Current Electricity
Important Formulae

1 Electric current $=\frac{Charge}{Time}$ or $I = \frac{q}{t} = \frac{ne}{t}$

2. In case of an electron revolving in a circle of radius r with speed v, period of revolution is $T = \frac{2\pi r}{v}$

Frequency of revolution, $v = \frac{1}{T} = \frac{v}{2\pi r}$, Current, $I = ev = \frac{ev}{2\pi r}$

3. Ohm's law, $R = \frac{v}{I}$ or V = IR

4. Current in terms of drift velocity (V_d) is $I = enAv_d$

5. Resistance of a uniform conductor, $R = \rho \frac{l}{A} = \frac{ml}{ne^2\tau A}$

6. Resistivity or specific resistance, $\rho = \frac{RA}{l} = \frac{m}{ne^2\tau}$

7. Conductance $= \frac{1}{R}$

8. Conductivity $= \frac{1}{Resistivity}$ or $\sigma = \frac{1}{\rho} = \frac{l}{RA}$

9. Current density $= \frac{Current}{Area}$ or $j = \frac{I}{A} = env_d$

10. Relation between current density and electric field,
$j = \sigma E$ or $E = \rho j$

11. Mobility $\mu = \frac{V_d}{E}$

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

13. The equivalent resistance R_s of a number of resistances connected in series is given by

$$R_s = R_1 + R_2 + R_3 + \ldots..$$

14. The equivalent resistance R_p of a number of resistances connected in parallel is given by

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots.$$

15. EMF of a cell, $E = \frac{W}{q}$

16. For a cell of internal resistance r, the emf is E = V + Ir = I (R + r)

17. Terminal p.d of a cell, $V = IR = \frac{E\,R}{R+r}$

18. Terminal p.d. when a current is being drawn from the cell, V = E – Ir

19. Terminal p.d. when the cell is being charged, V = E + Ir

20. Internal resistance of a cell, $r = R\,[\frac{E-V}{V}]$

21. For n cell in series, $I = \frac{nE}{R+nr}$

22. For n cells in parallel, $I = \frac{nE}{nR+r}$

23. Heat produced by electric current, $H = I^2Rt$ joule $= \frac{I^2 Rt}{4.18}$ cal

24. Electric power, $P = \frac{W}{t} = VI = I^2R = \frac{V^2}{R}$

25. Electric energy, $W = Pt = VIt = I^2Rt$

26. Potential gradient of the potentiometer wire, $k = \frac{V}{l}$

27. For comparing e.m.f.s of two cells, $\frac{E_2}{E_1} = \frac{l_2}{l_1}$

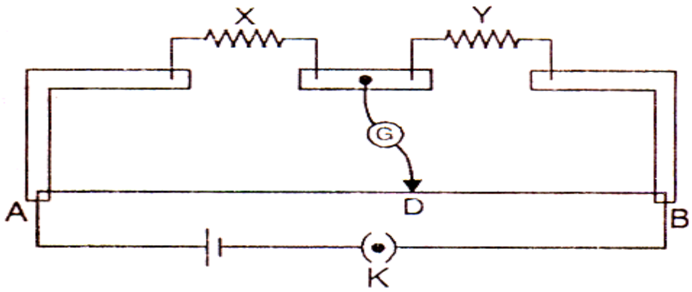
28. For measuring internal resistance of a cell, $r = \frac{l_1 - l_2}{l_2} \times R$

29. For a balanced Wheatstone bridge, $\frac{P}{Q} = \frac{R}{S}$, If X is the unknown resistance $\frac{P}{Q} = \frac{R}{X}$ or $X = \frac{RQ}{P}$

30. In a slide wire bridge, if balance point is obtained at l cm from the zero end, then $\frac{P}{Q} = \frac{R}{X} = \frac{l}{(100-l)}$

