3. CURRENT ELECTRICITY

PGT Physics-Practice Set

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SUMMARY

1. *Current* through a given area of a conductor is the net charge passing per unit time through the area.

2. To maintain a steady current, we must have a closed circuit in which an external agency moves electric charge from lower to higher potential energy. The work done per unit charge by the source in taking the charge from lower to higher potential energy (i.e., from one terminal of the source to the other) is called the electromotive force, or *emf*, of the source. Note that the emf is not a force; it is the voltage difference between the two terminals of a source in open circuit.

3. ***Ohm's law***: The electric current I flowing through a substance is proportional to the voltage V across its ends, i.e., $V \propto I$ or $V = RI$, where R is called the resistance of the substance. The unit of resistance is ohm: $1\Omega = 1VA^{-1}$.

4. The *resistance* R of a conductor depends on its length l and cross-sectional area A through the relation,

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

where ρ, called *resistivity* is a property of the material and depends on temperature and pressure.

5. ***Electrical resistivity*** of substances varies over a very wide range. Metals have low resistivity, in the range of $10^{-8}\Omega\text{m}$ to $10^{-6}\Omega\text{m}$. Insulators like glass and rubber have 10^{22} to 10^{24} times greater resistivity. Semiconductors like *Si* and *Ge* lie roughly in the middle range of resistivity on a logarithmic scale.

6. In most substances, the carriers of current are electrons; in some cases, for example, ionic crystals and electrolytic liquids, positive and negative ions carry the electric current.

7. ***Current density*** $\vec{j}$ gives the amount of charge flowing per second per unit area normal to the flow,

$$\vec{j} = nq\vec{v}_d$$

where n is the number density (number per unit volume) of charge carriers each of charge q, and $\vec{v}_d$ is the *drift velocity* of the charge carriers. For electrons $q = -e$. If $\vec{j}$ is normal to a cross-sectional area A and is constant over the area, the magnitude of the current I through the area is $nev_d A$.

8. Using $E = V/l$, $I = nev_d A$, and Ohm's law, one obtains

$$\frac{eE}{m} = \rho \frac{ne^2}{m} v_d$$

The proportionality between the *force* eE on the electrons in a metal due to the external field E and the drift velocity v_d (not acceleration) can be understood, if we assume that the electrons suffer collisions with ions in the metal, which deflect them randomly. If such collisions occur on an average at a time interval τ,

$$v_d = a\tau = eE\tau/m$$

where a is the acceleration of the electron. This gives $\rho = \frac{m}{ne^2\tau}$

9. In the temperature range in which resistivity increases linearly with temperature, the *temperature coefficient of resistivity* α is defined as the fractional increase in resistivity per unit increase in temperature.

10. Ohm's law is obeyed by many substances, but it is not a fundamental law of nature. It fails if

(a) V depends on I non-linearly.

(b) The relation between V and I depends on the sign of V for the same absolute value of V.

(c) The relation between V and I is non-unique.

An example of (a) is when ρ increases with I (even if temperature is kept fixed). A rectifier combines features (a) and (b). *GaAs* shows the feature (c).

11. When a source of emf ε is connected to an external resistance *R*, the voltage V_{ext} across *R* is given by $V_{ext} = IR = \frac{\varepsilon}{R+r} R$

where r is the *internal resistance* of the source.

12. (a) Total resistance *R* of n resistors connected in series is given by

$$R = R_1 + R_2 + ... + R_n$$

(b) Total resistance R of n resistors connected in *parallel* is given by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + ... + \frac{1}{R_n}$$

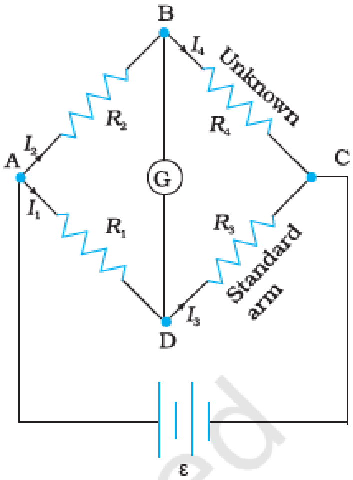
13. ***Kirchhoff's Rules*** –

(a) ***Junction Rule***: At any junction of circuit elements, the sum of currents entering the junction must equal the sum of currents leaving it.

