two copper wires, P and Q of the same area of cross-section are joined in parallel. The combination of wires is connected across a battery of potential difference V. If the length of the wires, P and Q are in the ratio 1 : 2, find the ratio of drift velocities of electrons in wires P and Q. [CBSE Practice Set-1 2023]**

Ans. Since the wires are connected in parallel, the potential difference 'V' across both wires will be the same.

The wires have the same resistivity ρ. Let the length of wires P and Q be L_1 and L_2 respectively. Let the drift velocities electrons in wires P and Q be v_{d_1} and v_{d_2} respectively.

$$I = neAv_d$$

v_d = drift velocity

$$\frac{L_1}{L_2} = \frac{1}{2}$$

$$V = RI = \frac{\rho L}{A} I$$

For wire P:

$$V = \left(\frac{\rho L_1}{A}\right) neAv_{d_1} \quad \text{....(ii)}$$

For wire Q:

$$V = \left(\frac{\rho L_2}{A}\right) neAv_{d_2} \quad \text{....(ii)}$$

Equating (i) and (ii)

$$L_1 v_{d_1} = L_2 v_{d_2}$$

$$\frac{v_{d_1}}{v_{d_2}} = \frac{L_2}{L_1}$$

$$\frac{v_{d_1}}{v_{d_2}} = \frac{2}{1}$$

Hence, the ratio of drift velocities of electrons in wires P and Q is 2 : 1.

[CBSE Marking Scheme Practice Set-1 2023]

SHORT ANSWER Type-II Questions (SA-II)

[**3** marks]

31. **(A) Define the term 'conductivity' of a metallic wire. Write its SI unit.**

(B) Using the concept of free electrons in a conductor, derive the expression for the conductivity of a wire in terms of number density and relaxation time. Hence, obtain the relation between current density and the applied electric field E. [CBSE 2018]

Ans. (A) Conductivity of a metallic wire is defined as its ability to allow electric charges or heat to pass through it. Numerically, conductivity of a material is reciprocal of its resistivity.

SI unit: $ohm^{-1}\ m^{-1}$ or mho m^{-1} or Siemen m^{-1}

(B) Consider a potential difference V be applied across a conductor of length l and cross section A.

Electric field inside the conductor, $E = \frac{V}{l}$.

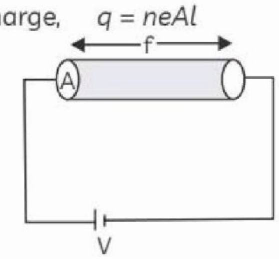
Due to the external field the free electrons inside the conductor drift with velocity v_d.

Let, number of electrons per unit volume = n,

charge on an electron = e

Total electrons in length, $l = nAl$ and,

total charge, $q = neAl$



And current, $I = \frac{q}{t}$

$$I = \frac{neAl}{\frac{l}{v_d}}$$

$$I = neAv_d$$

Therefore current per unit area, *i.e.*, current density

$$J = \frac{I}{A} = nev_d$$

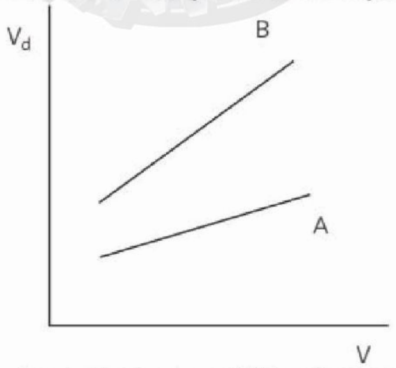
$$J = ne\left(\frac{eE\tau}{m}\right) = \left(\frac{ne^2\tau}{m}\right)E$$

$$J = \sigma E$$

which is the required expression.

32. **Variation of drift velocity (v_d) of free electrons with potential difference (V) applied across the ends of a conductor for two wires A and B of same metal and radii are shown in figure.**

(A) Which of them is longer in length?
(B) Which of them has lower resistance?
(C) What does the slope for wire depict?



33. Explain how electron mobility changes for a good conductor, when:

(A) the temperature of the conductor is decreased at constant potential difference, and

(B) applied potential difference is doubled at constant temperature. [Diksha]

Ans. The mobility of the charge carrier is the drift velocity acquired by it in a unit electric field.

$$\mu = \frac{v_d}{E} \quad ...(i)$$

$$v_d = \frac{qE\tau}{m} \quad ...(ii)$$

From eqn (i) and (ii) we get,

$$\therefore \quad \mu = \frac{q\tau}{m}$$

For electrons, $\mu_e = \frac{e\tau_e}{m}$

(A) When temperature of the conductor decreases, the relaxation time τ_e of the electrons in the conductor increases, so mobility increases.

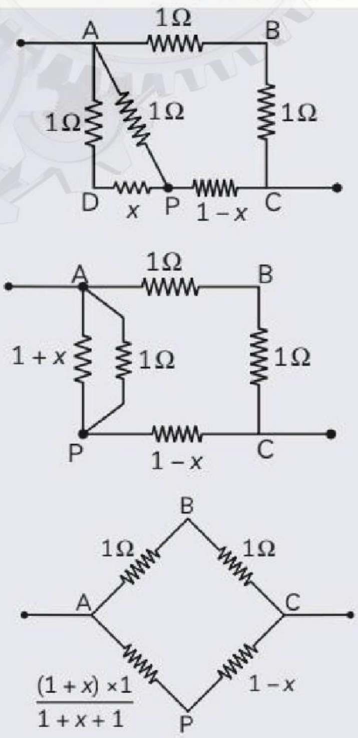
(B) Mobility is the independent of the applied potential difference.

34. **Define resistivity of a conductor, plot a graph showing the variation of resistivity with temperature for a metallic conductor. [Delhi Gov. SQP 2022]**

35. A wire of uniform cross-section and resistance 4 Ohm is bent in the shape of square ABCD. Point A is connected to a point P on DC by a wire AP of resistance 1 Ohm. When a potential difference is applied between A and C, the points B and P are seen to be at the same potential. What is the resistance of the part DP?

[CBSE SQP 2023]

Ans.



As the points B and P are at the same potential,

$$\frac{1}{1} = \frac{\frac{(1+x)}{(2+x)}}{(1-x)}$$

$$\Rightarrow \quad x = (\sqrt{2}-1) \text{ Ohm}$$

[CBSE Marking Scheme SQP 2023]

LONG ANSWER Type Questions (LA)

[**4** & **5** marks]

36. A room has AC run for 5 hours a day at a voltage of 220 V. The wiring of the room consists of Cu of 1 mm radius and a length of 10 m. Power consumption per day is 10

commercial units. What fraction of it goes in the joule heating in wires? What would happen if the wiring is made of aluminium of the same dimensions? [$\rho_{cu} = 1.7 \times 10^{-8}\ \Omega m$, $\rho_{Al} = 2.7 \times 10^{-8}\ \Omega m$] [NCERT Exemplar]

Ans. Given, power consumption in 5 hours = 10 units

Power consumption per hour = 2 units

$= 2\text{ KWh} = 2000\text{ J/s}$

As, we know that, $P = VI$

$$2000 = 220 \times I$$

$$I = \frac{2000}{220} = 9.1\text{ A}$$

Resistance of the wire, $R = \rho \frac{l}{A}$

Power consumption in first current carrying wire is given by,

$$P = I^2R$$

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

$$P = \rho \frac{l}{A} \times I^2$$

$$P = 1.7 \times 10^{-8} \times \frac{10}{\pi \times 10^{-6}} \times 82.64\text{ J/s}$$

$$P = 4.4\text{ J/s}$$

The fractional loss due to the joule heating in first wire $= \frac{4.4}{2000} \times 100 = 0.2\%$

Power loss in Al wire $= 4\frac{\rho_{AL}}{\rho_{CU}} = 4 \times \frac{2.7 \times 10^{-8}}{1.7 \times 10^{-8}}$

$= 1.6 \times 4$

$= 6.4\text{ J/s}$

The fractional loss due to the joule heating in second wire $= \frac{6.4}{2000} \times 100 = 0.32\%$

37. Explain the term drift velocity of electrons in a conductor. Hence, obtain the expression for the current through a conductor in terms of drift velocity. [CBSE SQP 2022]

Ans. Drift velocity: It is the average velocity acquired by the free electrons superimposed over the random motion in the direction opposite to electric field and along the length of the metallic conductor.

Derivation $I = neAV_d$

[CBSE Marking Scheme SQP 2022]

Detailed Answer: The average velocity of all the free electrons in the conductor is called the drift velocity of free electrons of the conductor. When a conductor is connected to a source of emf an electric field is established in the conductor, such that,

$$E = \frac{V}{L}.$$

where V = potential difference across the conductor and

L = length of the conductor.

The electric field exerts an electrostatics force '$-\vec{E}_e$' on each free electron in the conductor.

The acceleration of each electron is given by:

$$\vec{a} = -\frac{e\vec{E}}{m}$$

where, e = electric charge on the electron

and m = mass of electron

Acceleration and electric field are in opposite directions, so the electrons attain a velocity in addition to thermal velocity in the direction opposite to that of electric field.

$$\vec{v}_d = \frac{e\vec{E}}{m}\tau \quad ...(i)$$

$$E = \frac{-V}{L} \quad ...(ii)$$

where τ = relaxation time between two successive collision

Let n = number density of electrons in the conductor

No. of free electrons in the conductor

$= nAL$

Total charge on the conductor,

$q = nALe$

Time taken by this charge to cover the length L of the conductor,

$$t = \frac{L}{v_d}$$

Current, $I = \frac{q}{t}$

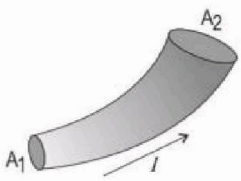
$$= \frac{nALe}{L} \times v_d$$

$$= nAev_d$$

Related Theory

➥ *Drift velocity is inversely proportional to the length of the conductor.*

38. For a current-carrying conductor of changing diameter as shown below, how does each of the following quantities vary along the two ends of conductors with area of cross sections A_1 and A_2 ? Give an explanation for each.



(A) Current (B) Current density (C) Resistance (D) Potential drop

[CBSE Competency QB 2023]

Ans. (A) Current: It remains the same along the length of the conductor. This is as per Kirchhoff's junction rule. Charge cannot collect at any point along the length of the conductor.

(B) Current density J varies inversely with area cross-section of the conductor. As J = I/A , more the area cross-section, less is the current density, for a constant current through the conductor.

(C) Resistance varies inversely with area cross section of the wire. R of the wire at broader parts will be lesser than along narrower part.

(D) Potential drop across two ends of the entire length of the conductor is as provided by the power source. The potential drop across different equal parts along the length of the wire varies in direct proportion to the resistance. Potential drop at narrower end will be more than at broader end (Resistance at narrower end is more than at broader end).

