Current Electricity

Electric Current: Current is a tensor quantity, while current density is a vector. Conventionally direction of current is taken along the direction of flow of positive charges. In metals charge carriers are only free electrons. In liquids charge carriers are positive and negative ions. In gases charge carries are positive ions and electrons. And in semi -conductors charge carriers are electrons and holes.

Drift velocity of electrons in a metal is of the order of 10^{-3} m/ s and is directly proportional to electric field (or potential difference applied). The current flows with speed of light. Mean velocity of electrons due to their thermal agitations (or random motion) is zero; while mean speed depends on temperature.

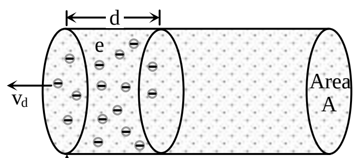


Figure : 6.1

Electric Current $I = \frac{q}{t} = \frac{dq}{dt}$ (scalar quantity)

Current Density $J = \frac{I}{A_n}$

Where, A_n = normal area

Current $I = \vec{j}\,\vec{A} = JA\cos\theta = neAv_d$ where v_d is drift velocity.

Ohm's Law

Under same physical conditions the voltage is directly proportional to electric current in dc circuits. $V = RI$ (Under same physical conditions)

- The resistance of a conductor is directly proportional to length and inversely proportional to cross-sectional area.
- At a given temperature, the specific resistance of a conductor is independent of dimensions but depends only on material.
- If a given mass of a material is stretched to decreases its cross-section, then its length also increase and then $R \propto l/a$ or $R\alpha \frac{l}{r^2}$.

Resistance $R = \frac{\rho l}{A} = \frac{2m}{ne^2\tau}.\frac{l}{A}$

Where,

ρ = Specific resistance

τ = Relaxation time,

n = Electron density in metre^{-3}

Stretching of Wire: If a conducting wire stretches, its length increases, area of cross -section decreases so resistance increases but volume remains constant.

Suppose for a conducting wire before stretching its length $= l_1$, area of cross -section $= A_1$, radius $= r_1$, diameter $= d_1$, and resistance $R_1 = \rho\frac{l_1}{A_1}$

After stretching length $= l_2$, area of cross-section $= A_2$, radius $= r_2$, diameter $= d_2$ and resistance $= R_2 = \rho\frac{l_2}{A_2}$

Ratio of resistances before and after stretching

$$\frac{R_1}{R_2} = \frac{l_1}{l_2}\times\frac{A_2}{A_1} = \left(\frac{l_1}{l_2}\right)^2 = \left(\frac{A_2}{A_1}\right)^2 = \left(\frac{r_2}{r_1}\right)^4 = \left(\frac{d_2}{d_1}\right)^4$$

- If length is given then, $R \propto l^2 \Rightarrow \frac{R_1}{R_2} = \left(\frac{l_1}{l_2}\right)^2$
- If radius is given then, $R \propto \frac{1}{r^4} \Rightarrow \frac{R_1}{R_2} = \left(\frac{r_2}{r_1}\right)^4$
- Resistance of a conducting body is not unique but depends on its length and area of cross -section i.e., how the potential difference is applied. See the following figures

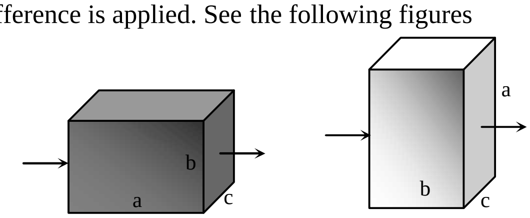


Figure: 6.2

For length = a, area of cross-section = b × c

Resistance $R = \rho\left(\frac{a}{b\times c}\right)$

For length = b, Area of cross-section = a × c

Resistance $R = \rho\left(\frac{b}{a \times c}\right)$

- Conductance $K = \frac{1}{R}$
- Specific resistance $\rho = \frac{ne^2\tau}{2m}$ (for metals)
- Conductivity $\sigma = \frac{1}{\rho} = \frac{2m}{ne^2\tau}$ (for metals)
- Ohm's Law $J = \sigma E$ (alternative form) or $V = Ri$. For Ohmic conductors (like iron, silver), $V - I$ graph is a straight line. And for non -ohmic conductors (like junction diode, torch bulb, thermistor), $V - I$ graph is non-linear.

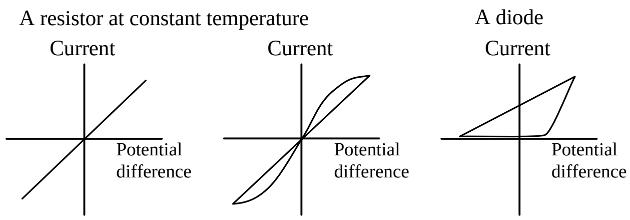


Figure: 6.3

- Effect of temperature on resistance: Generally metals offer more electrical resistance if temperature is increased. On the other hand the resistance offered by a non -metallic substance normally decreases with increase of temperature. $R_t = R_0(1 + \alpha t + \beta t^2); \alpha > \beta$.
- For linear variation or if t is not too large $R_t = R_0(1 + \alpha t)$. For metals α is positive and for semi -conductor α is negative.

Combination of Resistances

- Resistance in series:

  Net resistance $R = R_1 + R_2 + R_3$

  Net potential difference, $V = V_1 + V_2 + V_3$

  Current $i = i_1 + i_2 + i_3$ (same in all resistance)
- Resistances in parallel:

  Net resistance R is given by $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

  Net current $i = i_1 + i_2 + i_3$

  Potential difference $V = V_1 + V_2 + V_3$ (same across all resistances).

Note

Decoration of lights in festivals is an example of series grouping whereas all household appliances are connected in parallel grouping.

- Using n conductors of equal resistance, the number of possible combinations is 2^{n-1}.
- If the resistances of n conductors are totally different, then the number of possible combinations will be 2^n.
- If n identical resist ances are first connected in series and then in parallel, the ratio of the equivalent resistance is given by $\frac{R_s}{R_p} = \frac{n^2}{1}$.
- If a wire of resistance R is cut in n equal parts and then these parts are collected to form a bundle, then equivalent resistance of combination will be $\frac{R}{n^2}$.
- If equivalent resistance of R_1 and R_2 in series and parallel be R_s and R_p respectively then $R_1 = \frac{1}{2}\left[R_s + \sqrt{R_s^2 - 4R_sR_p}\right]$

  $R_2 = \frac{1}{2}\left[R_s - \sqrt{R_s^2 - 4R_sR_p}\right]$.

Internal Resistance r: Potential difference across the terminals of a cell $V = E - ir$ where r = internal resistance, E = emf of cell here $V = iR$. Internal resistance $r = \left(\frac{E}{V} - 1\right)R$ Where, R = external resistance.

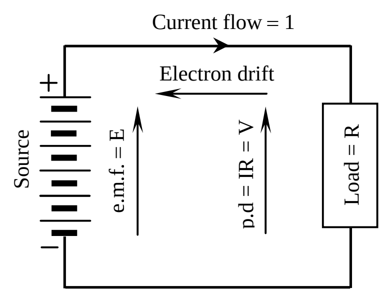


Figure : 6.4

Kirchhoff's Laws

Kirchhoff's first law (or current law) is based on conservation of charge. Junction Law: $\Sigma i = 0$ at any junction.

Current law: The sum of the currents into any junction is equal to the sum of the current out.

