CH-3

CURRENT ELECTRICITY

Exercises

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

Emf of the battery, $E = 12V$

Internal resistance of battery, $r = 0.4\,\Omega$

maximum current drawn from battery = I

According to Ohm's law,

$$E = Ir$$

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

$$\Rightarrow \frac{12}{0.4} = 30A$$

The maximum current drawn from the given battery is 30 A.

3.2 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 ~~internal~~ terminal voltage of the battery when the circuit is closed?

Ans. Emf of the battery, $E = 10\ V$
Internal resistance of the battery, $r = 3\ \Omega$

Current in the circuit, $I = 0.5\ A$

Resistance of the resistor $= R$
The relation for current using Ohm's law

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

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

$$= \frac{10}{0.5} = 20\ \Omega$$

$$\therefore R = 20 - 3 = 17\ \Omega$$

Terminal voltage of the resistor $= V$

According to Ohm's law

$$V = IR$$

$$= 0.5 \times 17$$

$$= 8.5\ V.$$

Therefore, the resistance of the ~~resto~~ resistor is ~~17~~ Ω and the terminal

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Q.3 (a) Three resistors 1Ω, 2Ω, 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 12 V and negligible internal resistance obtain the potential drop across each resistor.

Ans

(a) Three resistors of resistances 1Ω, 2Ω and 3Ω are combined in a series. Total resistance of combination is given by algebraic sum of individual resistances.

Total resistance = 1+2+3 = 6Ω

(b) Current flowing through the circuit = I
Emf of the battery ; E = 12 V

total resistances of the circuit, R = 6Ω

The relation for current using ohm's law is

$$I = \frac{E}{R} = \frac{12}{6} = 2A$$

Potential drop across 1Ω resistor = V_1
From ohm's law, the value V_1 can be obtained as

$V_1 = 2 \times 1 = 2V$ ...(i)

Potential drop across 2Ω resistor = V_2
From ohm's law, the value of V_2 can be obtained as

Potential drop across 3 Ω resistor:
From Ohm's law, the value of V_3 is obtained,

$$V_3 = 2 \times 3 = 6\ V \text{ ---(iii)}$$

Therefore, the potential drop across 1 Ω, 2 Ω and 3 Ω resistor are 2 V, 4 V, 6 V respectively.

3.4
(a) Three resistors 2 Ω, 4 Ω & 5 Ω are combined in series. What is the total resistance of the combination?

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

Ans
(a) There are three resistors of resistances,

$$R_1 = 2\Omega, \quad R_2 = 4\Omega, \quad R_3 = 5\Omega$$

They are connected in parallel. Hence total resistance (R) of the combination is given by,

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

$$= \frac{1}{2} + \frac{1}{4} + \frac{1}{5} = \frac{10+5+4}{20} = \frac{19}{20}$$

$\therefore R = \frac{20}{19} \Omega$

Therefore total resistance of the combination is $\frac{20}{19} \Omega$

(b) Emf of the battery, $V = 20V$

Current (I_1) flowing through resistor R_1 is given by

$I_1 = \frac{V}{R_1}$

$= \frac{20}{2} = 10A$

Current (I_2) flowing the Resistor R_2 is given by

$I_2 = \frac{V}{R_2}$

$= \frac{20}{4} = 5A$

Current (I_3) flowing through the resistor R_3 is given by

$I_3 = \frac{V}{R_3}$

$= \frac{20}{5} = 4A.$

Total current $= I = I_1 + I_2 \, I_3 = 10 + 5 + 4 = 19A$

~~Therefore, the current through a 100 Ω resistance of a heating element~~
~~What is the~~

Therefore, the current through each resistor is 10 A, 5 A and 4 A and the total current is 19 A

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

Ans Room temperature, $T = 27°C$
Resistance of the heating element at T, $R = 100\ \Omega$

Let T_1 is the increased temperature of the filament.