NUMERICAL Type Questions

39. Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area 1.0 × 10^{-7} m^2 carrying a current of 1.5 A. Assume the density of conduction electrons to be 9 × 10^{28} m^{-3}.

[CBSE 2014](2m)

Ans. Here, drift velocity

$$v_d = \frac{I}{nAq}$$

where, I is the current, *n* is the charge density, *q* is charge of the electron, and A is cross-sectional area.

$$v_d = \frac{1.5}{9\times10^{28}\times1.0\times10^{-7}\times1.6\times10^{-19}}$$

$$v_d = 10.4 \times 10^{-4} \text{ m/s}$$

40. Which has greater resistance : 1 kW electric heater or 100 W electric bulb, both are marked 220 V? (2m)

Ans.

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

For electric heater:

P_H = 1 kW = 1000 W, V = 220 V

$$R_H = \frac{220\times220}{1000} = 48.4\ \Omega$$

For electric bulb:

$$P_B = 100\text{ W}$$

$$R_B = \frac{220\times220}{100} = 484\ \Omega$$

Bulb has greater resistance.

CELLS, EMF AND INTERNAL RESISTANCE 2

TOPIC 1

SOME BASIC TERMS

Ever since the invention of cell they have come a long way from the initial rudimentary design to the present day cells that can accumulate energy to the tune of kW-Hrs. Cells are generally of two types – Primary and Secondary.

Primary cells are those that we generally use in day to day life like the AA-size or AAA-size dry cells used in torches, wireless mouse, remote controls *etc.* These cells uses electro-chemical reactions to generate power.

Secondary cells, also known as accumulators, are those cells that can be recharged. These include cells used in mobile phones, inverters and UPS, vehicles, power storage systems etc.

Let us understand a few things related to cells.

If a cell is not connected to the external circuit the potential difference across its terminals is known as EMF – Electro Motive Force. The name is a misnomer as it is not a force at all but rather a potential difference.

Just as every conductor has a resistance similarly every cell has an internal resistance as well. This resistance occurs due to the ionic movement through the electrolyte. This internal resistance comes into play when the cell is connected to the external circuit and current is drawn from the cell.

Now imagine an external resistance R is connected to a circuit where the internal resistance of the cell is r. Then,

$$E = V + Ir$$

Where, V=IR or the potential drop across the external resistance while E is the emf of the cell.

This leads us to the equation

$$E = I\,(R + r)$$

$$\Rightarrow \quad I = \frac{E}{R+r}$$

Hence, the current is maximum when the external resistance is zero. The internal resistance cannot become zero under any circumstance.

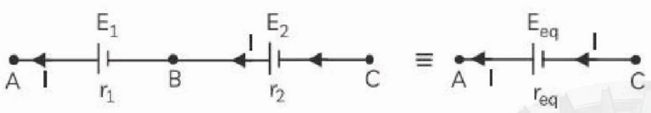
Also, we see that, $E = V$ *if* $I = 0$, since $r \neq 0$

Hence, if I = 0 then potential difference becomes the same as the emf of the cell. That is why we use cell in open circuit to measure its emf.

TOPIC 2

CELLS IN SERIES AND PARALLEL

Cells in Series



Cells in Series

Let us assume two cells have been connected in series. We will calculate the equivalent emf as well as the total internal resistance of the combination. From the figure we can see that,

$$E_1 = V_1 + Ir_1 \quad \text{and } E_2 = V_2 + Ir_2$$

which leads to $V_1 = E_1 - Ir_1$ and $V_2 = E_2 - Ir_2$

Hence on combining them,

$$V = V_1 + V_2$$

$$E - Ir = E_1 - Ir_1 + E_2 - Ir_2$$

which gives

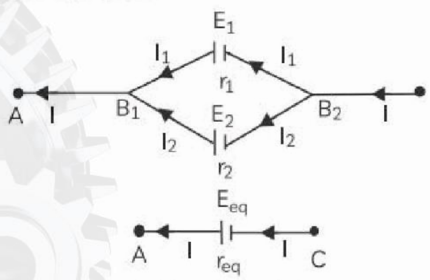
$$E = E_1 + E_2$$

and

$$r = r_1 + r_2$$

Hence the net emf is the sum of both emfs and net resistance is the sum of internal resistances.

Cells in Parallel



Cells in Parallel

Now let us look at cells when connected in parallel. In parallel the current divides and the voltage remains constant.

$$E_1 = V - I_1r_1 \text{ and } E_2 = V - I_2r_2$$

which gives us

Hence, $I_1 = \dfrac{V - E_1}{r_1}$ and $I_2 = \dfrac{V - E_2}{r_2}$

Since we know that, $I = I_1 + I_2$ and $I = \dfrac{V - E}{r}$

$$\frac{V-E}{r} = \frac{V-E_1}{r_1} + \frac{V-E_2}{r_2}$$

$$\frac{V}{r} - \frac{E}{r} = \frac{V}{r_1} + \frac{V}{r_2} - \left(\frac{E_1}{r_1} + \frac{E_2}{r_2}\right)$$

Comparing the LHS and RHS we get,

$$\frac{1}{r} = \frac{1}{r_1} + \frac{1}{r_2}$$

and

$$\frac{E}{r} = \frac{E_1}{r_1} + \frac{E_2}{r_2}$$

$$\Rightarrow \quad E = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$$

TOPIC 3

KIRCHHOFF'S RULES

Many a time when we are faced with a complicated circuit and we need to find out the equivalent resistance and the simple ideas of series and parallel resistance combinations are not enough; we have to take refuge in Kirchhoff's rules. So here are the two rules to be followed.

Junction Rule

The total current at a given junction of wires will always be zero. In other words the net incoming current will always be equal to the net outgoing current.

$$\Sigma I = 0.$$

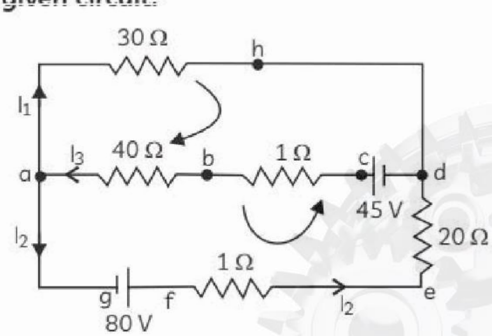
Loop Rule

The total change in potential difference of a loop containing cells and resistors is always zero.

$$\Sigma (E - Ir) = 0$$

Let us take an example to see how to invoke these two rules and solve the problem.

Example 2.1: Create the loop equations to solve for the given circuit.



Ans. Consider a current I_3 starting from the 45 V cell. It gets divided into two currents of I_1 and I_2 Such that they divide at junction *a* and come together to re-form the current I_3 at junction *d* due to junction rule.

Now let us write down the loops we will be following, shown by the two curved arrows. These arrows can be made clockwise or counter-clockwise as per our convenience.

Now in the upper loop

$$40I_3 + 30I_1 + 1I_3 - 45 = 0$$

In the lower loop

$$1I_3 + 40I_3 + 1I_2 + 20I_2 - 80 = 0$$

As can be noted we follow the following rule:

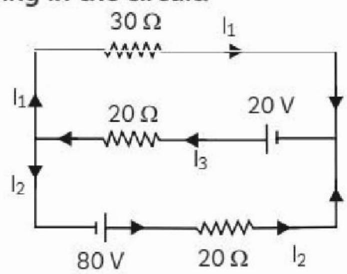
(1) If the loop and the current are in the same direction then IR will be positive else negative.

(2) If the loop points from the negative end of the cell to the positive end then $E = -ve$.

So now that we have two equations we still need a third equation since we have three variables. The third equation can be taken up as

$$I_3 = I_1 + I_2$$

Example 2.2: In the given figure determine the currents flowing in the circuit.



Ans. From the given figure we know that,

$$I_3 = I_1 + I_2$$

which means we can have the following equations:

$$-30I_1 + 20 - 20I_3 = 0$$

$$\Rightarrow \quad 3I_1 + 2I_3 = 2$$

$$-30I_1 + 20I_2 - 80 = 0$$

$$\Rightarrow \quad -3I_1 + 2I_2 = 8$$

Substituting the equations we get,

$$I_1 = -\frac{3}{4}\text{ A}$$

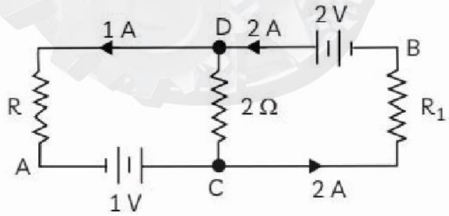
The negative sign shows the direction of I, is opposite to what we had taken.

Now substituting the values of I_1 we get

$$I_2 = \frac{23}{8} A$$

and $$I_3 = \frac{17}{8} A$$

Example 2.3: In the given figure assuming the potential at point A to be zero find the potential at point B.



Ans. By Kirchhoff's first law at the point D, $I_{DC} = 1\ A$

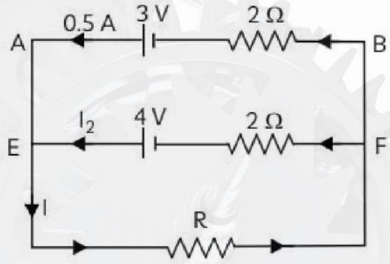
Along the loop ACDBA we get,

$$V_A + 1 + 2 - 2 = V_B$$

$$\Rightarrow \quad V_B = 1\ V$$

Since $V_A = 0$.

Example 2.4: Using Kirchhoff's laws find the voltage drop across R and the current in the arm EF.



Ans. First let us apply Kirchhoff's second rule in loop ABFEA,

$$V_B - 0.5 \times 2 + 3 = V_A$$

$$\Rightarrow \quad V_B - V_A = -2$$

$$V = V_A - V_B = 2\ V$$

Since the potential drop across AB is 2 V and R is in parallel with the upper row hence the potential drop across R is 2 V.

Now let us apply Kirchhoff's first rule at E we get

$$0.5 + I_2 = I$$

where I is the current through the resistor R.

Applying Kirchhoff's second rule we get,

$$-4 + 2I_2 - 0.5 \times 2 + 3 = 0$$

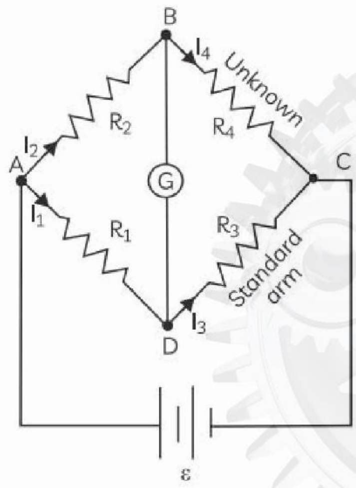
$$I_2 = 1\ A$$

Hence, the current in the arm EF is 1 A.