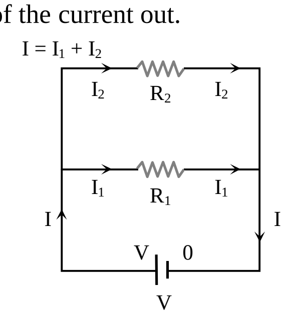


Figure: 6.5

For any branch of the circuit, the current out of the branch must be equal to the current into the branch. This is required by the conservation of electric charge. Any cross -section of the circuit must carry the total current. For a series circuit, the current is the same at any point in the circuit.

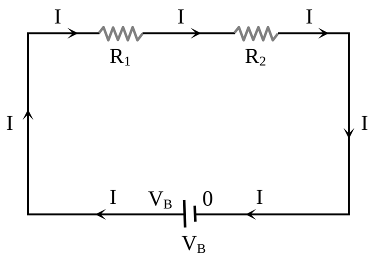


Figure: 6.6

Kirchhoff's second law (or voltage law) is based on conservation of energy. Loop law $\Sigma V = 0$ or $\Sigma iR = \Sigma E$ for a closed circuit.

Voltage Law: The net voltage drop around any closed loop path must be zero.

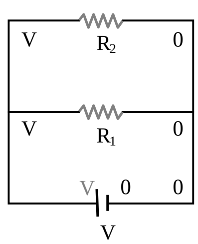


Figure: 6.7

For any path you follow around the circuit, the sum of the voltages rises (like batteries) must equal the sum of the voltage drops. Voltage represents energy per unit charge, and conservation of energy deman ds that energy is neither created nor destroyed.

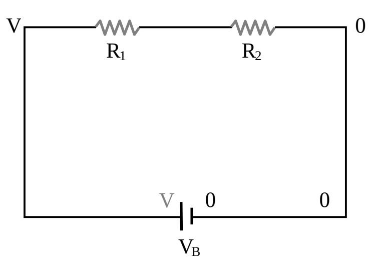


Figure: 6.8

Equivalent Resistance for Cube: If a skeleton cube is made with 12 equal resistances each having resistance R then the net resistance across:

- The longest diagonal (AG or EC or BH or DF) $= \frac{5}{6}R$
- The diagonal of face (e.g. AC, ED…, etc.) $= \frac{3}{4}R$
- A side (e.g. AB, BC, etc.) $= \frac{7}{12}R$

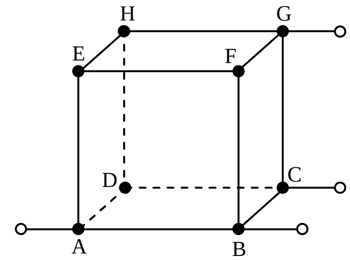


Figure: 6.9

Wheatstone's Bridge: When Wheatstone's bridge is balanced, the resistance in arm BD may be ignored while calculating the equivalent resistance of bridge between A and C.

- Condition of balance is $\frac{P}{Q} = \frac{R}{S}$
- Equivalent resistance between terminals connected to battery at balance.

$$\frac{1}{R_{eq}} = \frac{1}{P+Q} + \frac{1}{R+S}$$

- When battery and galvanometer arms of a Wheatstone's bridge are interchanged, the balance position remains undisturbed while sensitivity of bridge charges.
- A Wheatstone's bridge i s most sensitive if its all resistance P, Q, R, S are equal.

Met er Bridge: Unknown resistance $S = \frac{100 - l}{l} \times R$, where, l = balancing length in cm.

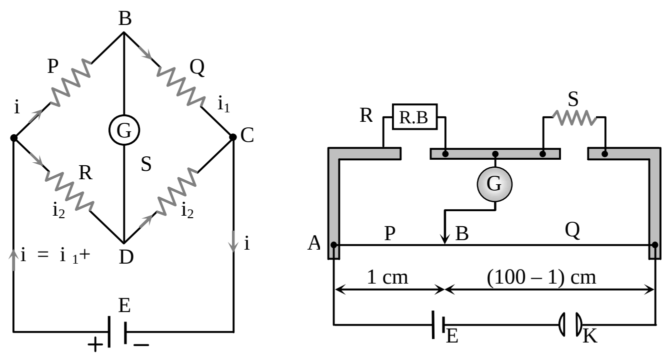


Figure : 6.10

Potentiometer: If L is length of potentiometer wire AB, Potential gradient $k = \frac{V_{AB}}{L} = i\rho$, where ρ is resistance per unit length of potentiometer wire

- EMF of a cell, $E = kl$
- For same potential gradient $\frac{E_1}{E_2} = \frac{l_1}{l_2}$

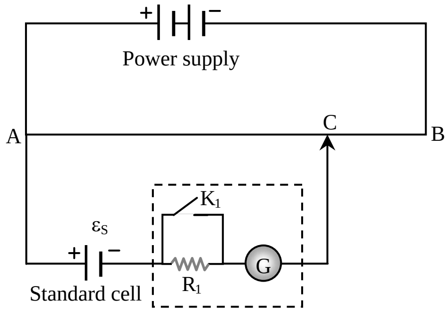


Figure: 6.11

Combinations of Cells

- In series: If n identical cells are in series $i = \dfrac{nE}{R + nr}$.

  Where,

  R = external resistance;

  r = internal resistance of a cell and

  E = emf of a cell

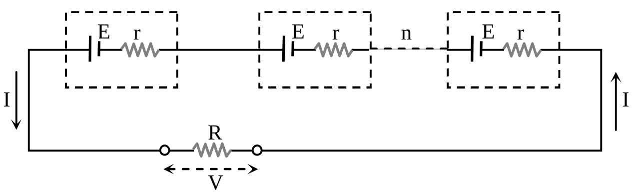


Figure: 6.12

- In parallel: n cells in parallel $i = \dfrac{E}{R + \left(\dfrac{r}{n}\right)}$

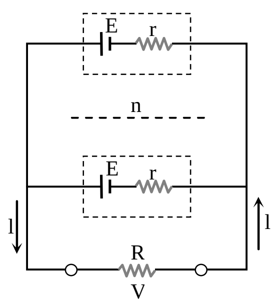


Figure: 6.13

- Mixed grouping: n cells in a now, m such rows in parallel

  $i = \dfrac{mnE}{mR + nr}$.

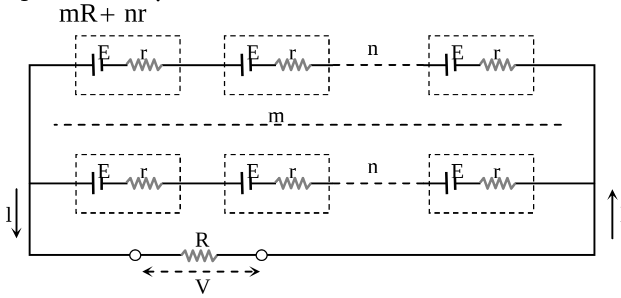


Figure: 6.14

For maximum current $R_{ext} = R_{int}$ or $R = \dfrac{nr}{m}$

- If two cells of different emfs are correctly connected in series $i = \dfrac{E_1 + E_2}{R + r_1 + r_2}$.
- If two cells of different emfs are wrongly connected in series i.e., (positive terminals connected together) $i = \dfrac{E_1 - E_2}{R + r_1 + r_2}$.