(b) ***Loop Rule***: The algebraic sum of changes in potential around any closed loop must be zero.

H.No. 40-D, G.F., Jia Sarai, Near IIT, Hauz Khas, New Delhi-16
Phone: 011-26865455/+91-9871145498, Website: www.physicsbyfiziks.com, Email: fiziks.physics@gmail.com

14. The Wheatstone bridge is an arrangement of four resistances $-R_1, R_2,\ R_3, R_4$ as shown in the figure.



The null-point condition is given by $\frac{R_1}{R_2} = \frac{R_3}{R_4}$ using which the value of one resistance can be determined, knowing the other three resistances.

15. The *potentiometer* is a device to compare potential differences. Since the method involves a condition of no current flow, the device can be used to measure potential difference; internal resistance of a cell and compare emf's of two sources.

Physical Quantity	Symbol	Dimensions	Unit	Remark
Electric current	I	$[A]$	A	SI base unit
Charge	Q, q	$[TA]$	C	
Voltage, Electric potential difference	V	$[M L^2T^{-3}A^{-1}]$	V	Work/charge
Electromotive force	ε	$\left[ML^2T^{-3}A^{-1}\right]$	V	Work/charge
Resistance	R	$\left[ML^2T^{-3}A^{-2}\right]$	Ω	$R = V/I$
Resistivity	ρ	$\left[ML^3T^{-3}A^{-2}\right]$	$\Omega\,\text{m}$	$R = \rho l/A$
Electrical conductivity	σ	$\left[M^{-1}L^{-3}T^3A^2\right]$	S	$\sigma = 1/\rho$
Electric field	E	$\left[MLT^{-3}A^{-1}\right]$	Vm^{-1}	$\frac{\text{Electric force}}{\text{charge}}$
Drift speed	v_d	$\left[LT^{-1}\right]$	m s^{-1}	$v_d = \frac{eE\tau}{m}$
Relaxation time	τ	$[T]$	s	
Current density	j	$\left[L^{-2}A\right]$	A m^{-2}	current/area
Mobility	μ	$\left[ML^3T^{-4}A^{-1}\right]$	$\text{m}^2\text{V}^{-1}\text{s}^{-1}$	v_d/E

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Question 1: (a) Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area $1.0\times10^{-7}\,m^2$ carrying a current of $1.5\,A$. Assume that each copper atom contributes roughly one conduction electron. The density of copper is $9.0\times10^3\,kg/m^3$, 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.

Question 2: (a) 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 (1) absence of electric field. (ii) presence of electric field?

Question 3: An electric toaster uses nichrome for its heating element. When a negligibly small current passes through it, its resistance at room temperature $\left(27.0\,^0C\right)$ 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 $1.70\times10^{4}\,{}^0C^{-1}$.

Question 4: The resistance of the platinum wire of a platinum resistance thermometer at the ice point is $5\,\Omega$ and at steam point is $5.39\,\Omega$. 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.

Question 5: At room temperature $\left(27.0\,^0C\right)$ the resistance of a heating element is $100\,\Omega$. What is the temperature of the element if the resistance is found to be $117\,\Omega$, given that the temperature coefficient of the material of the resistor is $1.70\times10^{-4}\,{}^0C^{-1}$.

Question 6: A silver wire has a resistance of 2.1Ω at $27.5\,^0C$, and a resistance of $2.7\,\Omega$ at $100\,^0C$. Determine the temperature coefficient of resistivity of silver.

Question 7:

A negligibly small current is passed through a wire of length $15\,m$ and uniform cross-section $6.0\times10^{-7}\,m^2$, and its resistance is measured to be 5.0Ω. What is the resistively of the material at the temperature of the experiment?

Question 8: A battery of emf $10V$ 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?

Question 9:

(a) Three resistors $1\Omega, 2\Omega$ and 3Ω are combined in series. What is the total resistance of the combination?