TOPIC 4

WHEATSTONE BRIDGE

Bridge is a topological system in electrical circuits in which two different circuit parts are interconnected through a third circuit element, known as bridge, such that the bridge can be adjusted as per requirement. Wheatstone bridge is one of the most famous ones which find use in a variety of laboratory situations as well as practical circuits.



Wheatstone Bridge Arrangement

Let us see how to derive the relation. We assume two clockwise loops ADBA and BDCB. The main current I from the cell of emf E is divided into two parts $I = I_1 + I_2$ and $I_2 = I_4 + I_g$ while $I_3 = I_1 + I_g$. Using Kirchhoff's rules we get the following two equations.

$$I_2 R_2 + I_g G - I_1 R_1 = 0$$

and

$$I_4 R_4 - I_3 R_3 - I_g G = 0$$

Wheatstone bridge is considered to be balanced when there is no current flowing through the galvanometer, *i.e.*, $I_g = 0$. This means $I_2 = I_4$, $I_3 = I_1$ and

$$I_2 R_2 = I_1 R_1$$

and

$$I_4 R_4 = I_3 R_3$$

Dividing the two equations we get

$$\frac{R_2}{R_4} = \frac{R_1}{R_3}$$

Using this relation we can find the unknown resistance if the other three are known.

OBJECTIVE Type Questions

[1 mark]

Multiple Choice Questions

1. A cell of internal resistance r connected across an external resistance R can supply maximum current when:
   (a) $R = r$ (b) $R > r$
   (c) $R = \frac{r}{2}$ (d) $R = 0$ [CBSE 2020]

Ans. *(d) $R = 0$*

Explanation: $I = \frac{E}{R+r}$, For maximum current the external Resistance R should be zero.

Caution

➥ *Students are often confused in internal and external resistance. Internal resistance is the resistance offered by the electrolyte in the cell.*

2. Kirchhoff's junction rule is a reflection of:
   (a) conservation of current density vector.
   (b) conservation of charge.
   (c) the fact that there is no accumulation of charges at a junction.
   (d) Both (b) and (c).

3. The internal resistance of a cell is the resistance of:
   (a) material used in the cell
   (b) electrolyte used in the cell
   (c) electrodes of the cell
   (d) vessel of the cell

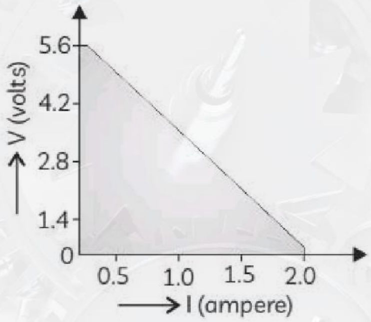
Ans. *(b) electrolyte used in the cell*

Explanation: The resistance offered by the electrolyte of a cell to the flow of current between the electrodes is called internal resistance of the cell.

Caution

➥ *Students are often confused about the value of internal resistance. The internal resistance of a freshly prepared cell is usually low but its value increases as we draw more current through it.*

4. A straight line plot showing the terminal potential difference (V) of a cell as a function of current (I) drawn from it, is shown in the figure. The internal resistance of the cell would be:



   (a) 2.8 ohms (b) 1.4 ohms
   (c) 1.2 ohms (d) Zero
   [CBSE Term-1 SQP 2021]

Ans. *(a) 2.8 ohms*

At $I = 0$,
$V = E$,
$\therefore$ $I = 2.0$,
$\therefore$ $E = 5.6$ V

$$r = \frac{E}{I} = \frac{5.6}{2.0} = 2.8\ \Omega$$

Correct option is (a).

[CBSE Marking Scheme Term-1 SQP 2021]

5. A cell of emf E is connected across an external resistance R. When current 'I' is drawn from the cell, the potential difference across the electrodes of the cell drops to V. The internal resistance 'r' of the cell is:
   (a) $\left(\frac{E-V}{E}\right)R$ (b) $\left(\frac{E-V}{R}\right)$
   (c) $\frac{(E-V)R}{I}$ (d) $\left(\frac{E-V}{V}\right)R$
   [CBSE 2023]

Ans. *(d) $\left(\frac{E-V}{V}\right)R$.*

Explanation:

$$V = E - Ir$$

$$r = \frac{E-V}{I}$$

Current is given by,

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

Therefore,

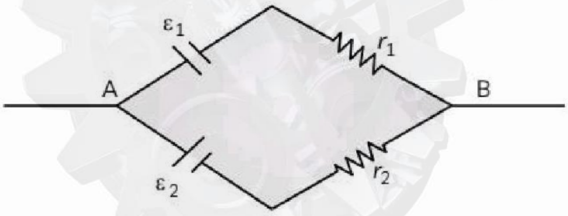
$$r = \left(\frac{E-V}{V}\right)R$$

6. The terminal voltage of a cell of emf E on short circuiting will be:

(a) E (b) $\frac{E}{2}$

(c) 2E (d) 0

7. Two batteries of emf ε_1 and ε_2 ($\varepsilon_2 > \varepsilon_1$) and internal resistances r_1 and r_2 respectively are connected in parallel as shown in figure.



(a) The equivalent emf ε_{eq} of the two cells is between ε_1 and ε_2, *i.e.* $\varepsilon_1 < \varepsilon_{eq} < \varepsilon_2$.

(b) The equivalent emf ε_{eq} is smaller than ε_1.

(c) The ε_{eq} is given by $\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2$ always.

(d) ε_{eq} is independent of internal resistances r_1 and r_2. [NCERT Exemplar]

Ans. *(a) The equivalent emf ε_{eq} of the two cells is between ε_1 and ε_2, i.e., $\varepsilon_1 < \varepsilon_{eq} < \varepsilon_2$.*

Explanation: The equivalent emf of this combination is given by,

$$\varepsilon_{eq} = \frac{\frac{\varepsilon_1}{r_1}+\frac{\varepsilon_2}{r_2}}{\frac{1}{r_1}+\frac{1}{r_2}} = \frac{\varepsilon_1\left(\frac{1}{r_1}+\frac{\frac{\varepsilon_2}{\varepsilon_1}}{r_2}\right)}{\frac{1}{r_1}+\frac{1}{r_2}}$$

As, $\frac{\varepsilon_2}{\varepsilon_1} > 1$

$$\Rightarrow \frac{\left(\frac{1}{r_1}+\frac{\frac{\varepsilon_2}{\varepsilon_1}}{r_2}\right)}{\frac{1}{r_1}+\frac{1}{r_2}} > 1 \text{ or } \varepsilon_{eq} > \varepsilon_1 \text{ and}$$

$$\varepsilon_{eq} < \varepsilon_2$$

So, $\varepsilon_1 < \varepsilon_{eq} < \varepsilon_2$

8. For any circuit the number of independent equations containing emf's, resistances and current equals:

(a) the number of junctions
(b) the number of branches
(c) the number of junctions – 1
(d) the number of branches – 1

Ans. *(b) the number of branches*

Explanation: In a circuit, each branch creates a loop. So, the number of independent equations containing emf's, resistances and current equals to the number of branches.

9. Ten identical cells of emf E and internal resistance r are connected in series to form a closed circuit. An ideal voltmeter connected across three cells will read:

(a) 3 E (b) 7 E
(c) 10 E (d) 13 E

Ans. *(a) 3 E*

Explanation: Total voltage of 10 cells $= 10 \times E = 10E$

Total resistance in 10 cells $= 10r$

$\therefore$ current in the circuit $I = \frac{10E}{10r} = \frac{E}{r}$

Potential difference across three cells,

$$V = I \times 3r = \frac{E}{r} \times 3r = 3E$$

Since, the voltmeter is ideal, therefore, it will read $3E$.

10. The emf of the battery is equal to its terminal potential difference:

(a) only when the battery is being charged.
(b) only when the large current is in the battery.
(c) only when there is no current in the battery.
(d) under all conditions.

11. For maximum current from a combination of cells, the cells should be grouped in:

(a) parallel
(b) series
(c) mixed
(d) depends upon the relative values of internal and external resistance

Ans. *(d) depends upon the relative values of internal and external resistance.*

Explanation: When cells are connected in series, then current through R,

$$I = \frac{nE}{nr+R}$$

When cells are connected in parallel, then current through R,

$$I = \frac{nE}{r+nR}$$

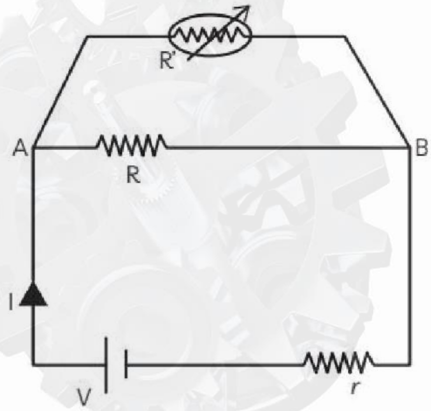
For maximum current from a combination of cells

If $nr + R > r + nR$ cells must be connected in parallel

If $r + nR > nr + R$ cells must be connected in series.

So, it depends on the relative values of internal and external resistances.

12. Consider a simple circuit shown in figure R' stands for a variable resistance. R' can vary from R_0 to infinity. r is internal resistance of the battery ($r << R < R_0$).



(a) Potential drop across AB is nearly constant as R' is varied.

(b) Current through R' is nearly a constant as R' is varied.

(c) Current I depends sensitively on R'.

(d) $I \geq \frac{V}{r+R}$ always. [NCERT Exemplar]

Ans. *(a) Potential drop across AB is nearly constant as R' is varied.*

(d) $I \geq \frac{V}{r+R}$ always.

Explanation: The potential drop is taking place across AB and r. The equivalent resistance of parallel combination of R and R' is always less than R. So, current will be greater than or equal to $\frac{V}{(r+R)}$.

13. The storage battery of a car has an emf 12 volt. If the internal resistance of the battery is 0.4 ohm. The maximum current that can be drawn from the battery will be:

(a) 15 A (b) 30 A

(c) 12 A (d) 20 A

[Delhi Gov. 2022]

Ans. *(b) 30 A*

Explanation: Given,

$$E = 12 \text{ V}$$
$$R = 0.4\ \Omega$$

Let I be the maximum current drawn from the battery.

We know, according to Ohm's law:

$$E = Ir$$
$$I = \frac{E}{r} = \frac{12}{0.4}$$
$$I = 30 \text{ A}$$

14. Kirchhoff's first rule $\Sigma I = 0$ and second rule $\Sigma IR = \Sigma E$ (Where the symbols have their usual meanings) are respectively based on:

(a) conservation of momentum and conservation of charge.

(b) conservation of energy, conservation of charge.

(c) conservation of charge, conservation of momentum.

(d) conservation of charge, conservation of energy. [CBSE Term-1 2021]

Ans. *(d) conservation of charge, conservation of energy*

Explanation: When currents in a circuit are steady, charges cannot accumulate or originate at any point of the circuit. So whatever charge flows towards the junction in any time interval, an equal charge must flow away from that junction in the same interval.

