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CURRENT ELECTRICITY

REVISION MODULE

CBSE XII

Welcome to the Current Electricity, Revision Module, Physics designed specifically for CBSE Class 12th, students. This module aims to provide a comprehensive review of the principles, laws, and applications of current electricity, a fundamental topic in physics.

- **Comprehensive Coverage:** This module covers all essential aspects of current electricity, ensuring thorough preparation for exams and assessments.
- **Clear Explanation:** Concepts are explained clearly and concisely, making it easy to understand and apply them in problem-solving.
- **Practice-oriented Approach:** Ample practice problems and numerical exercises allow for hands-on learning and mastery of the topic.

KEY - FEATURES

- **Electric Current and Resistance:** Explore the concept of electric current and resistance, understanding Ohm's law and its applications in determining the relationship between voltage, current, and resistance in electric circuits.
- **Electrical Circuits:** Study different types of electrical circuits, including series and parallel circuits, and analyze their characteristics, voltage drops, and current distributions. Understand how to calculate equivalent resistance in complex circuits.
- **Kirchhoff's Laws:** Delve into Kirchhoff's laws, including Kirchhoff's current law (KCL) and Kirchhoff's voltage law (KVL), and learn how to apply them to analyze and solve problems in electrical circuits, especially in the context of loop and nodal analysis.
- **DC Circuits:** Investigate direct current (DC) circuits, studying the behavior of resistors, capacitors, and inductors in DC circuits. Learn about the transient response of capacitive and inductive circuits and analyze their time constants.
- **Electrical Measurements:** Explore methods of measuring electrical quantities such as current, voltage, and resistance using appropriate instruments like ammeters, voltmeters, and ohmmeters. Understand the principles of operation and limitations of these instruments.
- **Electrical Power and Energy:** Learn about electrical power and energy, understanding the concepts of power dissipation, power rating, and energy consumption in electrical devices and appliances. Calculate electrical power and energy in various circuits and applications.
- **Applications and Devices:** Discover the practical applications of current electricity in everyday life, including lighting, heating, electromechanical systems, and electronic devices. Gain insights into the operation and characteristics of common electrical devices like bulbs, heaters, and resistors.

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CURRENT ELECTRICITY
REVISION MODULE

POINTS TO REMEMBER

The study of electric charges in motion is called current electricity.

1. Electric Current

The rate of flow of electric charges through a conductor is called electric current.

Current is defined as the rate of flow of electric charge.

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

or Instantaneous current, $I = \frac{dq}{dt}$

Conventionally, the direction of current is taken along the direction of flow of positive charge and opposite to the direction of flow of negative charge (electron).

Current is a scalar quantity. SI unit of electric current is ampere (A).

2. Flow of Electric Charges in a Metallic Conductor

A metallic conductor contains free electrons as charge carriers, while positive ions are fixed in the lattice. When no potential difference is applied, the motion of free electrons is random so there is no net current in any direction. When a potential difference is applied across the conductor the free electrons drift along the direction of positive potential so a current begins to flow in the conductor, the direction of current is opposite to the direction of the net electron flow.

3. Drift Velocity and Mobility

Drift velocity is defined as the average velocity with which the free electrons get drifted towards the positive end of the conductor under the influence of an external electric field applied. It is given by the relation

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

where m = mass of electron, e = charge of electron

E = electric field applied

τ = relaxation time $= \dfrac{\text{mean free path}}{\text{root mean square velocity of electrons}}$

Mobility of an ion is defined as the drift velocity per unit electric field *i.e.*,

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

Its unit is m^2/Vs.

4. Relation between Drift Velocity and Mobility with Electric Current

Current, in terms of drift velocity $I = neAv_d$,
Current, in terms of mobility $I = neA\mu E$,
where, n = number of free electrons per metre^3,
A = cross-sectional area of conductor.

5. Ohm's Law

It states that the current flowing in a conductor is directly proportional to the potential difference applied across the conductor provided physical conditions, *e.g.*, temperature, pressure, etc. remain the same.

$I \propto V$ or $V \propto I$ or $V = RI$

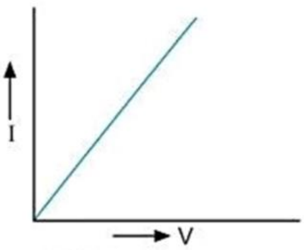
where R is called electrical resistance. Its unit is volt/ampere or ohm.

Ohm's law is not applicable to all types of conductor. It is applicable only for those conducting materials for which *V-I* graph is linear.

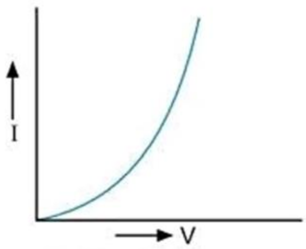
6. V-I Characteristics: Linear and Non-linear — Ohmic and Non-ohmic Conductors

The conductors or circuit elements for which *V-I* graph is linear are called **ohmic conductors**. The examples are metallic conductors.

On the other hand, the circuit elements for which *V-I* graph is non-linear are called **non-ohmic conductors.** The examples are junction diodes and transistors.



(i) Ohmic



(ii) Non-ohmic

Electrical Energy and Power

7. Joule's Law of Heating

The heat which is produced (or consumed) due to the flow of current in a conductor, is expressed in joules.

Mathematically, amount of heat produced (consumed) is proportional to square of amount of current flowing through conductor, electrical resistance of wire and the time of current flow through it.

So, $H \propto I^2Rt$

$$\Rightarrow \quad H = \frac{I^2Rt}{J}$$

where J is a joule constant. 1 joule constant is 4.18×10^3 J/k cal

$$\Rightarrow \quad H = \frac{I^2Rt}{J} = \frac{VIt}{J} = \frac{V^2}{JR}t$$

Where V is the potential difference across wire.

8. Power

Rate of energy dissipation in a resistor is called the power *i.e.*,

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

The unit of power is watt.

9. Resistivity (or Specific Resistance)

Resistivity of a substance is defined as the resistance offered by a wire of that substance of 1 metre length and 1 square metre cross-sectional area.

Resistivity depends only on the material and is independent of dimensions at a given temperature. The SI unit of resistivity is ohm × metre (Ωm).

10. Conductance and Conductivity

The reciprocal of resistance is called the conductance (G)

i.e., $$G = \frac{1}{R}$$

Its SI unit is $(\text{ohm})^{-1}$ or mho or siemen (S).

The reciprocal of resistivity is called the conductivity (σ).

i.e., $$\sigma = \frac{1}{\rho}$$

Its SI unit is ohm^{-1} metre^{-1} (or mho m^{-1}) or Sm^{-1}

11. Temperature Dependence of Resistance

The resistance of a metallic conductor increases with increase of temperature.

$$R_t = R_0 [1 + \alpha (t - t_0)]$$

where R_0 is resistance at 0°C and R_t is resistance at t°C and α is temperature coefficient of resistance.

In general if variation of temperature is not too large, then

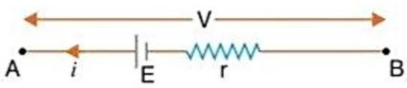
$$\alpha = \frac{R_2 - R_1}{R_1 (t_2 - t_1)} \text{ per}^\circ\text{C or per K}$$

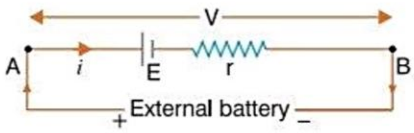
In terms of resistivity

$$\alpha_r = \frac{\rho_2 - \rho_1}{\rho_1 (t_2 - t_1)} \text{ per }^\circ\text{C or per K}$$

However, the resistance of a semiconductor decreases with rise in temperature.

12. Electric Cell





It is a device which converts chemical energy into electrical energy.

EMF of a cell (E) is defined as the maximum potential difference when no current is being drawn from the cell.

Terminal Potential difference (V) is defined as the potential difference when current is being delivered to external load resistance.

Internal Resistance (r) of a cell is the hindrance offered by the electrolyte of cell to the flow of current. Internal resistance of a cell depends on

(*i*) separation between electrodes.

(*ii*) area of immersed part of electrodes.

(*iii*) concentration and nature of electrolyte.

$$E = V + Ir \quad \Rightarrow \quad V = E - Ir$$

When a current I is passed in cell in opposite direction by external battery, then terminal potential difference $V = E + Ir$

13. Combination of Cells

(*i*) When n-identical cells are connected in series

$$\text{Current, } I\left(= \frac{E_{net}}{R_{ext} + R_{int}}\right) = \frac{nE}{R + nr}$$

For useful series combination, the condition is $R_{ext} >> R_{int}$

(*ii*) When m-identical cells are connected in parallel

$$I = \frac{E_{net}}{R_{ext} + R_{\text{int}}} = \frac{E}{R + r/m}$$

Condition of useful parallel combination is $R < r/m$.

(*iii*) When $N = mn$, cells are connected in mixed grouping (m-rows in parallel, each row containing n cells in series)

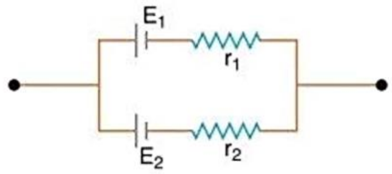
$$\text{Current, } I = \frac{nE}{R + \frac{nr}{m}} = \frac{mnE}{mR + nr}$$

Condition for useful mixed grouping is $R_{ext} = R_{int}$

i.e., $$R = \frac{nr}{m}$$

(*iv*) When two cells of different emfs E_1 and E_2 and different internal resistances r_1 and r_2 are connected in parallel as shown in fig. then net emf of combination is

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



Net internal resistance r_{int}

$$\frac{1}{r_{int}} = \frac{1}{r_1} + \frac{1}{r_2} \Rightarrow r_{int} = \frac{r_1 r_2}{r_1 + r_2}$$

14. Kirchhoff's Laws

(*i*) **First law (or junction law):** The algebraic sum of currents meeting at any junction in an electrical network is zero,

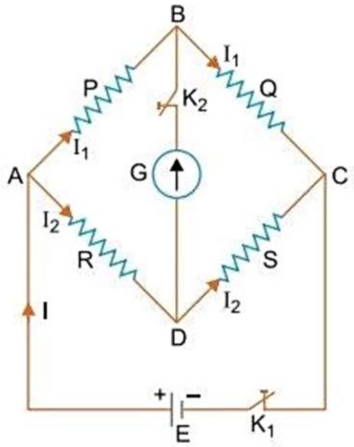
i.e., $\Sigma I = 0$

This law is based on conservation of charge.

(*ii*) **Second law (or loop law):** The algebraic sum of potential differences of different circuit elements of a closed circuit (or mesh) is zero, *i.e.*,

$$\Sigma V = 0$$

This law is based on conservation of energy.



15. Wheatstone's Bridge

It is an arrangement of four resistances *P*, *Q*, *R*, and *S* forming a closed circuit. A potential difference is applied across terminals *A* and *C*. A galvanometer is connected across *B* and *D*. The condition of null point (no deflection in galvanometer) is

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

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Multiple Choice Questions

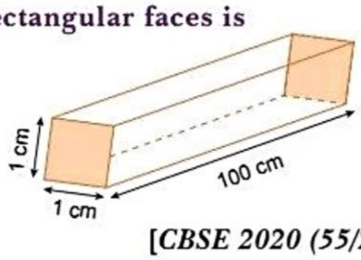
Choose and write the correct option(s) in the following questions.

1. The resistance of a metal wire increases with increasing temperature on account of *[CBSE 2020 (55/1/2)]*

(*a*) decrease in free electron density.
(*b*) decrease in relaxation time.
(*c*) increase in mean free path.
(*d*) increase in the mass of electron.

2. Dimensions of a block are 1cm × 1cm × 100 cm. If specific resistance of its material is 3×10^{-7} Ω m, then the resistance between the opposite rectangular faces is

(*a*) 3×10^{-9} Ω
(*b*) 3×10^{-7} Ω
(*c*) 3×10^{-5} Ω
(*d*) 3×10^{-3} Ω

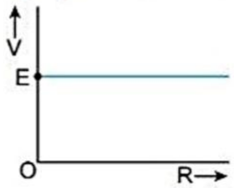


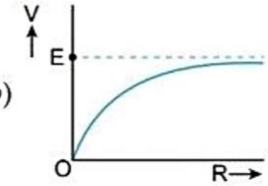
[CBSE 2020 (55/2/2)]

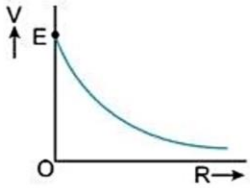
3. Resistivity of a given conductor depends upon

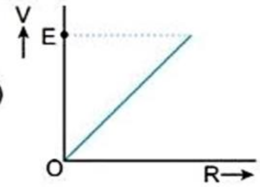
(*a*) temperature.
(*b*) length of conductor.
(*c*) area of cross-section.
(*d*) shape of the conductor.

4. A cell of emf (E) and internal resistance r is connected across a variable external resistance R. The graph of terminal potential difference V as a function of R is *[CBSE 2020 (55/4/1)]*

(*a*) 

(*b*) 

(*c*) 

(*d*) 

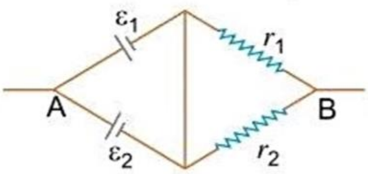
5. In a Wheatstone bridge, all the four arms have equal resistance R. If resistance of the galvanometer arm is also R, then equivalent resistance of the combination is

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

6. Consider a current carrying wire (current I) in the shape of a circle. Note that as the current progresses along the wire, the direction of J (current density) changes in an exact manner, while the current I remain unaffected. The agent that is essentially responsible for is *[NCERT Exemplar]*

(*a*) source of emf.
(*b*) electric field produced by charges accumulated on the surface of wire.
(*c*) the charges just behind a given segment of wire which push them just the right way by repulsion.
(*d*) the charges ahead.

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. *[NCERT Exemplar]*



(*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.

8. The drift velocity of the free electrons in a conducting wire carrying a current i is v. If in a wire of the same metal, but of double the radius, the current be $2I$, then the drift velocity of the electrons will be

(*a*) $v/4$ (*b*) $v/2$ (*c*) v (*d*) $4v$

9. The element of a heater is rated (P, V). If it is connected across a source of voltage $V/2$, then the power communed by it will be *[CBSE 2020 (55/3/1)]*

(*a*) P (*b*) $2P$
(*c*) $\frac{P}{2}$ (*d*) $\frac{P}{4}$

10. A metal rod of length 10 cm and a rectangular cross-section of 1cm × $\frac{1}{2}$ cm is connected to a battery across opposite faces. The resistance will be *[NCERT Exemplar]*

(*a*) maximum when the battery is connected across 1 cm × $\frac{1}{2}$ cm faces.
(*b*) maximum when the battery is connected across 10 cm × 1 cm faces.
(*c*) maximum when the battery is connected across 10 cm × $\frac{1}{2}$ cm faces.
(*d*) same irrespective of the three faces.

11. Which of the following characteristics of electrons determines the current in a conductor? [*NCERT Exemplar*]

(*a*) Drift velocity alone
(*b*) Thermal velocity alone
(*c*) Both drift velocity and thermal velocity
(*d*) Neither drift nor thermal velocity.

12. Temperature dependence of resistivity ρ(T) of semiconductors insulators and metals is significantly based on the following factors. [*NCERT Exemplar*]

(*a*) Number of charge carriers can change with temperature T.
(*b*) Time interval between two successive collision can depend on T.
(*c*) Length of material can be a function of T.
(*d*) Mass of carriers is a function of T.