Some Standard Results for Equivalent Resistance

Case (i):

$$R_{AB} = \frac{R_1R_2(R_3 + R_4) + (R_1 + R_2)R_3R_4 + R_5(R_1 + R_3)(R_2 + R_4)}{R_5(R_1 + R_2 + R_3 + R_4) + (R_1 + R_2)(R_3 + R_4)}$$

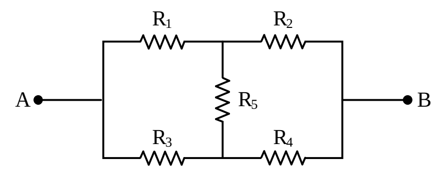


Figure: 6.15

Case (ii): $R_{AB} = \dfrac{2R_1R_2 + R_5(R_1 + R_2)}{2R_5 + R_1 + R_2}$

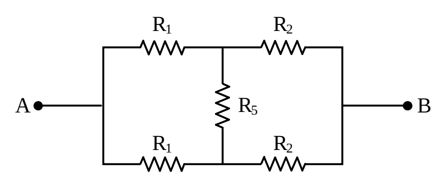


Figure: 6.16

Case (iii): $R_{AB} = \dfrac{1}{2}(R_1 + R_2) + \dfrac{1}{2}\left[(R_1 + R_2)^2 + 4R_3(R_1 + R_2)\right]^{1/2}$

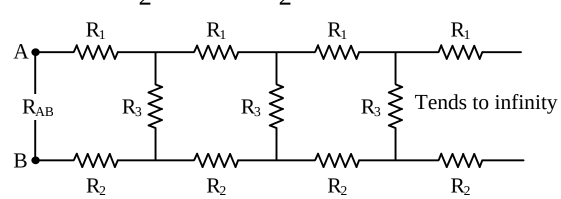


Figure: 6.17

Case (iv): $R_{AB} = \dfrac{1}{2}R_1\left[1 + \sqrt{1 + 4\left(\dfrac{R_2}{R_1}\right)}\right]$

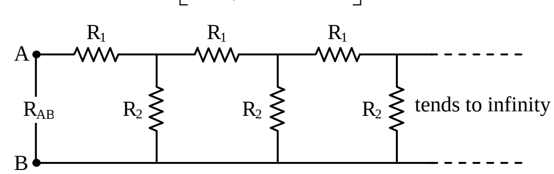


Figure: 6.18

- Transformation between Y or star and delta connection

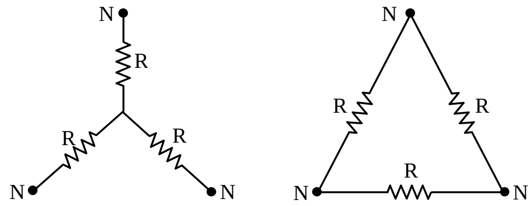


Figure: 6.19

- The transformation from Δ-load to Y-load. To compute the impedance R_y at a terminal node of the Y circuit with impedances R', R'' to adjacent node i $R_y = \frac{R'R''}{\Sigma R_\Delta}$ n the Δ circuit by $R_y = \frac{R'R''}{\Sigma R_\Delta}$ where R_Δ are all impedances in the Δ circuit. This yields the specific formulae

$$R_1 = \frac{R_b R_c}{R_a + R_b + R_c},\quad R_2 = \frac{R_a R_c}{R_a + R_b + R_c} \text{ and}$$

$$R_3 = \frac{R_a R_c}{R_a + R_b + R_c}$$

- Equations for the transformation from Y-load to Δ-load The general idea is to compute an impedance R_Δ in the Δ circuit by $R_\Delta = \frac{R_p}{R_{opposite}}$.

  Where, $R_p = R_1R_2 + R_2R_3 + R_3R_1$ is the sum of the products of all pairs of impedances in the Y circuit and $R_{opposite}$ is the impedance of the node in the Y circuit which is opposite the edge with R_Δ. The formula for the individual edges are thus

$$R_a = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_1},\quad R_b = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_2} \text{ and}$$

$$R_c = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_3}$$

$$Z_1 = \frac{Z_{12}Z_{13}}{Z_{12} + Z_{13} + Z_{23}}$$

$$Z_{12} = Z_1Z_2\left(\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3}\right)$$

Faraday's Laws

Mass of element deposited at electrode (i) $m = Zq = Zit$,

(ii) $\frac{m_1}{m_2} = \frac{W_1}{W_2}$

$Z =$ Electrochemical equivalent

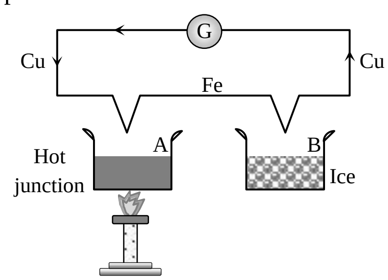
$W =$ Chemical equivalent

Where, $W = \frac{\text{atomic weight}}{\text{valency}}$

Faraday number $F = \frac{W}{Z} = 69500$Coul/g-equivalent

Thermoelectric Effects

- A thermocouple is a temperature-measuring device consisting of two dissimilar conductors that contact each other at one or more spots, where a temperature differential is experienced by the different conductors (or semiconductors). It produces a voltage when the temperature of one of the spots differs from the reference temperature at other parts of the circuit. Thermocouples are a widely used type of temperature sensor for measurement and control, and can also convert a temperature gradient into electricity. Commercial thermocouples are inexpensive, interchangeable, are supplied with standard connectors, and can measure a wide range of temperatures. Seebeck effect is reversible. Seebeck effect is reversible. The direction of current in Cu-Fe thermocouple is for Cu to Fe through hot junction and in Bi-Sb couple it is form Bi to Sb through hot junction. Bi-Sb couple is most sensitive. Induced e.m.f. a thermocouple $E = at + bt^2$



Variation of thermo e.m.f. with temperature

Figure: 6.20

- Neutral temperature: $t_n = -\left(\frac{a}{2b}\right)°C$

Neutral temperature is independent of temperature of cold junction. At neutral temperature, the thermo e.m.f. is maximum; but thermoelectricpower is zero.

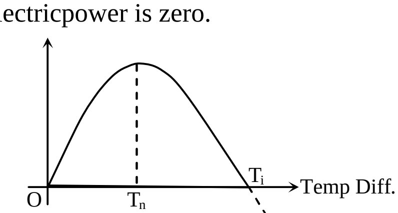


Figure: 6.21

- Temperature of inversion depends on temperature of cold junction (t_0) $t_n - t_0 = t_i - t_n$.

  Inversion temperature when t_0 is 0° then t_i is $= 2t_n = -\left(\frac{a}{b}\right)°C$.

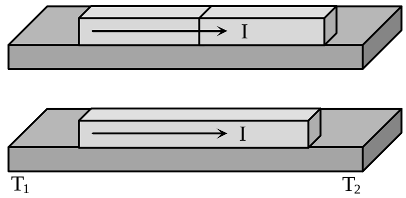


Figure: 6.22

- Thermoelectric power of a thermocouple, $P = \frac{dE}{dt} = a + bt$.
- Peltier coefficient, $\pi = T\frac{dE}{dt}$

  $\Pi_{12} I \equiv$ Power evolved at junction

- Thomson coefficient, $\sigma = -T\frac{dP}{dt}$

  $\tau I \nabla T \equiv$ Power evolved per unit volume
- Thomson coefficient of lead is zero

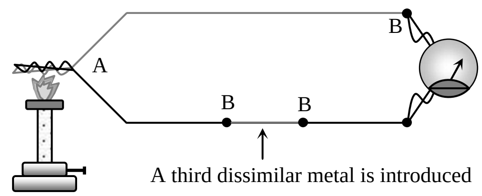
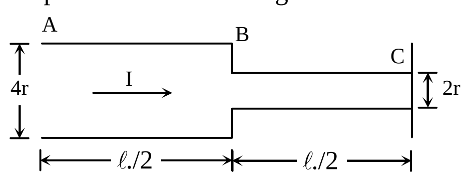


Figure: 6.23

- Law of Intermediate metals: $E_{AB} + E_{BC} = E_{AC}$

Multiple Choice Questions

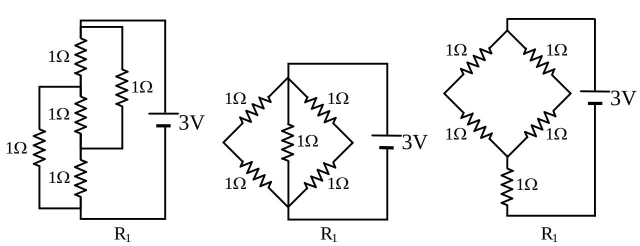
1. Consider a cylindrical element as shown in the figure. Current flowing the through element is I and resistivity of material of the cylinder is ρ. Choose the correct option out the following.