As the electrostatic force is a conservative force, so the work done by it along any closed path must be zero.

15. Two sources of equal emf are connected in series. This combination is, in turn connected to an external resistance R. The internal resistance of two sources are r_1 and r_2 ($r_2 > r_1$). If the potential difference across the source of internal resistance r_2 is zero, then R equal to:

(a) $\frac{r_1 - r_2}{r_2 - r_1}$ (b) $r_2 - r_1$

(c) $\frac{r_1 r_2}{r_2 - r_1}$ (d) $\frac{r_1 + r_2}{r_1 r_2}$

[CBSE Term-1 2021]

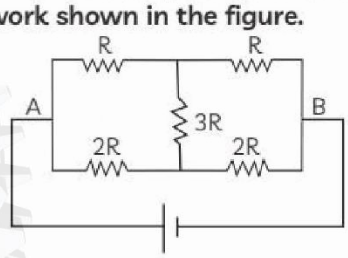
Ans. *(b) $r_2 - r_1$*

Explanation: Current flowing through the surface will be,

$$i = \frac{2\varepsilon}{R + r_1 + r_2}$$
$$V_{r_2} = \varepsilon - ir_2 = 0$$
$$\varepsilon - \frac{2\varepsilon \times r_2}{R + r_1 + r_2} = 0$$

By solving the equation, we get $R = r_2 - r_1$

16. Consider the following statements regarding the network shown in the figure.



(I) The equivalent resistance of the network between points A and B is $\frac{4}{3}$ R.

(II) The current in resistor 3 R is zero.

(III) The potential difference across R is equal to the potential difference across 2R.

Which of the above statement(s) is/are correct?

(a) (I) alone (b) (II) alone
(c) (II) and (III) (d) (I), (II) and (III)

Ans. *(d) (I), (II) and (III)*

Explanation: Due to balanced wheatstone bridge configuration current through 3R is zero. Also resistance is:

$$\left(\frac{1}{2R}+\frac{1}{4R}\right)^{-1} = \frac{4}{3}R$$

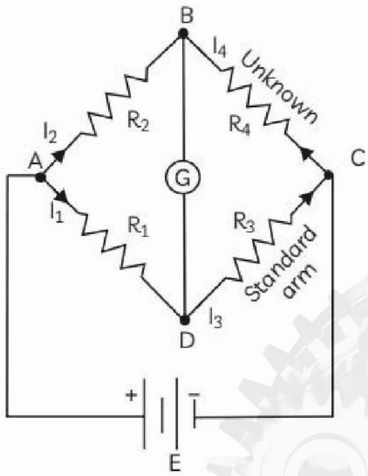
Since resistances are in parallel hence, potential difference is same.

17. In a Wheatstone bridge, all the four arms have equal resistance R. If the resistance of the galvanometer arm is also R, the equivalent resistance of the combination as seen by the battery is:

(a) R (b) 2R

(c) $\frac{R}{2}$ (d) $\frac{R}{4}$

18. The measurement of an unknown resistance R is to be carried out using Wheatstone bridge. Two students perform an experiment in two ways.
The first student takes $R_2 = 10\ \Omega$ and $R_1 = 5\ \Omega$. The other student takes $R_2 = 1000\ \Omega$ and $R_1 = 500\ \Omega$. In the standard arm, both take $R_3 = 5\ \Omega$. Both find $R = \frac{R_2}{R_1} R_3 = 10\ \Omega$ within errors.



(a) The errors of measurement of the two students are the same.

(b) Errors of measurement do depend on the accuracy with which R_2 and R_1 can be measured.

(c) If the student uses large values of R_2 and R_1, the currents through the arms will be feeble. This will make determination of null point accurately more difficult.

(d) Both (b) and (c). [NCERT Exemplar]

Ans. *(d) Both (b) and (c).*

Explanation: We observed that the Wheatstone bridge is most sensitive and accurate if resistances are of same value.

Thus, the errors of measurement of the two students depend on the accuracy and sensitivity of the bridge, which in turn depends on the accuracy with which R_2 and R_1 can be measured.

The currents through the arms of bridge is very weak, when R_2 and R_1 are larger.

This can make the determination of null point accurately more difficult.

Related Theory

➥ *Wheatstone bridge is an arrangement of four resistance which can be used to measure one of them in terms of rest.*

19. In a balanced Wheatstone's network, the resistances in arms Q and S are interchanged, result of this:

(a) galvanometer and the cell must be interchanged to balance

(b) galvanometer shows zero deflection

(c) network is not balanced

(d) network is still balanced [Diksha]

Ans. *(c) network is not balanced*

Explanation: For balancing of wheatstone bridge,

$$\frac{P}{Q} = \frac{R}{S}$$

$$\Rightarrow \quad PS = RQ$$

If resistance in arms Q and S are interchanged, Then,

$$\frac{P}{S} = \frac{R}{Q}$$

$$\Rightarrow \quad PQ = RS$$

Therefore, the Wheatstone bridge is unbalanced.

20. An ideal voltmeter has:

(a) zero resistance

(b) finite resistance less than G but greater than zero.

(c) resistance greater than G but greater than zero.

(d) infinite resistance [Diksha]

Ans. *(d) infinite resistance*

Explanation: An ideal voltmeter is that voltmeter which does not change the original potential difference, needs to have infinite resistance.

Caution

➥ *Students often get confused about infinite resistance but a voltmeter cannot be designed to have an infinite resistance.*

Assertion-Reason Questions

For Questions 21 to 25, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

(a) If both Assertion and Reason are true and Reason is correct explanation of Assertion.

(b) If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.

(c) If Assertion is true but Reason is false.

(d) If both Assertion and Reason are false.

21. Assertion (A): **A real cell has always some internal resistance.**

Reason (R): **When cell is in open circuit then I is equal to zero and V = E.**

Ans. *(b) If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.*

Explanation: In the real cell a part of the emf is consumed in doing work against the internal resistance. So, the potential difference across the terminals of the cell in a closed circuit is always less than its emf.

22. Assertion (A): **Kirchhoff's junction rule is based on conservation of charge.**

Reason (R): **A resistor obeys Ohm's law while a diode does not.**

[Delhi Gov. SQP 2022]

Ans. *(b) If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.*

Explanation: Kirchhoff's 2^{nd} law states that the sum of the potential drop across all the components in a loop must be zero. Thus, Kirchhoff's 2^{nd} law is based on the conservation of energy.

A diode is made up of semiconductors. Ohm's law says the current passing through a conductor is proportional to the potential difference across the conductor. In the case of a diode, the current through it does not linearly depend on the potential difference. Hence, diodes do not obey Ohm's law.

23. Assertion (A): **In primary and secondary cell of same emf, a secondary cell will provide a larger current.**

Reason (R): **The internal resistance of the secondary cell is more.**

24. Assertion (A): **In the Wheatstone bridge the arm BD and AC are called conjugate arms of the bridge.**

Reason (R): **When the bridge is balanced, then on interchanging the positions of the galvanometer and the battery there is no effect on the balance of the bridge.**

Ans. *(a) If both Assertion and Reason are true and Reason is correct explanation of Assertion.*

Explanation: If the bridge is balanced, then on interchanging the positions of the galvanometer and the battery, there is no effect on the balance of the bridge. That is why the BD and AC are called conjugate way of the bridge.

25. Assertion (A): **The electrolyte offers some resistance to the flow of current inside the cell.**

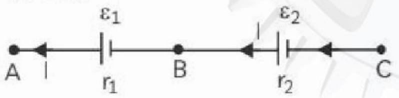
Reason (R): **Inside the electrolyte of the cell, the positive ions flow from the lower to the higher potential against the background of the other ions.**

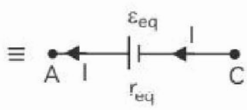
CASE BASED Questions (CBQs)

[**4** & **5** marks]

Read the following passages and answer the questions that follow:

26. *Like resistors, cells can be combined together in an electric circuit. And like resistors, one can, for calculating currents and voltages in a circuit, replace a combination of cells by an equivalent cell.*

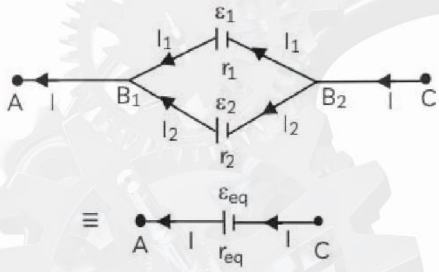




Consider first two cells in series, where one terminal of the two cells is joined together leaving the other terminal in either cell free. ε_1, ε_2 are the emf's of the two cells and r_1, r_2 their internal resistances, respectively.

The equivalent emf and equivalent internal resistance are:

$\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2$, *and* $r_{eq} = r_1 + r_2$



Next, consider a parallel combination of the cells. I_1 and I_2 are the currents leaving the positive electrodes of the cells. At the point B_1, I_1 and I_2 flow in whereas the current I flows out.

The equivalent emf and equivalent internal resistance are:

$$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2}$$

$$\frac{\varepsilon_{eq}}{r_{eq}} = \frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2}$$

(A) Three resistors of 4 Ω, 6 Ω, 12 Ω are connected in parallel and the combination is connected in series with 4 V battery with internal resistance of 2 Ω. The battery current is:

(a) 0.5 A (b) 1 A

(c) 2 A (d) 10 A

(B) Two cells of 1.25 V and 0.75 V and each of internal resistance 1 Ω are connected in parallel. The effective voltage will be:

(a) 0.75 V (b) 1.25 V

(c) 2 V (d) 1 V

(C) If two identical cells, when connected in series or in parallel, supply same amount of current through an external resistance of 2 Ω. The internal resistance of each cell is:

(a) 8 Ω (b) 2 Ω

(c) 4 Ω (d) 1 Ω

(D) Six identical cells, each of emf 6 V, are connected in parallel. The net emf across the battery is:

(a) 36 V

(b) 6 V

(c) 0 V

(d) Between 0 V and 6 V

(E) A battery with an emf of 12 V and an internal resistance of 1 Ω is used to charge a battery with an emf of 10 V and an internal resistance of 1 Ω. The current in the circuit is:

(a) 1 A (b) 2 A

(c) 4 A (d) 6 A

Ans. (A) *(b) 1 A*

Explanation: Here, $R_1 = 4\ \Omega$, $R_2 = 6\ \Omega$ and $R_3 = 12\ \Omega$

Potential difference $V = 4$ V

Equivalent resistance,

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

$$\frac{1}{R_P} = \frac{1}{4} + \frac{1}{6} + \frac{1}{12} = \frac{6}{12}$$

$$R_P = 2\ \Omega$$

So, the total resistance, R = (2 + 2) Ω

$$\text{Battery current, } I = \frac{V}{R} = \frac{4}{4} = 1\text{ A}$$

(C) *(b) 2 Ω*

Explanation: Let the internal resistance of the two cells be *r*.