13. A cell of internal resistance r is connected across an external resistance R can supply maximum current when [*CBSE 2020 (55/2/1)*]

(*a*) $R = r$ (*b*) $R > r$ (*c*) $R = \frac{r}{2}$ (*d*) $R = 0$

14. Kirchhoff's junction rule is a reflection of [*NCERT Exemplar*]

(*a*) conservation of current density vector.
(*b*) conservation of charge.
(*c*) the fact that the momentum with which a charged particle approaches a junction is unchanged (as a vector) as the charged particle leaves the junction.
(*d*) the fact that there is no accumulation of charged at a junction.

15. The ratio of current density and electric field is called [*CBSE 2020 (55/2/2)*]

(*a*) Resistivity (*b*) Conductivity
(*c*) Drift velocity (*d*) Mobility

16. The electrical resistance of a conductor [*CBSE 2020 (55/3/1)*]

(*a*) varies directly proportional to its area of cross-section.
(*b*) decreases with increase in its temperature.
(*c*) decreases with increase in its conductivity.
(*d*) independent or its shape but depends only on its volume.

17. For a fixed potential difference applied across a conductor, the drift speed of free electrons does not depend upon [*CBSE 2020 (55/2/3)*]

(*a*) free electron density in the conductor.
(*b*) mass of the electrons.
(*c*) length of the conductor
(*d*) temperature of the conductor.

18. 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 equals to [*CBSE 2022 (55/2/4), Term-1*]

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

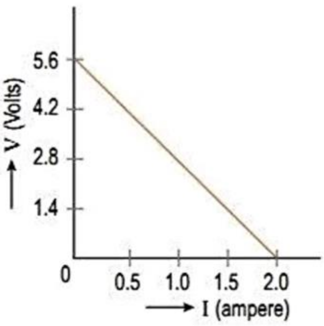
(*c*) $\frac{r_1 r_2}{r_2 - r_1}$ (*d*) $\frac{r_1 + r_2}{r_1 r_2}$

19. If n, e, τ and m have their usual meanings, then the resistance of a wire of length l and cross-sectional area A is given by [*CBSE 2022 (55/2/4), Term-1*]

(*a*) $\frac{ne^2A}{2m\tau l}$ (*b*) $\frac{ml}{ne^2\tau A}$

(*c*) $\frac{m\tau A}{ne^2 l}$ (*d*) $\frac{ne^2\tau A}{2ml}$

20. 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 then **[*CBSE Sample Paper-2022), Term-1*]**



(*a*) 2.8 ohms (*b*) 1.4 ohms (*c*) 1.2 ohms (*d*) zero

21. A car battery is charged by a 12 V supply, and energy stored in it is 7.20×10^5 J. The charge passed through the battery is **[*CBSE 2022 (55/2/4), Term-1*]**

(*a*) 6.0×10^4 C (*b*) 5.8×10^3 J (*c*) 8.64×10^6 J (*d*) 1.6×10^5 C

22. We use alloys for making standard resistors because they have **[*CBSE Sample Paper-2022, Term-1*]**

(*a*) low temperature coefficient of resistivity and high specific resistance
(*b*) high temperature coefficient of resistivity and low specific resistance
(*c*) low temperature coefficient of resistivity and low specific resistance
(*d*) high temperature coefficient of resistivity and high specific resistance

23. 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 **[*CBSE Sample Paper-2022, Term-1*]**

(*a*) $H/2$ (*b*) H (*c*) $2H$ (*d*) $4H$

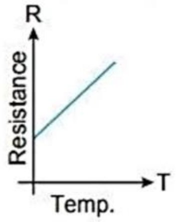
24. If the potential difference V applied across a conductor is increased to $2V$ with its temperature kept constant, free electrons in a conductor **[*CBSE Sample Paper-2022, Term-1*]**

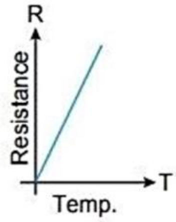
(*a*) remain the same (*b*) become half of its previous value
(*c*) be double of its initial value (*d*) become zero

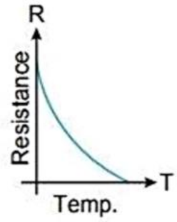
25. A battery is connected to the conductor of non-uniform cross section area. The quantities or quantity which remains constant is **[*CBSE Sample Paper-2022, Term-1*]**

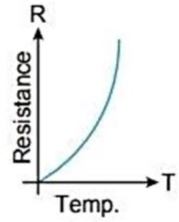
(*a*) electric field only (*b*) drift speed and electric field
(*c*) electric field and current (*d*) current only

26. For a metallic conductor, the correct representation of variation of resistance R with temperature T is **[*CBSE 2023 (55/1/1)*]**

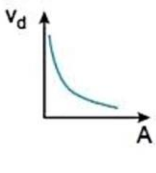
(*a*)


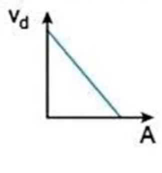
(*b*)


(*c*)


(*d*)


27. 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 **[*CBSE 2023 (55/1/1)*]**

(*a*)


(*b*)


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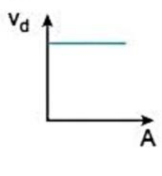
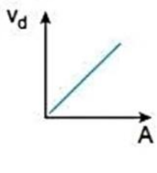


(*d*)


28. **A current of 0.8 A flows in a conductor of 40 Ω for 1 minute. The heat produced in the conductor will be** *[CBSE 2023 (55/2/1)]*

(*a*) 1445 J (*b*) 1536 J (*c*) 1569 J (*d*) 1640 J

29. **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** *[CBSE 2023 (55/2/1)]*

(*a*) $\left(\frac{E-V}{E}\right)R$ (*b*) $\left(\frac{E-V}{R}\right)$ (*c*) $\frac{(E-V)R}{I}$ (*d*) $\left(\frac{E-V}{V}\right)R$

30. **The current density due to drift of electrons in a conductor is given by (symbols have their usual meanings)** *[CBSE 2023 (55/3/1)]*

(*a*) $n\,e\,A\,v_d$ (*b*) $\frac{n\,A\,v_d}{e}$ (*c*) $\frac{n\,v_d}{e\,A}$ (*d*) $n\,e\,v_d$

Answers

1. (*b*)	**2.** (*b*)	**3.** (*a*)	**4.** (*b*)	**5.** (*a*)	**6.** (*b*)	**7.** (*a*)
8. (*b*)	**9.** (*d*)	**10.** (*a*)	**11.** (*a*)	**12.** (*a*), (*b*)	**13.** (*a*)	**14.** (*b*), (*d*)
15. (*b*)	**16.** (*c*)	**17.** (*a*)	**18.** (*b*)	**19.** (*b*)	**20.** (*a*)	**21.** (*a*)
22. (*a*)	**23.** (*c*)	**24.** (*c*)	**25.** (*d*)	**26.** (*a*)	**27.** (*a*)	**28.** (*b*)
29. (*d*)	**30.** (*d*)					

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(*a*) *Both A and R are true and R is the correct explanation of A.*

(*b*) *Both A and R are true but R is not the correct explanation of A.*

(*c*) *A is true but R is false.*

(*d*) *A is false and R is also false.*

1. **Assertion (*A*)** : An electron has a high potential energy when it is at a location associated with a more negative value of potential, and a low potential energy when at a location associated with a more positive potential. *[CBSE Sample Paper-2022, Term-1]*

Reason (*R*) : Electrons move from a region of higher potential to region of lower potential.

2. **Assertion (*A*)** : The current density is a vector quantity.

Reason (*R*) : Current density has magnitude current per unit area and is directed along the direction of current.

3. **Assertion (*A*)** : The connecting wires are made of copper.

Reason (*R*) : Copper has very high electrical conductivity.

4. **Assertion (*A*)** : Material used in construction of a standard resistance is constantan.

Reason (*R*) : The temperature coefficient of resistance of constantan is negligible.

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

Reason (*R*) : Drift speed of electrons in a metallic wire is very large. *[AIIMS 2017]*

6. **Assertion (*A*)** : With increase in drift velocity, the current flowing through a metallic conductor decreases.

Reason (*R*) : The current flowing in a conductor is inversely proportional to drift velocity.

7. **Assertion (*A*)** : The current flows in a conductor when there is an electric field within the conductor.
Reason (*R*) : The electrons in a conductor drift only in the presence of electric field.

8. **Assertion (*A*)** : The conductivity of an electrolyte is very low as compared to a metal at room temperature.
Reason (*R*) : The number density of free ions in electrolyte is much smaller as compared to number density of free electrons in metals. Further, ions drift much more slowly, being heavier. [*AIIMS 2015*]

9. **Assertion (*A*)** : The internal resistance of a cell is constant.
Reason (*R*) : Ionic concentration of the electrolyte remains same during use of a cell. [*CBSE 2023 (55/3/1)*]

10. **Assertion (*A*)** : When three electric bulbs of power 200 W, 100 W and 50 W are connected in series to a source, the power consumed by the 50 W bulb is maximum.
Reason (*R*) : In a series circuit, current is the same through each bulb, but the potential difference across each bulb is different. [*CBSE 2023 (55/4/1)*]

Answers

1. (*c*) **2.** (*a*) **3.** (*a*) **4.** (*a*) **5.** (*c*) **6.** (*d*) **7.** (*a*)
8. (*a*) **9.** (*d*) **10.** (*b*).

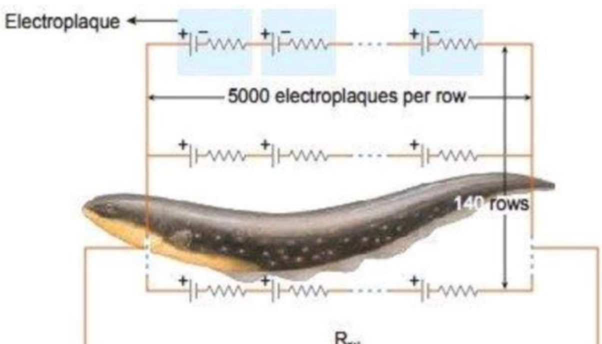
COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

1. **Eel: The Electric Fish**

Electric fish are able to generate current with biological cells called electroplaques, which are physiological emf devices. The electro-plaques in the South American ell shown in the photograph that opens this chapter are arranged in 140 rows, each row stretching horizontally along the body and each containing 5000 electro-plaques. The arrangement is suggested in figure each electro-plaque has an emf (ε) of 0.15V and an internal resistance (*r*) of 0.25Ω. The water surrounding the eel completes a circuit between the two ends of the electroplaque array, one end at the animal's head and the other near its tail.



(*i*) **If the water surrounding the eel has resistance R_w = 800 Ω how much current can the eel produce in the water?**
(*a*) 6.6 mA (*b*) 6.6 A
(*c*) 0.93 A (*d*) 9.3 mA

(ii) **If the cell has on emf of 4 V and the internal resistance of this cell is 0.2 Ω, it is connected to resistance of 3.8 Ω, terminal voltage through the cell will be**

(a) 3.8 V (b) 4 V (c) 0.2 V (d) 1.8 V

(iii) **For a cell, the terminal potential difference is 3.6 V, when the circuit is open. If the potential difference reduces to 3 V, when cell is connected to a resistance of 5 Ω, the internal resistance of cell is**

(a) 1 Ω (b) 2 Ω (c) 4 Ω (d) 8 Ω

(iv) **A group of girls connected 10 identical cell first in series and then in parallel across a bulb of resistance 50 Ω and they see that the reading of the ammeter 1 A in both cases. Then the internal resistance of any one cell will be**

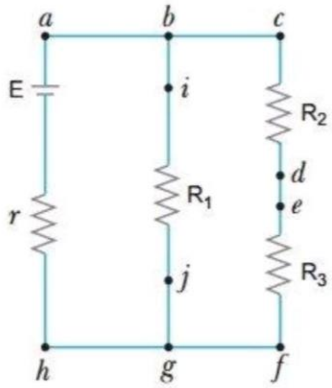
(a) 100 Ω (b) 50 Ω (c) 10 Ω (d) 5 Ω

OR

If *n* identical cells emf and internal resistance *r* are connected parallel then the equivalent emf of the combination will

(a) $\frac{Er}{n}$ (b) $\frac{E}{n}$ (c) E (d) $\frac{nE}{r}$

2. An experiment was set up with the circuit diagram shown in figure.
Given that $R_1 = 10\,\Omega, R_2 = R_3 = 5\,\Omega, r = 0\,\Omega$ and $E = 5$V **[*CBSE 2022 (55/2/4), Term-1, Modified*]**



(i) **The points with the same potential are**

(a) b, c, d (b) f, h, j (c) d, e, f (d) a, b, j

(ii) **The current through branch *bg* is**

(a) 1 A (b) $\frac{1}{3}$ A (c) $\frac{1}{2}$ A (d) $\frac{2}{3}$ A

(iii) **The power dissipated in R_1 is**

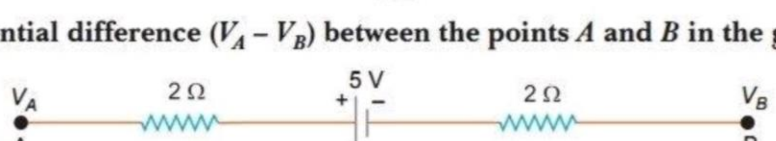
(a) 2 W (b) 2.5 W (c) 3 W (d) 4.5 W

(iv) **The potential difference across R_3 is**

(a) 1.5 V (b) 2 V (c) 2.5 V (d) 3 V

OR

The potential difference ($V_A - V_B$) between the points *A* and *B* in the given figure is



(a) – 3 V (b) +3 V (c) –13 V (d) +13 V

Explanations

1. (*i*) (*c*) The total emf, E_{row} along a row of 5000 electro-plaque

$$E_{row} = 5000\,E = 5000 \times 0.15 = 750 \text{ V}$$

Now, Total internal resistance in row,

$$r_{row} = (5000)r = (5000 \times 0.25) = 1250\ \Omega.$$

The equivalent resistance of this combination,

$$r_{eq} = \frac{r_{row}}{140} = \frac{1250}{140} = 8.93\ \Omega,\quad E_{net} = E_{row}$$

Hence, I produce by eel in water, $R_w = 800\ \Omega$

$$\therefore \quad I = \frac{E_{net}}{R + r_{eq}} = \frac{750}{800 + 8.93} = 0.927\text{A} \simeq 0.93 \text{ A}$$

[**Note:** In parallel combination of cell having equal internal resistance, $E_{net} = E$]

(*ii*) (*a*) Here, $I = \dfrac{E}{R+r} = \dfrac{4}{3.8+0.2} = \dfrac{4}{4} = 1 \text{ A}$

Now, $V = E - Ir = 4 - 1 \times 0.2 = 3.8$ V

(*iii*) (*a*) Given, $E = 3.6$ V, $V = 3$V, $R = 5\ \Omega$

then, $I = \dfrac{V}{R} = \dfrac{3}{5}$A.