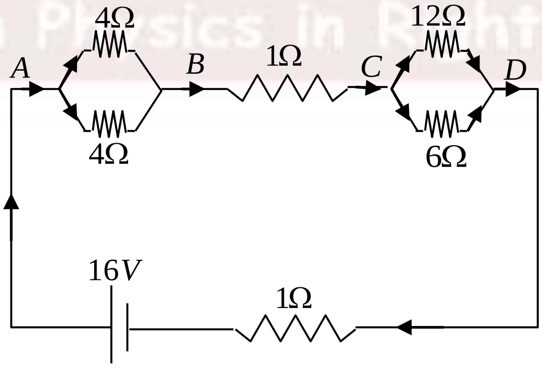
(b) If the combination is connected to a battery of emf $12V$ and negligible internal resistance, obtain the potential drop across each resistor.

Question 10:

(a) Three resistors $2\Omega, 4\Omega$ and 5Ω are combined in parallel. What is the total resistance of the combination?

(b) If the combination is connected to a battery of emf $20V$ and negligible internal resistance, determine the current through each resistor, and the total current drawn from the battery.

Question 11: A network of resistors is connected to a $16V$ battery with internal resistance of 1Ω, as shown in figure: (a) Compute the equivalent resistance of the network. (b) Obtain the current in each resistor. (c) Obtain the voltage drops V_{AB} V_{BC} and V_{CD}.



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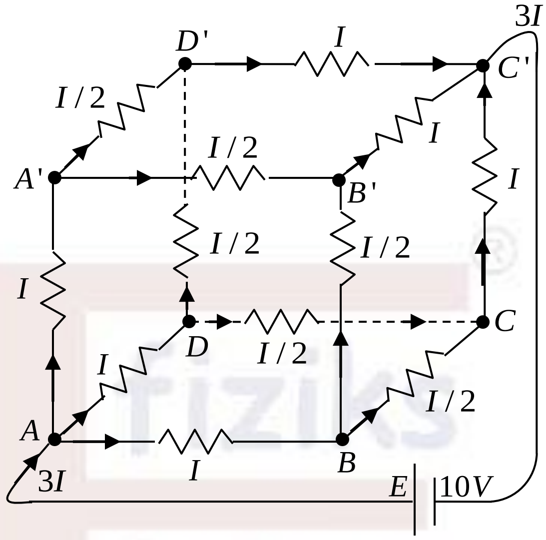
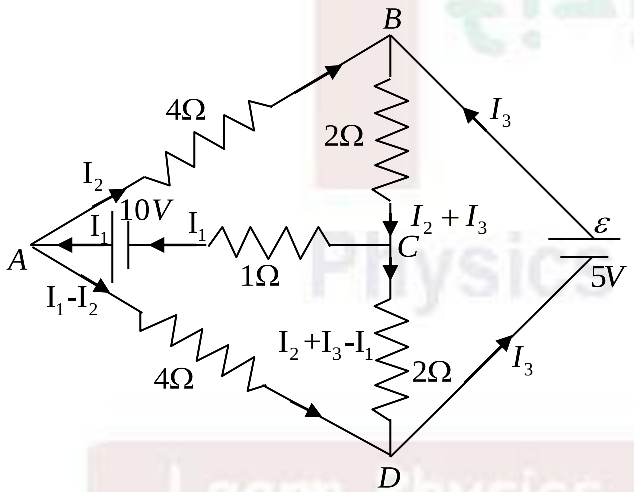
Question 12: A battery of $10V$ and negligible internal resistance is connected across the diagonally opposite corners of a cubical network consisting of 12 resistors each of resistance 1Ω (Figure below). Determine the equivalent resistance of the network and the current along each edge of the cube.

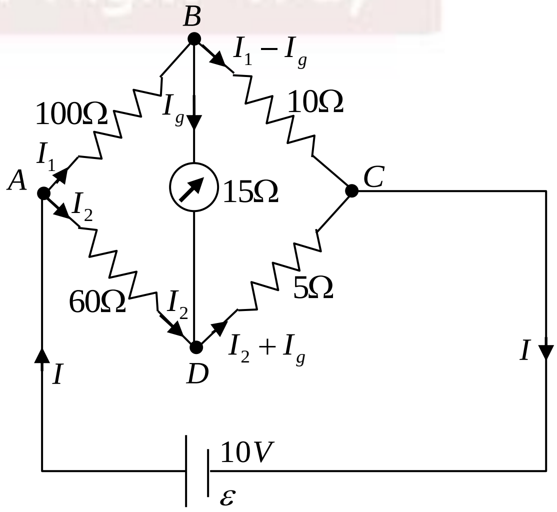


Question 13: Determine the current in each branch of the network shown in figure below.