When cells are connected in series, then current,

$$I_1 = \frac{2E}{R+2r} \quad ...(i)$$

When cells are connected in parallel, then current,

$$I_2 = \frac{E}{R+r/2} = \frac{2E}{2R+r} \quad ...(ii)$$

But, $I_1 = I_2$

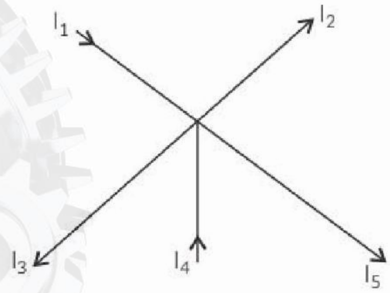
$$\Rightarrow \frac{2E}{R+2r} = \frac{2E}{2R+r}$$

$$\Rightarrow r = R = 2\ \Omega$$

27. *The formulae for series and parallel combinations of resistors are not always sufficient to determine all the currents and potential differences in the circuit. Two rules, called Kirchhoff's rules, are very useful for analysis of electric circuits.*

(1) *Junction rule: At any junction, the sum of the currents entering the junction is equal to the sum of currents leaving the junction.*

This applies equally well if instead of a junction of several lines, we consider a point in a line.



Here, $I_1 + I_4 = I_2 + I_3 + I_5$

(2) *Loop rule: The algebraic sum of changes in potential around any closed loop involving resistors and cells in the loop is zero.*

(A) What is branch?

(B) Explain the significance of Kirchhoff's laws.

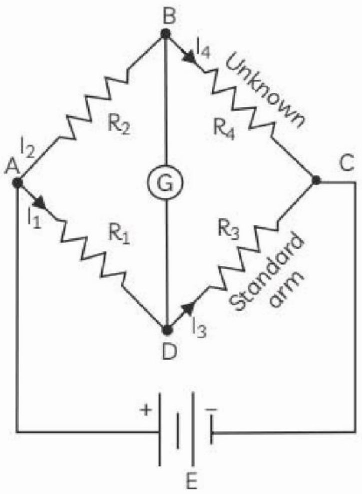
(C) Give the sign convention for applying the second rule.

Ans. (A) A branch is any part of a network that lies between two junctions.

(C) (1) The emf of the cell is taken as positive if the direction of the traversal is from its negative to the positive terminal and vice-versa.

(2) The current resistor (IR) product is taken as positive if the resistor is traversed in the same direction of assumed current and negative if the resistor is traversed in the opposite direction of assumed current.

28. *Wheatstone bridge is an application of Kirchhoff's rules. Consider the circuit shown in figure.*



The bridge has four resistors R_1, R_2, R_3 and R_4. Across one pair of diagonally opposite points (A and C in the figure) a source is connected. AC is called the battery arm. Between the other two vertices, B and D, a galvanometer G is connected. This line, shown as BD in the figure, is called the galvanometer arm. For simplicity, we assume that the cell has no internal resistance. In general, there will be currents flowing across all the resistors as well as a current I_g through G. Of special interest, is the case of a balanced bridge where the resistors are such that $I_g = 0$. We can easily get the balance condition, such that there is no current through G.

Let us suppose we have an unknown resistance, which we insert in the fourth arm; R_4 is thus not known. Keeping known resistances R_1 and R_2 in the first and second arm of the bridge, we go on varying R_3 till the galvanometer shows a null deflection. The bridge then is balanced, and from the balance condition the value of the unknown resistance R_4 is given by,

$$R_4 = R_3\left(\frac{R_2}{R_1}\right)$$

(A) The resistance of each arm of a Wheatstone bridge is 10 Ω. A resistance of 10 Ω is connected in series with the galvanometer. Then the equivalent resistance of the bridge across the battery will be:

(a) 10 Ω (b) 15 Ω
(c) 20 Ω (d) 25 Ω

(B) Three resistances R_1, R_2, R_3 each of 2 Ω and an unknown resistance R_4 form the four arms of a Wheatstone bridge circuit. When a resistance of 6 Ω is connected in parallel to R_4, the bridge gets balanced. What is the value of R_4?

(a) 2 Ω (b) 3 Ω
(c) 6 Ω (d) 1 Ω

(C) The resistances of the four arms *P*, *Q*, *R* and *S* in a Wheatstone bridge are 10 Ω, 30 Ω, 30 Ω and 90 Ω respectively. The emf and internal resistance of the cell are 7 V and 5 Ω respectively. If the galvanometer resistance is 50 Ω, the current drawn from the cell will be:

(a) 1 A (b) 0.2 A
(c) 0.1 A (d) 2 A

(D) In a Wheatstone bridge, three resistances *P*, *Q*, *R* are connected in the three arms and the fourth arm is formed by two resistances S_1 and S_2 connected in series. The condition for the bridge to be balanced will be:

(a) $\frac{P}{Q} = \frac{R}{S_1+S_2}$

(b) $\frac{P}{Q} = \frac{2R}{S_1+S_2}$

(c) $\frac{P}{Q} = \frac{R}{S_1-S_2}$

(d) $\frac{P}{Q} = R\frac{(S_1+S_2)}{S_1S_2}$

(E) In a Wheatstone bridge, the resistances of the four arms *P*, *Q*, *R* and *S* are 2 Ω, 5 Ω, 10 Ω and 25 Ω respectively and current flows in the circuit is 1.4 A. When galvanometer *G* shows no deflection, then the current in the 2 Ω resistor is:

(a) 1.4 A (b) 1.2 A
(c) 1.0 A (d) 0.4 A

Ans. (A) *(a) 10 Ω*

Explanation: Here, $R_1 = R_2 = R_3 = R_4 = 10\ \Omega$

Since, $\frac{R_1}{R_2} = \frac{R_3}{R_4} = 1,$

So, it is a balanced Wheatstone bridge and no current passes through the galvanometer.

As all arm resistances are equal so its equivalent resistance of the bridge across the battery will be 10 Ω.

(C) *(d)* 2 A

Explanation: Here, $P = 10\ \Omega$, $Q = 30\ \Omega$, $R = 30\ \Omega$ and $S = 90\ \Omega$

It is balanced Wheatstone bridge as

$$\frac{P}{Q} = \frac{R}{S}$$

Hence, no current flows in the galvanometer arm, so resistance 50 Ω becomes ineffective.

∴ The equivalent resistance of the circuit is:

$$R_{eq} = 5\ \Omega + \frac{(10\ \Omega + 30\ \Omega)(30\ \Omega + 90\ \Omega)}{(10\ \Omega + 30\ \Omega) + (30\ \Omega + 90\ \Omega)}$$

$R_{eq} = 35\ \Omega$

Current drawn from the cell,

$$I = \frac{7V}{35\ \Omega} = 0.2\ A$$

Caution

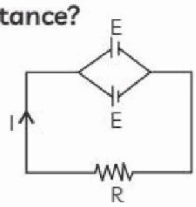
➥ *Students are often confused about the current flows in the galvanometer arm. For it check the balancing of the Wheatstone bridge by applying the condition*

$$\frac{P}{Q} = \frac{R}{S}$$

VERY SHORT ANSWER Type Questions (VSA)

[**1** mark]

29. Two identical cells, each of emf E, having negligible internal resistance, are connected in parallel with each other across an external resistance R. What is the current through this resistance?



[CBSE 2013]

Ans. The cells are arranged as shown in the circuit diagram. As the internal resistance is negligible, so total resistance of the circuit = R.

So, current through the resistance, $I = \frac{E}{R}$.

30. The emf of a cell is always greater than its terminal voltage. Why? Give reason. [CBSE 2013, 12]

31. Is the momentum conserved when charge crosses a junction in an electric circuit? Why or why not? [NCERT Exemplar]

32. Why the emf of a cell cannot be measured using voltmeter?

Ans. A voltmeter cannot be used to measure the emf of a cell because a voltmeter draws some current from the cell.

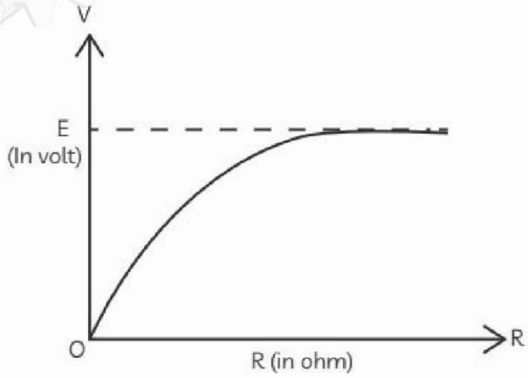
33. A cell of emf E and internal resistance *r* is connected across an external resistance R. Plot a graph showing the variation of P.D. across R, verses R. [NCERT Exemplar]

Ans. As we know that, $V = \dfrac{E}{1 + \frac{r}{R}}$

When, $R = 0;\ V = 0$

$R = \infty,\ V = E$

Hence, the potential difference increases with resistance after a certain value, it becomes constant equal to E



34. Internal resistance is the defect of the cell. Why?

35. State the condition in which terminal voltage across a secondary cell is equal to its emf. [CBSE 2000]

36. Wheatstone bridge, also known as resistance bridge, is used to calculate unknown resistance. It works on principle of null detection. Wheatstone bridge is used for precise measurement of low resistance. It is used along with optional amplifier to measure physical parameters such as light, temperature and strain. When is a Wheatstone bridge most sensitive?

Ans. The Wheatstone bridge is said to be most sensitive when all the four resistances in the arm of Wheatstone bridge are equal to one another.

SHORT ANSWER Type-I Questions (SA-I)

[2 marks]

37. **A cell of emf 'E' and internal resistance 'r' is connected across a variable resistor 'R'. Plot a graph showing variation of terminal voltage 'V' of the cell versus the current I. Using the plot, show how the emf of the cell and its internal resistance can be determined. [CBSE 2014]**

Ans. The terminal voltage 'V' of the cell is given by:

$$V = E - Ir$$

where, E is the emf of the cell, r is the internal resistance of the cell and, I is the current through the circuit.

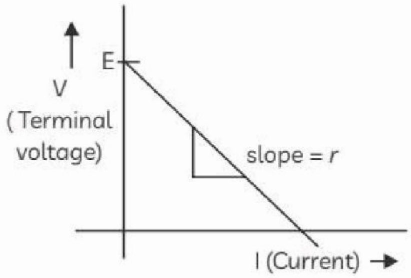
Comparing with the equation of a straight line:

$$y = mx + c,$$

we get,

$$y = V;\ x = I;\ m = -r;\ c = E$$

Graph showing variation of terminal voltage 'V' of the cell versus the current 'I'.

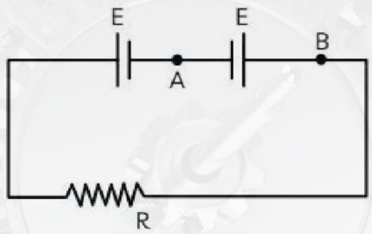


Emf of the cell = Intercept on V axis.