   (a) Power loss in first half is four times the power loss in second half
   (b) Voltage drop in first half is twice of voltage drop in second half
   (c) Current density in both halves are equal
   (d) Electric field in both halves is equal

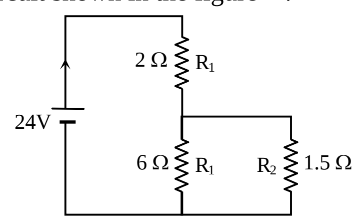
2. A resistance of 2Ω is connected across one gap of a meter-bridge (the length of the wire is 100 cm) and an unknown resistance, greater than 2Ω, is connected across the other gap. When these resistance are interchanged, the balance point shifts by 20 cm. Neglecting any corrections, the unknown resistance is :
   (a) $3\,\Omega$ (b) 4Ω
   (c) 5Ω (d) 6Ω

3. Figure shows three resistor configurations R_1, R_2 and R_3 connected to 3 V battery. If the power dissipated by the configuration R_1, R_2 and R_3 is P_1, P_2 and P_3, respectively, then



   (a) $P_1 > P_2 > P_3$ (b) $P_1 > P_3 > P_2$
   (c) $P_2 > P_1 > P_3$ (d) $P_3 > P_2 > P_1$

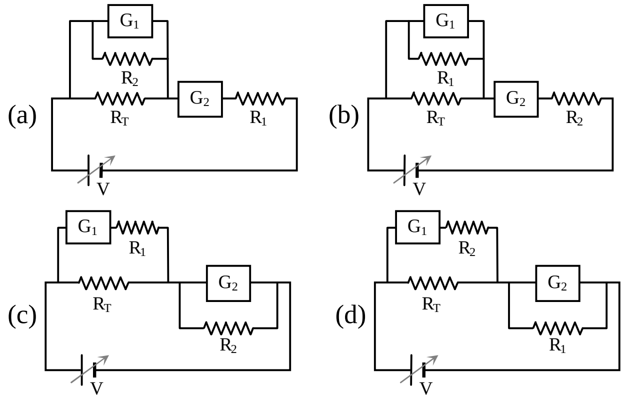
4. For the circuit shown in the figure :



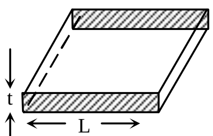
   (a) the current I through the battery is 7.5 mA
   (b) the potential difference across is R_L 18 V
   (c) ratio of powers dissipated in R_1 and R_2 is 3
   (d) if R_1 and R_2 are interchanged, magnitude of the power dissipated in R_L will decrease by a factor of 9.

5. Incandescent bulbs are designed by keeping in mind that the resistance of their filament increases with the increase in temperature. If at room temperature, 100 W, 60 W and 40 W bulbs have filament resistances R100, R60 and R40, respectively, the relation between these resistances is :
   (a) $\frac{1}{R_{100}} = \frac{1}{R_{40}} + \frac{1}{R_{60}}$ (b) $R_{100} = R_{40} + R_{60}$
   (c) $R_{100} > R_{60} > R_{40}$ (d) $\frac{1}{R_{100}} > \frac{1}{R_{60}} > \frac{1}{R_{40}}$

6. To verify Ohm's law, a student is provided with a test resistor R_T, a high resistance R_1, a small resistance R_2, two identical galvanometers G_1 and G_2, and a variable voltage source V. The correct circuit to carry out the experiment is :

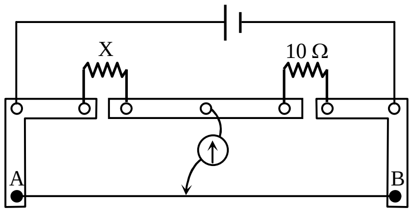


7. Consider a thin square sheet of side L and thickness t, made of a material of resistivity ρ. The resistance between two opposite faces, shown by the shaded areas in the figure is :



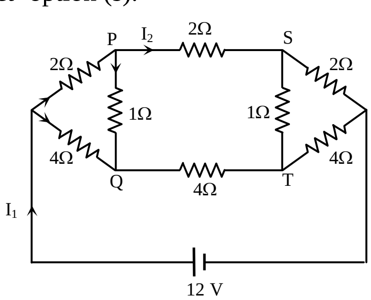
(a) directly proportional to L
(b) directly proportional to t
(c) independent of L
(d) independent of t

8. A meter bridge is set -up as shown, to determine an unknown resistance 'X' using a standard 10 ohm resistor. The galvanometer shows null point when tapping -key is at 52 cm mark. The end -corrections are 1 cm and 2 cm respectively for the ends A and B. The determined value of 'X' is:



(a) 10.2 ohm
(b) 10.6 ohm
(c) 10.8 ohm
(d) 11.1 ohm

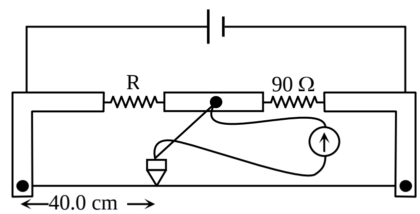
9. For the resistance network shown in the figure, choose the correct option (s).



(a) The current through PQ is zero
(b) $I_1 = 3A$
(c) The potential at S is less than that at Q
(d) $I_2 = 2A$

10. The supply voltage to a room is 120 V. The resistance of the lead wires is 6 **Ω**. A 60 W bulb is already switched on. What is the decrease of voltage across the bulb, when a 240 W heater is switched on in parallel to the bulb?
(a) zero volt
(b) 2.9 volt
(c) 13.3 volt
(d) 10.04 volt

11. During an experiment with a meter bridge, the galvanometer shows a null point when the jockey is pressed at 40.0 cm using a standard resistance of 90 **Ω**, as shown in the figure. The least count of the scale used in the meter bridge is 1 mm. The unknown resistance is

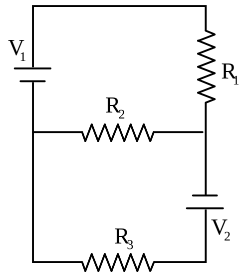


(a) $60 \pm 0.15\,\Omega$
(b) $135 \pm 0.56\,\Omega$
(c) $60 \pm 0.25\,\Omega$
(d) $135 \pm 0.23\,\Omega$

12. In a large building, there are 15 bulbs of 40 W, 5 bulbs of 100 W, 5 fans of 80 W and 1 heater of 1 kW. The voltage of the electric mains is 220 V. The minimum capacity of the main fuse of the building will be:
(a) 12 A
(b) 14 A
(c) 8 A
(d) 10 A

13. Heater of an electric kettle is made of a wire of length L and diameter d. It takes 4 minutes to raise the temperature of 0.5 kg water by 40 K. This heater is replaced by a new heater having two wires of the same material, each of length L and diameter 2 d. The way these wires are connected is given in the options. How much time in minutes will it take to raise the temperature of the same amount of water by 40 K?
(a) 4 if wires are in parallel
(b) 2 if wires are in series
(c) 1 if wires are in series
(d) 0.5 if wires are in parallel