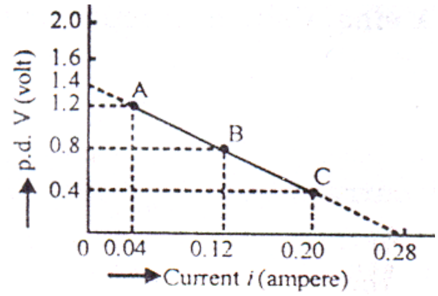
WORKSHEET (NUMERICALS) : LEVEL - I

1. What happens to the power dissipation if the value of electric current passing through a conductor of constant resistance is doubled?
2. A cell of emf 2 V and internal résistance 0.1 Ω is connected to a 3.9 Ω external resistance. What will be the current in circuit?
3. Calculate the resistivity of a material of a wire 1 m long, 0.4 mm in diameter and having a resistance of 2 ohm.
4. In a potentiometer arrangement; a cell of emf 1.25 V gives a balance point at 35.0 cm length of the wire. If the cell is replaced by another cell and the balance point shifts to 63.0 cm, what is the emf of the second cell?
5. A current is maintained in a conductor of cross-section 10^{-4} m^2. If the number density of free electrons be 9 x 10^{28} $m^{-3}$and the drift velocity of free electrons be 6.94 x10^{-9} m/s, calculate the current in the conductor.
6. A silver wire has a resistance of 2.1 Ω at 27.5 ^{0}C, and a resistance of 2.7 Ω at 100 ^{0}C. Determine the temperature coefficient of resistivity of silver.
7. Three resistors 1 Ω, 2 Ω and 3 Ω are combined in series. (a) 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, determine the total current drawn from the battery.
8. (a) Three resistors 2 Ω, 4 Ω and 5 Ω are combined in parallel. 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 and the total current drawn from the battery.
9. A Voltage of 30V is applied across a carbon resistor with first second and third rings of blue, black and yellow colours respectively. Calculate the value of current in mA, through the resistor.
10. In a meter bridge the balance point is found to be 39.5 cm from one end A, when the resistor Y is of 12.5 Ω . Determine the resistance of X.



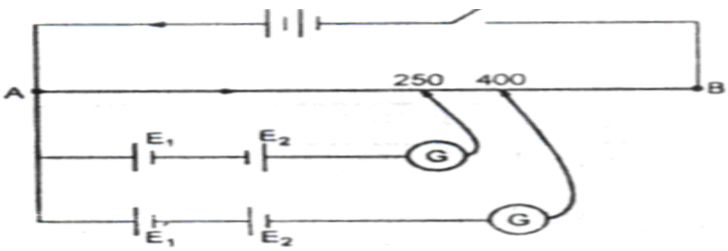
WORKSHEET (NUMERICALS) : LEVEL - II

1. A cell of emf 2 V and internal résistance 0.1 Ω is connected to a 3.9 Ω external resistance. What will be the p.d. across the terminals of the cell?
2. Out of the two bulbs marked 25W and 100W, which one has higher resistance.
3. A cell of 6 V and internal resistance 2Ω is connected to a variable resistor. For what value of current does maximum power dissipation occur in the circuit?
4. What is the largest voltage you can safely put across a resistor marked 98 Ω - 0.5 W?
5. Two heater wires of the same dimensions are first connected in series and them in parallel to a source of supply . What will be ratio of heat produced in two cases?
6. Using data given in graph determine (i) emf (ii) internal resistance of the cell.
(iii) For what current, does maximum power dissipation occur in the circuit?



7. You are given ‘n’ resistors each of resistance ‘r’. These are first connected to get of minimum possible resistance. In the second case these are again connected differently to get maximum possible resistance. Compute the ratio between the maximum and minimum values resistance so obtained.

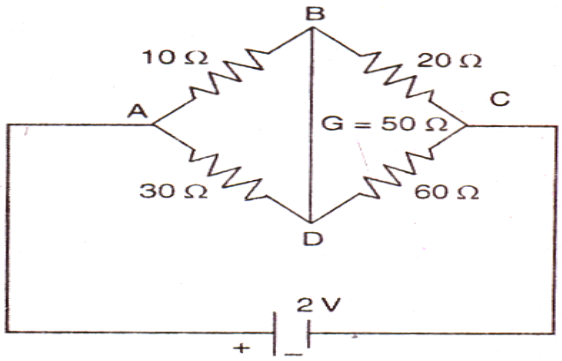
8. Two primary cells of emf E_1 and E_2 ($E_1 > E_2$) are connected to the potentiometer wire as shown in the figure. If the balancing lengths for the cells are 250 cm and 400 cm. Find the ratio of E_1 and E_2.