Internal resistance = slope of the line.

38. **First a set of n equal resistors of resistance R each are connected in series to a battery of emf E and internal resistance R. A current I is observed to flow. Then the n resistors are connected in parallel to the same battery. It is observed that the current is increased 10 times. What is 'n'? [NCERT Exemplar]**

39. **Two cells of same emf E but internal resistance r_1 and r_2 are connected in series to an external resistor R (figure). What should be the value of R so that the potential difference across the terminals of the first cell becomes zero?**



[NCERT Exemplar]

Ans. Effective emf of two cells = E + E = 2E

Effective resistance = $R + r_1 + r_2$

So, the electric current is given by:

$$I = \frac{2E}{R + r_1 + r_2}$$

The potential difference across the terminals of the first cell.

$$V_1 = E - Ir_1$$

$$\Rightarrow \quad E - \frac{2E}{R + r_1 + r_2} = 0$$

$$E = \frac{2Er_1}{r_1 + r_2 + R}$$

$$\Rightarrow \quad 1 = \frac{2r_1}{R + r_1 + r_2}$$

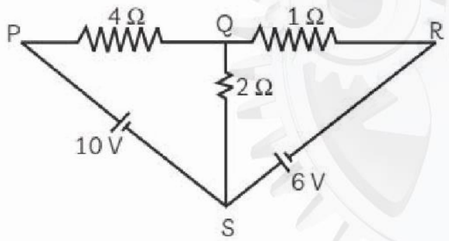
$$R = r_1 - r_2$$

40. **Accepting the single valuedness of electric potential in a steady circuit give Kirchhoff's second law. Explain.**

SHORT ANSWER Type-II Questions (SA-II)

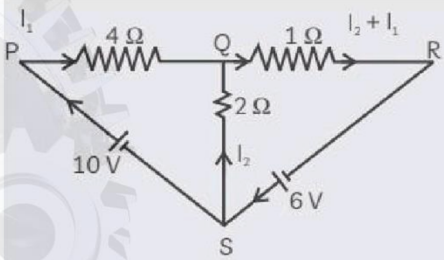
[3 marks]

41. **Using Kirchhoff's laws, calculate the current flowing through 4 Ω, 1 Ω, and 2 Ω resistors in the circuit shown.**



[CBSE Practice Set-1 2023]

Ans.



By using Kirchhoff's second law for closed-loop PQS we get

$$-4I_1 + 2I_2 + 10 = 0$$

$$4I_1 - 2I_2 = 10$$

$$2I_1 - I_2 = 5 \quad \text{...(i)}$$

By using Kirchhoff's second law for closed loop QRS we get

$$-(I_1 + I_2)1 + 6 - 2I_2 = 0$$

$$I_1 + 3I_2 = 6 \quad ...(ii)$$

solving (i) and (ii), we get

$$7I_1 = 21$$

$$I_1 = \frac{21}{7} = 3\text{ A}$$

$$I_2 = 1\text{ A}$$

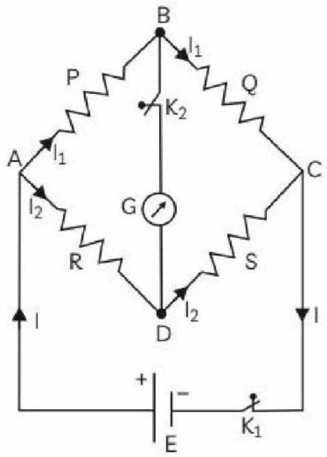
$$I_1 + I_2 = 3 + 1 = 4\text{ A}$$

Therefore, the current across 4 Ω resistor is 3 A, across 2 Ω resistor is 1 A, and across 1 Ω resistor is 4 A.

[CBSE Marking Scheme Practice Set-1 2023]

42. Use Kirchhoff's rules to obtain conditions for the balance condition in a Wheatstone bridge. [CBSE 2015]

Ans. Let us consider a Wheatstone bridge arrangement as shown below:



In figure, four resistance *P*, *Q*, *R* and *S* are connected in the form of four arms of a quadrilateral. Let the current given by battery in the balanced position be *I*. This current on reaching point *A* is divided into two parts I_1 and I_2. As there is no current in galvanometer in balanced state, therefore, current in resistances *P* and *Q* is I_1 and in resistances *R* and *S* it is I_2.

Applying Kirchhoff's first law *i.e.*, junction law at point *A*:

$$I - I_1 - I_2 = 0 \text{ or } I = I_1 + I_2 \quad ...(i)$$

Applying Kirchhoff's second law to closed mesh ABDA:

$$-I_1P + I_2R = 0 \text{ or } I_1P = I_2R \quad ...(ii)$$

Applying Kirchhoff's second law to mesh BCDB:

$$-I_1Q + I_2S = 0 \text{ or } I_1Q = I_2S \quad ...(iii)$$

Dividing equation (ii) by (iii), we get,

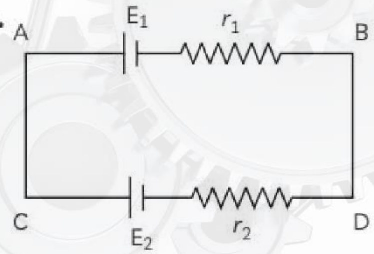
$$\frac{I_1P}{I_1Q} = \frac{I_2R}{I_2S} \text{ or } \frac{P}{Q} = \frac{R}{S}$$

This is the condition of balanced Wheatstone's bridge.

43. Suppose there is a circuit consisting of only resistances and batteries and we have to double (or increase it to *n*-times) all voltages and all resistances. Show that currents are unaltered. [NCERT Exemplar]

44. Two cells of emf E_1 and E_2 and internal resistances r_1 and r_2 are connected in parallel, with their terminals of the same polarity connected together. Obtain an expression for the equivalent emf of the combination. [CBSE 2023]

Ans.



$$(V_A - V_B) = E_1 - i_1r_1$$

$$(V_C - V_D) = E_2 - i_2r_2$$

$$i_1 = \frac{E_1 - V}{r_1}, \quad i_2 = \frac{E_2 - V}{r_2}$$

$$i = i_1 + i_2$$

$$\Rightarrow \quad = \frac{E_1 - V}{r_1} + \frac{E_2 - V}{r_2}$$

$$i = \frac{(E_1 - V)r_2 + (E_2 - V)r_1}{r_1 r_2}$$

$$V = \frac{E_1r_2 + E_2r_1}{(r_1 + r_2)} - \left(\frac{r_1 r_2}{r_1 + r_2}\right)i$$

Comparing it with, $V = E - iR$

We get, $$E_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$$

$$r_{eq} = \frac{r_1 r_2}{r_1 + r_2} = \frac{1}{r_1} + \frac{1}{r_2}$$

$$E_{eq} = \frac{\frac{E_1}{r_1} + \frac{E_2}{r_2}}{\frac{1}{r_1} + \frac{1}{r_2}}$$

Ans. We can measure the current by using following expressions:

(A) $I_1 = \frac{E}{R}$

Current in this case will be maximum because effective resistance is minimum.

So, $I_1 = 4.2$ A

(B) $I_2 = \frac{E}{r+R_1}$

Effective resistance is more than (A) and (D) but less than (C)

So, $I_2 = 1.05$ A

(C) $I_3 = \frac{E}{r+R_1+R_2}$

Effective resistance is maximum so current is minimum.

$I_3 = 0.42$ A

(D) $I_4 = \frac{E}{r+\frac{R_1R_2}{R_1+R_2}}$

Effective resistance is more than (A) but less than (B) and (C)

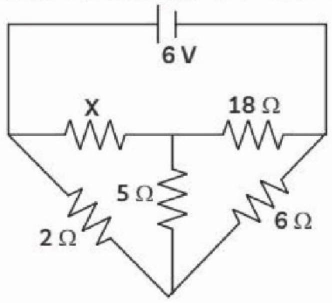
So, $I_4 = 1.4$ A

47. (A) What is a Wheatstone bridge?

(B) When is the bridge said to be balanced?

(C) Apply Kirchhoff's laws to derive the balanced condition of the wheatstone bridge.

(D) Find out the magnitude of resistance X in the circuit shown in figure. When no current flows through the 5 Ω resistance.

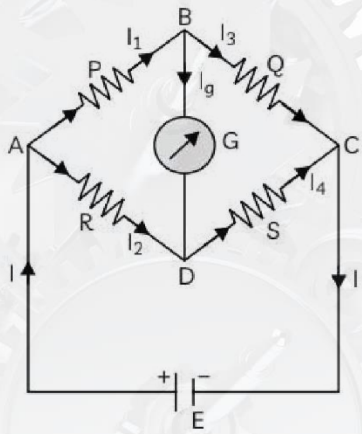


[Delhi Gov. SQP 2022]

Ans. (A) Wheatstone bridge, also known as the resistance bridge, calculates the unknown resistance by balancing two legs of the bridge circuit. One leg includes the component of unknown resistance.

(B) A Wheatstone bridge is said to be in a balanced condition when no current flows through the galvanometer. This condition can be achieved by adjusting the known resistance and variable resistance.

(C)



We apply Kirchhoff's current law in the shown circuit.

At junction B,

$$I_1 = I_g + I_3$$

At junction D,

$$I_2 + I_g = I_4$$

If current through the galvanometer is zero,

$$I_g = 0$$

thus, $I_1 = I_3$

and $I_2 = I_4$

Applying Kirchhoff's voltage law for loop ABDA,

$$I_1P + I_gG = I_2R$$

Applying Kirchhoff's voltage law for loop BCDB,

$$I_3Q = I_4S + I_gG$$

When $I_g = 0$,

$$I_1P = I_2R$$

and $I_3Q = I_4S$

But $I_1 = I_3$ and $I_2 = I_4$,

Therefore, $\frac{P}{Q} = \frac{R}{S}$

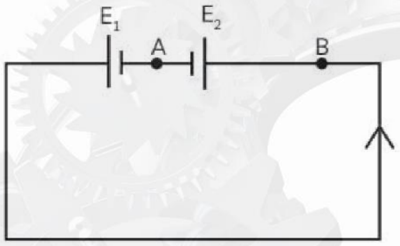
(D) As no current is flowing through the middle arm of 5 Ω resister, so the circuit represents a balanced wheatstone bridge. So,

$$\frac{X}{18} = \frac{2}{6}$$

or $X = \frac{2}{6} \times 18 = 6\ \Omega$

NUMERICAL Type Questions

48. The circuit in figure shows two cells connected in opposition to each other. Cell E_1 is of emf 6 V and internal resistance 2 Ω; the cell E_2 is of emf 4 V and internal resistance 8 Ω. Find the potential difference between the points A and B.