Now, $E = V + IR$

$$\therefore \quad r = \frac{E - V}{I} = \frac{3.6 - 3}{\frac{3}{5}} = \frac{0.6 \times 5}{3} = 1\ \Omega$$

(*iv*) (*b*) **Case I:** When cells connected in series, $E_{net} = 10\,E$

$$I = \frac{E_{net}}{R + 10r} = \frac{10E}{50 + 10\,r} \quad \text{...(i)}$$

Case II: When cell connected in parallal, $E_{net} = E$

$$I = \frac{E_{net}}{R + \frac{r}{10}} = \frac{E}{50 + \frac{r}{10}} \quad \text{...(ii)}$$

Now, in both case ammeter reading is same,

$$I_s = I_p$$

$$\Rightarrow \quad \frac{10E}{50 + 10r} = \frac{E}{50 + \frac{r}{10}}$$

$$\Rightarrow \quad 500 + \frac{10r}{10} = 50 + 10r \quad \Rightarrow \quad 9r = 450 \quad \therefore \quad r = \frac{450}{9} = 50\ \Omega$$

OR

(*c*) In parallel combination of cell,

$$E_{eq} = \frac{\frac{E_1}{r_1} + \frac{E_2}{r_2} + \ldots \frac{E_n}{r_n}}{\frac{1}{r_1} + \frac{1}{r_2} + \ldots \frac{1}{r_n}} = \frac{\frac{nE}{r}}{\frac{n}{r}} = E$$

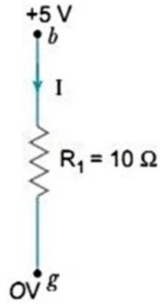
2. (*i*) (*b*) Here, $r = 0$, so no potential drop across r.

$\therefore$ P.d of cell $= V_a - V_h = (5 - 0) = 5$V

Now, $V_a = 5V$, $V_h = 0V$

From the circuit, common points a, b, i, c have same potential and common points h, g, j, f have same potential.

(ii) (*c*) Potential difference across bg,



$V_{bg} = +5 - 0 = 5$ V

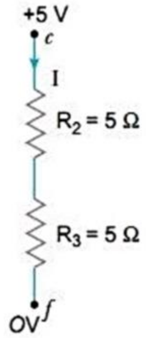
Current through branch bg,

$$\therefore \quad I = \frac{V_{bg}}{R_1} = \frac{5}{10} = \frac{1}{2}\text{A}$$

(iii) (*b*) Power dissipated in R_1,

$$P = \frac{V^2}{R} = \frac{(5)^2}{10} = \frac{25}{10} = 2.5 \text{ W}$$

(iv) (*c*) Potential difference across cf branch,



$$V_{cf} = (5 - 0) = 5\text{V}$$

$$R_{eq} = R_2 + R_3 = (5 + 5) = 10\,\Omega$$

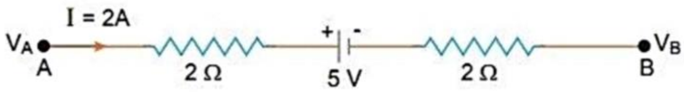
$$\therefore \quad I = \frac{V_{cf}}{R_{eq}} = \frac{5}{10} = \frac{1}{2}\text{A}$$

Then, potential difference across R_3,

$$\therefore \quad V = IR_3 = \frac{1}{2} \times 5 = 2.5 \text{ V}$$

OR

(*d*) From *KVL*,



$$V_{AB} = V_A - V_B = 2 \times 2 + 5 + 2 \times 2$$

$$= 4 + 5 + 4 = 13 \text{ V}$$

CONCEPTUAL QUESTIONS

Q. 1. 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. **[CBSE 2019 (55/1/2)]**

Ans. Drift velocity of electrons, v_d is given by,

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

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.

[Topper's Answer 2019]

Q. 2. Define the term 'Mobility' of electrons. Give its SI unit. **[*CBSE 2023 (55/4/1)*]**

Ans. Mobility is defined as the magnitude of the drift velocity acquired by it in a unit electric field.

The SI unit of mobility is m^2/Vs or $m^2 V^{-1}s^{-1}$.

Q. 3. How does the mobility of electrons in a conductor change, if the potential difference applied across the conductor is doubled, keeping the length and temperature of the conductor constant? **[*CBSE 2019 (55/1/1)*]**

Ans. Mobility is defined as the magnitude of drift velocity per unit electric field.

$$\mu = \frac{|v_d|}{E} = \frac{eE}{m.E}\tau = \frac{e}{m}\tau$$

At constant temperature and length, there is no change in relaxation time *i.e.*, $\tau \propto \frac{1}{T}$. Also it does not depend on potential difference.

Hence, on changing the potential difference, there is no change in mobility of electrons.

Q. 4. Define electrical conductivity of a conductor and give its SI unit. On what factors does it depend? **[*CBSE Delhi 2014, (East) 2016, CBSE 2023 (55/4/1)*]**

Ans. The conductivity of a material equals the reciprocal of the resistance of its wire of unit length and unit area of cross-section.

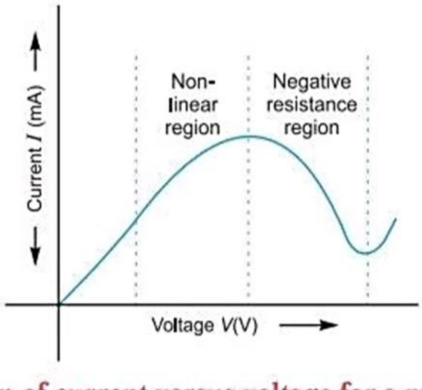
Its SI unit is

$$\left(\frac{1}{\text{ohm - metre}}\right) \text{ or ohm}^{-1}\text{ m}^{-1} \text{ or (mho m}^{-1}) \text{ or siemen m}^{-1}$$

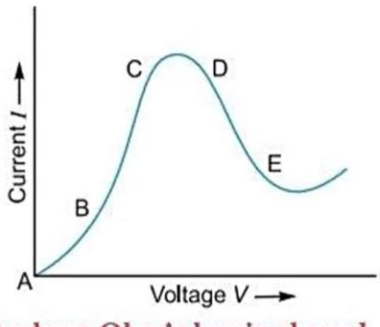
It depends upon number density, nature of material, relaxation time and temperature.

Q. 5. Plot a graph showing variation of current versus voltage for the material GaAs. **[*CBSE Delhi 2014*]**

Ans. The variation of electric current with applied voltage for GaAs is as shown.



Q. 6. Graph showing the variation of current versus voltage for a material GaAs is shown in the figure. Identify the region of

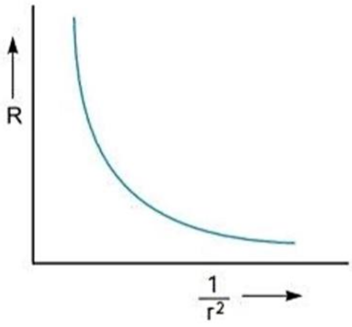


(*i*) negative resistance (*ii*) where Ohm's law is obeyed. **[*CBSE Delhi 2015*]**

Ans. (*i*) In region *DE*, material GaAs (Gallium Arsenide) offers negative resistance, because slope $\frac{\Delta V}{\Delta I} < 0$.

(*ii*) The region *BC* approximately passes through the origin, (or current also increases with the increase of voltage). Hence, it follows Ohm's law and in this region $\frac{\Delta V}{\Delta I} > 0$.

Q. 7. Plot a graph showing the variation of resistance of a conducting wire as a function of its radius, keeping the length of the wire and its temperature as constant. *[CBSE (F) 2013]*



Ans. Resistance of a conductor of length l, and radius r is given by

$$R = \rho\frac{l}{\pi r^2}; \qquad \text{thus} \qquad R \propto \frac{1}{r^2}$$

Q. 8. The emf of a cell is always greater than its terminal voltage. Why? Give reason. *[CBSE Delhi 2013]*

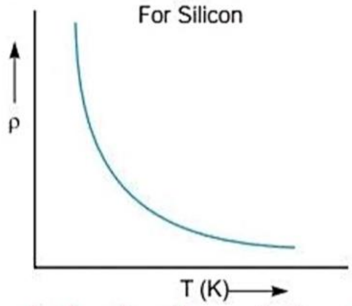
Ans. (*i*) In an open circuit, the emf of a cell and terminal voltage are same.

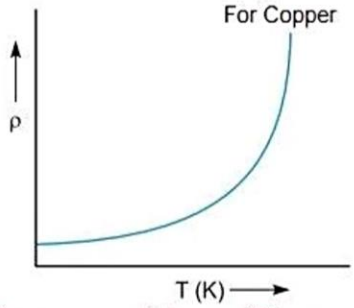
(*ii*) In closed circuit, a current is drawn from the source, so, $V = E - Ir$, it is true/valid, because each cell has some finite internal resistance.

Q. 9. Two materials Si and Cu, are cooled from 300 K to 60 K. What will be the effect on their resistivity? *[CBSE (F) 2013]*

Ans. In silicon, the resistivity increases.

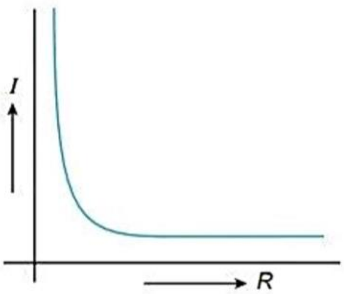
In copper, the resistivity decreases.





Q. 10. Plot a graph showing the variation of current '*I*' versus resistance '*R*', connected to a cell of emf *E* and internal resistance '*r*'.

Ans. $I = \dfrac{E}{r+R}$



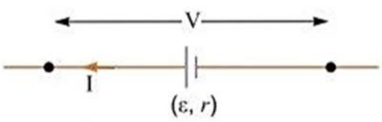
Q. 11. Give an example of a material each for which temperature coefficient of resistivity is (*i*) positive, (*ii*) negative. *[CBSE Sample Paper 2016]*

Ans. (*i*) Copper (Cu) (Temperature coefficient of resistivity (α) is positive for metals and alloys.)

(*ii*) Silicon (Si) (For semiconductors, α is negative)

Q. 12. A cell of emf 'ε' and internal resistance '*r*' draws a current '*I*'. Write the relation between terminal voltage '*V*' in terms of ε, *I* and *r*. *[CBSE Delhi 2013]*

Ans. The terminal voltage $V < \varepsilon$, so $V = \varepsilon - Ir$



Q. 13. Under what condition will the current in a wire be the same when connected in series and in parallel of *n* identical cells each having internal resistance *r* and external resistance *R* ? *[CBSE 2019 (55/4/1)]*

Ans. When internal resistance of cell r is equal to external resistance.

Let n identical cell of internal resistance r connected in series and parallel with external resistance R.

$$I_S = \frac{n\varepsilon}{R+nr} \qquad \text{and} \qquad I_P = \frac{\varepsilon}{R+\frac{r}{n}} = \frac{n\varepsilon}{Rn+r}$$

According to question,

$$I_S = I_P \Rightarrow \frac{n\varepsilon}{R + nr} = \frac{n\varepsilon}{Rn + r}$$

$$\Rightarrow R + nr = Rn + r \;\Rightarrow\; nr - r = Rn - R$$

$$\Rightarrow r\,(n-1) = R(n-1)$$

$$\therefore \qquad r = R$$

Q. 14. Two wires, one of copper and the other of manganin, have same resistance and equal thickness. Which wire is longer? Justify your answer. *[CBSE Guwahati 2015]*

Ans. Let l_1 and l_2 be lengths of copper and manganin wires having same resistance R and thickness *i.e.*, area of cross-section (A).

Resistance of copper wire, $R = \dfrac{\rho_1 l_1}{A}$

Resistance of manganin wire $R = \dfrac{\rho_2 l_2}{A}$

$\Rightarrow \quad \rho_1 l_1 = \rho_2 l_2$ (As ρl = constant)

Since $\rho_1 <<< \rho_2$ Then, $l_1 >>> l_2$

Hence, copper wire would be longer.

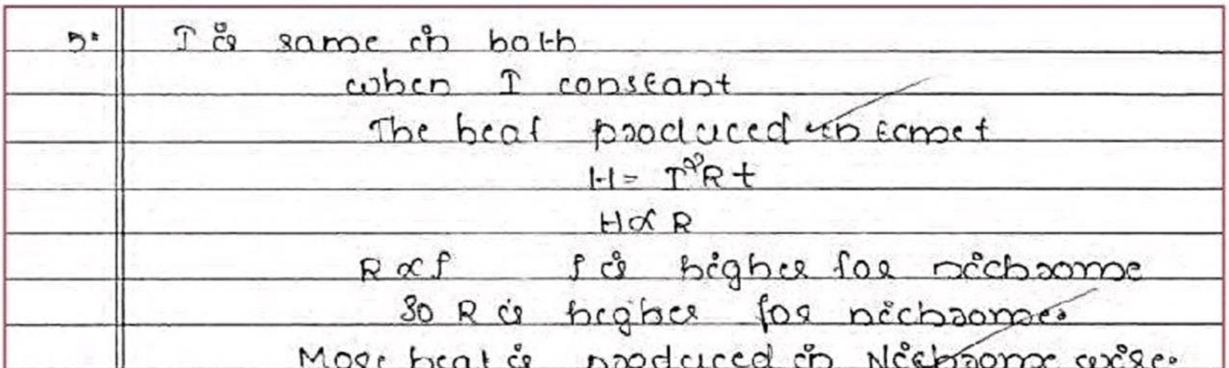
Q. 15. Two wires one of manganin and the other of copper have equal length and equal resistance. Which one of these wires will be thicker? *[CBSE (AI) 2012, (South) 2016] [HOTS]*

Ans. Resistance $R = \dfrac{\rho l}{A} = \dfrac{\rho l}{\pi r^2}$

Resistivity ρ of manganin is much greater than that of copper, therefore to keep same resistance for same length of wire, the manganin wire must be thicker.

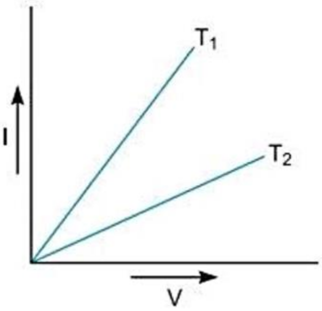
Q. 16. Nichrome and copper wires of same length and same radius are connected in series. Current I is passed through them. Which wire gets heated up more? Justify your answer. *[CBSE (AI) 2017]*

Ans.


Sol: I is same in both
when I constant
The heat produced in ~~ε...~~
H = I²Rt
H ∝ R
R ∝ ρ   ρ is higher for nichrome
So R is higher for nichrome
More heat is produced in Nichrome wire.

[Topper's Answer 2017]

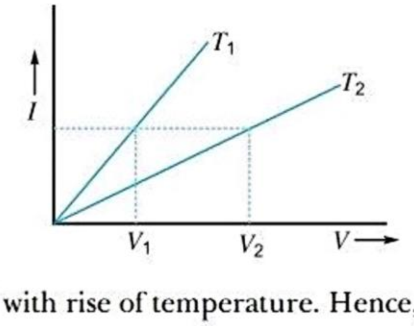
Q. 17. $I - V$ graph for a metallic wire at two different temperatures, T_1 and T_2 is as shown in the figure. Which of the two temperatures is lower and why? *[CBSE Allahabad 2015]*



Ans. If a constant current I flows through the conductor, resistance at temperature T_1 and T_2 is

$$R_1 = \frac{V_1}{I}$$

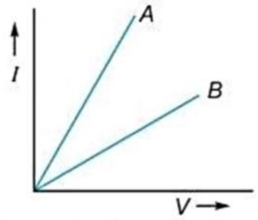
and $$R_2 = \frac{V_2}{I}$$



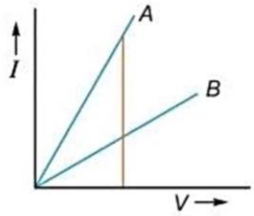
Since $V_2 > V_1 \;\Rightarrow\; R_2 > R_1$

The resistance of the wire increases with rise of temperature. Hence, T_1 is lower than T_2.