Resistance of heating element at T_1, $R_1 = 117\ \Omega$

Temperature co-efficient of the material of the filament,

$\alpha = 1.70 \times 10^{-4}\ °C^{-1}$

α is given by the relation,

$$\alpha = \frac{R_1 - R}{R\alpha}$$

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$$T_1 - 27 = \frac{117 - 100}{100(1.7 \times 10^{-4})}$$

$$T_1 - 27 = 1000$$

$$T_1 = 1027^{\circ}C$$

Therefore, at $1027^{\circ}C$, the resistance of the element is $117\,\Omega$

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

Ans Length of the wire, $l = 15$ m

Area of cross-section of the wire, $a = 6.0 \times 10^{-7}\ m^2$

Resistance of the material of the wire, $R = 5\,\Omega$

Resistivity of the material of the wire $= \rho$

Resistance is related with the resistivity as

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

$$\rho = \frac{RA}{l}$$

$$= \frac{5 \times 6 \times 10^{-7}}{15} = 2 \times 10^{-7}\ \Omega m$$

Therefore, the resistivity of the material is $2 \times 10^{-7}\ \Omega m$

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

Ans Temperature, $T_1 = 27.5°C$

Resistance of the silver wire at T_1, $R_1 = 2.1\,\Omega$

Temperature, $T_2 = 100°C$

Resistance of the silver wire at T_2, $R_2 = 2.7\,\Omega$

Temperature Co-efficient of silver = α

It is related with temperature and resistance as

$$\alpha = \frac{R_2 - R_1}{R_1 (T_2 - T_1)}$$

$$= \frac{2.7 - 2.1}{2.1(100 - 27.5)} = 0.0039°C$$

Therefore, the temperature co-efficient of silver is $0.0039°C^{-1}$

3.8 A heating element using nichrome ~~...~~ connected to a 230 V supply draws an initial current of 3.2A 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 co-efficient of resistance of nichrome averaged

Involved is $1.70 \times 10^{-4}\ C^{-1}$?

Ans Supply voltage, $V = 230\ V$

Initial current drawn, $I_1 = 3.2A$

Initial resistance = R_1 which is given by the relation,

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

$$= \frac{230}{3.2} = 71.87\ \Omega$$

Steady state value of the current, $I_2 = 2.8$

~~Resistance = R_2 which is given by the relation~~

Resistance at the steady state = R_2, which is given as

$$R_2 = \frac{230}{2.8} = 82.14\ \Omega$$

Temperature co-efficient of nichrome,
$$\alpha = 1.70 \times 10^{-4}\ {}^{\circ}C^{-1}$$

Initial temperature of nichrome, $T_1 = 27^{\circ}C$

Study State temperature reached by nichrome $= T_2$

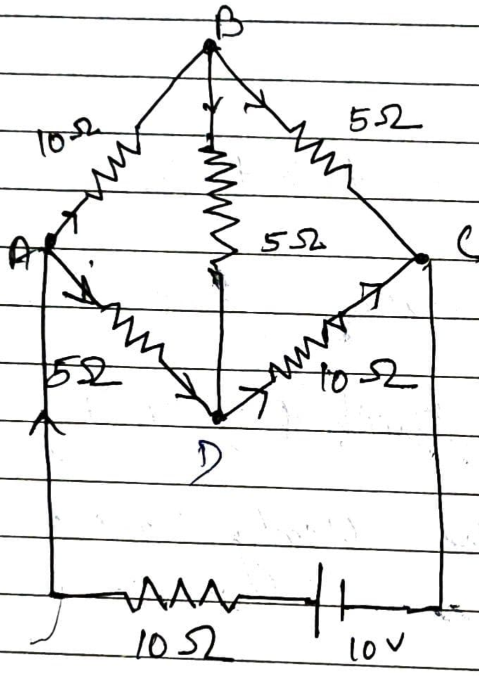
T_2 can be obtained by the relation for α,