9. Two identical cells of emf 1.5V each are joined in parallel providing supply to an external circuit consisting of two resistors of 13Ω each joined in parallel . A very high resistance voltmeter reads the terminal voltage of the cells to be 1.4V. Find the internal resistance of each cell.
10. Three cells of emf 2V, 1.8V and 1.5V are connected in series. Their internal resistances are 0.05Ω, 0.7Ω and 1Ω respectively. If this battery is connected to an external resistance of 4Ω, calculate :
(i) the total current flowing in the circuit. (ii) the p.d. across the terminals of the cell of emf 1.5V.

WORKSHEET (NUMERICALS): LEVEL - III

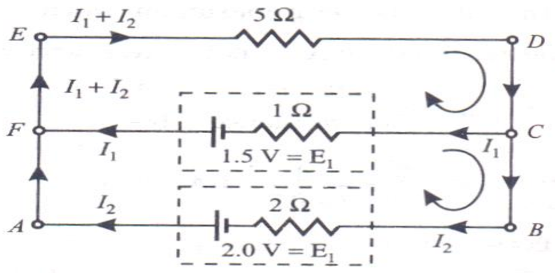
1. What is the current flowing in the arm BD of this circuit.



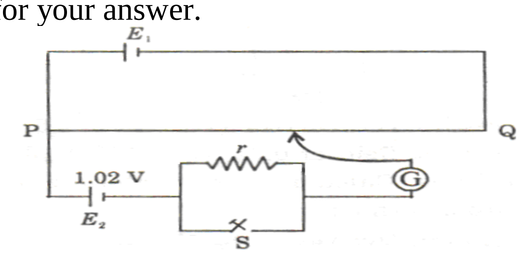
2. A cylindrical metallic wire is stretched to increase its length by 5%. Calculate the percentage change in its resistance.
3. Two cells of EMF 1V, 2V and internal resistances 2Ω and 1Ω respectively are connected in (i) series, (ii) parallel. What should be the external resistance in the circuit so that the current through the resistance be the same in the two cases? In which case more heat is generated in the cells?
4. Calculate the temperature at which the resistance of a conductor becomes 20% more than its resistance at 27^0C. The value of the temperature coefficient of resistance of the conductor is 2×10^{-4} / K.
5. Two metallic wires of the same material have the same length but cross sectional area is in the ratio of 1:2. They are connected (i) in series and (ii) in parallel. Compare the drift velocities of electrons in the two wires in both the cases.
6. Two wires X, Y have the same resistivity but their cross-sectional areas in the ratio 2:3 and lengths in the ratio 1:2. They are first connected in series and then in parallel to a dc source. Find out the ratio of the drift speeds of the electrons in the two wires for the two cases.

7. A room has AC run for 5 hours a day at a voltage of 220V. The wiring of the room consists of Cu of 1 mm radius and a length of 10m. Power consumption per day is 10 commercial units. What fraction of it goes in the joule heating in the wires? What would happen if the wiring is made of Al of the same dimensions? [$\rho_{Cu} = 1.7 \times 10^{-8}$ Ωm, $\rho_{Al} = 2.7 \times 10^{-8}$ Ωm]

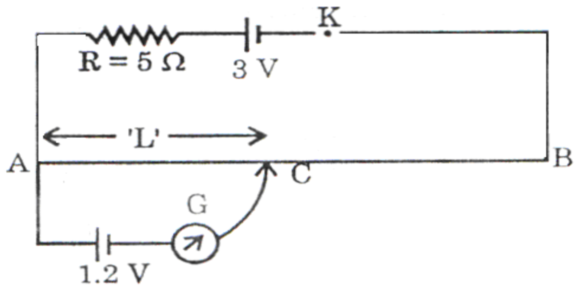
8. Two cells of emf 1.5 V and 2V and internal resistance 1 Ω and 2 Ω are connected in parallel to pass a current in the same direction through an external resistance of 5 Ω. (a) Draw Circuit Diagram. (b) Using Kirchhoff's laws, calculate the current through each branch of the circuit and p.d. across the 5 Ω resistor.



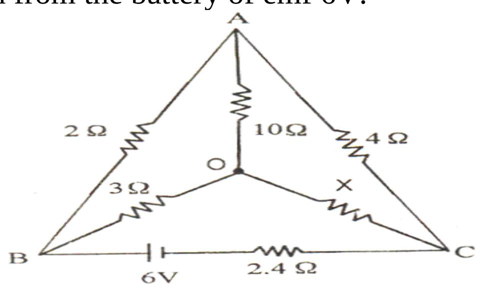
9. E_2 =1.02V, PQ=1m. When switch S open, null position is obtained at a distance of 51 cm from P. Calculate (i) potential gradient (ii) emf of the cell E_1 (iii) when switch S is closed, will null point move towards P or Q. Give reason for your answer.



