PHYSICS

Study Material for JEE Main & Advanced preparation

Prepared by Career Point Kota Experts

CAREER POINT

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PHYSICS

Class 11

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Note to the Students

Career Point offers this must have Study Package in Physics to meet the complete curriculum needs of engineering aspirants. The set comprises of 6 books: **Physics** - set of 3 books for class 11 and set of 3 books for Class 12. The set caters to the different requirements of students in classes XI and XII. It offers complete and systematic coverage of **JEE Main** and **JEE Advanced** syllabi and aims to provide firm foundation in learning and develop competitive edge in preparation of the JEE and other engineering entrance examinations.

COMPONENTS OF EACH CHAPTER

These books are designed with an engaging and preparation-focused pedagogy and offer a perfect balance of conceptual learning and problem solving skills.

Theory & Concepts

Each chapter consists of high quality theory that covers all the topics, sub-topics and concepts of JEE syllabus.

Current Electricity

1. ELECTRIC CURRENT

(a) It is the time rate of flow of charge through a conductor when there is net transfer of charge (say Δq) across a cross section during a time interval (say Δt), we define average electric current as

$$I_{av} = \frac{\Delta q}{\Delta t}$$

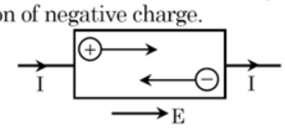
(b) We can also define instantaneous current at any instant 't' as $I_{in} = \frac{dq}{dt}$

(c) If magnitude and direction of I_{in} does not change with time then 't' is said to be **steady state current** or **direct current**.

(d) Current is one of the seven fundamental quantities. The S.I. unit of current is ampere.

$$1 \text{ Ampere} = \frac{1 \text{ Coulomb}}{1 \text{ Second}}$$

(e) The conventional direction of current is along the direction of flow of positive charge and opposite to motion of negative charge.



(f) When charge flow a cross section, the principle of conservation of charge is not violated. Hence a current carrying conductor always remains uncharged. This is also why current does not change with change in cross-section.

(g) Though current has direction. It is a scalar quantity because -

(i) It does not obey laws of vector addition.

(ii) Its direction merely represents the sense of flow of charge.

(h) To generate electric current one must have a source of charge carriers and source of energy (or emf).

Type of Material	Charge Carries
Metal	Free electrons
Semiconductors	Free electrons & holes
Gas / Electrolyte	+ve and –ve ions

NOTE Electric field inside an electrostatically charge conductor is zero. However in a current carrying conductor internal electric field is created by the source of emf. This is why in electrostatics the dielectric constant of conductor is infinite but not in current electricity.

Example Based on

Circulatory motion of charge

Example. 1

In hydrogen atom, the electron moves in an orbit of radius 0.5 Å with a speed of 2.2×10^6 m/s. The equivalent current will be.

(A) 1.12 m A (B) 4.32 m A

(C) 3.32 m A (D) 7.12 m A

Solution.(A)

$I = \frac{\text{charge}}{\text{time}}$ = charge on electron × frequency of oscillation = e.f. = e. $\frac{\omega}{2\pi} = \frac{ev}{2\pi r}$

Example. 2

A non-conducting ring of radius R carries linear charge density λ. The ring rotates with constant angular velocity ω(about its central axis). What will be the equivalent current ?

(A) $\lambda R \omega$ (B) $2\pi R\omega / \lambda$

(C) $\frac{\lambda\omega}{2\pi}$ (D) None

Solution.(A)

Total charge on the ring = $2\pi R\lambda$. Take any point A on the ring. As the ring rotates about the given axis, total charge crossing the point A in every rotation will be $Q = 2\pi R\lambda$.

Therefore by definition of current.

$$I = \frac{Q}{T} = Q f = Q \frac{\omega}{2\pi} = 2\pi R\lambda . \frac{\omega}{2\pi} = \lambda R\omega$$

2. CURRENT DENSITY

(a) The current density at a point is defined as a vector having magnitude equal to current per unit area surrounding that point and normal to the direction of charge flow. It is represented by $\vec{J}$.

(b) At a point P if current I passes normally through area dA (see figure), then $\vec{J} = \frac{d\vec{I}}{dA}$

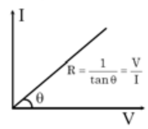
(c) The direction of current density is the direction of motion of positive charge at the point P.

Important Points

This part contains important concepts & formulas of chapter at one place in short manner, So that student can revise all these in short time.

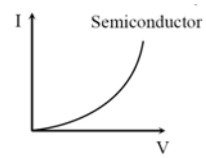
✦ Important Points

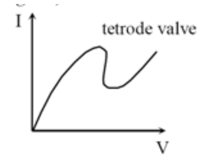
(a) A conducting device obeys ohm's law only if its physical state remains unchanged. In this case the graph between I and V is a straight line passing through origin (∵ $V \propto I$). Such a conductor (e.g. metals, alloys etc) is called ohmic-conductor having resistance (R) equal to reciprocal of slope of I-V. curve (see figure)



(b) Resistance of ohmic conductor is independent of applied voltage hence it is also called **static resistance**.

(c) For other substances such as gases, semiconductors, electrolytes etc, the I-V curve is not a straight line. Hence they are called nonohmic conductors. (see figure)





(d) For non ohmic conductors it is not possible to determine static resistance (R) as the curve has different slopes at different voltage.

(e) Therefore for these we define **dynamic resistance** (r) as ratio of change in voltage to change in current at a given voltage. It is also measured in ohm.

$$r = \frac{\Delta V}{\Delta I}$$

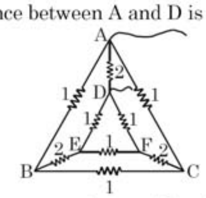
(f) Remember that static resistance R can never be negative, but dynamic resistance r may have negative value (as in case of tetrode valve)

Solved Examples (JEE Main / Advanced)

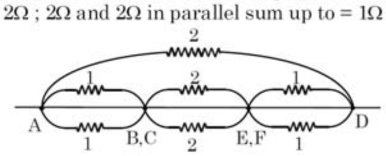
To understand the application of concepts, there is a solved example section. It contains large variety of all types of solved examples with explaination to ensure understanding the application of concepts.

SOLVED EXAMPLES

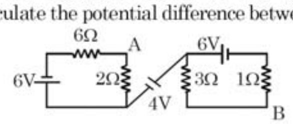
Ex.1 A network of nine conductors connects six points A, B, C, D, E and F as shown. The figures denote resistances in ohms. The equivalent resistance between A and D is



Sol. B and c are equipotential points and so are E and F. Here the circuit can be redrawn as shown in Figure. 1Ω and 1Ω in parallel sum up to 1/2W ; 2W and 2W in parallel sum up to 1 W ; 1/2W, 1 W, 1/2W in series sum up to 1/2 + 1 + 1/2 = 2Ω ; 2Ω and 2Ω in parallel sum up to = 1Ω .

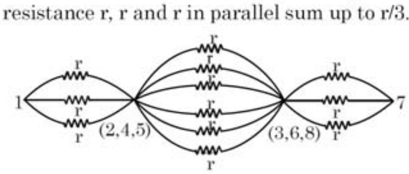


Ex.2 In the network shown in the figure below, calculate the potential difference between A and B.



Sol. The distribution of current is shown in Fig., keeping in view that the inflow and outflow of current in a cell must be the same. Applying the loop rule to the left and right loops.

Sol. Symmetry about entrance point 1 and exit point 7 shows that 2, 4, 5 are equipotential points and 5,6, and 8 are equipotential points. Hence the circuit can be redrawn as shown in Figure. The resistance r, r and r in parallel sum up to r/3.



r, r, r, r, r, r in parallel sum up to r/6 and r, r, r in parallel sum up to r/3. Next r/3. r/6, r/3 in series sum up to 5r/6.