$$\alpha = \frac{R_2 - R_1}{R_1 \ldots}$$

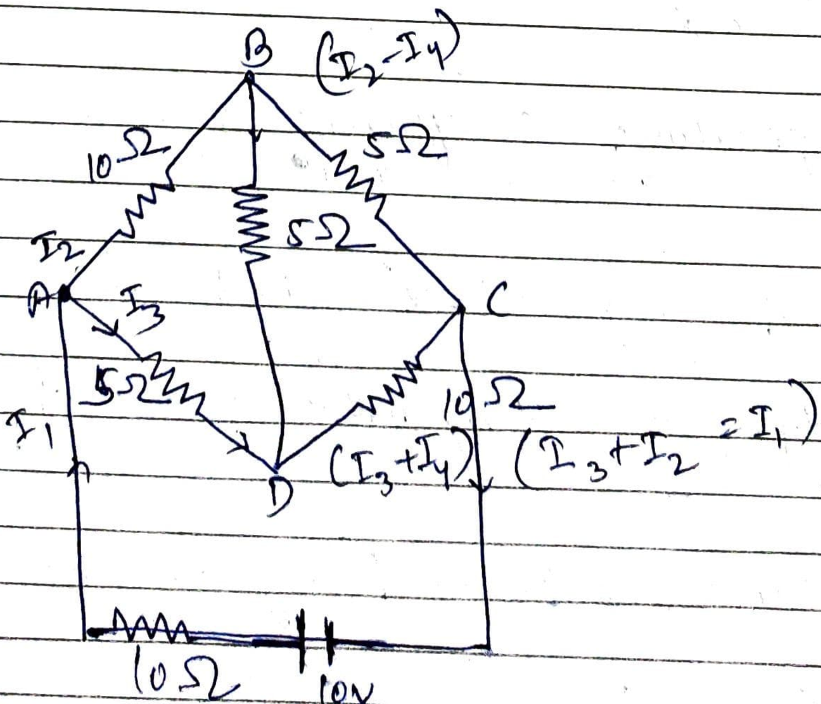
$$T_2 - 27^\circ C = \frac{82.14 - 71.87}{71.87 \times 1.7 \times 10^{-4}} = 840.5$$

$$T_2 = 840.5 + 27 = 867.5^\circ C$$

3.9 Determine the curreent in each breanch the network shown in figure



Ans



I_1 = current flowing through the outer circuit
I_2 = current flowing through branch AB
I_3 = current flowing through branch AD
$I_2 - I_4 \Rightarrow$ current flowing through branch BC

$I_3 + I_4$ = current flowing through branch CD

I_4 = current flowing through branch BD

For closed circuit ABDA, Potential is zero
i.e.
$10I_2 + 5I_4 - 5I_3 = 0$

$2I_2 + I_4 - I_3 = 0$

$I_3 = 2I_2 + I_4 \cdots (1)$

For closed circuit BCDB, potential is zero

$5(I_2 - I_4) - 10(I_3 + I_4) - 5I_4 = 0$

$5I_2 + 5I_4 - 10I_3 - 10I_4 - 5I_4 = 0$

$5I_2 - 10I_3 - 20I_4 = 0$

$I_2 = 2I_3 + 4I_4 \cdots (2)$

For closed circuit ABCFEA, potential is zero

$-10 + 10(I_1) + 10(I_2) + 5(I_2 - I_4) = 0$
$10 = 15I_2 + 10I_1 - 5I_4$
$3I_2 + 2I_1 - I_4 = 2 \cdots (3)$

From eq (1) and (2), we obtain

$I_3 = 2(2I_3 + 4I_4) + I_4$

$I_3 = 4I_3 + 8I_4 + I_4$

$-3I_3 = 9I_4$

$-3I_4 = +I_3$ ...(4)

Putting eq (4) in eq (1), we obtain

$I_3 = 2I_2 + I_4$

$-4I_4 = 2I_2$

$I_2 = -2I_4$ ...(5)

It is evident from the given figure that,

$I_1 = I_3 + I_2$ ...(6)

Putting eq (6) in eq (1), we obtain

$3I_2 + 2(I_3 + I_2) - I_4 = 2$

$5I_2 + 2I_3 - I_4 = 2$ ...(7)

Putting eq (4) and (5) in eq (7) we obtain

$5(-2I_4) + 2(-3I_4) - I_4 = 2$

$= -10I_4 - 6I_4 - I_4 = 2$

$\therefore I_4 = \frac{-2}{17}$ A.

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eq (4) reduces to

$$I_3 = -3(I_4)$$

$$= -3\left(\frac{-2}{17}\right) = \frac{6}{17} A$$

$$I_2 = -2(I_4)$$

$$\cancel{= -2\left(\frac{-2}{17}\right) - \left(\frac{-2}{17}\right) = \frac{6}{17} A}$$

$$= -2\left(\frac{-2}{17}\right) = \frac{4}{17} A$$

$$I_2 - I_4 = \frac{4}{17} - \left(\frac{-2}{17}\right) = \frac{6}{17} A$$

$$I_3 + I_4 = \frac{6}{17} + \left(\frac{-2}{17}\right) = \frac{4}{17} A$$

$$I_1 = I_3 + I_2$$

$$= \frac{6}{17} + \frac{4}{17} = \frac{10}{17} A$$

Therefore, current is branch AB $= \frac{4}{17} A$

In branch BC $= \frac{6}{17} A$

In branch CD $= \frac{-4}{17} A$

In branch AD $= \frac{6}{17} A$

In balance BD $= \left(\frac{-2}{17}\right) A$

Total current $= \frac{4}{17} + \frac{6}{17} + \frac{-4}{17} + \frac{-2}{17} = \frac{10}{17} A$