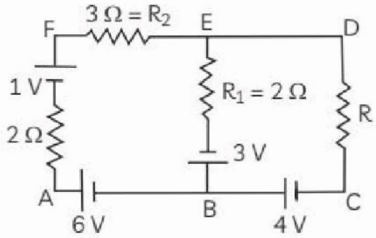
[NCERT Exemplar](2m)

Ans. Here. E_1 = 6 V, E_2 = 4 V, r_1 = 2 Ω and r_2 = 8 Ω
Equivalent emf of two cells = (6 - 4)V = 2 V,
Equivalent resistance = (2 + 8) Ω = 10 Ω,
Then the electric current is given by:

$$I = \frac{V}{R} = 0.2\text{ A}$$

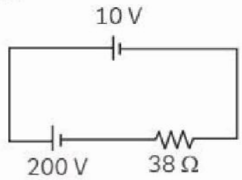
Here, $E_1 = V - Ir_1 = 6 - 0.2 \times 2 = 6 - 0.4 = 5.6$ V
Similarly, $E_2 = V + Ir_2, = 4 + 0.2 \times 8 = 4 + 1.6 = 5.6$ V
The potential between points A and B will be E_2 = 5.6 V. As current is flowing from B to A. Here potential at B is larger than A.

49. **Use Kirchhoff's rules to determine the potential difference between the points *A* and *D* when no current flows in the arm *BE* of the electric network shown in the figure.**



[CBSE 2015](2m)

50. **A 10 V cell of negligible internal resistance is connected in parallel across a battery of emf 200 V and internal resistance 38 Ω as shown in the figure. Find the value of current in the circuit.**



[CBSE 2018](2m)

Ans. Given: E_1 = 10 V; E_2 = 200 V, r = 38 Ω
Net emf,

$$E = E_2 - E_1$$
(∵ Two cells being in opposition)
E = 200 V – 10 V = 190 V

$$\therefore \quad \text{Current, } I = \frac{\text{Net emf}}{\text{Resistance}}$$

$$I = \frac{190\text{ V}}{38\ \Omega} = 5\text{A}.$$

51. **The plot of the variation of potential difference across a combination of three identical cells in series, versus current is shown below. What is the emf and internal resistance of each cell?**

[CBSE 2016](2m)

Ans. We know that,

$$V = E - Ir$$

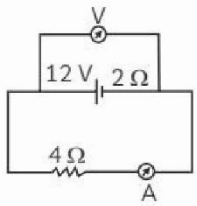
where, E is the e.m.f. and r is the total internal resistance.
When, I = 0,
Total emf = Terminal voltage
3 E = 6 V
Emf of each cell E = 2 V

52. **Two cells of emfs 1.5 V and 2.0 V having internal resistances 0.2 Ω and 0.3 Ω, respectively are connected in parallel. Calculate the emf and internal resistance of the equivalent cell.** [CBSE 2016](3m)

53. **A battery of emf 12 V and internal resistance 2 Ω is connected to a 4 Ω resistor as shown in the figure.**

(A) Show that a voltmeter when placed across the cell and across the resistor, in turn, gives the same reading.

(B) To record the voltage and the current in the circuit, why is voltmeter placed in parallel and ammeter in series in the circuit?



[CBSE 2016](3m)

Ans. We know that,
(A) Effective resistance of the circuit R_E = 6 Ω

$$\therefore \quad I = \frac{12}{6} = 2\text{ A}$$

Terminal potential difference across the cell can be calculated as,

$$V = E - Ir = 12 - 2 \times 2$$
$$V = 12 - 4 = 8\text{ V}$$

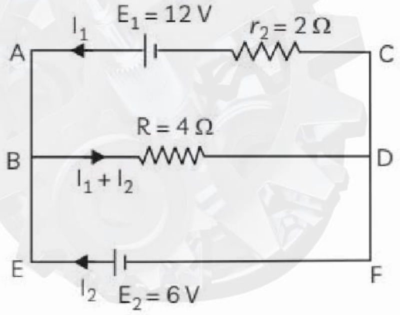
Also, potential difference across 4 Ω resistor can be calculated as,

$$V = IR = 2 \times 4 = 8\text{ V}.$$

So, a voltmeter when placed across the cell and across the resistor, gives the same reading.

(B) An ammeter is connected in series because it has very low resistance. So, when, an ammeter is connected in series, then there is not much increase in the resistance of the circuit and hence the current through the circuit unchanged.

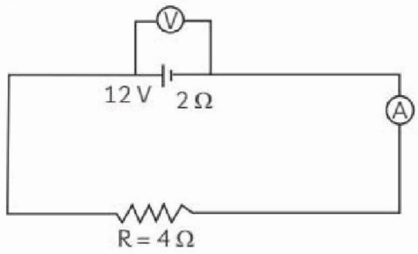
54. **In the electric network shown in the figure use Kirchhoff's rules to calculate the power, consumed by the resistance R = 4 Ω.**



(3m)

55. **(A) The potential difference applied across a given resistor is altered so that the heat produced per second increases by a factor of 9. By what factor does the applied potential difference change?**

(B) In the figure shown, an ammeter A and a resistor of 4 Ω are connected to the terminals of the source. The emf of the source is 12 V having the internal resistance of 2 Ω.



Calculate the voltmeter and ammeter readings. **[CBSE 2017](3m)**

Ans. (A) Heat produced,

$$H = \frac{V^2}{R}t$$

$$\Rightarrow \quad H \propto V^2$$

$$\frac{H'}{H} = \frac{V'^2}{V^2}$$

$$\frac{9H}{H} = \frac{V'^2}{V^2}$$

$$V'^2 = 9V^2$$

$$V' = 3V$$

So, potential difference is increased by a factor of 3.

(B) Current,
$$I = \frac{E}{R+r}$$

$$I = \frac{12}{4+2} = \frac{12}{6} = 2 \text{ A}$$

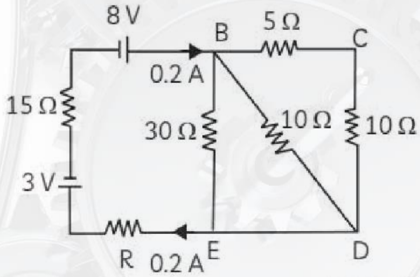
Ammeter reading = 2 A

Potential difference,

$$V = E - Ir$$
$$V = 12 - 2 \times 2$$
$$= 12 - 4$$
$$V = 8 \text{ V}$$

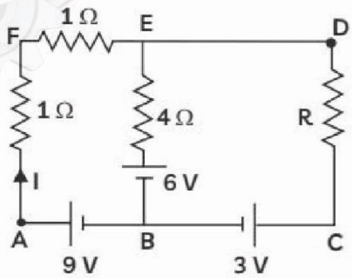
Voltmeter reading = 8 V.

56. **Calculate the value of the resistance *R* in the circuit shown in the figure so that the current in the circuit is 0.2 A. What would be the potential difference between points *B* and *E*?**



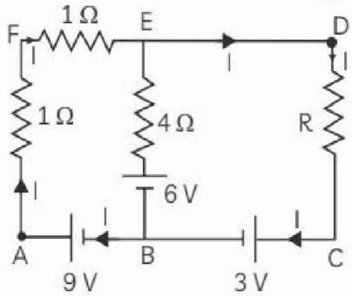
[CBSE 2013](3m)

57. **Using Kirchhoff's rules determine the value of unknown resistance *R* in the circuit so that no current flows through 4 Ω resistance. Also find the potential difference between A and D.**



[CBSE 2012](3m)

Ans. As no current flows through 4 Ω, the current in various branches as shown in the figure.



Applying Kirchhoff's loop rule on the closed loop AFEBA, we get,

$$-I - I - 4 \times 0 - 6 + 9 = 0$$

or $\quad 9 - 6 - 2I = 0$

or $\quad 2I = 3$

or $\quad I = \frac{3}{2}$ A ...(i)

Again, applying Kirchhoff's loop rule to the closed loop BEDCB, we get,

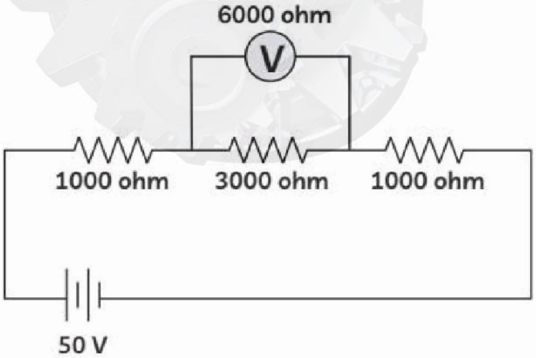
$$6 + 4 \times 0 - IR - 3 = 0 \text{ or } IR = 3$$

$$R = \frac{3}{I} = 3 \times \frac{2}{3} = 2\ \Omega \text{(Using (i))}$$

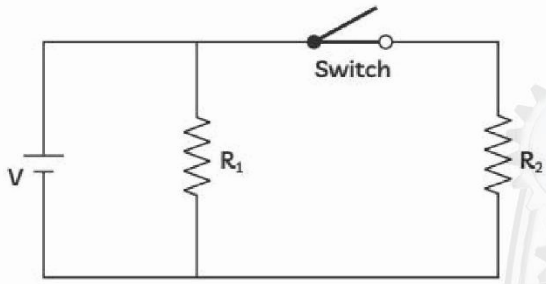
Potential difference between A and D =
Potential difference between A and E.

$$V_{AD} = 2I = 2 \times \frac{3}{2} = 3\text{ V}$$

58. (A) In the given dc circuit, a voltmeter whose resistance is 6000 ohm is used to measure the voltage drop across the 3000 ohm resistor. Determine the % difference in the voltmeter reading that is observed when compared to the true voltage across 3000 ohm resistor when the voltmeter is not connected.



(B) In the circuit given, consider $R_1 = r$, $R_2 = 2r$ and power supply of voltage V.



Determine the power consumed by the circuit in each of the following instances:

(i) when the switch is open

(ii) when the switch is closed

(iii) while the switch is closed, the resistor R_2 is heated so that its resistance is doubled.

[CBSE Question Bank 2023](5m)

Ans. (A) The true voltage drop across the three resistors in series is divided in proportion their resistances.

Voltage across 3000 ohm resistor V,

$$= \frac{3000}{1000+3000+1000} \times 50 = 30\text{ volt}$$

When the voltmeter of resistance 6000 ohm is connected across 3000 ohm, the effective resistance of the 3000 ohm arm will be,

$$= \frac{6000 \times 3000}{6000+3000} = 2000\text{ ohm}$$

So the voltmeter reading will be:

$$V' = \frac{2000}{1000+2000+1000} \times 50$$

$$= \frac{2000}{4000} \times 50\text{ volt}$$

$$= 25\text{ volt}$$

Percentage error

$$\frac{\Delta V}{V} \times 100 = \frac{V' - V}{V} \times 100$$

$$= \frac{25-30}{30} \times 100 = -16.6\%$$

Voltmeter reading will be 16.6% lesser than the true voltage across 3000 ohm resister.