Ex.4 Two resistors with temperature coefficients of resistance α_1 and α_2 have resistances R_{01} and R_{02} at 0°C .Find the temperature coefficient of the compound resistor consisting of the two resistors connected in parallel.

Sol. $R_1 = R_{01}(1+\alpha_1 t)$

and $R_2 = R_{02}(1+\alpha_2 t)$

Also $R = \frac{R_1 R_2}{R_1 + R_2} = R_0(1 + \alpha t)$

and $R_o = \frac{R_{01} R_{02}}{R_{01} + R_{02}}$

$\therefore \frac{R_{01} R_{02}}{R_{01} + R_{02}}(1+\alpha t)$

Practice Exercises

Exercise Level - 1 : It contains objective questions with single correct choice to ensure sufficient practice to accutrately appply formule and concepts.

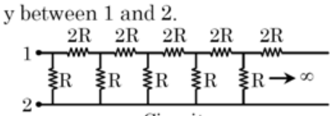
Exercise Level - 2 : It contains single objective type questions with moderate difficulty level to enhance the conceptual and application level of the student.

Exercise Level - 3 : It contains all variety of questions as per level of JEE Advanced such as MCQ, Column match, Passage based & Numerical type etc.

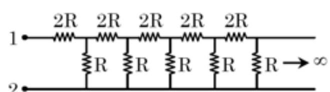
EXERCISE (Level-3)

Part-A : Multiple correct answer type questions

Q.1 Two circuits (as shown in figure) are called circuit A and circuit B. The equivalent resistance of circuit A is x and that of circuit B is y between 1 and 2.



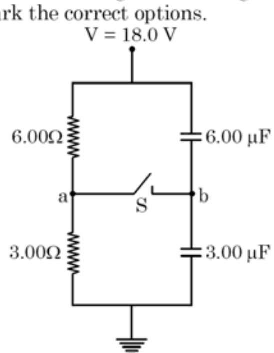
Circuit



Circuit

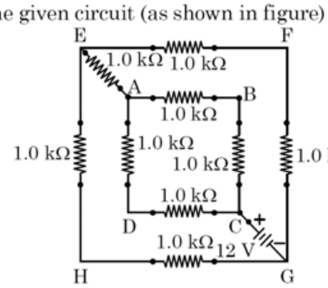
(A) y > x
(B) $y = (\sqrt{3} + 1)$ R
(C) $xy = 2R^2$
(D) y – x = 2R

Q.2 Study the following circuit diagram in figure and mark the correct options.



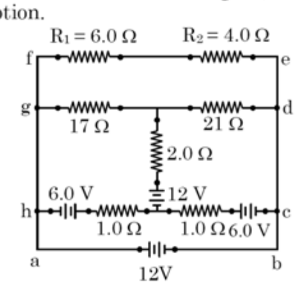
(A) The potential of point a with respect to point b in the figure when switch S is open is –6V.
(B) The points a and b are at the same potential, when S is opened.
(C) The charge flowing though switch S when it is closed is 54 μC.
(D) The final potential of b with respect to ground when switch S is closed is 8 V.

Q.3 In the given circuit (as shown in figure)



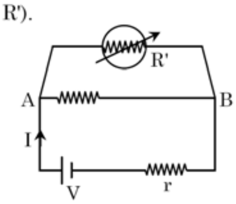
(B) the current provided by the source is 4 mA
(C) the current provided by the source is 8 mA
(D) voltage across points G and E is 4 V

Q.4 In the circuit shown in figure, mark the correct option.



(A) potential drop across R_1 is 3.2 V
(B) Potential drop across R_2 is 5.4 V
(C) Potential drop across R_1 is 7.2 V
(D) Potential drop across R_2 is 4.8 V

Q.5 Consider a simple circuit shown in figure stands for a variable resistance R'. R' can vary from R_0 to infinity, r is internal resistance of the battery (r << R << R').



(A) Potential drop across, AB is nearly constant as R' is varied
(B) Current through R' is nearly a constant as R' is varied
(C) Current I depends sensitively on R'
(D) $I \geq \dfrac{V}{r + R}$ always

Q.6 When no current is passed through a conductor–
(A) the free electrons do not move
(B) the average speed of free electrons over a large period of time is zero
(C) the average velocity of free electrons over a large period of time is zero
(D) the average of the velocities of all the free electrons at an instant is zero

Q.7 A current passes through a wire of non-uniform cross-section. Which of the following quantities are independent of the cross-section –
(A) the charge crossing in a given time interval
(B) drift velocity

Exercise Level - 4 : It contains previous years question of JEE Main (Section-A)/Advanced (Section-B) from Year 2005 to 2023.

EXERCISE (Level-4)

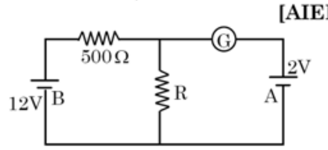
Old Examination Questions

Section-A [JEE Main]

Q.1 A moving coil galvanometer has 150 equal divisions. Its current sensitivity is 10 divisions per milliampere and voltage sensitivity is 2 divisions per millivolt. In order that each division reads 1 volt, the resistance in ohms needed to be connected in series with the coil will be - **[AIEEE-2005]**

(A) 10^3 (B) 10^5 (C) 99995 (D) 9995

Q.2 In the circuit, the galvanometer G shows zero deflection. If the batteries A and B have negligible internal resistance, the value of the resistor R will be- **[AIEEE-2005]**



(A) 200 Ω (B) 100 Ω (C) 500 Ω (D) 1000 Ω

Q.3 Two sources of equal emf are connected to an external resistance R. The internal resistances of the two sources are R_1 and $R_2 (R_2 > R_1)$. If the potential difference across the source having internal resistance R_2 is zero, then - **[AIEEE-2005]**

(A) $R = R_2 \times (R_1 + R_2)/(R_2 - R_1)$
(B) $R = R_2 - R_1$
(C) $R = R_1R_2/(R_1 + R_2)$
(D) $R = R_1R_2/(R_2 - R_1)$

Q.4 An energy source will supply a constant current into the load if its internal resistance is - **[AIEEE-2005]**

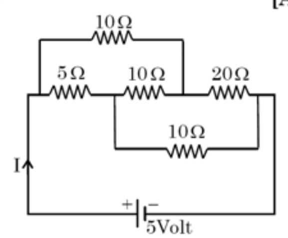
(A) equal to the resistance of the load
(B) very large as compared to the load resistance
(C) zero
(D) non-zero but less than the resistance of the load

Q.5 In a potentiometer experiment the balancing with a cell is at length 240 cm. On shunting the cell with a resistance of 2 Ω, the balancing length becomes 120 cm. The internal resistance of the cell is - **[AIEEE-2005]**

(A) 1 Ω (B) 0.5 Ω (C) 4 Ω (D) 2 Ω

(A) conservation of momentum, conservation of charge
(B) conservation of charge, conservation of energy
(C) conservation of charge, conservation of momentum
(D) conservation of energy, conservation of charge

Q.8 The current I drawn from the 5 volt source will be – **[AIEEE-2006]**



(A) 0.67 A (B) 0.17 A (C) 0.33 A (D) 0.5 A

Q.9 In a Wheatstone's bridge, three resistances P, Q and R are connected in the three arms and the fourth arm is formed by two resistances S_1 and S_2 connected in parallel. The condition for the bridge to be balance will be - **[AIEEE-2006]**

(A) $\frac{P}{Q} = \frac{R(S_1 + S_2)}{2S_1S_2}$ (B) $\frac{P}{Q} = \frac{R}{S_1 + S_2}$

(C) $\frac{P}{Q} = \frac{2R}{S_1 + S_2}$ (D) $\frac{P}{Q} = \frac{R(S_1 + S_2)}{S_1S_2}$

Q.10 An electric bulb is rated 220 volt – 100 watt. The power consumed by it when operated on 110 volt will be- **[AIEEE-2006]**

(A) 25 watt (B) 50 watt
(C) 75 watt (D) 40 watt

Q.11 The resistance of wire is 5 ohm at 50°C and 6 ohm at 100°C. The resistance of the wire at 0°C will be – **[AIEEE-2007]**

(A) 2 ohm (B) 1 ohm (C) 4 ohm (D) 3 ohm

Q.12 A 5 V battery with internal resistance 2 Ω and a 2V battery with internal resistance 1Ω are

Exercise Level - 5 : Advanced level a bit complex questions for students for solid rock prepertion for Top Rankers.