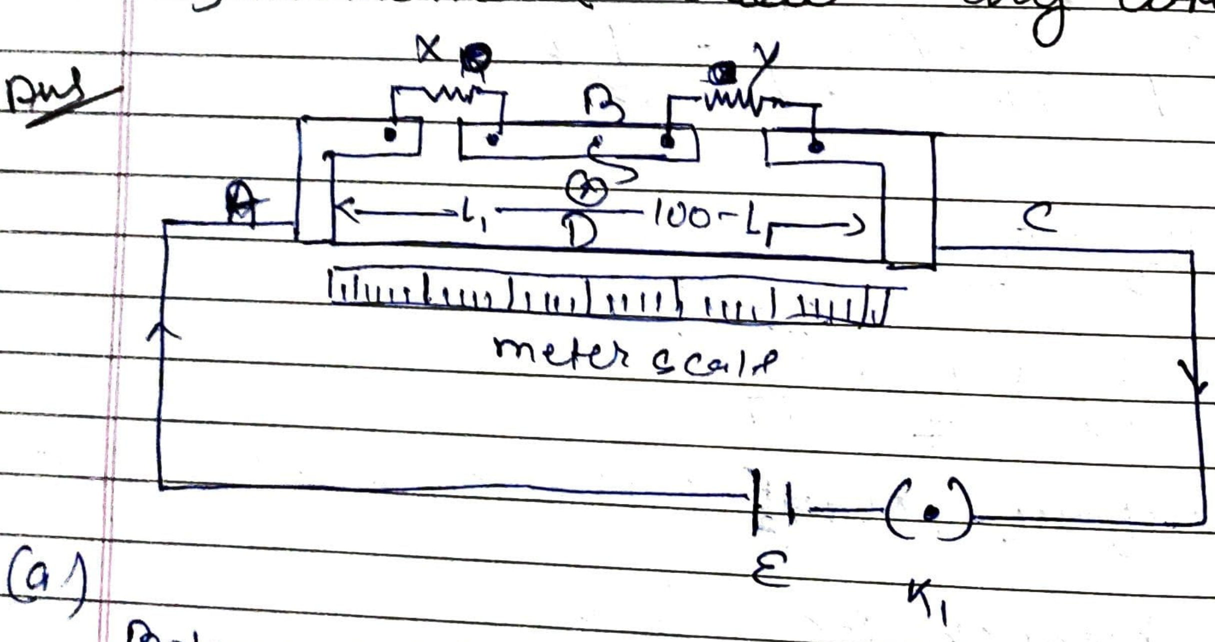
3.10

(a) In a metre bridge the balance point is found to be at 39.5 cm from the end A, when the resistor Y is of 12.5 Ω. Determine the resistance of X. Why are the connections between resistors in a wheatstone or metre bridge made of thick copper strips?

(b) Determine the balance point of the bridge above if X and Y are interchanged.

(c) What happens when the galvanometer and cell are interchanged at the balance point of the bridge? Would the galvanometer show any current?

Ans



(a)

Balance point from end A, $l_1 = 39.5$ cm

Resistance of the resistor $Y = 12.5\ \Omega$

Condition for the balance is given as

$$\frac{X}{Y} = \frac{100 - l_1}{l_1}$$

$$\Rightarrow X = \frac{100 - 39.5}{39.5} \times 12.5 = 8.2\ \Omega$$

Therefore, the resistance of resistor X is 8.2 Ω

The connection between resistors in a wheatstone or meter bridge is made of thick copper strips to minimize, the resistance which is not taken into consideration in the bridge formulae.

(b) If X and Y are interchanged, then l_1 and $100 - l_1$ get interchanged

The balance point of the bridge will be $100 - l_1$ from A

$100 - l_1 = 100 - 39.5 = 60.5$ cm

Therefore, the balance point is 60.5 cm from A.

(c) When the galvanometer and the scale are interchanged at the balanced point of the bridge, the galvanometer will show no deflection. Hence, no current would flow through the galvanometer.

3.11 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?

