



Chapter 3 : Current Electricity (Solved Examples & Exercises)

by - Tomar Sir

Notes

Step-by-step solutions · NCERT Examples 3.1–3.7 and Exercises 3.1–3.9 · Class 12 Physics

Part A — NCERT Solved Examples

Example 3.1

Question: (a) Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area $1.0 \times 10^{-7} \text{ m}^2$ carrying a current of 1.5 A. Assume that each copper atom contributes roughly one conduction electron. The density of copper is $9.0 \times 10^3 \text{ kg/m}^3$, and its atomic mass is 63.5 u. (b) Compare the drift speed obtained above with (i) thermal speeds of copper atoms at ordinary temperatures, (ii) speed of propagation of electric field along the conductor which causes the drift motion.

Solution:

(a) The electrons drift opposite to the field, i.e. in the direction of increasing potential. $v_d = \frac{I}{neA}$.

n = number of atoms per m^3 (one free electron per atom). 1 m^3 of copper has a mass of $9.0 \times 10^3 \text{ kg}$, and 6.0×10^{23} atoms have a mass of 63.5 g:

$$n = \frac{6.0 \times 10^{23}}{63.5} \times 9.0 \times 10^6 = 8.5 \times 10^{28} \text{ m}^{-3}$$

$$v_d = \frac{1.5}{8.5 \times 10^{28} \times 1.6 \times 10^{-19} \times 1.0 \times 10^{-7}} = 1.1 \times 10^{-3} \text{ m s}^{-1} = 1.1 \text{ mm s}^{-1}$$

(b) (i) The thermal speed of a copper atom of mass M , from $\langle \frac{1}{2} M v^2 \rangle = \frac{3}{2} k_B T$, is of the order $\sqrt{k_B T / M}$ — about $2 \times 10^2 \text{ m/s}$ at 300 K. The drift speed is about 10^{-5} times this.

(ii) The electric field travels along the conductor at the speed of an electromagnetic wave, $3.0 \times 10^8 \text{ m s}^{-1}$. The drift speed is smaller by a factor of 10^{-11} .

Answer: (a) $v_d \approx 1.1 \text{ mm s}^{-1}$; (b) the drift speed is extremely small compared with both.

Example 3.2

Question: (a) In Example 3.1, the electron drift speed is estimated to be only a few mm s^{-1} for currents in the range of a few amperes. How then is current established almost the instant a circuit is closed? (b) The electron drift arises due to the force experienced by electrons in the electric field inside the conductor. But force should cause acceleration. Why then do the electrons acquire a steady average drift speed? (c) If the electron drift speed is so small, and the electron's charge is small, how can we still obtain large amounts of current in a conductor? (d) When electrons drift in a metal from lower to higher potential, does it mean that all the 'free' electrons of the

metal are moving in the same direction? (e) Are the paths of electrons straight lines between successive collisions (with the positive ions of the metal) in the (i) absence of electric field, (ii) presence of electric field?

Answer:

- (a) The electric field is established throughout the circuit almost instantly (at the speed of light), causing a local electron drift at every point. Current does not have to wait for electrons to travel from one end to the other. (It does take a little while to reach its steady value.)
- (b) Each free electron does accelerate, increasing its drift speed until it collides with a positive ion. It loses its drift speed after the collision, then accelerates again. On average, electrons acquire only a drift speed.
- (c) Because the electron number density is enormous, $\sim 10^{29} \text{ m}^{-3}$.
- (d) By no means. The drift velocity is **superposed** on the large random velocities of the electrons.
- (e) In the absence of an electric field, the paths are straight lines; in the presence of a field, they are, in general, curved.

Example 3.3

Question: An electric toaster uses nichrome for its heating element. When a negligibly small current passes through it, its resistance at room temperature (27.0°C) is found to be $75.3\ \Omega$. When the toaster is connected to a 230 V supply, the current settles, after a few seconds, to a steady value of 2.68 A. What is the steady temperature of the nichrome element? The temperature coefficient of resistance of nichrome averaged over the temperature range involved is $1.70 \times 10^{-4} \text{ }^\circ\text{C}^{-1}$.