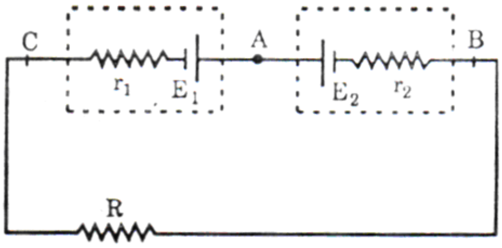
10. AB=100 cm, R_{AB}=10Ω. Find the balancing length AC.



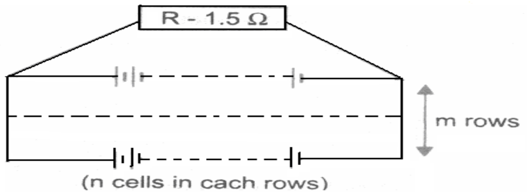
11. Find the value of the unknown resistance X in the circuit, if no current flows through the section AO. Also calculate the current drawn from the battery of emf 6V.



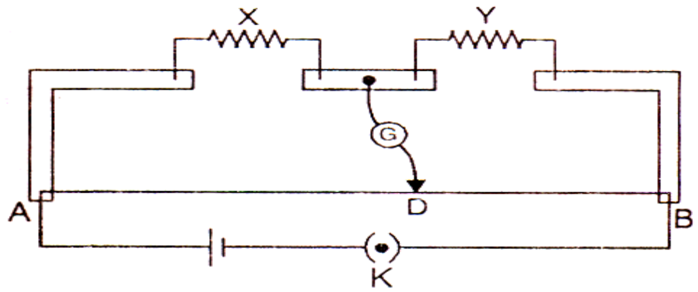
12. E_1 = 2V, E_2 = 4V, r_1 = 1Ω, r_2 = 2Ω, R = 5Ω
Calculate (i) current (ii) p. d. between B and A (iii) p. d. between A and C.



12 cells, each of emf 1.5V and internal resistance 0.5Ω, are arranged in m rows each containing n cells connected in series, as shown. Calculate the values of n and m for which this combination would send maximum current through an external resistance of 1.5Ω



13. The given figure shows the experimental set up of a meter bridge. The null point is found to be 60cm away from the end A with X and Y in position as shown. When a resistance of 15Ω is connected in series with 'Y', the null point is found to shift by 10cm towards the end A of the wire. Find the position of null point if a resistance of 30Ω were connected in parallel with 'Y'.



14. A cell of unknown emf E and internal resistance r, two unknown resistances R_1 and R_2 ($R_2>R_1$) and a perfect ammeter are given. The current in the circuit is measured in five different situations: (i) Without any external resistance in the circuit, (ii) With resistance R_1 only, (iii) With resistance R_2 only, (iv) With both R_1 and R_2 used in series combination and (v) With R_1 and R_2 used in parallel combination. The current obtained in the five cases are 0.42A, 0.6A, 1.05A, 1.4A, and 4.2A, but not necessarily in that order. Identify the currents in the five cases listed above and calculate E, r, R_1 and R_2.

ANSWERS: LEVEL - I

Q.No.	Expected Answers
1	P = I^2R. When electric current is doubled I' = 2 I Power becomes $P' = I'^2$R = $4I^2$R = 4P
2	I = $\frac{E}{r+R}$ = 0.5A
3	$\rho = R\frac{A}{l} = R\frac{\pi D^2}{4l} = 2\times\frac{3.14\times(0.4\times10^{-3})^2}{4\times1} = 2.5\times10^{-7}\,\Omega m$
4	$\frac{E_1}{E_2} = \frac{l_1}{l_2} \Rightarrow \frac{1.25}{E_2} = \frac{35}{63} \Rightarrow E_2 = \frac{63}{35}\times1.25 = 2.25V$
5	$I = neAv_d = 9\times10^{28}\times1.6\times10^{-19}\times10^{-4}\times6.94\times10^{-9} = 10A$
6	$\alpha = \frac{R_2 - R_1}{R_1(T_2 - T_1)} \Rightarrow \alpha = \frac{2.7-2.1}{2.1(100-27.5)} = 0.0039^0 C^{-1}$
7	(a) Total resistance $R_S = R_1 + R_2 + R_3 = 1+2+3 = 6\Omega$ (b) Current drawn from the battery $I = \frac{E}{R_S} = \frac{12}{6} = 2A$
8	(a) Total resistance, $\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{2}+\frac{1}{4}+\frac{1}{5} = \frac{19}{20}\Omega \Rightarrow R_P = \frac{20}{19}\Omega$ (b) Current drawn from the battery $I = \frac{E}{R_P} = \frac{20}{\left(\frac{20}{19}\right)} = 19A$
9	R = 60 x $10^4\,\Omega$ and $I = \frac{V}{R} = \frac{30}{60\times10^4} = 0.5\times10^{-4}A = 0.05mA$
10	$X = \frac{l}{100-l}Y = \frac{39.5}{100-39.5}\times12.5 = 8.16\Omega$