Answer key

Ankswer key is provided at the end of the exercise sheets.

ANSWER KEY

EXERCISE (Level-1)

1. (B)	**2.** (C)	**3.** (A)	**4.** (B)	**5.** (B)	**6.** (C)	**7.** (C)	**8.** (C)	**9.** (B)	**10.** (D)
11. (B)	**12.** (B)	**13.** (C)	**14.** (A)	**15.** (A)	**16.** (C)	**17.** (C)	**18.** (D)	**19.** (B)	**20.** (A)
21. (A)	**22.** (B)	**23.** (C)	**24.** (A)	**25.** (B)	**26.** (B)	**27.** (B)	**28.** (B)	**29.** (B)	**30.** (B)
31. (C)	**32.** (D)	**33.** (B)	**34.** (A)	**35.** (C)	**36.** (B)	**37.** (B)	**38.** (C)	**39.** (B)	**40.** (D)
41. (C)	**42.** (C)								

Revision Plan

We emphasis that every student should prepare his/her own revision plan. For this purpose there is Revision Plan Section in each chapter which student should prepare while going thorugh the study material. This will be useful at the time of final revision before final exam for quick & effective revision.

Revision Plan

Prepare Your Revision plan today!

After attempting Exercise Sheet, please fill below table as per the instruction given.

A. Write Question Number (QN) which you are unable to solve at your own in **column A**.

B. After discussing the Questions written in **column A** with faculty, strike off them in the manner so that you can see at the time question number during Revision, to solve such questions again.

C. Write down the Question Number you feel are important or good in the **column B**.

EXERCISE	COLUMN A	COLUMN B
	Questions unable to solve in first attempt	Good or Important questions
Level-1		
Level-2		
Level-3		
Level-4		
Level-5		

Online Solutions

Self explanatory and detailed soltuion of all excercises above are available on Career Point website **www.careerpoint.ac.in**

CURRENT ELECTRICITY

EXERCISE (Level-1)

Answer Key & Solution

Question Number	Solution	Question Number	Solution	Question Number	Solution	Question Number	Solution
1	Click Here	12	Click Here	23	Click Here	34	Click Here
2	Click Here	13	Click Here	24	Click Here	35	Click Here
3	Click Here	14	Click Here	25	Click Here	36	Click Here
4	Click Here	15	Click Here	26	Click Here	37	Click Here
5	Click Here	16	Click Here	27	Click Here	38	Click Here
6	Click Here	17	Click Here	28	Click Here	39	Click Here
7	Click Here	18	Click Here	29	Click Here	40	Click Here
8	Click Here	19	Click Here	30	Click Here	41	Click Here
9	Click Here	20	Click Here	31	Click Here	42	Click Here
10	Click Here	21	Click Here	32	Click Here		
11	Click Here	22	Click Here	33	Click Here		

Sol.1 [B]

Given

$I = 1.1\ A$

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

$A = \pi r^2 = p \times (0.05)^2$

$= 78.5 \times 10^{-4}\ cm^2$

$$v_d = \frac{I}{neA}$$

$$n = \frac{6\times10^{23}}{7cm^3} = 0.86 \times 10^{23} / m^3$$

$$v_d = \frac{1.1}{0.86\times1.6\times10^{-19}\times78.5\times10^{-4}}$$

(volume of 63g Cu)

$v_d = 0.01$ cm/s.

$= 0.1$ mm/s

Top

CURRENT ELECTRICITY

JEE ADVANCED SYLLABUS

1. *Ohm's law*

2. *Series and parallel arrangements of resistances and cells*

3. *Kirchhoff's laws and applications to networks*

4. *charging and discharging of capacitor*

5. *Heating effect of current*

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EXERCISE	COLUMN A	COLUMN B
	Questions unable to solve in first attempt	Good or Important questions
Level-1		
Level-2		
Level-3		
Level-4		
Level-5		

Revision Strategy :

Whenever you wish to revision this chapter, follow the following steps-

Step-1: Review your theory notes.

Step-2: Solve Questions of column A

Step-3: Solve Questions of Column B

Step-4: Solve questions from other Question Bank, Problem book etc.

Current Electricity

1. ELECTRIC CURRENT

(a) It is the time rate of flow of charge through a conductor when there is net transfer of charge (say Δq) across a cross section during a time interval (say Δt), we define average electric current as

$$I_{av} = \frac{\Delta q}{\Delta t}$$

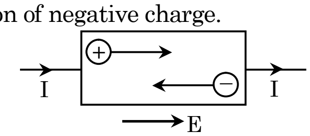
(b) We can also define instantaneous current at any instant 't' as $I_{in} = \frac{dq}{dt}$

(c) If magnitude and direction of I_{in} does not change with time then 't' is said to be **steady state current** or **direct current**.

(d) Current is one of the seven fundamental quantities. The S.I. unit of current is ampere.

$$1 \text{ Ampere} = \frac{1 \text{ Coulomb}}{1 \text{ Second}}$$

(e) The conventional direction of current is along the direction of flow of positive charge and opposite to motion of negative charge.



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(g) Though current has direction. It is a scalar quantity because -

(i) It does not obey laws of vector addition.

(ii) Its direction merely represents the sense of flow of charge.

(h) To generate electric current one must have a source of charge carriers and source of energy (or emf).

Type of Material	Charge Carries
Metal	Free electrons
Semiconductors	Free electrons & holes
Gas / Electrolyte	+ve and –ve ions

NOTE Electric field inside an electrostatically charge conductor is zero. However in a current carrying conductor internal electric field is created by the source of emf. This is why in electrostatics the dielectric constant of conductor is infinite but not in current electricity.

Example Based on

Circulatory motion of charge

Example. 1

In hydrogen atom, the electron moves in an orbit of radius 0.5 Å with a speed of 2.2×10^6 m/s. The equivalent current will be.

(A) 1.12 m A (B) 4.32 m A

(C) 3.32 m A (D) 7.12 m A

Solution.(A)

$I = \frac{\text{charge}}{\text{time}}$ = charge on electron × frequency of oscillation = e.f. = e. $\frac{\omega}{2\pi} = \frac{ev}{2\pi r}$

Example. 2

A non-conducting ring of radius R carries linear charge density λ. The ring rotates with constant angular velocity ω(about its central axis). What will be the equivalent current ?

(A) $\lambda R \omega$ (B) $2\pi R\omega / \lambda$

(C) $\frac{\lambda\omega}{2\pi}$ (D) None

Solution.(A)

Total charge on the ring = $2\pi R\lambda$. Take any point A on the ring. As the ring rotates about the given axis, total charge crossing the point A in every rotation will be $Q = 2\pi R\lambda$.