Q. 18. **Two metallic resistors are connected first in series and then in parallel across a dc supply. Plot of I –V graph is shown for the two cases. Which one represents a parallel combination of the resistors and why?** [*CBSE Bhubaneshwer 2015*]



Ans. Line A represents the parallel combination.



Reason: At a given potential difference V, current in the combination A is more than in the combination B.

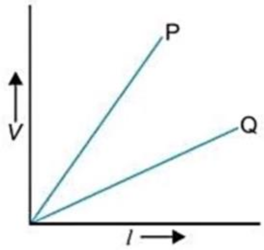
i.e., $I_A > I_B$

Since $R_A = \dfrac{V}{I_A}$ and $R_B = \dfrac{V}{I_B}$

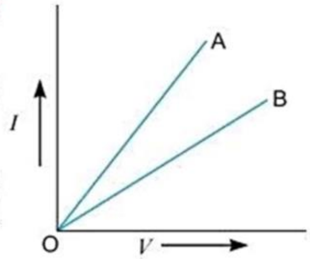
$\Rightarrow$ $R_A < R_B$

Q. 19. **The variation of potential difference V with length l in the case of two potentiometer P and Q is as shown. Which of these two will you prefer for comparing the emfs of two primary cells and why?** [*CBSE (East) 2016*] [*HOTS*]

Ans. For greater accuracy of potentiometer, the potential gradient (slope) $\dfrac{V}{l}$ must be as small as possible. In the graph given the slope $\dfrac{V}{l}$ is smaller for a potentiometer Q; hence we shall prefer potentiometer Q for comparing the emfs of two cells.



Q. 20. **I – V graph for two identical conductors of different materials A and B is shown in the figure. Which one of the two has higher resistivity?** [*CBSE (Chennai) 2015*] [*HOTS*]



Ans. The resistivity of material B is higher.

Reason: If the same amount of the current flows through them, then $V_B > V_A$, and from Ohm's law $R_B > R_A$. Hence the resistivity of the material B is higher.

Q. 21. **For household electrical wiring, one uses Cu wires or Al wires. What considerations are kept in mind?** [*NCERT Exemplar*]

Ans. Two considerations are required: (*i*) cost of metal, and (*ii*) good conductivity of metal. Cost factor inhibits silver. Cu and Al are the next best conductors.

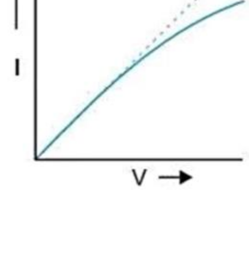
Q. 22. **Why are alloys used for making standard resistance coils?** [*NCERT Exemplar*]

Ans. Alloys have

(*i*) low value of temperature coefficient and the resistance of the alloy does not vary much with rise in temperature.

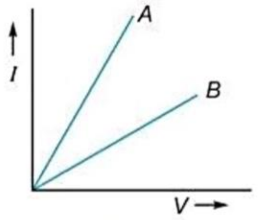
(*ii*) high resistivity, so even a smaller length of the material is sufficient to design high standard resistance.

Q. 23. **The I-V characteristics of a resistor are observed to deviate from a straight line for higher values of current as shown in the adjoining figure why?** [*HOTS*]

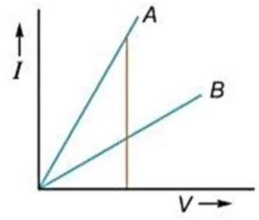


Ans. At higher value of current, sufficient heat is produced which raises the temperature of resistor and so causes increase in resistance.

Q. 18. **Two metallic resistors are connected first in series and then in parallel across a dc supply. Plot of I –V graph is shown for the two cases. Which one represents a parallel combination of the resistors and why?** **[*CBSE Bhubaneshwer 2015*]**



Ans. Line A represents the parallel combination.



Reason: At a given potential difference V, current in the combination A is more than in the combination B.

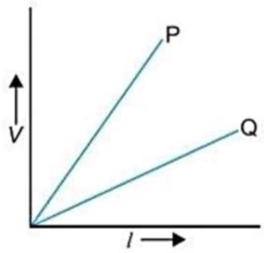
i.e., $I_A > I_B$

Since $R_A = \frac{V}{I_A}$ and $R_B = \frac{V}{I_B}$

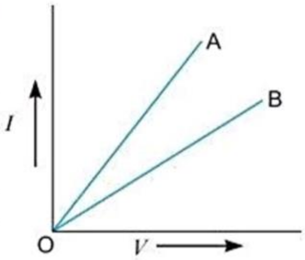
$\Rightarrow \quad R_A < R_B$

Q. 19. **The variation of potential difference V with length l in the case of two potentiometer P and Q is as shown. Which of these two will you prefer for comparing the emfs of two primary cells and why?** **[*CBSE (East) 2016*] [*HOTS*]**

Ans. For greater accuracy of potentiometer, the potential gradient (slope) $\frac{V}{l}$ must be as small as possible. In the graph given the slope $\frac{V}{l}$ is smaller for a potentiometer Q; hence we shall prefer potentiometer Q for comparing the emfs of two cells.



Q. 20. ***I – V*** **graph for two identical conductors of different materials A and B is shown in the figure. Which one of the two has higher resistivity?** **[*CBSE (Chennai) 2015*] [*HOTS*]**



Ans. The resistivity of material B is higher.

Reason: If the same amount of the current flows through them, then $V_B > V_A$, and from Ohm's law $R_B > R_A$. Hence the resistivity of the material B is higher.

Q. 21. **For household electrical wiring, one uses Cu wires or Al wires. What considerations are kept in mind?** **[*NCERT Exemplar*]**

Ans. Two considerations are required: (*i*) cost of metal, and (*ii*) good conductivity of metal. Cost factor inhibits silver. Cu and Al are the next best conductors.

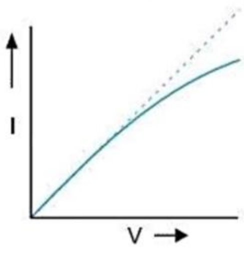
Q. 22. **Why are alloys used for making standard resistance coils?** **[*NCERT Exemplar*]**

Ans. Alloys have

(*i*) low value of temperature coefficient and the resistance of the alloy does not vary much with rise in temperature.

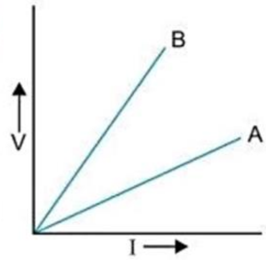
(*ii*) high resistivity, so even a smaller length of the material is sufficient to design high standard resistance.

Q. 23. **The *I-V* characteristics of a resistor are observed to deviate from a straight line for higher values of current as shown in the adjoining figure why?** **[*HOTS*]**



Ans. At higher value of current, sufficient heat is produced which raises the temperature of resistor and so causes increase in resistance.

Q. 24. *V-I* graphs for parallel and series combinations of two metallic resistors are shown in figure. Which graph represents parallel combination? Justify your answer. [*HOTS*]



Ans. Graph '*A*' represents parallel combination.

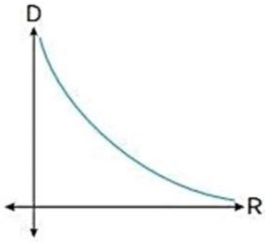
Reason: In series combination the effective resistance, $R = \frac{V}{I}$ is more than parallel combination. The slope of a line of *V-I* graph represents resistance. The slope of *B* is more than *A*. Therefore *B* represents series combination and A represents parallel combination.

Q. 25. Draw a graph to show a variation of resistance of a metal wire as a function of its diameter keeping its length and material constant. [*CBSE Sample Paper 2017*]

Ans. $R = \rho \frac{l}{A} \quad \Rightarrow \quad \rho \frac{l}{\pi r^2} = \rho \frac{4l}{\pi D^2}$

i.e. $R \propto \frac{1}{D^2}$

Hence, graph of resistance (*R*) versus diameter (*D*) is of the following form.



Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. Define the terms (*i*) drift velocity, (*ii*) relaxation time. [*CBSE Delhi 2011, (AI) 2013*]

Ans. (*i*) **Drift Velocity:** The average velocity acquired by the free electrons of a conductor in a direction opposite to the externally applied electric field is called drift velocity. The drift velocity will remain the same with lattice ions/atoms.

(*ii*) **Relaxation Time:** The average time of free travel of free electrons between two successive collisions is called the **relaxation time**.

Q. 2. Define the term 'mobility' of charge carriers in a current carrying conductor. Obtain the relation for mobility in terms of relaxation time. [*CBSE 2020 (55/2/1)*]

Ans. (21) The drift velocity attained by the charge carries in unit electric field is defined as 'mobility' of charge carries in a current-carrying conductor.

$\therefore$ mobility $(\mu) = \frac{v_d}{E}$

We know, drift velocity, $v_d = a\tau$, where τ is relaxation time, and a is acceleration of the charge carrier.

Now, in presence of electric field E, acceleration 'a' of a charged particle of charge 'e' $= \frac{eE}{m}$

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

$\Rightarrow \frac{v_d}{E} = \frac{e\tau}{m} \Rightarrow \boxed{\mu = \frac{e\tau}{m}}$

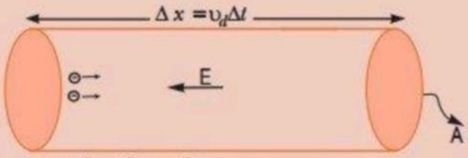
$\therefore$ μ is charge times relaxation time divided by mass of the particle m.

[*Topper's Answer 2020*]

Q. 3. Define the term 'drift velocity' of electrons in a current carrying conductor. Obtain the relationship between the current density and the drift velocity of electrons. [*CBSE 2020 (55/2/1)*]

Ans. The average speed with which electrons move when an electric field or potential difference is applied is called drift velocity. **1**

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



The amount of charge crossing the area A in time Δt **½**

$$I\Delta t = ne\, A\left|\vec{v}_d\right|\Delta t$$

Hence current density **½**

$$j = \frac{I}{A} = ne\, v_d$$

[*CBSE Marking Scheme 2020 (55/2/1)*]

Q. 4. Differentiate between the random velocity and the drift velocity of electrons in an electrical conductor. Give their order of magnitudes. [*CBSE 2020 (55/3/1)*]

Ans. **1**

	Random Velocity (v)	Drift Velocity (v_d)
1.	The velocity acquired by the free electrons in the absence of electric field.	The average velocity acquired by the free electrons in the presence of electric field.
2.	The average ramdom velocity is zero.	The average drift velocity is not zero.
3.	Has quite a large value.	Has a very small value.

Order of magnitude of random velocity in 10^2 m/s. **½ + ½**

Order of magnitude of drift velocity is 10^{-3} m/s. [*CBSE Marking Scheme 2020 (55/3/1)*]

Q. 5. A battery of emf 12 V and internal resistance 4 Ω is connected to an external resistance *R*. If the current in the resistance is 0.5 A, calculate the value of (*a*) *R*, and (*b*) the terminal voltage of the battery. [*CBSE 2020 (55/3/2)*]

Ans. Current, $I = \frac{E}{R+r}$

$\Rightarrow \quad E = I(R + r)$

$\Rightarrow \quad 12 = 0.5\,(R + 4)$

$\therefore \quad R = 24 - 4 = 20\ \Omega$

Terminal voltage across the battery,

$$V_T = E - Ir = 12 - 0.5 \times 4 = \mathbf{10\ V}$$

Q. 6. Write two differences between the emf and terminal potential difference of a cell. What is the most important precaution that one should take while drawing current from a cell? [*CBSE 2023 (55/4/1)*]

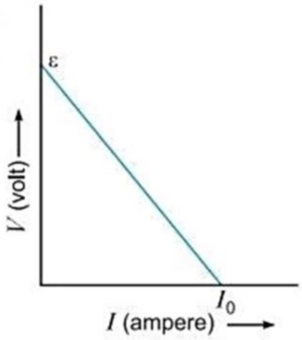
Ans.

EMF	Terminal Potential Difference (T.P.D)
(*i*) EMF is the maximum potential difference that a cell is able to produce when there is no current flow across it.	(*i*) Terminal voltage is the potential difference across of the terminals when the circuit is switched on.
(*ii*) EMF is measured using a potentiometer.	(*ii*) It is measured using voltmeter.
(*iii*) The value of EMF is always greater than *T.P.D* due to open circuit.	(*iii*) The value of *T.P.D* is always lower than that of EMF due to the potential drop.

Precaution: (1) Some external resistance should be connected to cell in series.

(2) Short circuiting should be avoided.

Q. 7. Plot a graph showing variation of voltage verses the current drawn from the cell. How can one get information from this plot about the emf of the cell and its internal resistance? **[*CBSE (F) 2016*]**



Ans. $V = \varepsilon - Ir \Rightarrow r = \dfrac{\varepsilon - V}{I}$

At $I = 0, V = \varepsilon$

When $V = 0,\quad I = I_0, r = \dfrac{\varepsilon}{I_0}$

The intercept on *y*-axis gives the emf of the cell. The slope of graph gives the internal resistance.

Q. 8. 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 Delhi 2016*]**

Ans. Given, $E_1 = 1.5\text{ V},\quad r_1 = 0.2\,\Omega$

$E_2 = 2.0\text{ V},\quad r_2 = 0.3\,\Omega$

Emf of equivalent cell,

$$E = \frac{\frac{E_1}{r_1} + \frac{E_2}{r_2}}{\frac{1}{r_1} + \frac{1}{r_2}} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2} = \left(\frac{1.5 \times 0.3 + 2 \times 0.2}{0.2 + 0.3}\right) = \frac{0.45 + 0.40}{0.5}\text{V} = \mathbf{1.7\ V}$$

Internal resistance of equivalent cell,

$$\frac{1}{r} = \frac{1}{r_1} + \frac{1}{r_2} \Rightarrow r = \frac{r_1 r_2}{r_1 + r_2} = \left(\frac{0.2 \times 0.3}{0.2 + 0.3}\right)\Omega = \frac{0.06}{0.5}\Omega = \mathbf{0.12\,\Omega}$$

Q. 9. When 5 V potential difference is applied across a wire of length 0.1 m, the drift speed of electrons is 2.5×10^{-4} m/s. If the electron density in the wire is $8 \times 10^{28}\ \text{m}^{-3}$, calculate the resistivity of the material of wire. **[*CBSE (North) 2016*]**

Ans. We know $I = neAv_d,\ I = \dfrac{V}{R}$ and $R = \rho\dfrac{l}{A}$

So $\quad \dfrac{V}{R} = neAv_d$

$$\frac{V}{nev_d l} = \frac{RA}{l} \Rightarrow \rho = \frac{V}{nev_d l}$$

$$\rho = \frac{5}{8 \times 10^{28} \times 1.6 \times 10^{-19} \times 2.5 \times 10^{-4} \times 0.1}\Omega\text{m} = 1.56 \times 10^{-5}\,\Omega\text{m}$$

$$\approx \mathbf{1.6 \times 10^{-5}\,\Omega m}$$

Q. 10. Two conducting wires *X* and *Y* of same diameter but different materials are joined in series across a battery. If the number density of electrons in *X* is twice that in *Y*, find the ratio of drift velocity of electrons in the two wires. **[*CBSE (AI) 2011*]**

Ans. In series current is same,

So, $\quad I_X = I_Y = I = neAv_d$

For same diameter, cross-sectional area is same

$A_X = A_Y = A$

$\therefore \quad I_X = I_Y \Rightarrow n_x eAv_x = n_y eAv_y$

Given $\quad n_x = 2n_y \Rightarrow \dfrac{v_x}{v_y} = \dfrac{n_y}{n_x} = \dfrac{n_y}{2n_y} = \mathbf{\dfrac{1}{2}}$

Q. 11. 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 *[CBSE Ajmer 2015]*

(i) V is halved? **(ii) l is doubled?**

(iii) D is halved?