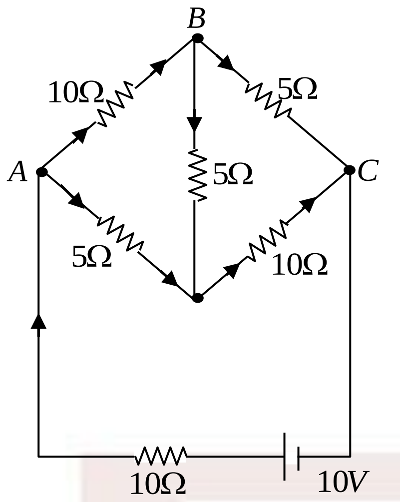


Question 14: The four arms of a Wheatstone bridge (Figure below) have the following resistances: $AB = 100\Omega, BC = 10\Omega, CD = 5\Omega$ and $DA = 60\Omega$.

A galvanometer of 15Ω resistance is connected across BD. Calculate the current through the galvanometer when a potential difference of $10V$ is maintained across AC.



Question 15: Determine the current in each branch of the network shown in figure:



Question 16:

A storage battery of emf $8.0V$ and internal resistance 0.5Ω is being charged by a $120V\ DC$ 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?

Question 17: The number density of free electrons in a copper conductor is $8.5\times10^{28}\ m^{-3}$. 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 $2.0\times10^{-6}\,m^2$ and it is carrying a current of $3.0\,A$.

Question 18:

(a) Six lead-acid type of secondary cells each of emf $2.0V$ and internal resistance 0.015Ω are joined in series to provide a supply to a resistance of 8.5Ω. What are the current drawn from the supply and its terminal voltage?

(b) A secondary cell after long use has an emf of $1.9V$ and a large internal resistance of 380Ω. What maximum current can be drawn from the cell? Could the cell drive the starting motor of a car?

Question 19: Two wires of equal length, one of aluminum and the other of copper have the same resistance. Which of the two wires is lighter? Hence explain why aluminum wires are preferred for overhead power cables.

($\rho_{Al} = 2.63\times10^{8}\,\Omega m, \rho_{Cu} = 1.72\times10^{-8}\,\Omega m$, Relative density of $Al = 2.7$, of $Cu = 8.9$)

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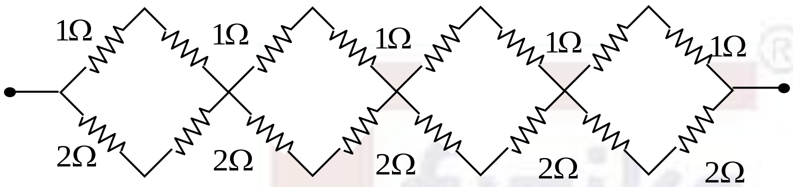
Question 20:

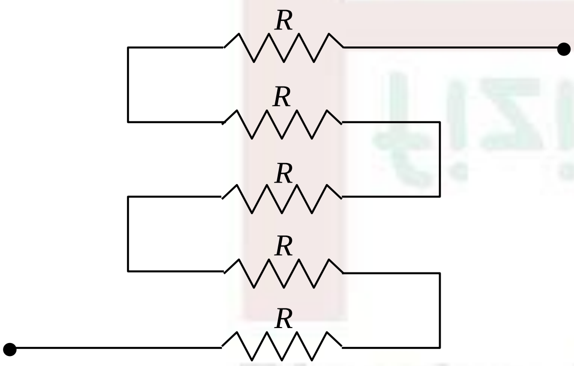
(a) Given n resistors each of resistance R, how will you combine them to get the (i) maximum (ii) minimum effective resistance? What is the ratio of the maximum to minimum resistance?

(b) Given the resistances of $1\Omega, 2\Omega, 3\Omega$, how will you combine them to get an equivalent resistance of (i) $(11/3)\Omega$ (ii) $(11/5)\Omega$ (iii) 6Ω (ii) $(6/11)\Omega$?

(c) Determine the equivalent resistance of networks shown in Figure.



(a)



(b)

Question 21: Determine the current drawn from a $12V$ supply with internal resistance 0.5Ω by the infinite network shown in Figure. Each resistor has 1Ω resistance.