ANSWERS: LEVEL - 2

Q.No.	Expected Answers
1	I = $\frac{E}{r+R}$ = 0.5A. V = E – IR = 1.95 V
2	R = $\frac{V^2}{P}$ ⇒ R α $\frac{1}{P}$. The bulb marked 25W has higher resistance than the bulb marked 100W.
3	For maximum power dissipation, r = R = 2Ω . I = $\frac{E}{r+R}$ = 1.5A
4	V = $\sqrt{PR}$ = 7Volt.
5	$H_S = \frac{V^2}{2R}$ and $H_P = \frac{2V^2}{R}$ ∴ $H_S : H_P$ = 1:4
6	(i) Emf = 1.4V (ii) Internal resistance of the cell r = $\frac{E-V}{I}$ = 5Ω (iii)For maximum power dissipation I = $\frac{E}{r+R}$ = .14A

7	To get minimum, resistors are connected in parallel. $R_p = \frac{r}{n}$ To get maximum, resistors are connected in series. $R_s = nr$ $$\frac{R_S}{R_P} = \frac{nr}{\left(\frac{r}{n}\right)} = n^2$$
8	$E_1 - E_2 = 250\ \phi$ $E_1 + E_2 = 400\ \phi$ $\Rightarrow E_1 : E_2 = 13 : 3$
9	1.5 – Ir = 13 I and 1.4 = 1.5 – Ir $\Rightarrow$ Ir = 0.1 $\Rightarrow$ I = $\frac{1.4}{13}$ A and r = $\frac{13}{14}\Omega$
10	(i) I = $\frac{2+1.8+1.5}{0.05+0.7+1+4} = \frac{5.3}{5.75} =$ 0.92A (ii) The p.d. across the terminals of the cell of emf 1.5V = E – Ir = 0.58V

ANSWERS: LEVEL - 3

Q.No.	Expected Answers
1	The Wheatstone bridge is a balanced because $\frac{P}{Q} = \frac{R}{S}$. Hence there is no current flowing through arm BD..
2	$Al = A'l' \Rightarrow A = \frac{105}{100}A'$ $R = \rho\frac{l}{A} \Rightarrow \frac{R_1}{R_2} = \frac{lA'}{l'A} \Rightarrow R_2 = (1.05)^2 R_1$ % Change = $\frac{R_2 - R_1}{R_1}$X100 = 10.25%
3	For series combination, $I_S = \frac{3}{3+R}$ and For series combination, $I_P = \frac{\frac{5}{3}}{\frac{2}{3}+R} = \frac{5}{3R+2}$ Given $I_S = I_P \Rightarrow R = \frac{9}{4} = 225\ \Omega$. In series combination more heat is generated in the cells
4	$R_2 = R_1[1+\alpha(T_2 - T_1)] \Rightarrow R + 0.2R = R[1 + 2\times10^{-4}(T_2 - 300)] \Rightarrow T_2 = 1300K$
5	(i) In series, current in both wires is same. Drift velocity $v_d = \frac{I}{neA}, \frac{v_{d1}}{v_{d2}} = \frac{A_2}{A_1} = \frac{2}{1}$ (ii) In parallel, p.d. across the both wires is same. Drift velocity $v_d = \frac{eV\tau}{ml}$ $\frac{v_{d1}}{v_{d2}} = \frac{l_1}{l_2} = \frac{1}{1}$.
6	(i) When wires are connected in series: In series, the current remains the same; so we use the relation i = neAv_d, Resistivity, $\rho = \frac{m}{ne^2\tau} \Rightarrow n = \frac{m}{e^2\tau\rho} \Rightarrow i = \left\{\frac{m}{e^2\tau\rho}\right\}eAv_d$ or $i = \frac{m}{e\tau\rho}Av_d \Rightarrow v_d \propto \frac{1}{A} \therefore \frac{(v_d)_X}{(v_d)_Y} = \frac{A_Y}{A_X} = \frac{3}{2}$ (ii) When wires are connected in parallel: In parallel, the potential difference is same. In this case we apply the formula for drift velocity.