Solution: With a very small current, heating is negligible, so $T_1 = \text{room temperature}$ and $R_1 = 75.3\ \Omega$. In the steady state:

$$R_2 = \frac{230\text{ V}}{2.68\text{ A}} = 85.8\ \Omega$$

Using $R_2 = R_1 [1 + \alpha (T_2 - T_1)]$:

$$T_2 - T_1 = \frac{R_2 - R_1}{R_1 \alpha} = \frac{85.8 - 75.3}{75.3 \times 1.70 \times 10^{-4}} = 820^\circ\text{C}$$

$$T_2 = 820 + 27.0 = 847^\circ\text{C}$$

Answer: The steady temperature is **847°C** (when the heating effect of the current equals the heat lost to the surroundings).

Example 3.4

Question: The resistance of the platinum wire of a platinum resistance thermometer at the ice point is $5\ \Omega$ and at steam point is $5.23\ \Omega$. When the thermometer is inserted in a hot bath, the resistance of the platinum wire is $5.795\ \Omega$. Calculate the temperature of the bath.

Solution: $R_0 = 5\ \Omega$, $R_{100} = 5.23\ \Omega$, $R_t = 5.795\ \Omega$. Using $R_t = R_0 (1 + \alpha t)$:

$$t = \frac{R_t - R_0}{R_{100} - R_0} \times 100 = \frac{5.795 - 5}{5.23 - 5} \times 100 = \frac{0.795}{0.23} \times 100$$

Answer: $t = 345.65^\circ\text{C}$.

Example 3.5

Question: A battery of 10 V and negligible internal resistance is connected across the diagonally opposite corners of a cubical network consisting of 12 resistors each of resistance $1\ \Omega$ (Fig. 3.16). Determine the equivalent resistance of the network and the current along each edge of the cube.

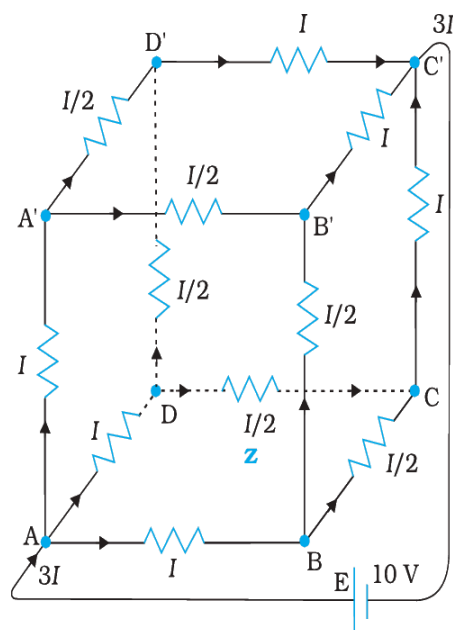


Fig. 3.16

Solution: The network is not reducible to series and parallel combinations, but it has a clear **symmetry**.

- The paths AA', AD and AB are symmetrically placed, so each carries the same current, say I . Total current = $3I$.
- At the corners A', B and D, the incoming current I splits equally into the two outgoing branches: $I/2$ each.
- By symmetry, the three edges reaching C' each carry I , adding to $3I$.

Apply Kirchhoff's loop rule to the closed loop ABCC'EA:

$$-IR - \frac{1}{2}IR - IR + \varepsilon = 0 \Rightarrow \varepsilon = \frac{5}{2}IR$$

$$R_{eq} = \frac{\varepsilon}{3I} = \frac{5}{6}R$$

For $R = 1\ \Omega$, $R_{eq} = \frac{5}{6}\ \Omega$. For $\varepsilon = 10\text{ V}$, the total current:

$$3I = \frac{10\text{ V}}{(5/6)\ \Omega} = 12\text{ A} \Rightarrow I = 4\text{ A}$$

Answer: $R_{eq} = 5/6\ \Omega$. The edges from A and into C' carry 4 A each; the six middle edges carry 2 A each.