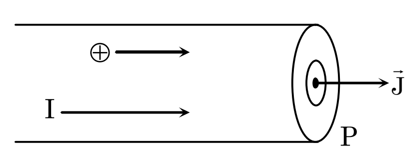
Therefore by definition of current.

$$I = \frac{Q}{T} = Q\,f = Q\,\frac{\omega}{2\pi} = 2\pi R\lambda . \frac{\omega}{2\pi} = \lambda R\omega$$

2. CURRENT DENSITY

(a) The current density at a point is defined as a vector having magnitude equal to current per unit area surrounding that point and normal to the direction of charge flow. It is represented by $\vec{J}$.

(b) At a point P if current I passes normally through area dA (see figure), then $\vec{J} = \frac{d\vec{I}}{dA}$



(c) The direction of current density is the direction of motion of positive charge at the point P.

(d) Note that the area ΔA is normal to the current ΔI. If ΔA is not normal to I, but makes angle θ with the normal then

$$\vec{J} = \frac{dI}{\text{normal component of area}} = \frac{dI}{dA\cos\theta}$$

$$\Rightarrow dI = JdA\cos\theta \Rightarrow I = \int \vec{J}.d\vec{A}$$

(e) Unit is ampere / meter^2 and dimension is $[M^0 L^{-2} T^0 A]$.

(f) In case of uniform flow of charge current density can also be defined as.

$$J = \frac{I}{A} = n.e.v_d,$$

where n = no. of charge carriers per unit volume.

A = Area of cross-section,

v_d = drift velocity of charge carriers.

(g) If a source of emf produces electric field inside a conductor of resistively ρ, then current density at any point inside the conductor is

$$\vec{J} = \frac{\vec{E}}{\rho} = \sigma\vec{E} \quad (\sigma = \frac{1}{\rho} = \text{conductivity}).$$

3. MECHANISM OF CURRENT FLOW IN METALS

(a) In the absence of potential difference across a conductor.

(i) Its free electrons ($n \approx 10^{23}$ per cc.) behave identical to molecules of an ideal gas.

(ii) They move within the lattice-space of the crystal with large thermal speeds given by

$$v_{rms} = \sqrt{\frac{3kT}{m}} \approx 10^5 \text{ m/s}.$$

where m = mass of electron

(iii) However due to continuous collisions with metal lattice the electrons move in zig-zag fashion. Therefore net transfer of charge across the cross-section is zero. Thus no current flow inside the conductor.

(iv) Here it should be remembered that time interval between two successive collision of an electron is called relaxation time (τ) and the path covered is called mean free path (λ). τ and λ are related as.

$$\tau = \frac{\lambda}{v_{rms}}$$

(b) When potential difference is applied between the ends of a conductor it sets up internal electric field ($|\vec{E}| = V/L$). Under the action of the field free electrons start drifting (opposite to) with a constant average velocity. It is known as drift velocity (v_d). Due to drifting of free electrons electric current begins to flow inside the conductor.

(c) It can be shown that $v = u + at$ here $v = v_d$, u = initial velocity = 0

$$a = F/m = \frac{eE}{m} \quad \{\text{as } F = qE\}$$

$$t = \tau$$

$$v_d = -\frac{eE}{m}.\tau = \frac{eV}{mL}.\tau,$$

where (–ve) sign indicates that electrons move opposite to the field.

Here, e $\rightarrow$ electron charge

m $\rightarrow$ electron mass

V $\rightarrow$ potential difference

L $\rightarrow$ Length of conductor

(d) Since $v_{rms} \propto \sqrt{T}$ and $\tau \propto \frac{1}{v_{rms}}$ hence $\tau \propto \frac{1}{\sqrt{T}}$.

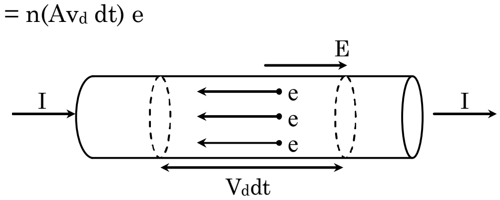
This shows that as the temperature is increased, relaxation time and drift velocity decreases.

> **NOTE** Though magnitude of drift velocity is very small ($\approx$ 1mm / sec) it is responsible for the effects of current, magnetic effect, thermal effect etc.

4. RELATION BETWEEN I AND v_d

Consider any cylindrical element of a conductor of area of cross section A. If its free electrons are drifting with velocity v_d, the length of the element swept in time dt will be v_d dt. If the conductor has n free electrons per unit volume the number of electron in this volume will be n (Av_ddt).

All these electrons cross the area A in time dt. Thus charge crossing in time dt across time area A is $dQ = n(Av_d\,dt)\,e$



or $$I = \frac{dQ}{dt}$$

$$I = neAv_d \quad \text{and} \quad J = \frac{I}{A} = nev_d$$

5. MOBILITY

(a) Drift velocity acquired by a charge carrier (free electrons holes, ions etc.) per unit electric field is defined as its mobility. It is denoted by μ.

$$\mu = \frac{v_d}{E} = \frac{e\tau}{m} \qquad [\because v_d = \frac{eE}{m}\tau]$$

(b) It is measured in $= \frac{m/s}{volt/m} = \frac{(meter)^2}{volt \times sec}$

(c) Its dimension is $\mu = \frac{(AT)T}{M} = M^{-1}T^2A^1$

Example Based on

Drift velocity

Example. 3

One end of an aluminium wire, whose diameter is 2.5 mm is welded to one end of a copper wire whose diameter is 2.0 mm. The composite wire carries a steady current 6.25 A. The current densities in Al and Cu will be respectively -

(A) 127 A/cm², 200 A/cm² (B) 126 A/cm², 180 A/cm²
(C) 125 A/cm², 160 A/cm² (D) 125 A/cm², 180 A/cm²

Solution. (A)

$\because \quad J = I/A = \dfrac{I}{\pi r^2}$

$\therefore \quad$ For Al, $J = \dfrac{6.25}{\frac{\pi}{4}\times 2.5^2 \times 10^{-6}} = 127 \times 10^6\ A/m^2$

$= 127\ A/cm^2$

and for copper $J = \dfrac{6.25}{\frac{\pi}{4}\times 2^2 \times 10^{-6}} = 200\ A/cm^2$

Example. 4

A silver wire of 1mm diameter carries a charge of 90 coulombs in 1 hour and 15 minutes. Silver contains 5.8×10^{28} free electrons per cm³. The current (in amp.) in wire and drift velocity of the electron will be respectively -

(A) 0.02, 2.69×10^{-7} (B) 0.03, 3.69×10^{-7}
(C) 3.2, 2.69×10^{-7} (D) 2.3, 3.69×10^{-7}

Solution. (A)

$\because \quad i = \dfrac{q}{t} = \dfrac{90\ \text{coulombs}}{4500\ \text{sec}} = 0.02$ ampere

$J = \dfrac{i}{A} = \dfrac{i}{\pi r^2} = \dfrac{0.02\,\text{amp}}{\pi(0.05)^2\,\text{meter}^2}$

$= 2.55 \times 10^4\ \text{amp/m}^2$

$v_d = \dfrac{J}{ne} = \dfrac{2.55\times 10^4}{(5.8\times 10^{28})(1.6\times 10^{-19})}$

$= 2.69 \times 10^{-7}$ m/sec.

Example. 5

The area of cross-section, length and density of a piece of a metal of atomic weight 60 are 10^{-6} m², 1.0 m and $5 \times 10^{+3}$ kg/m³ respectively. Find number of free electrons per unit volume if every atom contributes one free electron and the drift velocity of electron in the metal when the current of 16A passes through it (Given Avogadro number = 6×10^{23}/mole)

(A) $5 \times 10^{28}/m^3$, 2×10^{-3} m/s

(B) $2.5 \times 10^{28}/m^3$, 1×10^{-3} m/s

(C) $10 \times 10^{28}/m^3$, 3×10^{-3} m/s

(D) None of the above.