	$v_d = \frac{e\tau E}{m} = \frac{e\tau V}{ml}$ For same temperature τ is same, so $v_d \propto \frac{1}{l} \therefore \frac{(v_d)_X}{(v_d)_Y} = \frac{l_Y}{l_X} = \frac{2}{1}$
7	Power consumption = 2 units/hour = 2kW = 2000 J/s I = P/V = 9A Power loss in wire = $I^2R = I^2\rho l/A$ = 4 J/s =0.2% of total power consumption Power loss in Aluminium wire = 4 ρ_{Cu}/ρ_{Al} = 6.4 J/s = 0.32 % of total power consumption
8	(b) $I = I_1+I_2$, $5I+ I_1 = 1.5$ and $5I+2I_2 = 2$ $\Rightarrow$ I = 5/17 A I_1 = 0.5/17 A and I_2 = 4.5/17 A. P.d. across 5 Ω resistance = 5I = 1.47V
9	(i) Potential gradient $k = \frac{E_2}{l_2}$ = 0.02V/cm (ii) emf of the cell $E_1 = k\,l_{PQ}$ = 2V When switch S is closed, null point is not affected because no current drawn from cell E_1 at the null point.
10	$I = \frac{E_1}{R_{AB}+R}$ = 0.2A ; $\phi = \frac{IR_{AB}}{l_{AB}}$ = 2 x 10^{-2} V/cm ; $E_2 = \phi\, l_{AC} \Rightarrow l_{AC}$ = 60cm.
11	ABCD is a balanced Wheatstone bridge since there is no current in section AO. $\frac{P}{Q} = \frac{R}{S} \Rightarrow \frac{2}{4} = \frac{3}{X} \Rightarrow$ X = 6Ω, R_{BC} = 3.6 + 2.4 = 6Ω , Current drawn by circuit = 1A.
12	Net emf = $E_2 - E_1$ = 2V, Total resistance = R+ r_1 + r_2 = 0.25A (i) I = 0.25A (ii) $V_{AB} = E_2 - Ir_2$ = 3.5V (iii) $V_{AC} = E_1 + Ir_1$ = 2.25V
13	Resistance of one row = nr, Resistance of m rows $R_{int} = \frac{nr}{m}$ For max. current, $R_{int} = R_{eext} \Rightarrow \frac{nr}{m} = R \Rightarrow 0.5n = 1.5m \Rightarrow n = 3m$ ……….(1) Total cells = nm…….. (2) ; On solving (1) & (2), n=6 and m= 2
14	Formula $\frac{X}{Y} = \frac{l}{100-l}$, $\frac{X}{Y} = \frac{60}{40} \Rightarrow 2X = 3Y$ ……………..(1) When a resistance of 15Ω is connected in series with 'Y' $\frac{X}{Y+15} = \frac{50}{50} \Rightarrow X = Y + 15$ ………(2) On solving (1) & (2), X = 45 Ω , Y = 30Ω When a resistance of 30Ω is connected in series with 'Y' $\frac{X}{Y+30} = \frac{l}{100-l} \Rightarrow l = 75cm$ from end A.
15	(i) $I_1 = \frac{E}{r}$, (ii) $I_2 = \frac{E}{r+R_1}$, (iii) $I_3 = \frac{E}{r+R_2}$, (iv) $I_4 = \frac{E}{r+R_1+R_2}$, (v) $I_5 = \frac{E}{r+\frac{R_1R_2}{R_1+R_2}}$ This is clear that $I_1 > I_5 > I_2 > I_3 > I_4$. Hence $I_1 = 4.2A, I_5 = 1.4A, I_2 = 1.05A, I_3 = 0.6A, I_4 = 0.42A$. Putting these values in (i) to (v) and on solving, $E = 4.2V, R_1 = 3\Omega, R_2 = 6\Omega, r = 1\Omega$