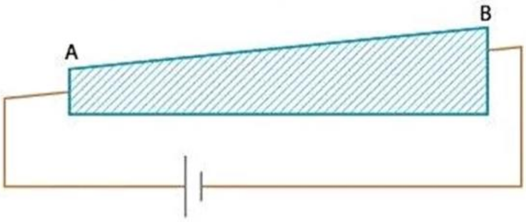
Ans. Drift velocity, $v_d = \frac{I}{neA} = \frac{V/R}{neA} = \frac{V}{neA\left(\frac{\rho l}{A}\right)} = \frac{V}{ne\rho\, l}$

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

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

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

Q. 12. A steady current flows through a wire AB, as shown in the figure. What happens to the electric field and the drift velocity along the wire? Justify your answer. *[CBSE 2023 (55/4/1)]*



Ans. According to Ohm's Law, $J = \sigma E$

So, $J \propto E \Rightarrow E \propto \frac{1}{A}$

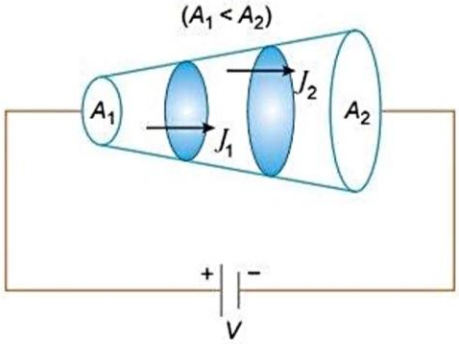
Along the wire if A increases then E will decreases.

Drift velocity, $v_d = \mu E$

(Here, μ = constant)

$v_d \propto E \Rightarrow v_d \propto \frac{1}{A}$

Similarly, if A increases v_d will decreases.



Q. 13. A wire of length L_0 has a resistance R_0. It is gradually stretched till its length becomes $2\,L_0$.

(a) Plot a graph showing variation of its resistance R with its length L during stretching.

(b) What will be its resistance when its length becomes $2L_0$? *[CBSE 2020 (55/4/1)]*

Ans. (a) Intially, $R_0 = \frac{\rho L_0}{A_0}$

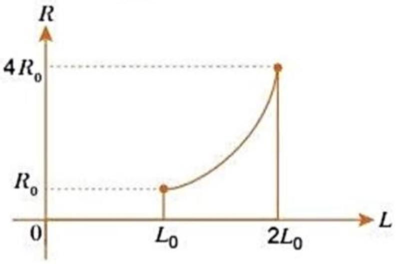
On stretching, the total volume is constant

$A_0 L_0 = AL$ [Where A and L are area and length after stretching]

$$A = \frac{L_0 A_0}{L}$$

$$\frac{R}{R_0} = \frac{\rho L}{A}\frac{A_0}{\rho L_0} = \frac{L}{\frac{L_0 A_0}{L}}\frac{A_0}{L_0} = \frac{L^2 A_0}{L_0^2 A_0} = \frac{L^2}{L_0^2}$$

$$R = R_0\left(\frac{L}{L_0}\right)^2 \Rightarrow R \propto L^2$$

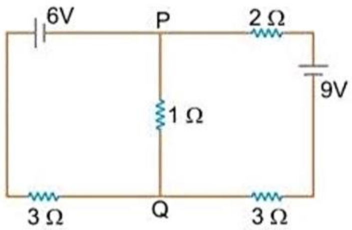


(b) When $L = 2L_0$

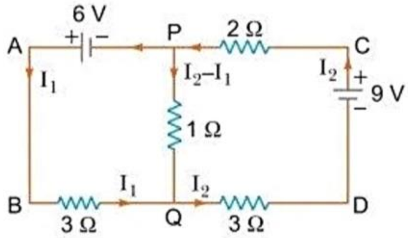
$R = 4\,R_0$

Q. 14. Find the magnitude and direction of current in 1Ω resistor in the given circuit.

[*CBSE (South) 2016*]



Ans. For the mesh *APQBA*



$$-6-1(I_2-I_1)+3I_1=0$$

or $$-I_2+4I_1=6 \qquad ...(i)$$

For the mesh *PCDQP*

$$2I_2-9+3I_2+1(I_2-I_1)=0$$

or $$6I_2-I_1=9 \qquad ...(ii)$$

Solving (*i*) and (*ii*), we get

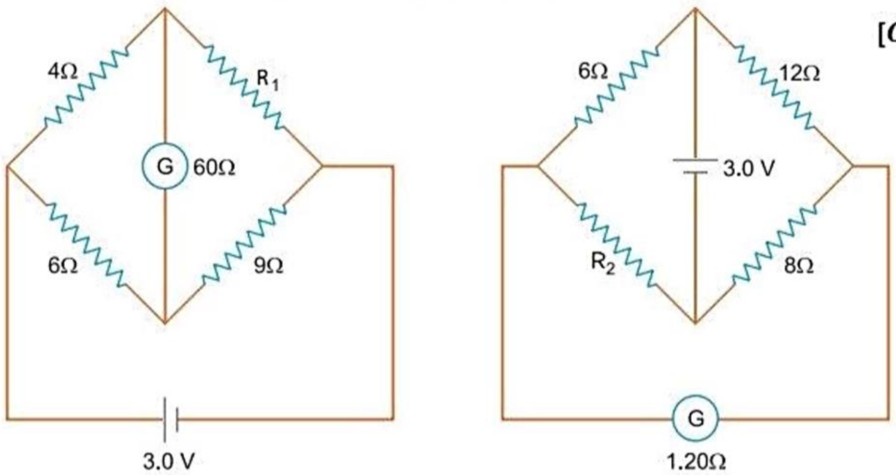
$$I_1=\frac{45}{23}\text{A} \quad \text{and} \quad I_2=\frac{42}{23}\text{A}$$

∴ Current through the 1 Ω resistor $=(I_2-I_1)=\mathbf{\frac{-3}{23}A}$

Hence the direction of current in 1 Ω resistor from *Q* to *P* in the circuit.

Q. 15. Figure shows two circuits each having a galvanometer and a battery of 3 V. When the galvanometers in each arrangement do not show any deflection, obtain the ratio $\frac{R_1}{R_2}$.

[*CBSE (AI) 2013*]



Ans. For balanced Wheatstone bridge, no current flows through the galvanometer.

$$\frac{4}{R_1}=\frac{6}{9}$$

$$\Rightarrow \quad R_1=\frac{4\times 9}{6}=6\ \Omega$$

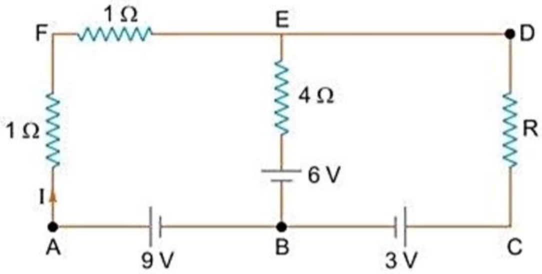
For another circuit,

$$\frac{6}{12}=\frac{R_2}{8}\Rightarrow R_2=\frac{6\times 8}{12}=4\ \Omega$$

$$\therefore \text{ Ratio, } \frac{R_1}{R_2}=\frac{6}{4}=\mathbf{\frac{3}{2}}$$

Q. 16. Using Kirchoff'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 Delhi 2012] [HOTS]



Ans. Applying Kirchhoff's loop rule for loop $ABEFA$,

$$-9 + 6 + 4 \times 0 + 2I = 0$$

$$I = 1.5 \text{ A} \quad \text{...}(i)$$

For loop $BCDEB$

$$3 + IR + 4 \times 0 - 6 = 0$$

$\therefore \quad IR = 3$

Putting the value of I from (i) we have

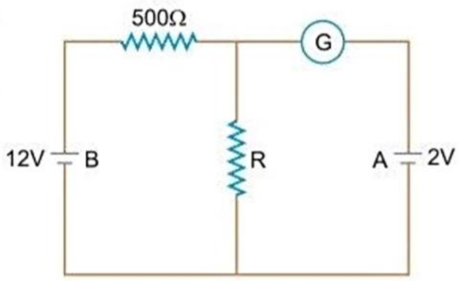
$$\frac{3}{2} \times R = 3 \Rightarrow R = 2\Omega$$

Potential difference between A and D through path $ABCD$,

$$9 - 3 - IR = V_{AD}$$

or $\quad 9 - 3 - \frac{3}{2} \times 2 = V_{AD} \quad \Rightarrow \quad V_{AD} = \mathbf{3\ V}$

Q. 17. In the circuit shown in the figure, the galvanometer 'G' gives zero deflection. If the batteries A and B have negligible internal resistance, find the value of the resistor R. **[CBSE (F) 2013] [HOTS]**



Ans. If galvanometer G gives zero deflection, than current of source of 12 V flows through R, and voltage across R becomes 2 V.

Current in the circuit $I = \frac{\varepsilon}{R_1 + R_2} = \frac{12}{500 + R}$

and $\quad V = IR = 2$

$$\left(\frac{12.0}{500 + R}\right) R = 2$$

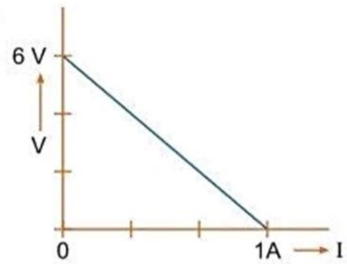
$\Rightarrow \quad 12R = 1000 + 2R$

$\Rightarrow \quad 10R = 1000$

$\therefore \quad R = \mathbf{100\ \Omega}$

Q. 18. The plot of the variation of potential difference across a combination of three identical cells in series, versus current is shown alongside. What is the emf and internal resistance of each cell?

[CBSE (Central) 2016] [HOTS]



Ans. We know that for a circuit

$$V = E_{eq} - Ir_{eq} \quad \text{...}(i)$$

From graph, when $I = 0$ A, then $V = 6$ V and when $I = 1$ A then $V = 0$ V

Putting, $V = 6$ V and $I = 0$ A in eq. (i)

$$6 = E_{eq} - 0.\, r_{eq} \quad \Rightarrow \quad E_{eq} = 6 \text{ V}$$

$$E_{eq} = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 \Rightarrow \quad \varepsilon_1 = \varepsilon_2 = \varepsilon_3 = \varepsilon = \frac{E_{eq}}{3} = 2 \text{ V}$$

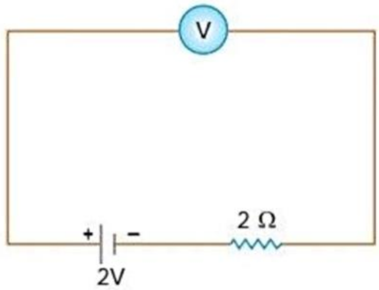
And, when $I = 1$ A, and $V = 0$ V

$$0 = 6 - 1.\, r_{eq} \quad \Rightarrow \quad r_{eq} = 6\ \Omega$$

$$r_{eq} = r_1 + r_2 + r_3 \Rightarrow \quad r_1 = r_2 = r_3 = r = \frac{r_{eq}}{3} = \mathbf{2\ \Omega}$$

Q. 19. A voltmeter of resistance 998 Ω is connected across a cell of emf 2 V and internal resistance 2 Ω. Find the potential difference across the voltmeter and also across the terminals of the cell. Estimate the percentage error in the reading of the voltmeter. [*CBSE 2019 (55/5/1)*]

Ans. We have, $V = E - Ir$



$\Rightarrow \quad 998 \times I = 2 - 2I$

$\Rightarrow \quad 1000 \times I = 2$

$\therefore \quad I = \dfrac{2}{1000} = 0.002$ A

Now, $V = 0.002 \times 998$

$V = 1.996$ V

Then $\Delta V = 2 - 1.996$

$= 0.004$ V

$\therefore \quad \% \text{ error} = \dfrac{0.004}{2} \times 100 = \mathbf{0.2\%}$

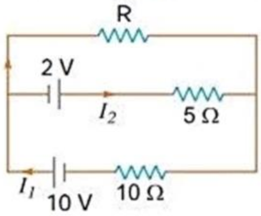
Q. 20. Two wires *A* and *B* of the same material and having same length, have their cross sectional areas in the ratio 1 : 6. What would be the ratio of heat produced in these wires when same voltage is applied across each? [*CBSE Sample Paper 2017*]

Ans. As given, $A_A : A_B = 1 : 6$

$H = V^2t/R \quad \text{and} \quad R = \dfrac{\rho l}{A}$

$$H_A = \frac{V^2 t}{\rho l/A_A}; \quad H_B = \frac{V^2 t}{\rho l/A_B} \Rightarrow \frac{H_A}{H_B} = \frac{V^2 t \times A_A}{\rho l} \times \frac{\rho l}{V^2 t A_B} \Rightarrow \frac{H_A}{H_B} = \frac{A_A}{A_B} = \mathbf{1:6}$$

Q. 21. Two cells of emf 10 V and 2 V and internal resistance 10 Ω and 5 Ω respectively, are connected in parallel as shown. Find the effective voltage across *R*. [*CBSE Sample Paper 2016*]

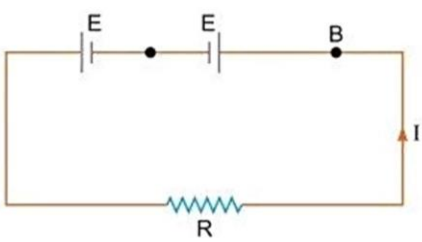


Ans. The effective voltage across *R* is given by $\varepsilon_{eq} = \dfrac{\left(\dfrac{\varepsilon_1}{r_1} + \dfrac{\varepsilon_2}{r_2}\right)}{\left(\dfrac{1}{r_1} + \dfrac{1}{r_2}\right)} = \dfrac{\left(\dfrac{10}{10} - \dfrac{2}{5}\right)}{\left(\dfrac{1}{10} + \dfrac{1}{5}\right)}$

$\therefore \quad \varepsilon_{eq} = \mathbf{2\ V}$

Q. 22. Two cells of same emf *E* but internal resistance r_1 and r_2 are connected in series to an external resistor *R* (Fig.). What should be the value of *R* so that the potential difference across the terminals of the first cell becomes zero. [*NCERT Exemplar*] [*HOTS*]

Ans. From the circuit shown, $I = \dfrac{E + E}{R + r_1 + r_2}$



$V_1 = E - Ir_1 = E - \dfrac{2E}{r_1 + r_2 + R} r_1 = 0$

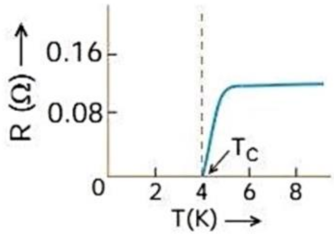
or $\quad E = \dfrac{2Er_1}{r_1 + r_2 + R}$