(B) (i) When the switch is open:

$$\text{Power}_1 = \frac{V^2}{R_1} = \frac{V^2}{r}$$

(ii) When the switch is closed:

$$\text{Power}_2 = \frac{V^2}{R_{eq}} = \frac{3V^2}{2r}$$

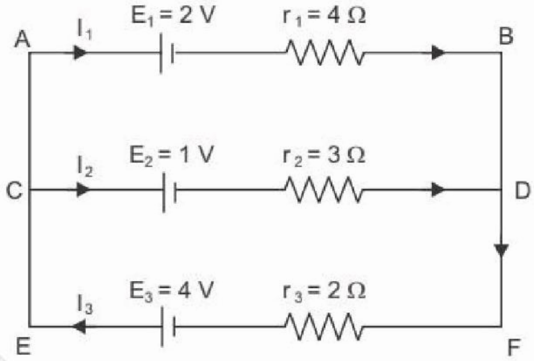
(iii) When R_2 is heated, its value = 4r Ω

$$\text{Power}_3 = \frac{5V^2}{4r}$$

59. (A) The emf of a cell is always greater than its terminal voltage. Why? Give reason.

(B) Two electric bulbs P and Q have their resistances in the ratio of 1 : 2. They are connected in series across a battery. Find the ratio of the power dissipation in these bulbs.

(C) Use Kirchhoff's rules to write the expressions for the currents I_1, I_2 and I_3 in the circuit diagram shown below.



[Delhi Gov. SQP 2022](5m)

Ans. (A) The emf of the cell is always greater than its terminal voltage; Since the potential drop across the cell caused by its low internal resistance, the emf of a cell is higher than its terminal voltage.

(B) Given, Bulb resistance are in ratio 1 : 2 (P:Q)

We know that, Power = I^2R

Taking ratio, $\frac{P_P}{P_Q} = \frac{I^2R_P}{I^2R_Q}$

Since bulbs are connected in series current flowing will be same so $I_p = I_Q = I$

Taking ratio, $\frac{P_P}{P_Q} = \frac{R_P}{R_Q} = \frac{1}{2}$

(C) Applying Kirchhoff's junction Law at C

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

Applying KVL to mesh ABDC

$$-2 - 4I_1 + 3I_2 + 1 = 0$$

$$\Rightarrow \quad 4I_1 - 3I_2 = -1 \quad ...(ii)$$

Applying KVL to mesh CDFE

$$-1 - 3I_2 + 2I_3 + 4 = 0$$

$$-3I_2 + 2I_3 = -3 \quad ...(iii)$$

Solving the equations

Using equation (i) the equation (iii) becomes

$$-3I_2 - 2(I_1 + I_2) = -3$$

$$\Rightarrow \quad -5I_2 - 2I_1 = -3 \quad ...(iv)$$

Solving (ii) and (iv), we get

$$I_1 = \frac{2}{13} A, I_2 = \frac{7}{13} A$$

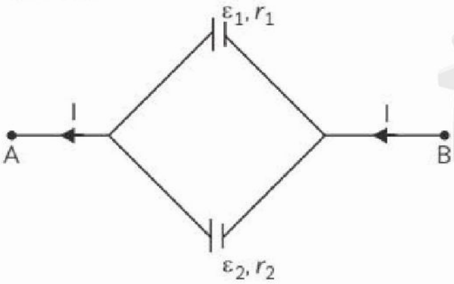
So, $I_3 = I_1 + 1_2 = \frac{9}{13} A$

60. **Two cells of emfs ε_1 and ε_2 and internal resistances r_1 and r_2 respectively are connected in parallel as shown in the figure. Deduce the expression for the:**

(A) equivalent emf of the combination

(B) equivalent internal resistance of the combination

(C) potential difference between the points A and B.



[CBSE SQP 2022](5m)

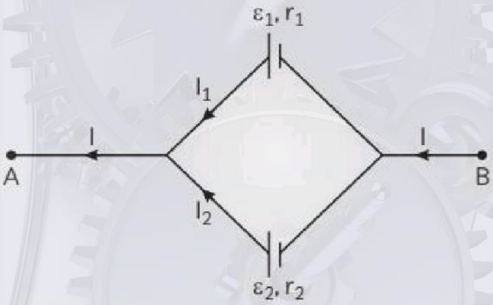
Ans. Here, $I = I_1 + I_2$ ...(i)

Let V = Potential difference between A and B.

For cell ε_1

Then, $V = \varepsilon_1 - I_1 r_1$

$$\Rightarrow \quad I_1 = \frac{\varepsilon_1 - V}{r_1}$$



Similarly, for cell ε_2

$$= \frac{\varepsilon_2 - V}{r_2}$$

Putting these values in equation (*i*)

$$I = \frac{\varepsilon_1 - V}{r_1} + \frac{\varepsilon_2 - V}{r_2}$$

or $$I = \left(\frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2}\right) - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

or $$V = \left(\frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2}\right) - I\left(\frac{r_1 r_2}{r_1 + r_2}\right) \quad ...(ii)$$

Comparing the above equation with the equivalent circuit of *emf* 'ε_{eq}' and internal resistance 'r_{eq}' then,

$$V = \varepsilon_{eq} - I r_{eq} \quad ...(iii)$$

Then

(A) $$\varepsilon_{eq} = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2}$$

(B) $$r_{eq} = \frac{r_1 r_2}{r_1 + r_2}$$

[CBSE Marking Scheme SQP 2022]

TOPPER'S CORNER

OBJECTIVE Type Questions

[1 mark]

Multiple Choice Questions

1. A cell of internal resistance r connected across an external resistance R can supply maximum current when:

(A) $R = r$ (B) $R > r$ (C) $R = \frac{r}{2}$ (D) $R = 0$

Ans. (D) $R = 0$

[CBSE Topper 2020]

2. The number of electrons flowing through a conductor per second is 3.3×10^{19}. The current flowing through the conductor is:

(A) 2.0 A (B) 3.4 A (C) 48 A (D) 5.3 A

Ans. $\frac{dN}{dt} = 3.3\times10^{19}$, $I = \frac{dq}{dt} = e\frac{dN}{dt} = 3.3\times10^{19}\times1.6\times10^{-19} = 5.28\,A$

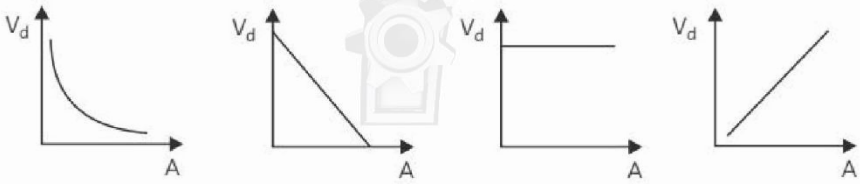
d) 5.3 A

[CBSE Topper 2023]

VERY SHORT ANSWER Type Questions (VSA)

[1 mark]

3. A steady current flows through a metallic wire whose area of cross-section (A) increases continuously from one end of the wire to the other. The magnitude of drift velocity (v_d) of the free electrons as a function of 'A' can be shown by:



(a) (b) (c) (d)

Ans. $J = \frac{I}{A}$, A increases ⇒ J decreases, $J = nev_d$ ⇒ $J \propto v_d$ ⇒ v_d decreases

$\frac{I}{neA} = v_d \Rightarrow v_d \propto \frac{1}{A}$

[CBSE Topper 2023]

4. When a potential difference is applied across the ends of a conductor, how is the drift velocity of the electrons related to the relaxation time?

Ans. Drift velocity of electrons, v_d is given by

$$\vec{v}_d = \frac{-e\vec{E}}{m}\tau$$

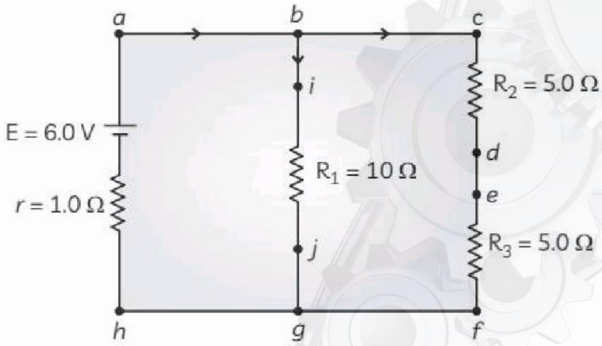
where, $\vec{E}$ is the external electric field and 'τ' is the relaxation time.
Hence, we can see that magnitude of drift velocity of electron varies linearly with relaxation time for a constant potential difference (and also electric field).
Thus, drift velocity of electrons is related directly to the relaxation time.

[CBSE Topper 2019]

SHORT ANSWER Type-I Questions (SA-I)

[2 marks]

5. The following figure shows a circuit diagram. We can find the currents through and potential differences across different resistors using Kirchoff's rules.



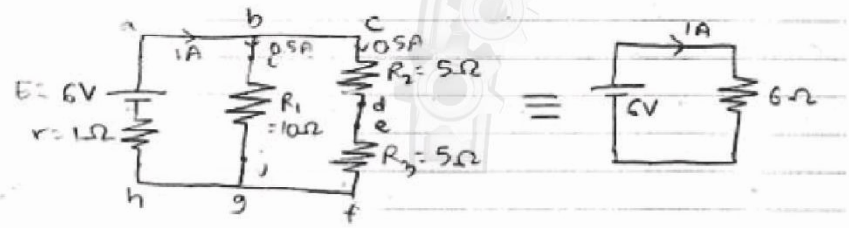
Answer the following questions based on the above:

(a) Which points are at the same potential in the circuit?

(b) What is the current through arm bg?

(c) Find the potential difference across resistance R_3.

Ans.



a) Points having the same potential are:

i) a, b, c, i

ii) h, g, f, j

iii) d, e

b) $R_{eff} = 6\Omega \Rightarrow I_{tot} = 1A$

Current splits equally between arms bg and cf.

$\therefore I_{bg} = 0.5\,A$

c) $I_{cf} = 0.5A = I_3$

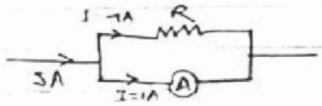
$\therefore V_3 = I_3 R_3 = 0.5 \times 5 = 2.5V$

The potential difference across resistor R_3 is $2.5\,V$

[CBSE Topper 2023]

5. An ammeter of resistance 0.8 Ω can measure a current up to 1.0 A. Find the value of shunt resistance required to convert this ammeter to measure a current up to 5.0 A.

Ans. Let the shunt resistance be of R Ω and it is connected in parallel with ammeter of resistance 0.8 Ω.
In the converted ammeter, 5 A current can enter.
∵ ammeter can take upto 1A, remaining 4A flows through shunt.



∵ R and ammeter are in parallel,

$4R = 1 \times 0.8$

$\Rightarrow R = \frac{0.8}{4} = 0.2\,\Omega$

∴ value of shunt = 0.2 Ω (Ans)

[CBSE Topper 2020]