14. Two ideal batteries of emf V_1 and V_2 and three resistances R_1, R_2 and are R_3 connected as shown in the figure. The current in resistance R_2 would be zero if



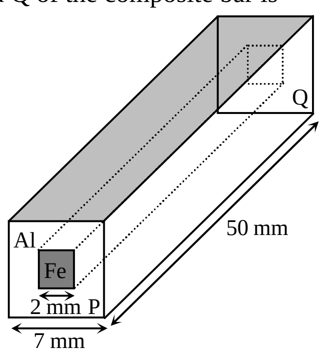
(a) $V_1 = V_2$ and $R_1 = R_2 = R_3$

(b) $V_1 = V_2$ and $R_1 = 2R_2 = R_3$

(c) $V_1 = 2V_2$ and $2R_1 = 2R_2 = R_3$

(d) $2V_1 = V_2$ and $2R_1 = R_2 = R_3$

15. In an aluminium (Al) bar of square cross section, a square hole is drilled and is filled with iron (Fe) as shown in the figure. The electrical resistivities of Al and Fe are $2.7 \times 10^{-8}\,\Omega$m and $1.0 \times 10^{-7}\,\Omega$ m, respectively. The electrical resistance between the two faces P and Q of the composite bar is



(a) $\frac{2475}{64}\,\mu\Omega$ (b) $\frac{1875}{64}\,\mu\Omega$

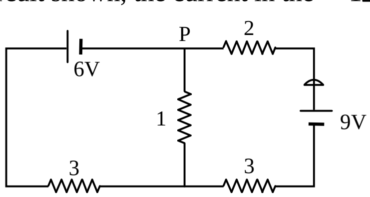
(c) $\frac{1875}{49}\,\mu\Omega$ (d) $\frac{2475}{132}\,\mu\Omega$

16. When 5V potential difference is applied across a wire of length 0.1 m, the drift speed of electrons is $2.5 \times 10^{-4}\,\text{ms}^{-1}$. If the electron density in the wire is $8 \times 10^{28}\,\text{m}^{-3}$, the resistivity of the material is close to:

(a) $1.6 \times 10^{-8}\,\Omega$m (b) $1.6 \times 10^{-7}\,\Omega$ m

(c) $1.6 \times 10^{-6}\,\Omega$m (d) $1.6 \times 10^{-5}\,\Omega$m

17. In the ci rcuit shown, the current in the 1Ω resistor is:



(a) 1.3 A, from P to Q

(b) 0 A

(c) 0.13 A, form Q to P

(d) 0.13 A, from P to Q

18. A galvanometer having a coil resistance of 100 Ω gives a full scale deflection, when a current of 1 mA is passed through it. The value of the resistance, which can convert this galvanometer into ammeter giving a full scale deflection for a current of 10 A, is:

(a) 0.01Ω (b) $2\ \Omega$

(c) $0.1\ \Omega$ (d) $3\ \Omega$

19. The temperature dependence of resistances of Cu and undoped Si in the temperature range 300 –400 K, is best described by:

(a) Linear increase for Cu, linear increase for Si

(b) Linear increase for Cu, exponential increase for Si

(c) Linear increase for Cu, exponential decrease for Si

(d) Linear decrease for Cu, linear decrease for Si

20. Consider two identical galvanometers and two identical resistors with resistance R. If the internal resistance of the galvanometers $R_C < R/2$, which of the following statement(s) about any one of the galvanometers is (are) true?

(a) The maximum voltage range is obtained when all the components are connected in series

(b) The maximum voltage range is obtained when the two resistors and one galvanometer are connected in series, and the second galvanometer is connected in parallel to the first galvanometer

(c) The maximum current range is obtained when all the components are connected in parallel

(d) The maximum current range is obtained when the two galvanometers are connected in series, and the combination is connected in parallel with both the resistors.

21. In the circuit shown below, the key is pressed at time $t = 0$. Which of the following statement(s) is (are) true?

(a) The voltmeter displays –5 V as soon as the key is pressed, and displays +5 V after a long time

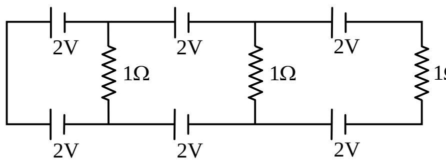
(b) The voltmeter will display 0 V at time $t = \ell n\,2$ seconds

(c) The current in the ammeter becomes 1/ e of the initial value after 1 second

(d) The current in the ammeter becomes zero after a long time

22. Which of the following statements is false?
 (a) A rheostat can be used as a potential divider.
 (b) Kirchhoff's second law represents energy conservation
 (c) Wheatstone bridge is the most sensitive when all the four resistance are of the same order of magnitude.
 (d) In a balanced Wheatstone bridge if the cell and the galvanometer are exchanged, the null point is disturbed.

23. In the above circuit the current in each resistance is:



(a) 0.25 A (b) 0.5 A
(c) 0 A (d) 1 A

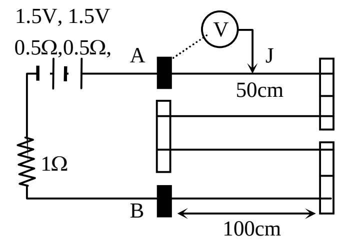
24. When a current of 5 mA is passed through a galvanometer having a coil of resistance 15 **Ω**, it shows full scale deflection. The value of the resistance to be put in series with the galvanometer to convert it into a voltmeter of range 0 –10 V is
(a) 2.045×10^3 Ω (b) 2.535×10^3 Ω
(c) 4.005×10^3 Ω (d) 1.985×10^3 Ω

25. Two batteries with e.m.f. 12 V and 13 V are connected in parallel across a load resistor of 10 **Ω**. The internal resistances of the two batteries are 1 **Ω** and 2 **Ω** respectively. The voltage across the load lies between
(a) 11.7 V and 11.8 V (b) 11.6 V and 11.7 V
(c) 11.5 V and 11.6 V (d) 11.4 V and 11.5 V

26. On interchanging the resistances, the balance point of a meter bridge shifts to the left by 10 cm. The resistance of their series combination is 1 k **Ω**. How much was the resistance on the left slot before interchanging the resistances?
(a) 910 Ω (b) 990 Ω
(c) 505 Ω (d) 550 Ω

27. In a potentiometer experiment, it is found that no current passes through the galvanometer when the terminals of the cell are connected across 52 cm of the potentiometer wire. If the cell is shunted by a resistance of 5 **Ω**, a balance is found when the cell is connected across 40 cm of the wire. Find the internal resistance of the cell.
(a) 2.5 Ω (b) 1 Ω
(c) 1.5 Ω (d) 2 Ω

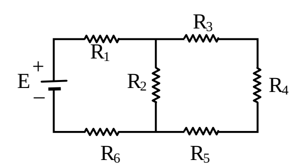
28. In the circuit shown, a four-wire potentiometer is made of a 400 cm long wire, which extends between A and B. The resistance per unit length of the potentiometer wire is r = 0.01 **Ω**/cm. If an ideal voltmeter is connected as shown with jockey J at 50 cm from end A, the expected reading of the voltmeter will be:



(a) 0.20 V (b) 0.25 V
(c) 0.75 V (d) 0.50V

29. A cell of internal resistance r drives current through an external resistance R. The power delivered by the cell to the external resistance will be maximum when :
(a) R = 1000 r (b) R = 0.001 r
(c) R = 2 r (d) R = r