$\Rightarrow \quad r_1 + r_2 + R = 2r_1 \Rightarrow R = \mathbf{r_1 - r_2}$

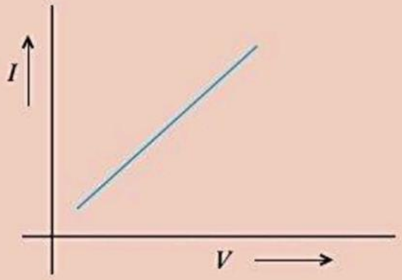
Q. 23. (*a*) **Draw a graph showing the variation of current versus voltage voltage in an electrolyte when an external resistance is also connected.**

(*b*) **The graph between resistance (R) and temperature (T) for Hg is shown in the figure. Explain the behaviour of Hg near 4K.**

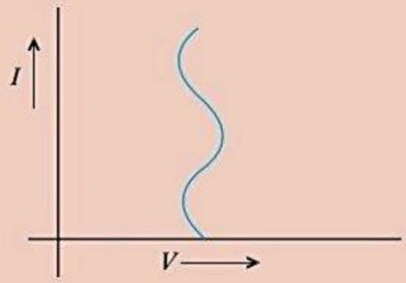
[CBSE 2019 (55/4/1)]



Ans. (*a*) Note : Award this 1 mark even if the student draw the following or some other non linear graph **1**



OR



(*b*) At a temperature of 4 K, the resistance of Hg becomes zero. **1**

Note - Award this 1 mark if the student writes that Hg becomes a super conductor at temperature of 4 K

[CBSE Marking Scheme 2019 (55/4/1)]

Q. 24. **At room temperature (27.0°C), the resistance of a heating element is 100 Ω. At what temperature does the resistance of the element change to 117 Ω? Given that the temperature coefficient of the material of the resistor is 1.70×10^{-4} °C^{-1}.** *[NCERT]*

Ans. Given, $R_{27} = 100\ \Omega$, $R_t = 117\ \Omega$, $t = ?$, $\alpha = 1.70 \times 10^{-4}/°C$

Temperature Coefficient, $\alpha = \dfrac{R_t - R_{27}}{R_{27}(t-27)}$, temperature t is unknown

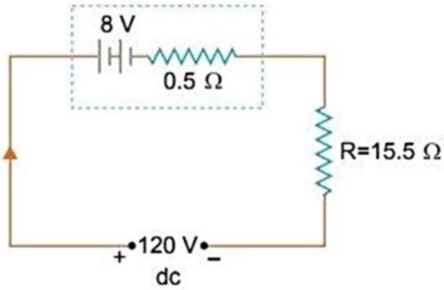
$$\Rightarrow \quad t - 27 = \frac{R_t - R_{27}}{R_{27}.\alpha} = \frac{117-100}{100 \times 1.70 \times 10^{-4}} = 1000$$

$$\Rightarrow \quad t = 1000 + 27 = \mathbf{1027°C}$$

Q. 25. **A storage battery of emf 8.0 V and internal resistance 0.5 Ω is being charged by a 120 V dc supply using a series resistor of 15.5 Ω. What is the terminal voltage of the battery during charging? What is the purpose of having a series resistor in the charging circuit?** *[NCERT]*

Ans. When battery is being charged by a 120 V d.c. supply, the current in battery is in opposite direction than normal connections of battery of supplying current. So the potential difference across battery

$$E = V + IR$$



Given $E = 8$ V, $r = 0.5\ \Omega$, $R = 15.5\ \Omega$

Current in circuit, $I = \dfrac{120-8}{15.5+0.5} = \dfrac{112}{16} = 7$ A

$\therefore \quad V = 8 + 7 \times 0.5 = \mathbf{11.5\ V}$

Series resistance limits the current drawn from external dc source. In the absence of series resistance the current may exceed the safe-value permitted by storage battery.

Short Answer Questions

Each of the following questions are of 3 marks.

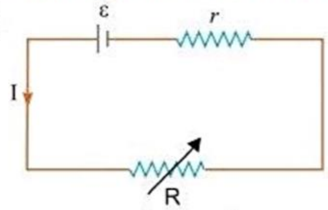
Q. 1. A variable resistor R is connected across a cell of emf E and internal resistance r.

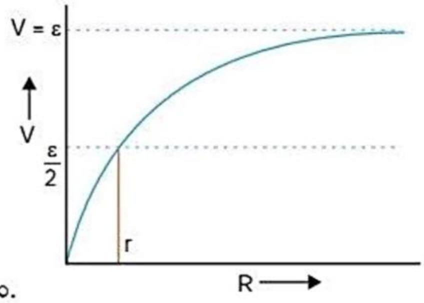
(a) Draw the circuit diagram.

(b) Plot the graph showing variation of potential drop across R as function of R.

(c) At what value of R current in circuit will be maximum? [*CBSE Sample Paper 2021*]

Ans. (a)





(b) $V = IR = \left(\dfrac{\varepsilon}{R+r}\right)R = \dfrac{\varepsilon}{(R+r)/R} = \dfrac{\varepsilon}{1+\dfrac{r}{R}}$

(c) Maximum current is drawn when $R = 0$, $I = \dfrac{V}{R} = \dfrac{V}{0} = \infty$.

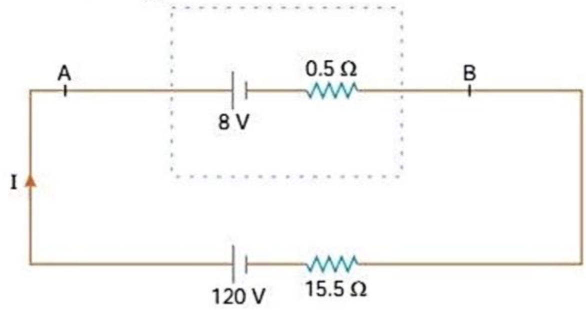
Q. 2. A storage battery of emf 8 V and internal resistance 0.5 ohm is being charged by d.c. supply of 120 V using a resistor of 15.5 ohm.

(a) Draw the circuit diagram.

(b) Calculate the potential difference across the battery.

(c) What is the purpose of having series resistance in this circuit? [*CBSE Sample Paper 2021*]

Ans. (a) Circuit diagram:



(b) $I_{net} = \dfrac{V_{net}}{R+r} = \dfrac{120-8}{15.5+0.5} = \dfrac{112}{16} = 7\text{A}$

Applying Kirchoff's rule,

$$V_B + 0.5(7) + 8 = V_A$$

$$3.5 + 8 = 11.5 = V_A - V_B$$

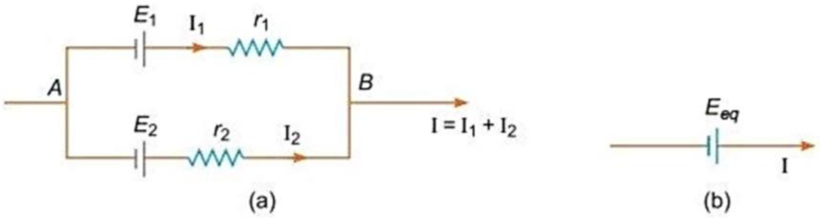
∴ Potential difference, $V_A - V_B$ = **11.5 V**

(c) Series resistance limits the current through the source.

Q. 3. (a) Two cells of emf E_1 and E_2 have their internal resistances r_1 and r_2, respectively. Deduce an expression for the equivalent emf and internal resistance of their parallel combination when connected across an external resistance R. Assume that the two cells are supporting each other.

(b) In case the two cells are identical, each of emf $E = 5$ V and internal resistance $r = 2\ \Omega$, calculate the voltage across the external resistance $R = 10\ \Omega$. [*CBSE 2020 (55/1/1)*]

Ans. (*a*)



Let I_1 and I_2 be the currents leaving the positive, terminals of the cells, and at the point B

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

Let V be the potential difference between points A and B of the combination of the cells, so

$$V = E_1 - I_1r_1 \quad ...(ii)$$

and $$V = E_2 - I_2r_2 \quad ...(iii)$$

From equation (*i*), (*ii*) and (*iii*), we get

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

$$= \left(\frac{E_1}{r_1} + \frac{E_2}{r_2}\right) - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right) \quad ...(iv)$$

Fig. (*b*) shows the equivalent cell, so for the same potential difference

$$V = E_{eq} - Ir_{eq}$$

or $$I = \frac{E_{eq}}{r_{eq}} - \frac{V}{r_{eq}} \quad ...(v)$$

On comparing Eq. (*iv*) and (*v*), we get

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

and $$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} \Rightarrow r_{eq} = \frac{r_1r_2}{r_1 + r_2}$$

On further solving, we have

$$E_{eq}\left(\frac{1}{r_1} + \frac{1}{r_2}\right) = \frac{E_1}{r_1} + \frac{E_2}{r_2} \Rightarrow E_{eq} = \frac{E_1r_2 + E_2r_1}{r_1 + r_2}$$

(*b*) $E_{eff} = \frac{5\times2+5\times2}{2+2} = 5\text{ V}$ and $r_{eff} = \frac{2\times2}{2+2} = 1\,\Omega$

Now, $I = \frac{E_{eff}}{R + r_{eff}} = \frac{5}{10+1} = \frac{5}{11}\text{A}$

$\therefore$ Voltage across R, $V = IR = \frac{5}{11}\times10 = \frac{50}{11}\text{V} = \mathbf{4.54\ V}$

Q. 4. 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*.

Ans. The acceleration, $\vec{a} = -\frac{e}{m}\vec{E}$

The average drift velocity is given by, $v_d = -\frac{eE}{m}\tau$

(τ = average time between collisions or relaxation time)

If n is the number of free electrons per unit volume, the current I is given by

$$I = neA|v_d|$$

Ans. (*a*)

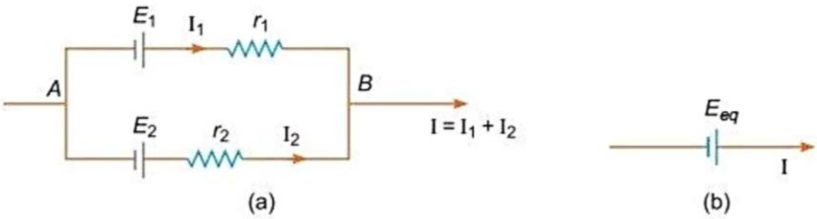


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Fig. (*b*) shows the equivalent cell, so for the same potential difference

$$V = E_{eq} - Ir_{eq}$$

or

$$I = \frac{E_{eq}}{r_{eq}} - \frac{V}{r_{eq}} \qquad ...(v)$$

On comparing Eq. (*iv*) and (*v*), we get

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and

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

On further solving, we have

$$E_{eq}\left(\frac{1}{r_1} + \frac{1}{r_2}\right) = \frac{E_1}{r_1} + \frac{E_2}{r_2} \quad \Rightarrow \quad E_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$$

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The average drift velocity is given by, $v_d = -\dfrac{eE}{m}\tau$

(τ = average time between collisions or relaxation time)

If n is the number of free electrons per unit volume, the current I is given by

$$I = neA|v_d|$$

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$$= \frac{e^2 A}{m} \tau n |E|$$

But $I = |j| A$ (where j= current density)

Therefore, we get

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

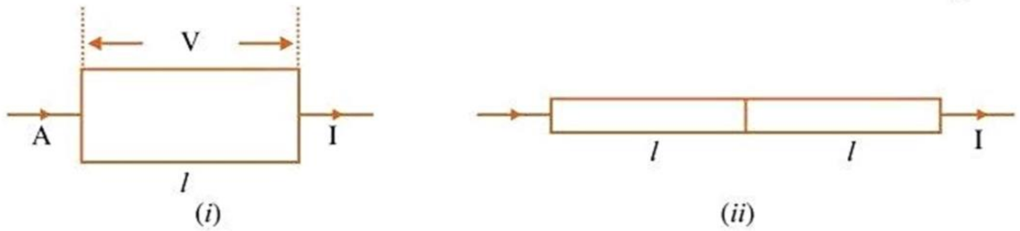
The term $\frac{ne^2}{m}\tau$ is conductivity.

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

$$\Rightarrow \qquad J = \sigma E$$

Q. 5. 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 $2l$ so that the current in the rod is still I?

[*CBSE (F) 2016*]



Ans. Let resistance of metal rod having cross sectional area A and length l be R_1

$$\Rightarrow \qquad R_1 = \rho \frac{l}{A}$$

Also, resistance of metal rod having cross sectional area $\frac{A}{2}$ and length $2l$

$$R_2 = \rho \frac{2l}{\frac{A}{2}} \qquad \left[\because R = \rho \frac{l}{A}\right]$$

$$= 4 R_1$$

Let V' be potential difference maintained across rod. When the rod is cut parallel and rejoined by length, the length of the conductor becomes $2l$ and area decreases by $\frac{A}{2}$.

For maintaining same current,

$$I = \frac{V}{R_1} = \frac{V'}{R_2}$$

$$I = \frac{V}{R_1} = \frac{V'}{4R_1} \Rightarrow V' = 4V$$

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

Q. 6. Two metallic wires, P_1 and P_2 of the same material and same length but different cross-sectional areas, A_1 and A_2 are joined together and connected to a source of emf. Find the ratio of the drift velocities of free electrons in the two wires when they are connected (*i*) in series, and (*ii*) in parallel. **[*CBSE (F) 2017*]**

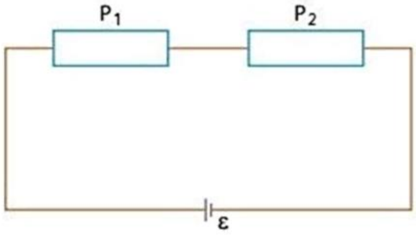
Ans. We know that,

$$I = neAv_d \qquad \Rightarrow \qquad v_d = \frac{I}{neA}$$

Let R_1 and R_2 be resistances of P_1 & P_2 and A_1 & A_2 are their cross sectional areas respectively.

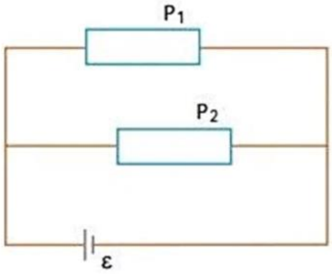
$\therefore \quad R_1 = \rho\frac{l}{A_1}$ and $R_2 = \rho\frac{l}{A_2}$

(*i*) When connected in series,



$$\therefore \quad \frac{v_{d_1}}{v_{d_2}} = \frac{\dfrac{\varepsilon}{\left(\dfrac{\rho l}{A_1}+\dfrac{\rho l}{A_2}\right)neA_1}}{\dfrac{\varepsilon}{\left(\dfrac{\rho l}{A_1}+\dfrac{\rho l}{A_2}\right)neA_2}} = \frac{A_2}{A_1}$$

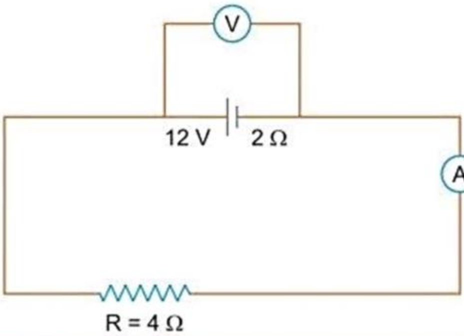
(*ii*) When, connected in parallel,



$$\therefore \frac{v_{d_1}}{v_{d_2}} = \frac{\dfrac{\varepsilon}{\dfrac{\rho l}{A_1}}\cdot\dfrac{1}{neA_1}}{\dfrac{\varepsilon}{\dfrac{\rho l}{A_2}}\cdot\dfrac{1}{neA_2}} = 1$$

Q. 7. (*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 an internal resistance of 2 Ω. Calculate the voltmeter and ammeter readings.** *[CBSE (AI) 2017]*



Ans.

