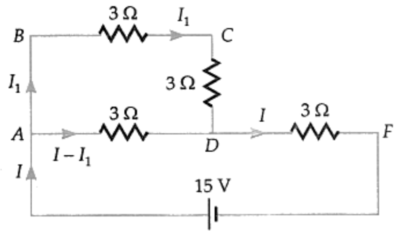
Solution

CURRENT ELECTRICITY

Class 12 - Physics

1. In semiconductors, Ohm's law is obeyed only for low electric fields (E < 10^6 Vm^{-1}). Above this field, the current becomes independent of the applied voltage.
2. One volt of emf may be defined as the amount of energy equal to one joule required to drive one coulomb of charge once around the closed circuit.
3. i = 2μ A, t = 5 min = 5 $\times$ 60 sec
   q = it = 2 $\times$ 10^{-6} $\times$ 5 $\times$ 60
   = 10 $\times$ 60 $\times$ 10^{-6} c = 6 $\times$ 10^{-4} c
4. The electrical conductivity (σ) of a metallic wire is defined as the ratio of the current density to the electric field it creates. Its SI unit is ohm per metre $(\Omega - m)^{-1}$.
5. As R = $\frac{V}{I}$. Clearly, slope of V-I graph gives resistance R. As graph B has a greater slope than A, so graph B represents series combination (higher resistance) and graph A represents parallel combination (lower resistance).
6. As P = $\frac{V^2}{R}$, hence for same V, the thicker wire will produce more heat because of its smaller resistance.
7. Here P = 500 W, V = 200 V
   R = $\frac{V^2}{P} = \frac{200 \times 200}{500} = 80\Omega$
   When the voltage drops to 160 V, rate of heat production is
   $P' = \frac{V'^2}{R} = \frac{160 \times 160}{80}$ = 320 W
   % Drop in heat production
   = $\frac{P - P'}{P} \times 100 = \frac{180 \times 100}{500}$ = 36%
8. The circuit is a balanced Wheatstone bridge. Its effective resistance R is given by
   $\frac{1}{R} = \frac{1}{3+2} + \frac{1}{6+4} = \frac{3}{10}$ or R = $\frac{10}{3}\Omega$
   $\therefore$ Current, I = $\frac{V}{R} = \frac{2}{\frac{10}{3}}$ = 0.6 A
9. Given that,
   Power (P) = 630 W and
   Voltage (V) = 210 V,
   Current Drawn (I) = ?
   In DC source, we know that
   power = voltage x current drawn
   P = VI
   Therefore, $I = \frac{P}{V} = \frac{630}{210} = 3\text{A}$
10. By maintaining a potential difference between the two ends of the conductor.
11. Resistances of the two bulbs are
   R_1 = $\frac{V^2}{P_1} = \frac{220 \times 220}{100}$ = 484 Ω
   R_2 = $\frac{V^2}{P_2} = \frac{220 \times 220}{25}$
   R_s = R_1 = R_2 = 484 + 1936 = 2420 Ω
   i. I = $\frac{V}{R_s} = \frac{220}{2420} = \frac{1}{11}\mathbf{A}$
   ii. V_1 = R_1I = 484 $\times \frac{1}{11}$ = 44 V
   V_2 = R_2I = 1936 $\times \frac{1}{11}$ = 176 V
   iii. P_1 = I^2R_1 = $\left(\frac{1}{11}\right)^2 \times$ 484 = 4 W
   P1 = I^2R_1 = $\left(\frac{1}{11}\right)^2 \times$ 1936 = 16 W
12. In the steady-state (when the capacitor is fully charged), no current flows through the branch CEF. The given circuit then reduces to the equivalent circuit shown in Figure.



The equivalent resistance of the circuit is

R = $\frac{6 \times 3}{6+3} + 3 = 5\Omega$

Current drawn from the battery,

I = $\frac{15\text{ V}}{5\Omega}$ = 3 A

Current through the branch BCD,

I_1 = $\frac{3}{6+3} \times I = \frac{3}{9} \times 3$ = 1 A

Current through the arm DF = I = 3 A

P.D. across the capacitor = P.D. between points C and F

= P.D. across CD + P.D. across DF

= 3 $\times$ 1 + 3 $\times$ 3 = 12V

13. i. Here E = 12 V, I = 90 A, r = 5.0 $\times$ $10^{-2}\Omega$

    Terminal voltage, V = E - Ir = 12 - 4.5 = 7.5 V.

    ii. The maximum current can be drawn from a battery by shorting it.

    Then V = 0 and I_{max} = $\frac{\varepsilon}{r} = \frac{12}{500}$ A = 24 mA.

    Clearly, the battery is useless for starting the car and must be charged again.

    iii. During discharge of the accumulator, the current inside the cells (of the accumulator) is opposite to what it is when the accumulator discharges. That is, during charging, current flows from the + ve to -ve terminal inside the cells. Consequently, during charging V = E + Ir

    Hence V must be greater than 12 V during charging.