Example 3.6

Question: Determine the current in each branch of the network shown in Fig. 3.17.

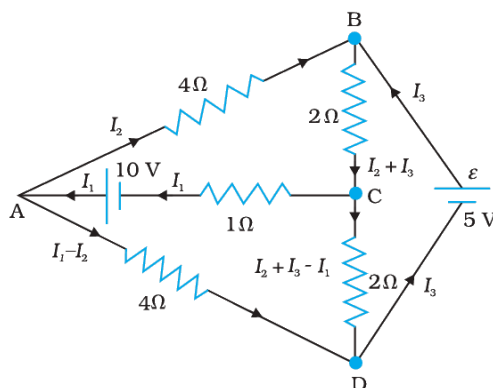


Fig. 3.17

Solution: Use the junction rule to assign currents with three unknowns I_1, I_2, I_3 . Apply the loop rule to three loops.

Loop ADCA:

$$10 - 4(I_1 - I_2) + 2(I_2 + I_3 - I_1) - I_1 = 0 \Rightarrow 7I_1 - 6I_2 - 2I_3 = 10$$

Loop ABCA:

$$10 - 4I_2 - 2(I_2 + I_3) - I_1 = 0 \Rightarrow I_1 + 6I_2 + 2I_3 = 10$$

Loop BCDEB:

$$5 - 2(I_2 + I_3) - 2(I_2 + I_3 - I_1) = 0 \Rightarrow 2I_1 - 4I_2 - 4I_3 = -5$$

Solving:

$$I_1 = 2.5 \text{ A}, \quad I_2 = \frac{5}{8} \text{ A}, \quad I_3 = 1\frac{7}{8} \text{ A}$$

Answer:

Branch	Current
AB	$5/8 \text{ A}$
CA	$2\frac{1}{2} \text{ A}$
DEB	$1\frac{7}{8} \text{ A}$
AD	$1\frac{7}{8} \text{ A}$
CD	0 A
BC	$2\frac{1}{2} \text{ A}$

Check (loop BADEB): $5 + \left(\frac{5}{8} \times 4\right) - \left(\frac{15}{8} \times 4\right) = 5 + 2.5 - 7.5 = 0 \checkmark$

Example 3.7

Question: The four arms of a Wheatstone bridge (Fig. 3.19) have the following resistances: $AB = 100 \Omega$, $BC = 10 \Omega$, $CD = 5 \Omega$, and $DA = 60 \Omega$. A galvanometer of 15Ω resistance is connected across BD . Calculate the current through the galvanometer when a potential difference of 10 V is maintained across AC .

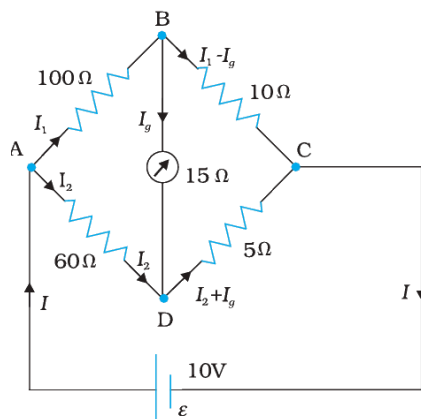


Fig. 3.19

Solution:

Mesh BADB:

$$100I_1 + 15I_g - 60I_2 = 0 \Rightarrow 20I_1 + 3I_g - 12I_2 = 0 \quad (a)$$

Mesh BCDB:

$$10(I_1 - I_g) - 15I_g - 5(I_2 + I_g) = 0 \Rightarrow 2I_1 - 6I_g - I_2 = 0 \quad (b)$$