15 (a) Heat per second is $\frac{V^2}{R}$

Initially $H_1 = \frac{V_1^2}{R}$ The R is fixed.

Then $H_2 = 9H_1 = \frac{9V_1^2}{R} = \frac{3^2 V_1^2}{R} = \frac{(3V_1)^2}{R}$.

The potential difference is increased by a factor of 3.

(b) $V = \mathcal{E} - Ir$

Total current = $\frac{\text{Total emf}}{\text{Total resistance}}$

$= \frac{12}{2+4}$

$= \frac{12}{6} = 2A$

The ammeter reading is 2A

The voltmeter reading is $V = \mathcal{E} - Ir$

$= 12 - 2\times 2$

$= 12 - 4$

$= 8V$

[Topper's Answer 2017]

$$\Rightarrow \quad \frac{15}{2}I = 10$$

$$\therefore \quad I = \frac{2\times10}{15} = \frac{20}{15}\text{A} = \frac{4}{3}\text{A} \qquad ½$$

$$\text{Now,} \quad R_{eq} = \frac{V}{3I} = \frac{10\times15}{3\times20} = 2.5\,\Omega \qquad ½$$

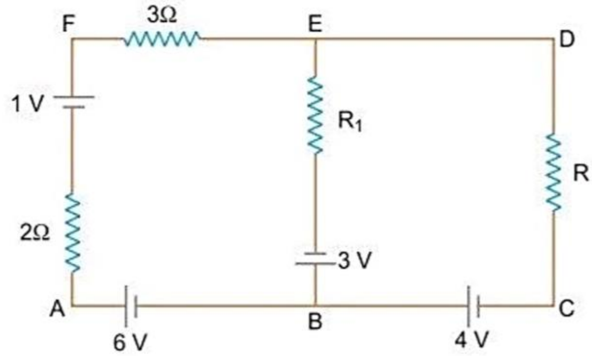
$$\text{Current} = I_{AB}\,(= I_{AA'} = I_{AD} = I_{D'C'} = I_{B'C'} = I_{CC'}) = \frac{4}{3}\text{A} \qquad ½$$

$$I_{DD'}\,(= I_{A'B'} = I_{A'D'} = I_{DC} = I_{BC} = I_{BB'}) = \frac{2}{3}\text{A} \qquad ½$$

[CBSE Marking Scheme 2019 (55/3/1)]

Q. 11. 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 Allahabad 2015]



Ans. According to Kirchhoff's junction rule at *E* or *B*

$I_3 = I_2 + I_1$

Since $I_2 = 0$ in the arm *BE* as given in the question

$\Rightarrow \quad I_3 = I_1$

Using loop rule in the loop *AFEBA*

$$-2I_3 + 1 - 3I_3 - I_2 R_1 + 3 + 6 = 0$$

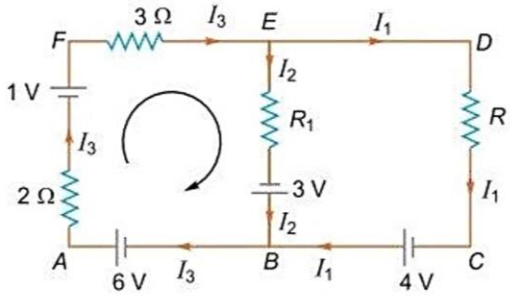
$$\Rightarrow \quad 2I_3 + 3I_3 + I_2R_1 = 10$$

Since $I_2 = 0$, so

$$5I_3 = 10$$

$$\Rightarrow \quad I_3 = 2\text{ A}$$

$$\therefore \quad I_3 = I_1 = 2\text{A}$$



The potential difference between *A* and *D*, along the branch *AFED* of the closed circuit.

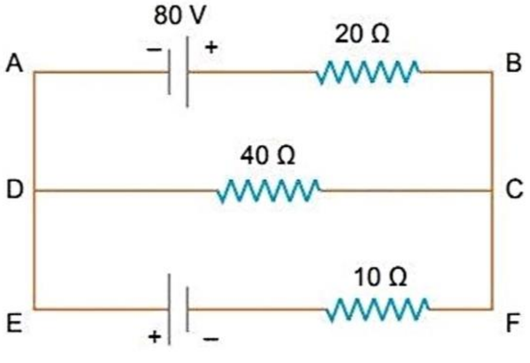
$$V_A - 2I_3 + 1 - 3\,I_3 - V_D = 0$$

$$\Rightarrow \quad V_A - V_D = 2I_3 - 1 + 3I_3$$

$$= 2\times2 - 1 + 3\times2 = \mathbf{9\ V}$$

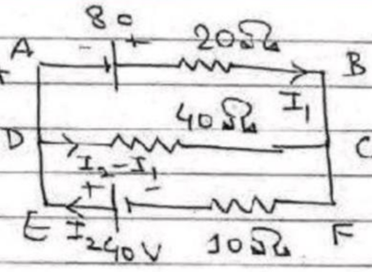
Q. 12. Using Kirchhoff's rules, calculate the current through the 40 Ω and 20 Ω resistors in the following circuit.

[CBSE 2019 (55/1/2)]



Ans.

16. Distributing the current as shown using Kirchhoff's junction rule at all the junctions



Now applying Kirchhoff's ~~voltage~~ loop rule in the loop ABCDA

$$80 - 20I_1 + 40(I_2 - I_1) = 0$$

$$80 = 20I_1 + 40I_1 - 40I_2$$

$$80 = 60I_1 - 40I_2$$

$$\text{OR} \quad 4 = 3I_1 - 2I_2 \quad \text{— (1)}$$

Now, applying Kirchhoff's loop rule in the loop DCFED,

$$-40(I_2 - I_1) - 10I_2 + 40 = 0$$

$$\text{OR} \quad 40 = 10I_2 + 40I_2 - 40I_1$$

$$\text{OR} \quad 4 = 5I_2 - 4I_1 \quad \text{— (2)}$$

Solving (1) & (2),

~~$8 = 6I_1 - 4I_2$~~

$$16 = 12I_1 - 8I_2 \quad \text{(From (1))}$$

$$\text{and } 12 = 15I_2 - 12I_1 \quad \text{(From (2))}$$

(Adding)

$$28 = 7I_2$$

$$\text{OR} \quad I_2 = 4\text{ A} \quad \text{— (3)}$$

and from (1),

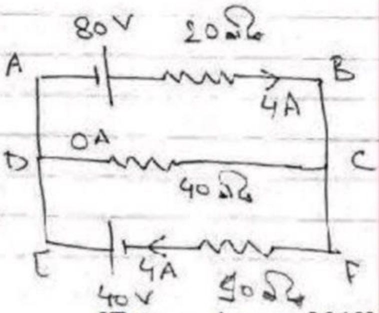
$$4 = 3I_1 - 2I_2$$

$$4 = 3I_1 - 2(4)$$

$$\text{OR} \quad I_1 = 4\text{ A}$$

So, the circuit becomes.

Hence, no current flows through inner 40 ohm resistor and 4A ~~goes~~ flows ~~from~~ through rest of the resistors.



[*Toppers Answer 2019*]

Q. 13. The potential difference across a resistor '*r*' carrying current '*I*' is *Ir*.

(*i*) Now if the potential difference across '*r*' is measured using a voltmeter of resistance 'R_V', show that the reading of voltmeter is less than the true value.

(*ii*) Find the percentage error in measuring the potential difference by a voltmeter.

(*iii*) At what value of R_V, does the voltmeter measures the true potential difference?

[*CBSE Sample Paper 2016*] [*HOTS*]

Ans. (*i*) $V = Ir$ (without voltmeter R_V)

$$V' = \frac{IrR_V}{r + R_V} = \frac{Ir}{1 + \frac{r}{R_V}}$$

$$V' < V$$

(*ii*) Percentage error $\left(\frac{V - V'}{V}\right) \times 100 = \left(\frac{r}{r + R_V}\right) \times 100$

(*iii*) $R_V \to \infty, V' = Ir = V$

Q. 14. 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 at a steady value of 2.8 A. What is the steady temperature of the heating element if the room temperature is 27°C? Temperature coefficient of resistance of nichrome averaged over the temperature range involved is 1.7×10^{-4} per °C. [*NCERT*] [*HOTS*]

Ans. Resistance of heating element at room temperature $t_1 = 27°$ C is

$$R_1 = \frac{V}{I_1} = \frac{230}{3.2}\Omega$$

Resistance of heating element at steady state temperature t_2°C is

$$R_2 = \frac{V}{I_2} = \frac{230}{2.8}\Omega$$

Temperature coefficient of resistance $\alpha = \frac{R_2 - R_1}{R_1 \times (t_2 - t_1)}$

$$\therefore \quad t_2 - t_1 = \frac{R_2 - R_1}{R_1 . \alpha} = \frac{\left(\frac{230}{2.8}\right) - \left(\frac{230}{3.2}\right)}{\frac{230}{3.2} \times 1.7 \times 10^{-4}} = \frac{3.2 - 2.8}{2.8 \times 1.7 \times 10^{-4}} = 840.3°C$$

$\therefore$ Steady state temperature, $t_2 = 840.3 + t_1 = 840.3 + 27 = \mathbf{867.3°C}$

CONSTRUCTED RESPONSE QUESTIONS AS PER NEP

Long Answer Questions

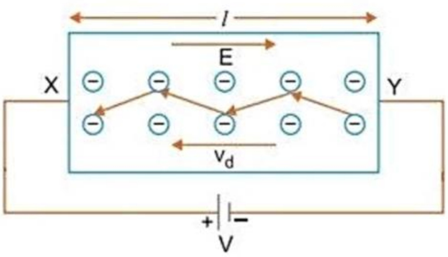
Each of the following questions are of 5 marks.

Q. 1. Derive an expression for drift velocity of free electrons in a conductor in terms of relaxation time of electrons. [*CBSE Delhi 2009*]

OR

Explain how the average velocity of free electrons in a metal at constant temperature, in an electric field, remains constant even though the electrons are being constantly accelerated by this electric field.

Ans. Consider a metallic conductor *XY* of length l and cross-sectional area A. A potential difference V is applied across the conductor *XY*. Due to this potential difference an electric field $\vec{E}$ is produced in the conductor. The magnitude of electric field strength $E = \frac{V}{l}$ and its direction is from *X* to *Y*.



This electric field exerts a force on free electrons; due to which electrons are accelerated.

The electric force on electron $\vec{F} = -e\vec{E}$ (where $e = +1.6 \times 10^{-9}$ coulomb).

If m is the mass of electron, then its acceleration

$$\vec{a} = \frac{\vec{F}}{m} = -\frac{e\vec{E}}{m} \qquad ...(i)$$

This acceleration remains constant only for a very short duration, since there are random forces which deflect the electron in random manner. These deflections may arise as

(*i*) ions of metallic crystal vibrate simple harmonically around their mean positions. Different ions vibrate in different directions and may be displaced by different amounts.

(*ii*) direct collisions of electrons with atoms of metallic crystal lattice.

In any way after a short duration called relaxation time, the motion of electrons become random. Thus, we can imagine that the electrons are accelerated only for a short duration. As average velocity of random motion is zero, if we consider the average motion of an electron, then its initial velocity is zero, so the velocity of electron after time τ (*i.e.,* drift velocity $\vec{v}\,d$) is given by the relation $\vec{v} = \vec{u} + \vec{a}\,t$

(here $\vec{u} = 0, v = \vec{v}_d, t = \tau, \vec{a} = -\frac{e\vec{E}}{m}$)

$$\vec{v}_d = 0 - \frac{e\vec{E}}{m}\tau \quad \Rightarrow \vec{v}_d = -\frac{e\tau}{m}\vec{E} \qquad ...(ii)$$

At given temperature, the relaxation time τ remains constant, so drift velocity remains constant.

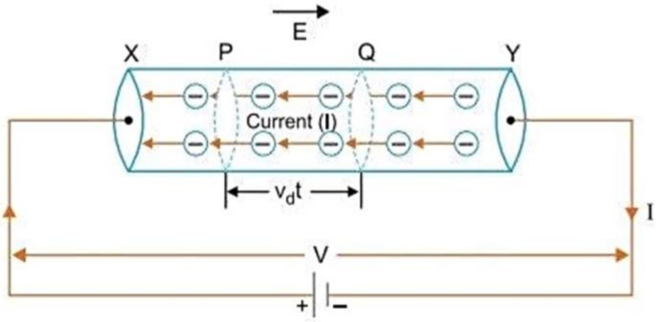
Q. 2. Establish a relation between electric current and drift velocity. ***[CBSE (AI) 2013]***

OR

Prove that the current density of a metallic conductor is directly proportional to the drift speed of electrons.

Ans. Relation between electric current and drift velocity:

Consider a uniform metallic wire XY of length l and cross-sectional area A. A potential difference V is applied across the ends X and Y of the wire. This causes an electric field at each point of the wire of strength



$$E = \frac{V}{l}. \qquad ...(i)$$

Due to this electric field, the electrons gain a drift velocity v_d opposite to direction of electric field. If q be the charge passing through the cross-section of wire in t seconds, then

$$\text{Current in wire } I = \frac{q}{t} \qquad ...(ii)$$

The distance traversed by each electron in time t =average velocity × time = $v_d t$

If we consider two planes P and Q at a distance $v_d\,t$ in a conductor, then the total charge flowing in time t will be equal to the total charge on the electrons present within the cylinder PQ.

The volume of this cylinder = cross sectional area × height

$$= A\,v_d\,t$$

If n is the number of free electrons in the wire per unit volume, then the number of free electrons in the cylinder $= n\,(Av_d\,t)$

If charge on each electron is $-e$ ($e = 1.6 \times 10^{-19}$C), then the total charge flowing through a cross-section of the wire

$$q = (nAv_d t)(-e) = -neAv_d t \quad ..(iii)$$

$\therefore$ Current flowing in the wire,

$$I = \frac{q}{t} = \frac{-neAv_d t}{t}$$

i.e., current $I = -neAv_d$ ...(*iv*)

This is the relation between electric current and drift velocity. Negative sign shows that the direction of current is opposite to the drift velocity.

Numerically $I = -neAv_d$ ...(*v*)

$\therefore$ Current density, $J = \dfrac{I}{A} = nev_d$

$\Rightarrow$ $J \propto v_d$.

That is, current density of a metallic conductor is directly proportional to the drift velocity.

Q. 3. Deduce Ohm's law using the concept of drift velocity.

OR

Define the term 'drift velocity' of charge carriers in a conductor. Obtain the expression for the current density in terms of relaxation time. **[*CBSE (F) 2014*]**

OR

Define relaxation time of the free electrons drifting in a conductor. How is it related to the drift velocity of free electrons? Use this relation to deduce the expression for the electrical resistivity of the material. **[*CBSE (AI) 2012*]**

OR

(*i*) On the basis of electron drift, derive an expression for resistivity of a conductor in terms of number density of free electrons and relaxation time. On what factors does resistivity of a conductor depend? **[*CBSE 2023 (55/2/1)*]**

(*ii*) Why alloys like constantan and manganin are used for making standard resistors? **[*CBSE Delhi 2016*]**

Ans. Relaxation time of free electrons drifting in a conductor is the average time elapsed between two successive collisions.