14. Electromotive force EMF of battery = 8 Volt

    Internal resistance of battery r = 0.5 Ω

    Supply Voltage V = 120 Volt

    Resistance of resistor R = 15.5 Ω

    Effective voltage in circuit = V1

    Since Resistance R is connected in series. Hence, we can write V_1 = V - E

    V_1 = 120V - 8V = 112 V

    Current flowing in the circuit:

    $\Rightarrow I = \frac{V_1}{R+r}$

    $\Rightarrow I = \frac{112\text{V}}{15.5\Omega + 0.5\Omega}$

    $\Rightarrow I = \frac{112\text{V}}{16\Omega}$

    I = 7 Ampere

    By Ohm's Law, Voltage across resistor R is given by V = IR

    V = 7A $\times$ 15.5 Ω

    $\Rightarrow$V = 108.5 Volt

    Supply Voltage = Terminal Voltage of battery + Voltage drop across Resistor R

    Therefore Terminal Voltage of battery = 120 V - 108.5 V = 11.5 Volt

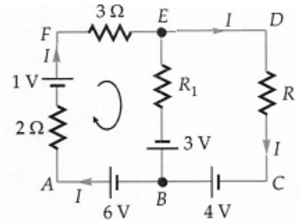
    The series resistor in the charging circuit reduces the current drawn from the external supply and the current will be too high in its absence. Series resistor in the charging circuit limits the current drawn from the external source.

15. As no current flows in arm BE so the potential difference across R_1 will be zero.

    Now applying Kirchhoff's law for loop AFEBA, 6 + 1 + 3 = 2i + 3i or i = 2A

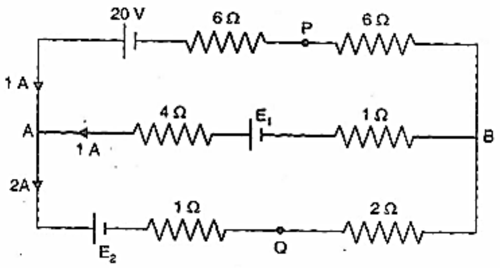
    The potential difference across A and D along AFD, V_A - 2i + 1 - 3i = V_D

or $V_A - V_D = 5i - 1 = 5(2) - 1 = 9V$

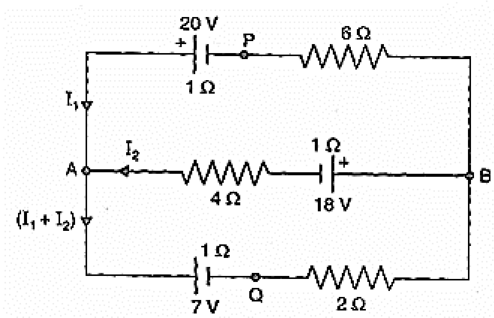


16. i. It is clear that 1 A current flows in the circuit from B to A.
Applying Kirchhoff's law to the loop PAQBP,
$20 - E_2 = 12 \times 1 + (1 \times 2) + (2 \times 2) = 18$
Hence, E_2 = 2V

Thus the potential difference between the points A and B is:



ii. On reversing the polarity of the battery E_1, the current distributions will be changed. Let the currents be I_1 and I_2 as shown in the following figure.



Applying Kirchhoff's law for the loop PABP,
$20 + E_1 = (6 + 1)I_1 - (4 + 1)I_2$
or $38 = 7I_1 - 5I_2$ ...... (i)
Similarly for the loop ABQA,
$4I_2 + I_2 + 18 + 2(I_1 + I_2) + (I_1 + I_2) + 7 = 0$
Or $3I_1 + 8I_2 = - 25$ ...... (ii)
Solving equation (i) and (ii) for I_1 and I_2 we get
$I_1 = 2.52$ and $I_2 = -4.07A$
Hence, $V_{ab} = -5 \times (4.07) + 18$
= -20.35 + 18
= -2.35V

17. i. Let us consider a conductor of length ' l ' , cross-sectional Area ' A ' and having ' n ' number of electrons per unit volume drifting with drift velocity v_d.
$I = neAv_d ... (i)$
When these electrons are moving, they collide with another electrons and in between the two successive collision the time taken is called relaxation time (τ).
Electric field inside the wire is given by
E = V/l ...(ii)
where,E is electric field, l is the length of the conductor and V is potential.
If relaxation time is τ, the drift speed (v_d) is given by,
$v_d = e\tau E/m$
where, m = mass of electron, τ = relaxation charge, e = electronic charge and E = electric field.