Mesh ADCEA:

$$60I_2 + 5(I_2 + I_g) = 10 \Rightarrow 13I_2 + I_g = 2 \quad (c)$$

Multiply (b) by 10: $20I_1 - 60I_g - 10I_2 = 0$. Subtract from (a):

$$63I_g - 2I_2 = 0 \Rightarrow I_2 = 31.5I_g$$

Substitute into (c):

$$13(31.5I_g) + I_g = 2 \Rightarrow 410.5I_g = 2 \Rightarrow I_g = 4.87 \text{ mA}$$

Answer: $I_g = 4.87 \text{ mA}$ (the bridge is not balanced, since $100/10 \neq 60/5$).

Part B — NCERT Exercises**Exercise 3.1**

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

Solution: The maximum current flows when the external resistance is zero (short circuit):

$$I_{max} = \frac{\varepsilon}{r} = \frac{12}{0.4} = 30 \text{ A}$$

Answer: 30 A.

Exercise 3.2

Question: A battery of emf 10 V and internal resistance 3Ω 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?

Solution:

$$I = \frac{\varepsilon}{R + r} \Rightarrow R + r = \frac{10}{0.5} = 20 \Omega \Rightarrow R = 20 - 3 = 17 \Omega$$

$$V = \varepsilon - Ir = 10 - 0.5 \times 3 = 8.5 \text{ V}$$

Answer: $R = 17 \Omega$; terminal voltage = 8.5 V.

Exercise 3.3

Question: At room temperature (27.0°C) the resistance of a heating element is 100Ω . What is the temperature of the element if the resistance is found to be 117Ω , given that the temperature coefficient of the material of the resistor is $1.70 \times 10^{-4}^\circ\text{C}^{-1}$?

Solution:

$$R_2 = R_1 [1 + \alpha (T_2 - T_1)] \Rightarrow T_2 - T_1 = \frac{R_2 - R_1}{R_1 \alpha} = \frac{117 - 100}{100 \times 1.70 \times 10^{-4}} = 1000^\circ\text{C}$$

$$T_2 = 1000 + 27 = 1027^\circ\text{C}$$

Answer: 1027°C .

Exercise 3.4

Question: A negligibly small current is passed through a wire of length 15 m and uniform cross-section $6.0 \times 10^{-7} \text{ m}^2$, and its resistance is measured to be 5.0Ω . What is the resistivity of the material at the temperature of the experiment?

Solution:

$$\rho = \frac{RA}{l} = \frac{5.0 \times 6.0 \times 10^{-7}}{15} = 2.0 \times 10^{-7} \Omega \text{ m}$$

Answer: $\rho = 2.0 \times 10^{-7} \Omega \text{ m}$.

Exercise 3.5

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

Solution:

$$\alpha = \frac{R_2 - R_1}{R_1 (T_2 - T_1)} = \frac{2.7 - 2.1}{2.1 \times (100 - 27.5)} = \frac{0.6}{152.25} = 0.0039^\circ\text{C}^{-1}$$

Answer: $\alpha = 3.9 \times 10^{-3}^\circ\text{C}^{-1}$.

Exercise 3.6

Question: A heating element using nichrome connected to a 230 V supply draws an initial current of 3.2 A which settles after a few seconds to a steady value of 2.8 A . What is the steady temperature of the heating element if the room temperature is 27.0°C ? Temperature coefficient of resistance of nichrome averaged over the temperature range involved is $1.70 \times 10^{-4}^\circ\text{C}^{-1}$.

Solution: At room temperature: $R_1 = \frac{230}{3.2} = 71.875 \Omega$. In the steady state: $R_2 = \frac{230}{2.8} = 82.143 \Omega$.

$$T_2 - T_1 = \frac{R_2 - R_1}{R_1 \alpha} = \frac{82.143 - 71.875}{71.875 \times 1.70 \times 10^{-4}} = 840^\circ\text{C}$$

$$T_2 = 840 + 27 = 867^\circ\text{C}$$

Answer: About 867°C .