Deduction of Ohm's Law: Consider a conductor of length l and cross-sectional area A. When a potential difference V is applied across its ends, the current produced is I. If n is the number of electrons per unit volume in the conductor and v_d the drift velocity of electrons, then the relation between current and drift velocity is

$$I = -neAv_d \quad ...(i)$$

where $-e$ is the charge on electron ($e = 1.6 \times 10^{-19}$ C)

Electric field produced at each point of wire, $E = \dfrac{V}{l}$ ...(*ii*)

If τ is relaxation time and E is electric field strength, then drift velocity

$$v_d = -\frac{e\tau E}{m} \quad ...(iii)$$

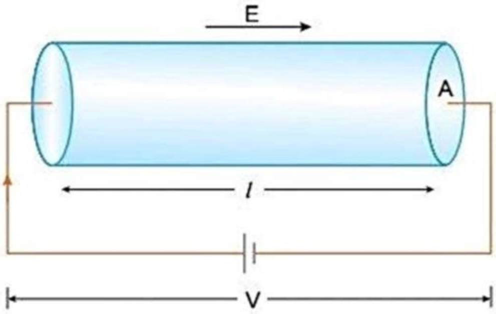
Substituting this value in (*i*), we get

$$I = -neA\left(-\frac{e\tau}{m}E\right) \quad \text{or} \quad I = \frac{ne^2\tau}{m}AE \quad ...(iv)$$

As $E = \dfrac{V}{l}$ [From (*ii*)]

$$I = \frac{ne^2 \tau A}{m} \frac{V}{l} \quad \text{or} \quad \frac{V}{I} = \frac{m}{ne^2 \tau} \cdot \frac{l}{A} \qquad \ldots(v)$$

Current density $J\left(= \frac{I}{A}\right) = \frac{ne^2 \tau}{ml} V.$



This is relation between current density J and applied potential difference V.

Under given physical conditions (temperature, pressure) for a given conductor

$$\frac{m}{ne^2 \tau} \cdot \frac{l}{A} = \text{Constant}$$

$\therefore$ This constant is called the resistance of the conductor (*i.e.* R).

i.e., $$R = \frac{m}{ne^2 \tau} \cdot \frac{l}{A} \qquad \ldots(vi)$$

From (v) and (vi); $\frac{V}{I} = R$ ...(vii)

This is Ohm's law. From equation (vi) it is clear that the resistance of a wire depends on its length (l), cross-sectional area (A), number of electrons per m^3 (n) and the relaxation time (τ)

Expression for resistivity:

As $$R = \frac{\rho l}{A} \qquad \ldots(viii)$$

Comparing (vi) and ($viii$), we get

Resistivity of a conductor $\rho = \frac{m}{ne^2 \tau}$

Clearly, resistivity of a conductor is inversely proportional to number density of electrons and relaxation time.

Resistivity of the material of a conductor depends upon the relaxation time, *i.e.,* temperature and the number density of electrons.

This is because constantan and manganin show very weak dependence of resistivity on temperature.

Q. 4. Derive condition of balance of a Wheatstone bridge.

OR

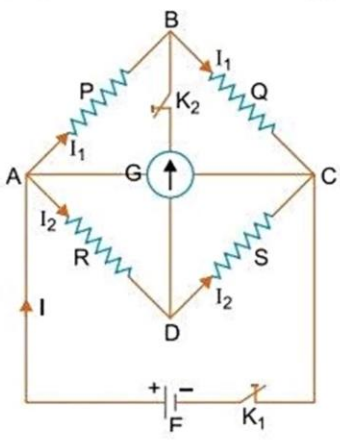
Draw a circuit diagram showing balancing of Wheatstone bridge. Use Kirchhoff's rules to obtain the balance condition in terms of the resistances of four arms of Wheatstone Bridge.

[*CBSE Delhi 2013, 2015*]

Ans. Condition of balance of a Wheatstone bridge:

The circuit diagram of Wheatstone bridge is shown in fig.

P, Q, R and S are four resistance forming a closed bridge, called Wheatstone bridge. A battery is connected across A and C, while a galvanometer is connected between B and D. When the bridge is balanced, there is no current in galvanometer.



Derivation of Formula: Let the current flowing in the circuit in the balanced condition 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 condition, current in resistances P and Q is I_1 and in resistances R and S it is I_2.

Applying Kirchhoff's I law at point A,

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

Applying Kirchhoff's II law to closed mesh $ABDA$,

$$-I_1 P + I_2 R = 0 \quad \text{or} \quad I_1 P = I_2 \; R \qquad \ldots(ii)$$

Applying Kirchhoff's II law to mesh $BCDB$,

$$-I_1 Q + I_2 S = 0 \quad \text{or} \quad I_1 Q = I_2 S \qquad \ldots(iii)$$

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

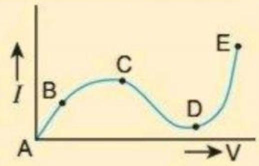
$$\frac{I_1 P}{I_1 Q} = \frac{I_2 R}{I_2 S} \quad \text{or} \quad \frac{P}{Q} = \frac{R}{S}$$

This is the ***condition of balance of Wheatstone bridge.***

Questions for Practice

1. Choose and write the correct option in the following questions.

(*i*) From the graph between current *I* and voltage *V* shown below, identify the portion corresponding to negative resistance



(*a*) *AB* (*b*) *BC* (*c*) *CD* (*d*) *DE*

(*ii*) The potential difference across a cell in an open circuit is 8 V. It falls to 4 V when a current of 4 A is drawn from it. The internal resistance of the cell is ***[CBSE 2023 (55/1/1)]***

(*a*) 4 Ω (*b*) 3 Ω (*c*) 2 Ω (*d*) 1 Ω

(*iii*) 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 throught the wire will be ***[CBSE Sample Paper 2022, Term-1]***

(*a*) 2:3 (*b*) 3:2 (*c*) 8:27 (*d*) 27:8

(*iv*) Which one of the following is not a scalar quantity? ***[CBSE 2023 (55/3/1)]***

(*a*) Electric field (*b*) Voltage (*c*) Resistivity (*d*) Power

(*v*) $m^2V^{-1}s^{-1}$ is the SI unit of which of the following? ***[CBSE 2020 (55/3/1)]***

(*a*) Drift velocity (*b*) Mobility (*c*) Resistivity (*d*) Potential gradient

(*vi*) In a current carrying conductor, the ratio of the electric field and the current density at a point is called ***[CBSE 2020 (55/2/1)]***

(*a*) Resistivity (*b*) Conductivity (*c*) Resistance (*d*) Mobility

(*vii*) Ohm's law is obeyed by ***[CBSE 2020 (55/2/3)]***

(*a*) extrinsic semiconductors. (*b*) intrinsic semiconductors.
(*c*) metals at low temperature. (*d*) metals at high temperature.

(*viii*) The resistance of a metal wire increases with increasing temperature on account of ***[CBSE 2020 (55/1/2)]***

(*a*) decrease in free electron density. (*b*) decrease in relaxation time.
(*c*) increase in mean free path. (*d*) increase in the mass of electron.

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

(a) ***Both A and R are true and R is the correct explanation of A.***

(b) ***Both A and R are true but R is not the correct explanation of A.***

(c) ***A is true but R is false.***

(d) ***A is false and R is also false.***

(*i*) **Assertion (*A*) :** The drift velocity of electrons in a metallic conductor decreases with rise of temperature of conductor.

Reason (*R*) : On increasing temperature, the collision of electrons with lattice ions increases; this hinders the drift of electrons.

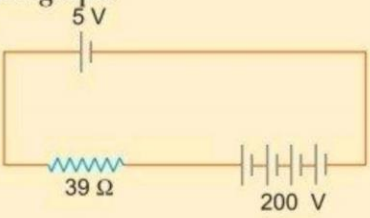
(*ii*) **Assertion** (*A*) **:** The resistance of a given mass of copper wire is inversely proportional to the square of length.

Reason (*R*) **:** When a copper wire of given mass is stretched to increase its length, its cross-sectional area also increases.

3. State the two Kirchhoff's rules used in electric networks. How are these rules justified?

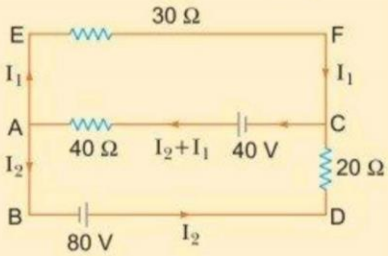
4. Show variation of resistivity of copper as a function of temperature in a graph.

5. A 5 V battery of negligible internal resistance is connected across a 200 V battery and a resistance of 39 Ω as shown in the figure. Find the value of the current flowing in the circuit.



6. 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 (AI) 2013*]**

7. Using Kirchhoff's rules, calculate the current in the arm *AC* of the given circuit.



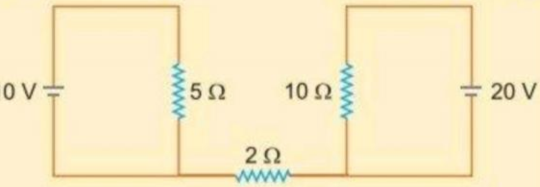
8. A cell of emf '*E*' and internal resistance '*r*' is connected across a variable resistor '*R*'. Plot a graph showing variation of terminal voltage '*V*' of the cell versus the current '*I*'. Using the plot, show how the emf of the cell and its internal resistance can be determined.

9. Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area 2.5×10^{-7} m^2 carrying a current of 1.8 A. Assume the density of conduction electrons to be 9×10^{28} m^{-3}.

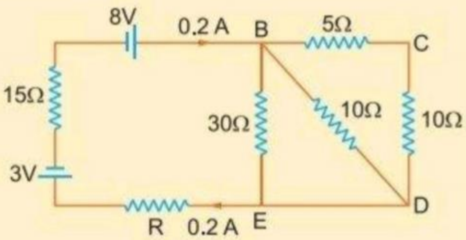
10. A wire of 20 Ω resistance is gradually stretched to double its original length. It is then cut into two equal parts. These parts are then connected in parallel across a 4.0 volt battery. Find the current drawn from the battery.

11. A conductor of length '*l*' is connected to a *dc* source of potential '*V*'. If the length of the conductor is tripled by gradually stretching it, keeping '*V*' constant, how will (*i*) drift speed of electrons and (*ii*) resistance of the conductor be affected? Justify your answer. **[*CBSE (F) 2012*]**

12. What will be the value of current through the 2 Ω resistance for the circuit shown in the figure? Give reason to support your answer. **[*CBSE (F) 2013*] [*HOTS*]**



13. 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 (AI) 2012*] [*HOTS*]**



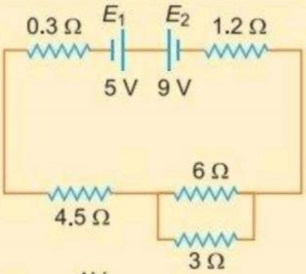
14. The storage battery of a car has an emf of 12 V. If the internal resistance of the battery is 0.4 Ω, what is the maximum current that can be drawn from the battery? **[*NCERT*]**

15. A battery of emf 10 V and internal resistance 3 Ω is connected to a resistor. If the current in the circuit is 0.5 A, what is the resistance of the resistor? What is the terminal voltage of the battery when the circuit is closed. **[*NCERT*]**

16. A negligibly small current is passed through a wire of length 15 m and uniform cross-section 6.0×10^{-7} m^2 and its resistance is measured to be 5.0 Ω. What is the resistivity of the material at the temperature of the experiment? **[*NCERT*]**

17. A silver wire has a resistance 2.1 Ω at 27.5°C and a resistance of 2.7 Ω at 100°C. Determine the temperature coefficient of the resistivity of silver.

18. Two cells E_1 and E_2 of emf's 5 V and 9 V and internal resistances of 0.3 Ω and 1.2 Ω respectively are connected to a network of resistances as shown in the figure. Calculate the value of current flowing through the 3 Ω resistance.



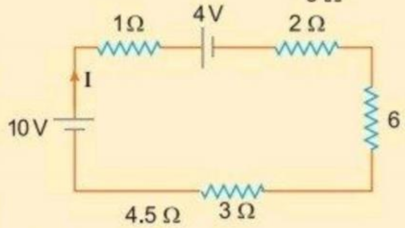
19. (*i*) Derive an expression for drift velocity of free electrons.

(*ii*) How does drift velocity of electrons in a metallic conductor vary with increase in temperature? Explain.

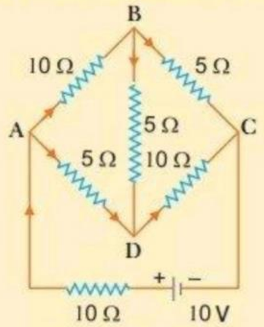
20. (*i*) High current is to be drawn safely from (1) a low-voltage battery, and (2) a high-voltage battery. What can you say about the internal resistance of the two batteries?

(*ii*) Calculate the energy supplied by the batteries to the circuit shown in the figure, in one minute.

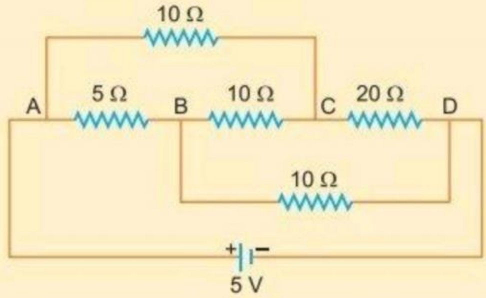
[*CBSE 2023 (55/4/1)*]



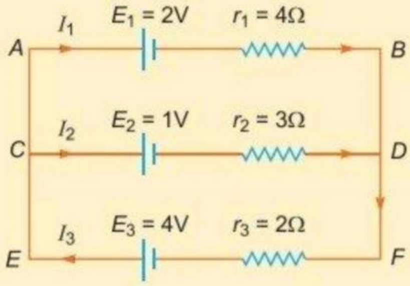
21. Determine the current in each branch of the network shown in figure.



22. Calculate the value of the current drawn from a 5 V battery in the circuit as shown. **[*CBSE (F) 2013*]**



23. State Kirchhoff's rules. Use these rules to write the expressions for the currents I_1, I_2 and I_3 in the circuit diagram shown. **[*CBSE (AI) 2010*]**



Answers

1. (*i*) (*c*) (*ii*) (*d*) (*iii*) (*c*) (*iv*) (*a*) (*v*) (*b*) (*vi*) (*a*) (*vii*) (*c*) (*viii*) (*b*) **2.** (*i*) (*a*) (*ii*) (*d*) **5.** 5 A **6.** $\frac{\varepsilon}{R}$ **7.** $\frac{22}{13}$ A

9. 5×10^{-4} **10.** 0.2 A **12.** 0A **13.** 1V **14.** 30 A **15.** 17Ω, 8.5V

16. 2×10^{-7}Ωm **17.** 0.0039/°C **18.** $\frac{1}{3}$A **20.** (*ii*) 180J

21. $\frac{4}{7}$A, $\frac{6}{17}$A, $\frac{6}{17}$A, $\frac{4}{17}$A, $\frac{2}{17}$A, $\frac{10}{17}$A **22.** 0.5 A **23.** $I_1 = \frac{2}{13}$A, $I_2 = \frac{7}{13}$A, $I_3 = \frac{9}{13}$A,