Solution. (A)

Mass of metal = $A\ell d$

[Mass = Volume × density]

$\therefore\ m = 10^{-6} \times 1 \times 5 \times 10^3 = 5 \times 10^{-3}$ kg

Number of atoms in mass 5×10^{-3} kg

$= \dfrac{Nm}{M} = \dfrac{(6\times 10^{23})(5\times 10^{-3})}{60\times 10^{-3}} = 5 \times 10^{22}$

$\therefore$ Number of atoms per unit volume

$= \dfrac{5\times 10^{22}}{10^{-6}\,m^3} = 5 \times 10^{28}/m^3$

This also represents the number of free electrons. If v_d be the drift velocity,

then $\quad i = neAv_d \quad$ or $\quad v_d = \dfrac{i}{neA}$

$= \dfrac{1.6}{(5\times 10^{28})(1.6\times 10^{-19})(10^{-6})} = 2 \times 10^{-6}$ m/sec

Example. 6

The total momentum of electrons in a straight wire of length ℓ = 1000m carrying a current I = 70A, will be- (in N.s)

(A) 0.40×10^{-6} (B) 0.20×10^{-6}
(C) 0.80×10^{-6} (D) 0.16×10^{-6}

Solution. (A)

We know $I = neAv_d$

where $\quad v_d \rightarrow$ drift velocity,

$n \rightarrow$ density of electron.

Total no. of electron $N = nA\ell$

Total momentum (p) of electron

$= Nmv_d$ or $p = (nA\ell m)\dfrac{I}{neA} = \dfrac{I\ell m}{e}$

$\Rightarrow \quad p = \dfrac{70\times 1000\times 9.3\times 10^{-31}}{1.6\times 10^{-19}} = 0.40\mu$ N.s

Example Based on

Current in discharge tube

Example. 7

A current is established in a gas discharge tube of cross-section 8×10^{-4} m² when a sufficiently high potential difference (say 32 kV) is applied across the two electrodes in the tube. The gas ionises, electrons move towards the positive terminal and positive ions towards the negative terminal. What are the magnitude and sense of the current in a hydrogen discharge tube in which 3×10^{18} electrons and 2×10^{18} protons move past cross-sectional area of the tube in each second ?

Solution.

As current is rate of low of charge in the direction which positive charge will move, the current due to electrons will be

$$I_e = \frac{n_e}{t} \times q_e = 3 \times 10^{18} \times 1.6 \times 10^{-19} = 0.48 \text{ A}$$

pin the direction from positive to negative electrode (which is opposite to the motion of electrons). And the current due to protons

$$I_p = \frac{n_p}{t} \times q_p = 2 \times 10^{18} \times 1.6 \times 10^{-19} = 0.32 \text{ A}$$

in the direction from positive to negative electrode (which is also the direction of motion of protons). So the total current

$$I = I_e + I_p = 0.48 + 0.32 = 0.8 \text{ A}$$

Ans.

from anode to cathode of discharge tube.

Example Based on

Mobility

Example. 8

The air gap between two parallel plates separated by a distance d = 2 cm is ionized by X-rays. Each plate has an area S = 500 cm^2. Find the concentration of positive ions if a voltage V = 100 V produces a current I = 3 μA. The mobilities of air ions are $\mu_+ = 1.37\ cm^2\ V^{-1}\ s^{-1}$, $\mu_- = 1.91\ cm^2\ V^{-1}\ s^{-1}$.

Solution.

The mobility of an ion is the drift velocity acquired in unit electric field, i.e., $v_d = \mu E$. If n_+ be the concentration of positive ions and n_- that of negative ions, then $n_+ = n_-$.

j_+ = current density due to + ions = $v_d^+ n_+ e$

$= (\mu_+ E)\, n_+ e$

j_- = current density due to – ions = $v_d^- n_- e$

$= \mu_- E n_- e$

$\therefore$ I (total current) $= S(j_+ + j_-) = SeE(\mu_+ n_+ + \mu_- n_-)$

$\Rightarrow$ $I = SneE(\mu_+ + \mu_-)$ $\quad (\because n_+ = n_- = n)$

$\Rightarrow$ $I = SneV(\mu_+ + \mu_-)/d$

$$\Rightarrow n = \frac{Id}{S(\mu_+ + \mu_-)eV}$$

Here

$$n = \frac{3 \times 10^{-6} \times 2 \times 10^{-2}}{500 \times 10^{-4}(1.37 + 1.91) \times 10^{-4} \times 1.6 \times 10^{-19} \times 100}$$

$= 2.3 \times 10^{14}\ m^{-3}$

6. RESISTANCE

(a) The property of a conductor due to which it opposes the flow of current through it is called it's electrical resistance.

(b) This property exists not only in metals but also in electrolytes, semiconductors etc.

(c) In case of metals obstruction in the drifting of free electrons (by metal lattice) gives rise to resistance.

✦ Ohm's Law

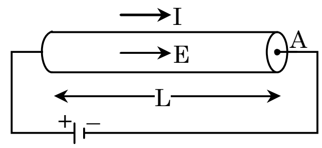
If there is no change in the physical state (such as temperature etc) of a conductor, magnitude of current is directly proportional to applied potential difference.

i.e. $\quad V \propto I$

$\quad V = RI$

Where R is a constant called 'Electrical Resistance' of the conductor

PROOF



We know that

$$I = nev_dA \text{ and } v_d = \frac{eE}{m}\tau = \frac{eV}{mL}\tau$$

Thus $\quad I = \frac{ne^2\tau}{m} A \frac{V}{L},\ V = \left[\left(\frac{m}{ne^2\tau}\right)\frac{L}{A}\right] I$

Comparing it with V = RI,

we get resistance of a given conductor as

$$R = \left(\frac{m}{ne^2\tau}\right)\frac{L}{A}$$

where, m → mass of electrons,

e → charge of electrons,

n → no. of free electrons per unit volume,

L → Length of the conductor

A → Area of cross section perpendicular to current flow

NOTE

(1) Differential form of ohm's law can be written as $\vec{J} = \frac{\vec{E}}{\rho}$; where $\rho = \frac{m}{ne^2\tau}$ is known as resistivity of the conductor.

(2) This relation is extremely important from the point of view of JEE as a wide variety of questions can be framed on this formula.

(a) S.I unit of resistance (R) is ohm (Ω) and its dimension is $[M^1 L^2 T^{-3} A^{-2}]$.

(b) Since $\rho = R\frac{A}{L}$, hence S.I units of resistivity is ohm-meter (Ω-m) and its dimension is $[ML^3T^{-3}A^{-2}]$.

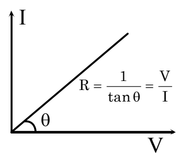
(c) The quantity $\left(\frac{1}{R}\right)$ is called conductance (G) of the conductor having unit mho or siemens.

(d) Similarly the quantity $\left(\frac{1}{\rho}\right)$ is called conductivity (σ) of the material having units mho/meter.

(e) Resistivity or conductivity depends only on nature of material and temperature. With rise of temperature resistivity increases and conductivity decreases.

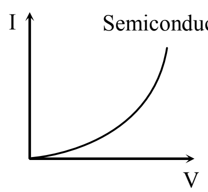
✦ Important Points

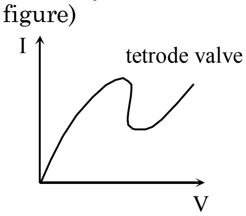
(a) A conducting device obeys ohm's law only if its physical state remains unchanged. In this case the graph between I and V is a straight line passing through origin ($\because V \propto I$). Such a conductor (e.g. metals, alloys etc) is called ohmic-conductor having resistance (R) equal to reciprocal of slope of I-V. curve (see figure)



(b) Resistance of ohmic conductor is independent of applied voltage hence it is also called **static resistance**.