Putting the value of V_d in Eq. (i). we get

$\Rightarrow \quad I = \frac{ne^2\tau}{m} AE$ ...(iii)

$I = me^2\tau AV/ml$ [From Eqs. (ii)]

$\Rightarrow J = I/A = ne^2\tau V/ml$

ii. Given, $I = 1.5A, n = 9 \times 10^{28}\mathrm{m}^{-3}$

$A = 1.0 \times 10^{-7}\mathrm{m}^2$

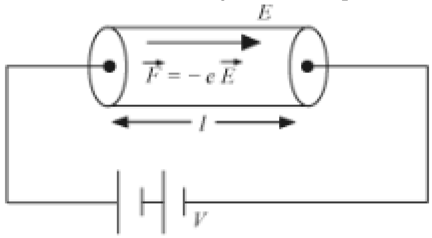
$\because \quad v_d = \frac{I}{neA}$

$\Rightarrow v_d = \frac{15}{9\times10^{28}\times1.6\times10^{-19}\times1.0\times10^{-7}}$

$\Rightarrow v_d = 1.04 \times 10^{-3}\mathrm{m/s}$

18. The property of a material that allows flows of electrons (or any charged particle) between two points of the material when a potential difference is applied between these two points is called conductivity of a wire.

SI unit of conductivity: Siemens per metre



Drift velocity of electrons in a conductor is given as

$v_d = \frac{eE\tau}{m}$ .... (1)

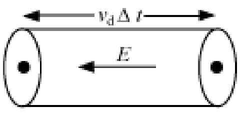
where,

E = electric field set up across a conductor

m = mass of electron

τ = average relaxation time

Now the current flowing the conductor can be derived as



We know that

l = neAv_d ..... (2)

n $\rightarrow$ Number of free electrons per unit volume or number density

Now from equation (1) and (2), we get

$I = \frac{ne^2A\tau E}{m}$ ...... (3)

Since resistivity of a conductor is given as

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

Now, we know that conductivity of a conductor is mathematically defined as the reciprocal of resistivity of the conductor. Thus,

$\rho = \frac{1}{\sigma}$ .... (4)

where, σ = conductivity of the conductor. Thus, from equation (3) and (4), we get

$\sigma = \frac{ne^2\tau}{m}$ .... (5)

Now, from equation (3) and (5), we have

$\frac{I}{A} = \sigma E$ .... (6)

and current density is given as

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

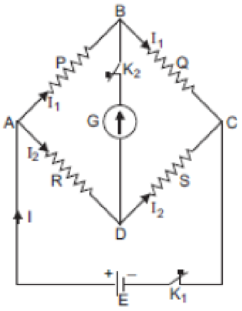
Thus, J = σE

19. a. **Kirchhoff's I rule:** It states that, at any junction, the sum of the currents entering the junction is equal to the sum of the currents leaving the junction.

Kirchhoff's II rule: It states that, the algebraic sum of the charges in potential around any closed loop involving resistors and cells in the loop is zero.

Conditions balance of a Wheatstone bridge:

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 B and D. Current is absent in the galvanometer's balance point.

Derivation of Formula: Let the current given by battery in the balanced position be I. This current on reaching point A is divided into two parts I_1 and I_2. At the balanced point, current is zero.

Applying Kirchhoff's I law at point A,

$I - I_1 - I_2 = 0$ or

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

Applying Kirchhoff's II law to closed mesh ABDA,

$-I_1P + I_2R = 0$ or

$I_1P = I_2R$ ..... (ii)

Applying Kirchhoff's II law to mesh BCDB,

$-I_1Q + I_2S = 0$ or

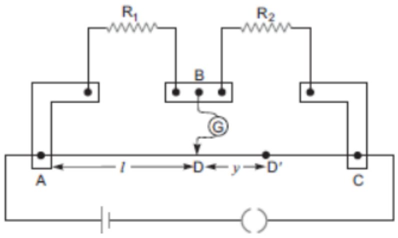
$I_1Q = I_2S$ ...... (iii)

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

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

$\Rightarrow \frac{P}{Q} = \frac{R}{S}$; which is the required condition of balance for Wheatstone bridge.

b.



For null point at D, balance length l_1 = 40cm

So, $\frac{R_1}{R_2} = \frac{AD}{DC} = \frac{40}{(100-40)} = \frac{2}{3}$ ..... (i)

If resistance 10Ω is connected in series or R_1, balance point shifts towards $'\lambda'$ i.e., AD = 60cm

$\frac{R_1+10}{R_2} = \frac{AD'}{D'C} = \frac{60}{100-60} = \frac{3}{2}$ ..... (ii)

$\frac{R_1}{R_2} + \frac{10}{R_2} = \frac{3}{2}$

From equations (i) and (ii), we have

$\frac{2}{3} + \frac{10}{R_2} = \frac{3}{2}$

$\Rightarrow \frac{10}{R_2} = \frac{3}{2} - \frac{2}{3} = \frac{9-4}{6} = \frac{5}{6}$

$\Rightarrow R_2 = \frac{10\times 6}{5} = 12 \text{ ohm}$

From equation (i), we have

$\frac{R_1}{12} = \frac{2}{3}$

$\Rightarrow R_1 = \frac{12\times 2}{3} = 8 \text{ ohm}$