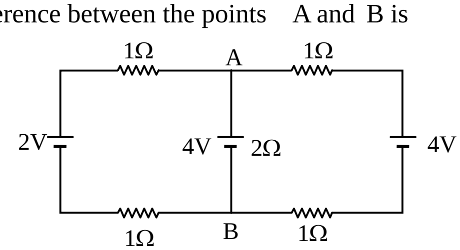
30. In the figure shown, what is the current (in Ampere) drawn from the battery? You are given:
R_1 = 15 **Ω**, R_2 = 10 **Ω**, R_3 = 20 **Ω**, R_4 = 5 **Ω**, R_5 = 25 **Ω**, R_6 = 30 **Ω**, E = 15 V



(a) 7/18 (b) 13/24
(c) 9/32 (d) 20/3

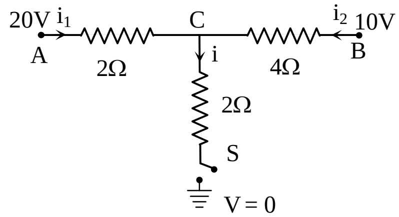
31. A carbon resistance with colour band is 200 **Ω** . If red band is replaced by green band then the new resistance is:
(a) 500Ω (b) 300Ω
(c) 400Ω (d) 100Ω

32. An electric circuit is shown in figure. The potential difference between the points A and B is



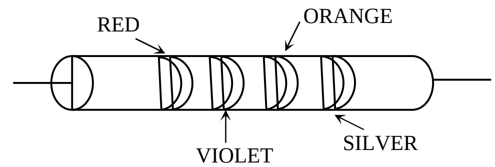
(a) $\frac{10}{3}$ (b) $\frac{20}{3}$
(c) $\frac{5}{3}$ (d) $\frac{7}{3}$

33. When the switch S, in the circuit shown is closed, then the value of current i will be:



(a) 3 A (b) 5A (c) 4A (d) 2A

34. A resistance is sown in the figure. Its value and tolerance are given respectively by:



(a) 27 KΩ, 20% (b) 270KΩ, 5%

(c) 270KΩ, 10% (d) 27KΩ, 10%

35. A copper wire is stretched to make it 0.5% longer. The percentage chare in its electrical resistance if its volume remains unchanged is :

(a) 2.5% (b) 0.5%

(c) 1.0% (d) 2.0%

ANSWERS and SOLUTIONS

1. (b) $\frac{R_1}{R_2} = \frac{A_1}{A_2} = \frac{4}{1}$

$\Rightarrow \frac{P_1}{P_2} = \frac{I^2 R_1}{I^2 R_2} = \frac{4}{1}$

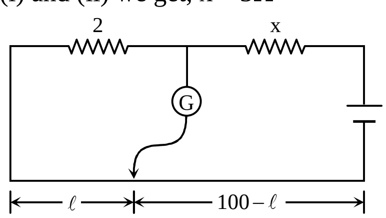
$\Rightarrow \frac{V_1}{V_2} = \frac{IR_1}{IR_2} = \frac{4}{1}$

$\Rightarrow \frac{J_1}{J_2} = \frac{1}{4}$

2. (a) $\frac{2}{x} = \frac{\ell}{100-\ell}$ . . .(i)

$\frac{x}{2} = \frac{\ell+20}{80-\ell}$ . . .(ii)

Solving (i) and (ii) we get, x = 3Ω



3. (c) $P = \frac{V^2}{R}$

$\Rightarrow R_1 = 1\,\Omega,\ R_2 = \frac{1}{2}\,\Omega,\ R_3 = 2\,\Omega$

$\therefore P_2 > P_1 > P_3$

4. (a, b) $24 - 2\times10^3\, I - 6\times10^3 (I-i) = 0$

$\Rightarrow 24 - 2\times10^3\, I - 1.5\times10^3 i = 0$

Hence, I = 7.5 mA

i = 6 mA

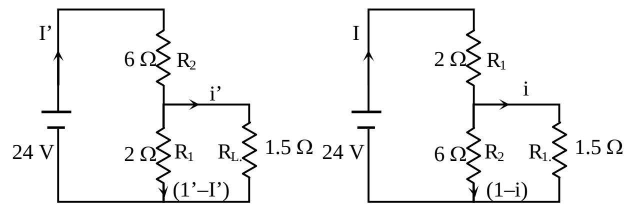
$\Rightarrow 24 - 6\times10^3 I' - 2\times10^3 (I' - i') = 0$

$\Rightarrow 24 - 6\times10^3 I' - 1.5\times10^3 i' = 0$

$\Rightarrow I' = 3.5\,mA$

$\Rightarrow i' = 2\,mA$

$\Rightarrow \frac{P_1}{P_2} = \frac{6^2}{2^2} = 9$



5. (d) Power $\propto 1/R$

6. (c) G_1 is acting as voltmeter and G_2 is acting as ammeter.

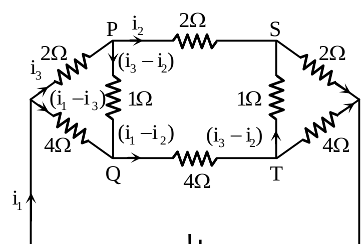
7. (c) $R = \frac{\rho L}{Lt}$

8. (b) $\frac{X}{10} = \frac{53}{50}$

$\Rightarrow X = \frac{53}{50}\times10 = 10.6\,\Omega$

(Include the end corrections as well in the calculated length)

9. (a, b, c, d) $i_{ST} = (i_1 - i_2) - (i_1 - i_3)$



$= (i_3 - i_2)$ (TtoS)

$-2i_3 - (i_3 - i_2)1 + 4(i_1 - i_3) = 0$

$-7i_3 + i_2 + 4i_1 = 0$

$7i_3 = i_2 + 4i_1$ . . .(i)

$-2i_2 + (i_3 - i_2)1 + (i_1 - i_2)4 + (i_3 - i_2)1 = 0$

$-8i_2 + 2i_3 + 4i_1 = 0$ . . .(ii)

$\Rightarrow \quad i_3 = 4i_2 - 2i_1$

$\Rightarrow \quad 7i_3 = i_2 + 4i_1$

$(i_3 = 4i_2 - 2i_1) \times 7$
$\;\; - \quad - \quad +$

$\Rightarrow \quad 0 = -27i_2 + 18i_1$

$\Rightarrow \quad 2i_1 = 3i_2$

$\Rightarrow \quad i_3 = 4i_2 - 2\left(\frac{3i_2}{2}\right)$ (From eq. (ii))

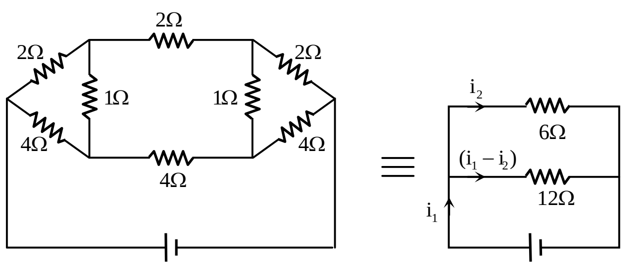
$\Rightarrow \quad i_3 = 4i_2 - 3i_2$

$\Rightarrow \quad i_3 = i_2$

$\Rightarrow \quad i_3 - i_2 = 0$

$\Rightarrow \quad i_{PQ} = 0$ . . . Ans. (a)

$\Rightarrow \quad i_{PQ} = i_{ST} = 0$



Eq. circuit will be

$\Rightarrow \quad i_2 = \frac{12}{6} = 2A$ . . . Ans. (d)

$(i_1 - i_2) = \frac{12}{12} = 1A$

$i_1 = 3A$ . . . Ans. (b)

$V_p > V_S$ (As current is going from P to S)

$V_p = V_Q$

$\Rightarrow \quad V_Q > V_S$ . . . Ans. (c)

Alternate : This can also be judge directly by symmetry which shows current in PQ and ST is 0.