(c) For other substances such as gases, semiconductors, electrolytes etc, the I-V curve is not a straight line. Hence they are called nonohmic conductors. (see figure)





(d) For non ohmic conductors it is not possible to determine static resistance (R) as the curve has different slopes at different voltage.

(e) Therefore for these we define **dynamic resistance** (r) as ratio of change in voltage to change in current at a given voltage. It is also measured in ohm.

$$r = \frac{\Delta V}{\Delta I}$$

(f) Remember that static resistance R can never be negative, but dynamic resistance r may have negative value (as in case of tetrode valve)

✦ Factors Affecting Resistance of Metals & Alloys

We know that

$$R = \frac{m}{ne^2\tau} \cdot \frac{\ell}{A}, \quad \tau = \frac{\lambda}{v_{rms}} \text{ and } v_{rms} = \sqrt{\frac{3kT}{m}}$$

Hence we can conclude that resistance of a given metallic / alloy conductor, depends upon :

(a) Length of conductor ($\because R \propto L$)

(b) Area of cross section ($\because R \propto \frac{1}{A} \propto \frac{1}{r^2}$)

(c) Nature of material ($\because R \propto \frac{1}{n}$)

(d) Temperature ($R \propto \frac{1}{\tau}$ and $\tau \propto \frac{1}{\sqrt{T}}$)

Greater the temperature, lesser will be relaxation time hence greater will be resistance.

NOTE **(1)** In some text books resistance is derived as $R = \frac{ne^2\tau}{2m}\frac{\ell}{A}$ and not as given above. Students are advised not be confused or worried, as it does not affect the proportionality relationship of n, L, A and τ. with the resistance.

(2) While determining the resistance of a conductor one should be careful while choosing area of cross section. Only the faces lying perpendicular to the flow of current should be selected. [see example 9 and 10]

Example Based on

Resistance

Example. 9

As shown in the figure resistivity of the material of the block is ρ. Find resistance of the block when battery is connected between

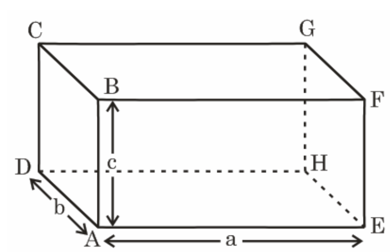
(a) Faces ABCDA and EFGHE and

(b) Faces CBFGC and ADHEA.

Solution.

(a) In this case area of cross section of the face lying perpendicular to current is bc, while the length is a, hence

$$R = \rho\frac{L}{A} = \frac{\rho a}{bc}$$



(b) Similarly A = ab and L = c.

Thus $R = \rho\frac{c}{ab}$

Example. 10

A cylindrical tube of length L has inner radius a and outer radius b as shown in the figure. What is the resistance of the tube between (a) its ends (b) its inner and outer surface. [resistivity of its material is ρ].

Solution.

(a) In case of electrical conduction, field at a point inside a conductor is given by -

$J = \sigma E$

i.e., $E = \rho J$ [as $\sigma = (1/\rho)$] ... (1)

As here the current and field are along the axis of the tube, consider the tube to be made up of large number of coaxial annular disc and considering a disc of thickness dx at distance x from one end as shown in fig. We have.

$$E = -\frac{dV}{dx} \text{ and } J = \frac{I}{\pi(b^2 - a^2)} \quad [\text{as } S = \pi\,(b^2 - a^2)]$$

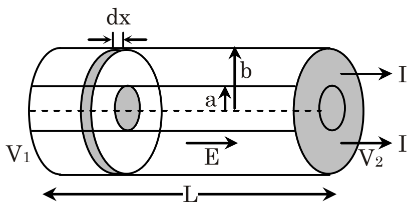
So eqn. (1) reduces to -

$$-\frac{dV}{dx} = \rho\frac{I}{\pi(b^2 - a^2)}$$

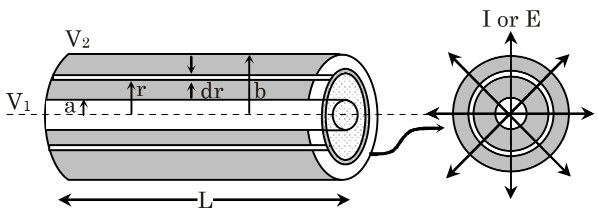
$$\text{i.e., } -\int_{V_1}^{V_2} dV = \int_0^L \frac{\rho I\, dx}{\pi(b^2 - a^2)}$$

$$\text{or} \quad V = (V_1 - V_2) = \frac{\rho L I}{\pi(b^2 - a^2)}$$

$$\text{so} \quad R = \frac{V}{I} = \frac{\rho L}{\pi(b^2 - a^2)}$$ **Ans.**



(A)



(B)

(b) As here the field is radial, consider the tube to be made up of large number of concentric cylindrical shells and considering a shell of radius r and thickness dr as shown in fig. we have

$$E = -\frac{dV}{dr} \quad \text{and} \quad J = \frac{I}{2\pi r L}$$

[as here $S = 2\pi r L$]

So eqn. (1) for this case becomes -

$$-\frac{dV}{dr} = \frac{\rho I}{2\pi r L}$$

$$\text{i.e., } -\int_{V_1}^{V_2} dV = \int_a^b \frac{\rho I\, dr}{2\pi r L}$$

$$\text{or} \quad V = (V_1 - V_2) = \frac{\rho I}{2\pi L}\log_e\left[\frac{b}{a}\right]$$

$$\text{so} \quad R = \frac{V}{I} = \frac{\rho}{2\pi L}\log_e\left[\frac{b}{a}\right]$$ **Ans.**

✦ Important Results

(a) Effect of stretching a wire on its resistance.

(i) If the length of wire is changed.

$\frac{R_1}{R_2} = \frac{\ell_1^2}{\ell_2^2}$ as mass remains unchanged ($\ell_1 A_1 = \ell_2 A_2$)

(ii) If the radius of wire is changed.

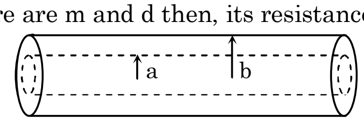
$$\frac{R_1}{R_2} = \frac{r_2^4}{r_1^4}$$

(b) If a conductor is stretched to n times its original length its new resistance will be n^2 times the original value.

(c) If a conductor is stretched such that it radius is reduced to $1/n^{th}$ of its original value, its new resistance will be increased n^4 times.

(d) Effect of Percentage Change in Length

Consider a cylindrical wire of length L, area of cross section A ($= \pi r^2$). If mass and density of wire are m and d then, its resistance would be.



$R = \rho\frac{\ell}{A}$ [ρ = resistivity of material]

$R = \frac{\rho d}{m}\ell^2$ [$\because A\,\ell\, d$ = mass of wire]

$R = k\,.\,\ell^2$ [$\frac{\rho d}{m}$ = constt.]

$$\frac{R_2}{R_1} = \frac{\ell^2\left[1 + \frac{x}{100}\right]}{\ell^2}$$

$$\left[\begin{array}{l} \ell_1 = \ell \\ \ell_2 = x\% \text{ more than } \ell = \ell\left[1 + \frac{x}{100}\right] \end{array}\right]$$

Therefore Percentage change in resistance

$$\frac{R_2 - R_1}{R_1} \times 100 = \frac{\left[1 + \frac{x}{100}\right]^2 - 1}{1} \times 100 \approx 2x\ \%$$

[apply binomial theorem]

NOTE We can conclude that if wire is stretched to increase its length by x% then its resistance increases by 2x %. However this is true only when x < 5 %. However if percentage change in the length is more than 5% then the student is advised not to take binomial approximation. [see example 11(a) & (b)]

Example Based on

Change of resistance

Example. 11

Calculate the percentage change in the resistance of a conducting wire if to is stretched to increase its length by (a) 0.1 % & (b) 20%

Solution.