Exercise 3.7

Question: Determine the current in each branch of the network shown in Fig. 3.20.

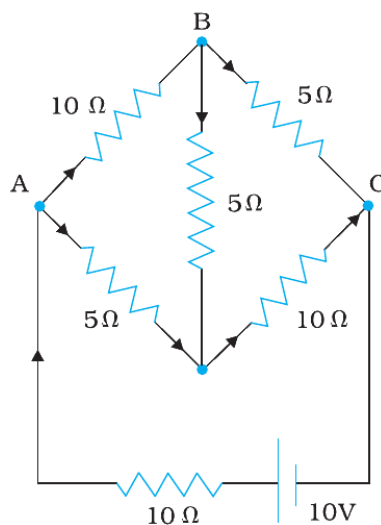


Fig. 3.20

Solution: Let D be the bottom node. Arms: $AB = 10 \Omega$, $BC = 5 \Omega$, $AD = 5 \Omega$, $DC = 10 \Omega$, $BD = 5 \Omega$. The 10 V battery with a 10Ω resistor is connected between C and A. Let the total current be I , with I_1 in AB, I_2 in AD, and I_3 from B to D. By the junction rule, BC carries $I_1 - I_3$ and DC carries $I_2 + I_3$; $I = I_1 + I_2$.

Loop ABDA: $10I_1 + 5I_3 - 5I_2 = 0 \Rightarrow 2I_1 + I_3 - I_2 = 0$

Loop BCDB: $5(I_1 - I_3) - 10(I_2 + I_3) - 5I_3 = 0 \Rightarrow I_1 - 2I_2 - 4I_3 = 0$

Outer loop (through battery, A-B-C): $10(I_1 + I_2) + 10I_1 + 5(I_1 - I_3) = 10 \Rightarrow 25I_1 + 10I_2 - 5I_3 = 10$

Solving:

$$I_1 = \frac{4}{17} \text{ A}, \quad I_2 = \frac{6}{17} \text{ A}, \quad I_3 = -\frac{2}{17} \text{ A}$$

(I_3 negative means the current in BD flows from **D to B**.)

Answer:

Branch	Current
AB	4/17 A
AD	6/17 A
D → B	2/17 A
BC	6/17 A
DC	4/17 A
Main circuit (battery)	10/17 A

(The equivalent resistance of the network between A and C is 7Ω , so $I = 10 / (10 + 7) = 10/17 \text{ A}$ ✓.)

Exercise 3.8

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

Solution: The supply opposes the battery's emf during charging:

$$I = \frac{120 - 8}{15.5 + 0.5} = \frac{112}{16} = 7 \text{ A}$$

While charging, current flows into the positive terminal, so

$$V = \varepsilon + Ir = 8 + 7 \times 0.5 = 11.5 \text{ V}$$

Answer: Terminal voltage = 11.5 V. The series resistor **limits the current** drawn from the external supply. Without it, the current would be dangerously high ($112/0.5 = 224 \text{ A}$).

Exercise 3.9

Question: The number density of free electrons in a copper conductor estimated in Example 3.1 is $8.5 \times 10^{28} \text{ m}^{-3}$. How long does an electron take to drift from one end of a wire 3.0 m long to its other end? The area of cross-section of the wire is $2.0 \times 10^{-6} \text{ m}^2$ and it is carrying a current of 3.0 A.

Solution:

$$v_d = \frac{I}{neA} = \frac{3.0}{8.5 \times 10^{28} \times 1.6 \times 10^{-19} \times 2.0 \times 10^{-6}} = 1.1 \times 10^{-4} \text{ m s}^{-1}$$

$$t = \frac{l}{v_d} = \frac{3.0}{1.1 \times 10^{-4}} = 2.7 \times 10^4 \text{ s}$$

Answer: About $2.7 \times 10^4 \text{ s}$, i.e. **7.5 hours**.