10. (0) $R_b = \frac{(120)^2}{60} = 240\,\Omega$

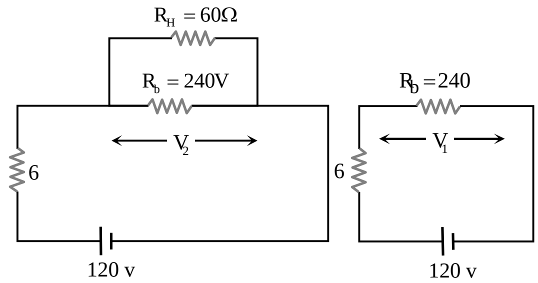
$R_H = \frac{240}{4} = 60\,\Omega$

$V_1 = 120\,\frac{240}{246} = 120\,.\frac{40}{41}V$

$V_2 = 120\frac{(R_b \parallel R_H)}{(R_b \parallel R_H) + 6} = 120\frac{48}{54} = 120\frac{8}{9}V$

Loss in potential $= V_1 - V_2$

$= 120\left(\frac{40}{41} - \frac{8}{9}\right) = 10.40\,V.$



(No option matches)

11. (c) $R = \frac{x}{100 - x}90$

$\therefore \quad R = 60\Omega$

$\frac{dR}{R} = \frac{100}{(x)(100 - x)}dx$

$\therefore \quad dR = 0.25\Omega$

$\therefore \quad dR = \frac{100}{(40)(60)}0.1 \times 60 = 0.25\Omega$

Alternatively

$\frac{dR}{R} = \frac{0.1}{40} + \frac{0.1}{60}$

12. (a) $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$

$\Rightarrow \quad P = \frac{V^2}{R_{eq}} = \frac{V^2}{R_1} + \frac{V^2}{R_2} + ...$

$= 15 \times 40 + 5 \times 100 + 80 \times 5 + 1 \times 1000 = 2500$ w

$\Rightarrow \quad P = VI$

$\Rightarrow \quad P = 2500 = 220I$

$\Rightarrow \quad I = \frac{250}{22} = \frac{125}{11}$

13. (b, d) $H = \frac{V^2}{R}4 = \frac{V^2}{R/2}t_1\,\frac{V^2}{R/8}t_2$

$\Rightarrow \quad t_1 = 2$ min.

$\Rightarrow \quad t_2 = 0.5$ min.

14. (a, b, d) $V_1 = \frac{R_1(V_1 + V_2)}{R_1 + R_3}$

$\Rightarrow \quad V_1R_3 = V_2R_1$

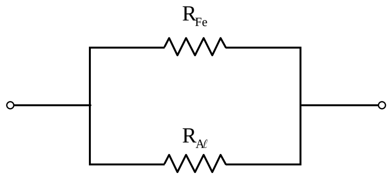
$V_2 = \frac{R_3(V_1 + V_2)}{R_1 + R_3}$

$\Rightarrow \quad V_2R_1 = V_2R_3$

15. (b) $R_{Fe} = \frac{\rho_{Fe} \times 50 \times 10^{-3}}{(2 \times 10^{-3})^2} = 1250\,\mu\Omega$

$\Rightarrow \quad R_{Al} = \frac{\rho_{A\ell} \times 50 \times 10^{-3}}{(49 - 4) \times 10^{-6}} = 30\,\mu\Omega$

$$\Rightarrow \quad R_{eq} = \frac{1250 \times 30}{1280} = \frac{1875}{64}\ \mu\Omega$$



16. (d) $\upsilon_d = \dfrac{i}{Ane}$

$$\therefore \quad \frac{i}{A} = \upsilon_d \cdot ne$$

$$\Rightarrow \quad i = \frac{V}{R} = \frac{V}{\rho \frac{\ell}{A}}$$

$$\therefore \quad \rho = \frac{V}{\frac{i}{A}\ell}$$

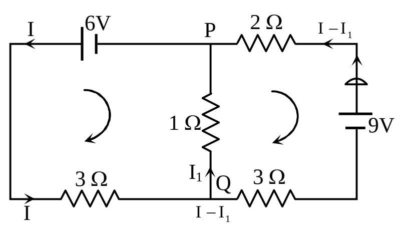
$$\Rightarrow \quad \rho = \frac{V}{\upsilon_d \cdot ne\,\ell}$$

$$\Rightarrow \quad \rho = \frac{5}{2.5 \times 10^{-4} \times 8 \times 10^{28} \times 1.6 \times 10^{-19} \times 0.1}$$

$$= \frac{2}{8 \times 1.6 \times 10^{-4}}$$

$$= \frac{1}{6.4} \times 10^{-4} = 1.6 \times 10^{-5}\ \Omega m$$

17. (c) Apply KVL, $-6 + I_1 + 3I = 0$



$\therefore \quad 3I + I_1 = 6$ . . . (i)

$2(I - I_1) - 9 + 3(I - I_1) - I_1 = 0$

$\therefore \quad 5I - 6I_1 = 9$ . . . (ii)

Solving equations (i) and (ii) we get,

$$I_1 = \frac{3}{23} = 0.13\text{A}$$

Form Q to P

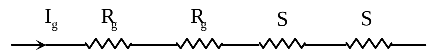
18. (a) $S = \dfrac{i_g G}{1 - i_g}$ Here $i_g = 10^{-3}$ A

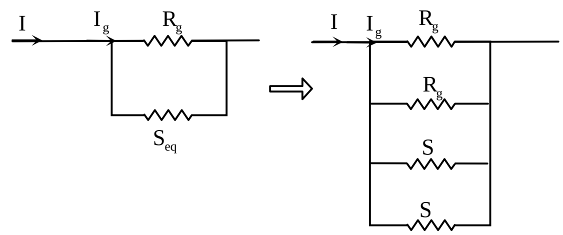
$\Rightarrow \quad G = 10^2\,\Omega,\ I = 10\text{A}$

$\Rightarrow \quad S = 10^{-2}\,\Omega$

19. (c) For conductor (Cu) resistance increases linearly and for semiconductor resistance decreases exponentially in given temperature range.

20. (a, c) For max. voltage $v_{max} = 1[R_g + S_{eq}]$



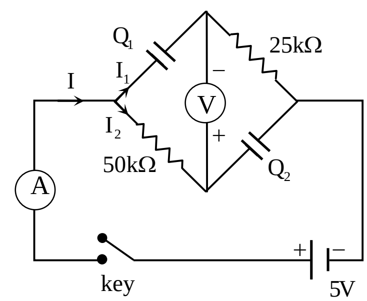


For max. current here S_{eq}. will be

Parallel combination of two shunt and one galvanometer.