(a) As explained above (put x = 0.1) percentage change in resistance

$$= \frac{R_2 - R_1}{R_1} \times 100\ \%$$

$$= \left\{\left[1+\frac{0.1}{100}\right]^2 - 1\right\} \times 100 \approx 0.2\%$$

(b) Percentage Change

$$R = \left\{\left(1+\frac{20}{100}\right)^2 - 1\right\} \times 100 \quad \text{put } x = 20$$

$$= \{(1.2)^2 - 1\} \times 100 = [1.44 - 1] \times 100 = 44\ \%$$

Note that since percentage change in length is 20% then percentage increase in resistance is not 40 % but 44 %.

Example. 12

If resistance of a wire formed by 1.cc of copper be 2.46 Ω. The diameter of wire is 0.32 mm, then the specific resistance of wire will be -

(A) 1.59×10^{-6} ohm. cm (B) 2.32×10^{-6} ohm. cm

(C) 3.59×10^{-6} ohm. cm (D) 1.59×10^{-8} ohm. cm

Solution. (A)

$$\text{length of wire} = \frac{(\text{volume})}{(\text{Area})} = \frac{1}{3.14 \times (0.016)^2}$$

$$\rho = \frac{RA}{\ell} = \frac{(2.46)3.14 \times (0.016)^2}{\left(\dfrac{1}{3.14 \times (0.016)^2}\right)} = 1.59 \times 10^{-6}\ \text{ohm. cm}$$

ρ will be same for any shape of wire formed by metal.

Example. 13

A given piece of wire of length ℓ, cross sectional area A and resistance R is stretched uniformly to a wire of length 2ℓ. The new resistance will be -

(A) 2R (B) 4R

(C) R/2 (D) Remains unchanged

Solution. (B)

$$R = \frac{\rho\ell}{A} \text{ and } R' = \frac{\rho(2\ell)}{A'},$$

ρ = specific resistance.

$$\therefore \frac{R'}{R} = \left(\frac{2\ell}{\ell}\right)\left(\frac{A}{A'}\right)$$

Further $A\ell = A'(2\ell)$ [Volume remains conserved]

$\Rightarrow A/A' = 2$

$$\therefore \frac{R'}{R} = 4 \text{ or } R' = 4R$$

Example. 14

A given piece of wire of length ℓ, radius r and resistance R is stretched uniformly to a wire of radius (r/2). The new resistances will be -

(A) 2R (B) 4R (C) 8R (D) 16R

Solution. (D)

The volume of given wire remains unchanged, hence

$A\ell = A'\ell'$ or $(A'/A) = (\ell/\ell')$

$$R = \rho\frac{\ell}{A} \text{ and } R' = \frac{\rho\ell'}{A'}$$

$$\therefore \frac{R'}{R} = \frac{A}{A'}\frac{\ell}{\ell'} = \left(\frac{A}{A'}\right)^2$$

$$\therefore \frac{R'}{R} = \left(\frac{\pi r^2}{\pi r'^2}\right)^2 = 16 \qquad [\because r' = \frac{r}{2}]$$

$\Rightarrow R' = 16R$

Example. 15

The resistance of wire is 50π then the graph between log V and log I is -

(A) straight line passing through origin

(B) parabola

(C) hyperbola

(D) none of the above.

Solution. (D)

$V = IR \Rightarrow \log V = \log I + \log R$

This is a straight line but not passing through origin.

Example. 16

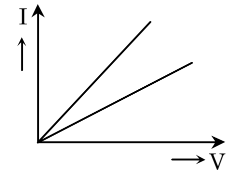
The current voltage graph for a given metallic wire at two different temperatures T_1 and T_2 are shown in fig. Which is true -

(A) $T_1 = T_2$ (B) $T_1 > T_2$

(C) $T_1 < T_2$ (D) None of the above.

Solution. (C)

The slope of I - V curve



$$\frac{1}{V} = \frac{1}{R}$$

i.e. slope $\propto \frac{1}{R}$

The slope of graph at temperature T_1 is greater than that at temperature T_2.

$\therefore$ Resistance at T_2 > Resistance at T_1

For metallic wire the resistance R increases with increase of temperature.

Hence $T_2 > T_1$.

✦ Temperature Dependence of Resistance and Resistivity

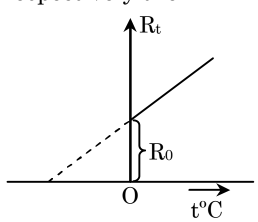
(a) We have discussed earlier that resistance as well as resistivity changes with change in temperature. This variation can be explained on the basis of temperature coefficient of resistance (or resistivity).

(b) The temperature coefficient of resistance is defined as fractional change in resistance per unit rise of temperature. It is denoted by α and is measured in $^oC^{-1}$ or K^{-1}.

$\alpha = \frac{\Delta R}{E} \times \frac{1}{\Delta \theta}$, therefore

$\Delta R = R\,\alpha\,\Delta\theta$.

If R_t and R_0 are resistance of a conductor at t^oC and 0^oC respectively then



$R_t - R_0 = R_0\,\alpha\,(t - 0)$

$R_t = R_0\,[1 + \alpha\, t]$

where α = coefficient at 0^oC.

If temperature coefficient of resistance at $t_1{}^oC$ is α and resistance is R_1 then resistance at any other temp. t_2 will be.

$R_2 = R_1\,[1 + \alpha\,(t_2 - t_1)]$

From the above discussion it is clear that.

(i) resistance changes linearly with temperature provided α is constant.

This can be represented graphically as -

(ii) $\alpha_{metals} = +$ ve

$\alpha_{alloys} = 0$

$\alpha_{electrolyte} = -$ ve

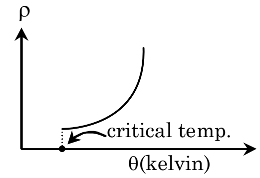
(c) The temperature coefficient of resistivity changes with temperature as

$\rho = \rho_0\,[1 + \alpha\,\Delta\theta + \beta\,(\Delta\theta)^2 + ...]$

where α & β are called temperature coefficients of resistivity.

If $\Delta\theta$ is small $\rho = \rho_0\,[1 + \alpha\,\Delta\theta]$

(d) The general relationship can be represented graphically as :



(e) The graph shows that at critical temperature the resistivity absolutely falls to zero. This phenomenon is known as **super-conductivity**.

Example Based on

Effect of temperature

Example. 17

Resistivity and temperature coefficient of resistivity of a material at a temperature T_0 is ρ_0 and α respectively. Prove that resistivity of the conductor at the temperature T would be $\rho = \rho_0\,[1 + \alpha\,(T - T_0)]$, provided the quantity $T - T_0$ is small. Assume α remains constant during the temp range.

Solution.

By definition of temperature coefficient of resistivity.

$$\frac{d\rho}{\rho\, dT} = \alpha \Rightarrow \int_{\rho_0}^{\rho} \frac{d\rho}{\rho} = \int_{T_0}^{T} \alpha\, dT$$

$$\ell n\left(\frac{\rho}{\rho_0}\right) = \alpha\,(T - T_0)$$

$$\rho = \rho_0\, e^{\alpha(T - T_0)}$$

Using expansion of $e^x = 1 + \frac{x}{1!} + \frac{x^2}{2!} + \frac{x^3}{3!} + ...$

Where $x = T - T_0$, since $T - T_0$ is small, we can neglect higher terms.