A. Emf of storage battery, $E = 8.0$ V

Internal resistance of the battery,
$r = 0.5 \Omega$

DC supply voltage, $V = 120$ V

Resistance of the resistors, $R = 15.5 \Omega$

effective voltage of the circuit =

R is connected to the storage battery is series. Hence it can be written as

$V^1 = V - E$

$V^2 = 120 - 8 = 112$ V

Current flowing in circuit = I, which is given by the relation

$$I = \frac{V'}{R + r}$$

$$= \frac{112}{15.5 + 5} = \frac{112}{16} = 7 \text{ A}$$

voltage across Resistor R given by the product, $IR = 7 \times 15.5 = 108.5$ V

DC supply voltage = Terminal voltage of battery + voltage drop across R Terminal voltage of battery $= 120 - 108.5 = 11.5$ V.

A series resistor in a charging circuit limits the current drawn from the external source. The current will be extremely high in its absence. This is very dangerous

3.12 In a potentiometer arrangement a cell of emf 1.25 V gives a balance point at 35 cm length of the wire. If the cell is replaced by another cell and the balance point shifts to 63 cm. What is the emf of the second cell?

Ans. Emf of the cell, $E_1 = 1.25$ V

Balance point of the ~~poti~~ potentimeter $l_1 = 35$ cm

The cell is replaced by another cell of emf E_2

New Balance point of the potentimeter $l_2 = 63$ cm

The balance condition is given by the relation

$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$

$$E_1 = E_2 \times \frac{l_2}{l_1}$$

$$= 1.25 \times \frac{63}{35} = 2.25 \text{ V}$$

Therefore, the emf of second cell is 2.25

3.13 The number density of free electrons in a copper conductor estimated in Ex. 3.1 is $8.5 \times 10^{28} m^{-3}$. 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 $2.0 \times 10^{-6} m^2$ and it is carrying a current 3.0 A.

Ans Number density of free electrons in a copper conductor, $n = 8.5 \times 10^{28} m^{-3}$ length of the copper wire, $l = 3.0 m$

Area of cross-section of the wire, $A = 2.0 \times 10^{-6} m^2$.

Current carried by the wire, $I = 3.0$ A which is given by the relation,

$I = nAeV_d$

where

e = Electric charge $= 1.6 \times 10^{-19} C$

$= \frac{\text{length of wire } (l)}{\text{Time taken to cover } (t)}$

V_d = drift velocity.

$I = nAe \frac{l}{t}$

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

$= \frac{3 \times 8.5 \times 10^{28} \times 2 \times 10^{-6} \times 1.6 \times 10^{-19}}{3.0}$

$= 2.7 \times 10^{4}$ s

Therefore time taken by an electron to drift from one end of wire to other is 2.7×10^{4} sec

3.14 Surface charge density of earth = $\sigma = 10^{-9}\ Cm^{-2}$
Current over the entire globe = $I = 1800\ A$
Radius of earth, $r = 6.37 \times 10^6\ m$

Surface area of earth
$A = 4\pi r^2$
$= 4\pi \times (6.37 \times 10^6)^2$
$= 5.09 \times 10^{14}\ m^2$

Charge of earth surface,
$q = \sigma \times A$
$= 10^{-9} \times 5.09 \times 10^{14}$
$= 5.09 \times 10^5\ C$

Time taken to neutralise the earth surface
$= t$

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

~~Current~~ t
$t = \frac{q}{I} = \frac{5.09 \times 10^5}{1800} = 282.77\ sec$

Therefore, time taken to neutralise the earth surface = 282.77 sec

3.5 (a) Number of secondary cells, n = 6
Emf of each secondary cell = E = 2.0 V
Internal resistance of each cell, r = 0.0

Series resistor is connected to the combi[...] of the cells.

Resistance of the resistor, $R = 8.5\,\Omega$

Current drawn from the supply, I, wh[...] is given by the relation:

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

$$= \frac{6 \times 2}{8.5 + 6 \times 0.015}$$

$$= \frac{12}{8.59} = 1.39\,A$$

Terminal voltage = $V = IR$

$$= 1.39 \times 8.5 = 11.87\,A$$

(a) Therefore, the current drawn from the supply is 1.39 A and termina[...] voltage is 11.87 A

(b) After a long use, emf of secondary cell, $E = 1.9\,V$

Internal resistance of the cell,

$r = 380\,\Omega$

Hence, maximum Current $= \frac{E}{r} = \frac{1.9}{380} = 0.005A$

Therefore, the maximum current drawn from the cell is 0.005 A. Since a large current is required to start the motor of a car, the cell cannot be used to start a motor.