21. (a, b, c, d) $q_1 = (200 \times 10^{-3})[1 - e^{t/1}]$

$q_2 = (100 \times 10^{-3})[1 - e^{t/1}]$



$$\Rightarrow \quad \frac{q_1}{C} = (50 \times 10^3)\frac{dq_2}{dt}$$

$$\Rightarrow \quad \frac{(200 \times 10^{-3})(1 - e^{-t})}{40 \times 10^{-6}} = (50 \times 10^3)(100 \times 10^{-3})[e^{-t}] \otimes$$

$$\Rightarrow \quad (1 - e^{-t})\frac{10^6}{20} = 50 \times 10^3 (e^{-t}) \quad \frac{1}{2} = e^{-t}$$

$$\Rightarrow \quad t = \ell n 2 \qquad \Rightarrow I = I_1 + I_2$$

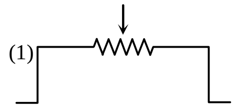
$$= (200 \times 10^{-3})(e^{-t}) + (100 \times 10^{-3})\,e^{-t}$$

$$= 100 \times 10^{-3}[2e^{-t} + e^{-t}]$$

$$= (300 \times 10^{-3})\,e^{-t} = \left(\frac{300 \times 10^{-3}}{e}\right)$$

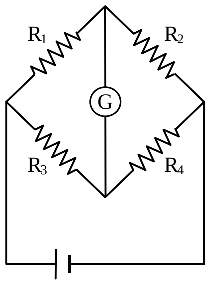
At $t = \infty, I = 0$

22. (d)

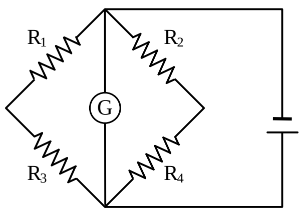


On interchanging cell and galvanometer

(1)



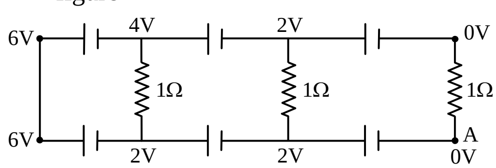
On balancing condition $\frac{R_1}{R_3} = \frac{R_2}{R_4}$ . . .(i)



On balancing condition $\frac{R_1}{R_2} = \frac{R_3}{R}$ . . .(ii)

As we see both equation (a) and (b) are same. So 4^{th} statement is false.

23. (c) Taking voltage of point A as = 0
Then voltage at other points can be written as shown in figure

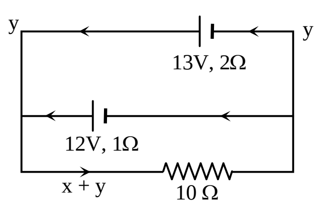


Hence, voltage across all resistance is zero.
Hence, current = 0

24. (d) $10 = (5 \times 10^{-3})(15 + R)$

$\Rightarrow$ $r = 1985\Omega$

25. (c) Applying KVL in loops $12 - x - 10(x + y) = 0$



$\Rightarrow$ $12 = 11x + 10y$ . . .(i)

$\Rightarrow$ $13 = 10x + 12y$ . . .(ii)

Solving $x = \frac{7}{16}A,\ y = \frac{23}{32}A$

$\Rightarrow$ $V = 10(x + y) = 11.56\ V$

Alternate : $r_{eq} = \frac{2}{3}\Omega,\ R = 10\Omega$

$$\frac{E_{eq}}{r_{eq}} = \frac{E_1}{r_1} + \frac{E_2}{r_2}$$

$\Rightarrow$ $E_{eq} = \frac{37}{3}V$

$\Rightarrow$ $V = \frac{E_{eq}}{R + r_{eq}} R = 11.56V$

26. (d) $\frac{R_1}{R_2} = \frac{I}{(100 - I)}$

$\Rightarrow$ $\frac{R_2}{R_1} = \frac{(I - 10)}{(110 - I)}$

$\Rightarrow$ $(100 - I)(110 - I) = I(I - 10)$

$\Rightarrow$ $11000 + I^2 - 210I = I^2 - 10I$

$\Rightarrow$ $I = 55\ cm$

$\Rightarrow$ $R_1 = R_2\left(\frac{55}{45}\right)$

$\Rightarrow$ $R_1 + R_2 = 1000\ \Omega$

$\Rightarrow$ $R_1 = 550\ \Omega$

27. (c) $\because\ E \propto I_1$ and $E - ir \propto I_2$

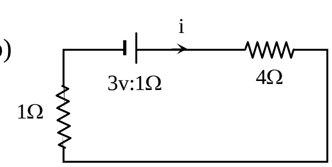
$\therefore$ $\frac{E}{E - ir} = \frac{I_1}{I_2}$

$\Rightarrow$ $\frac{E}{E - \left(\frac{E}{r + 5}\right) \times r} = \frac{52}{40}$

$\Rightarrow$ $\frac{r + 5}{5} = \frac{13}{10}$

$\Rightarrow$ $r = 1.5\,\Omega$

28. (b)

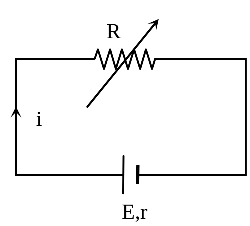


Resistance of wire AB = 400 × 0.01 = 4Ω

$i = \frac{3}{6} = 0.5A$

Now voltmeter reading = i (Resistance of 50 cm length)
= (0.5A) (0.01 × 50) = 0.25 volt

29. (d)



Current $i = \frac{E}{r+R}$

Power generated in R

$P = i^2 R$

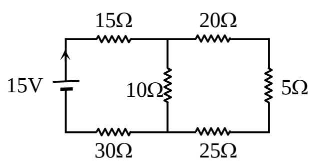
$P = \frac{E^2 R}{(r+R^2)}$

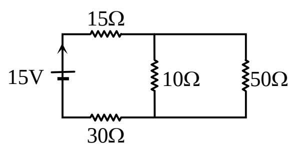
For maximum power $\frac{dP}{dR} = 0$

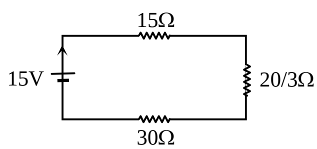
$E^2\left[\frac{(r+R)^2 \times 1 - R \times 2(r+R)}{(r+R)^4}\right] = 0$

$\Rightarrow$ r = R

30. (c)







$R_{eq} = 15 + \frac{25}{3} + 30 = \frac{45+25+90}{3} = \frac{160}{3}$

$I = \frac{E}{R_{eq}} = \frac{15\times 3}{160} = \frac{9}{32}$ amp

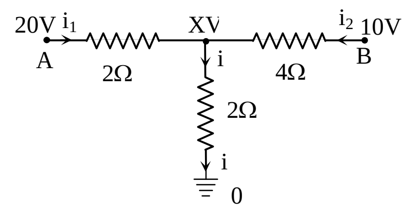
31. (a) Significant figure of red band is 2 and for green is 5
So new resistance 500 Ω

32. (a) Applying parallel combination of batteries

$$\varepsilon eq = \frac{\frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2} + --}{\frac{1}{r_1} + \frac{1}{r_2} + --} = \frac{\frac{2}{2}+\frac{4}{2}+\frac{4}{2}}{\frac{1}{2}+\frac{1}{2}+\frac{1}{2}}$$

$$\varepsilon_{eq} = \frac{10}{2\cdot 3/2} = \frac{10}{3}V$$

33. (b) Let voltage at C = XV



KCL: $i_1 + i_2 = i$

$$\frac{20-x}{2} + \frac{10-x}{4} = \frac{x-10}{2}$$

$\Rightarrow$ X = 10 and i = 5 amp.

34. (d) Colour code:
Red violet orange silver
$R = 27 \times 10^3\, \Omega \pm 10\%$
$= 27\ K\Omega \pm 10\%$

35. (c) $R = \frac{\rho\ell}{A}$ and volume (V) = $A\ell$

$R = \frac{\rho\ell^2}{A}$

$\Rightarrow \; = \frac{\Delta R}{R} = \frac{2\Delta\ell}{\ell} = 1\%$

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