Therefore $e^{\alpha(T-T_0)} = 1 + \alpha\,(T - T_0)$

Hence $\rho = \rho_0\,[1 + \alpha\,(T - T_0)]$

Example Based on

Temperature coefficient

Example. 18

The temperature coefficient of resistance of a conductor at 0^oC is $0.0125\ /\ ^oC$. If its resistance at 300 K is R, at what temperature it will rise to 2R ?

Solution.

Wrong Method :

Given $\alpha = 0.0125\ ^oC^{-1}$ at 0^oC temp.

$T_1 = 300\ K = 27^oC$ $R_1 = R$

$T_2 = ?$ $R_2 = 2R$

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

$2R = R\,[1 + 0.0125\,(T_2 - 27)]$

solving this we get

$t_2 = 107^oC = 380\ K$.

This is not a proper method, as the **correct formula** is

$R_t = R_0 [1 + \alpha (t - 0)]$

where R_0 = resistance at 0ºC.

Correct Method :

$R_2 = R_0 [1 + \alpha (t_2 - \theta)]$

$2R = R_0 [1 + 0.0125 (t_2)]$ ...(1)

$R_1 = R_0 [1 + 0.0125 (t_1)]$

$R = R_0 [1 + 0.0125 (t_1)]$ ...(2)

By (1) & (2) $\frac{R}{2R} = \frac{R_0[1+0.0125\,t_1]}{R_0[1+0.0125\,t_2]}$

put t_1 = 27ºC in this we get

$\Rightarrow t_2$ = 134ºC = 407 K

> **NOTE** However if in a numerical problem, nothing is mentioned about temperature at which α is given then the formula $R_2 = R_1 [1 + \alpha(t_2 - t_1)]$ can be used. The answer arrived at would be approximately correct.

Example. 19

At any temperature t ºC, two resistances R_1 and R_2 have temperature coefficients α_1 & α_2 respectively. Find equivalent temperature coefficient of their resultant if they are connected in -

(a) series and (b) parallel.

Assume α_1 and α_2 remain constant with temperature.

Solution.

(a) In series combination

At t_1ºC, $R = R_1 + R_2$

At t_2ºC $R' = R_1' + R_2'$

$= R_1 [1 + \alpha_1 (t_2 - t_1)] + R_2 [1 + \alpha_2 (t_2 - t_1)]$

$= R_1 + R_2 + (R_1\alpha_1 + R_2\alpha_2) (t_2 - t_1)$

If temperature coefficient of the series equivalent is α_s then

$R' = R [1 + \alpha_s (t_2 - t_1)] = (R_1 + R_2) [1 + \alpha_s (t_2 - t_1)]$ or,

$R_1 + R_2 + (R_1\alpha_1 + R_2\alpha_2) (t_2 - t_1)$

$= R_2 + R_1 + (R_1 + R_2) \alpha_s (t_2 - t_1)$

$\alpha_s = \frac{R_1\alpha_1 + R_2\alpha_2}{R_1 + R_2}$ **Ans.**

(b) In parallel combination

At t_1ºC, $R = \frac{R_1 R_2}{R_1 + R_2}$

At t_2ºC, $R' = \frac{R_1' R_2'}{R_1' + R_2'}$

$= \frac{R_1[1+\alpha_1(t_2-t_1)]\,R_2[1+\alpha_2(t_2-t_1)]}{R_1 + R_2 + (R_1\alpha_1 + R_2\alpha_2)(t_2 - t_1)}$ ...(1)

If temperature coefficient of the parallel equivalent is α_p, then

$R' = R [1 + \alpha_p (t_2 - t_1)]$ ...(2)

where $R = \frac{R_1 R_2}{R_1 + R_2}$

from eq (1) and (2)

$$\frac{R_1 R_2[1+\alpha_p \Delta t]}{R_1 + R_2} = \frac{R_1 R_2[1+\alpha_1\Delta t][1+\alpha_2\Delta t]}{R_1 + R_2\left[1+\frac{R_1\alpha_1 + R_2\alpha_2}{R_1+R_2}\Delta t\right]}$$

put $t_2 - t_1 = \Delta t$

$$1 + \alpha_p \Delta t = \frac{[1+(\alpha_1+\alpha_2)\Delta t + \alpha_1.\alpha_2.\Delta t^2]}{1+\frac{R_1\alpha_1 + R_2\alpha_2}{R_1+R_2}.\Delta t},$$

cancelling the term ($\alpha_1 . \alpha_2 \Delta t^2$) we get

$$1 + \alpha_p \Delta t = \frac{1+(\alpha_1+\alpha_2)\Delta t}{1+\frac{R_1\alpha_1 + R_2\alpha_2}{R_1+R_2}.\Delta t}$$

$$1 + \alpha_p \Delta t + \frac{(R_1\alpha_1 + R_2\alpha_2)\Delta t}{R_1+R_2} + \left[\frac{R_1\alpha_1 + R_2\alpha_2}{R_1+R_2}\right]\alpha_p \Delta t^2 = 1 + (\alpha_1 + \alpha_2)\Delta t$$

Again cancelling the higher product term, we get.

$$1 + \alpha_p \Delta t + \frac{(R_1\alpha_1 + R_2\alpha_2)\Delta t}{R_1+R_2} = 1 + (\alpha_1 + \alpha_2)\Delta t$$

therefore

$$\alpha_p\Delta t = \left[\alpha_1 + \alpha_2 - \frac{R_1\alpha_1 + R_2\alpha_2}{R_1+R_2}\right]\Delta t$$

$$\Rightarrow \alpha_p = \frac{R_1\alpha_2 + R_2\alpha_1}{R_1+R_2}$$

Example Based on

Miscellaneous

Example. 20

Two identical metallic balls of radius a are placed in a homogeneous poorly conducting medium with resistivity ρ. Find the resistance of the medium between the balls, under the condition that the distance between them is much larger than their size.

Solution.

Let us impart (mentally) charges +q and –q to the balls. Since the balls are at a large distance from one another, electric field near the surface of each ball is partially determined only by the charge of the nearest sphere and its charge can be considered to be uniformly distributed over the surface.

Surrounding the positively charged ball by a concentric sphere adjoining directly the ball's surface, we write the expression for the current through this sphere as.

$i = 4\pi a^2 j$

where j is current density

From ohm's law

$$J = \frac{E}{\rho},$$

where $E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{a^2}$

$$i = 4\pi a^2 j = 4\pi a^2 \frac{E}{\rho} = 4\pi a^2 \frac{q}{4\pi\varepsilon_0}\frac{1}{a^2}\frac{1}{\rho} = \frac{q}{\varepsilon_0\rho}$$

If the potential difference between the balls is V, then

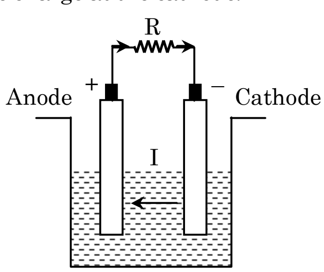
$V = V_+ - V_- = \dfrac{+q}{4\pi\varepsilon_0 a} - \dfrac{-q}{4\pi\varepsilon_0 a} = \dfrac{2q}{4\pi\varepsilon_0 a}$, but from ohm's law $R = \dfrac{V}{I} = \dfrac{\rho}{2\pi a}$

7. CELL OR SOURCE OF EMF

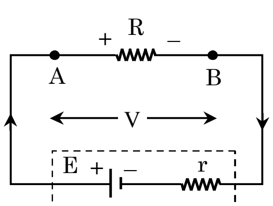
(a) It is a device which converts other forms of energy into electrical energy. There are various types of sources of emf available – electrochemical cell, solar cell, thermoelectric couple, dynamo, etc. However we will confine our discussion to electrochemical cell only and in this chapter, the term cell is used to refer to electrochemical cell (ECC).

(b) An ECC converts chemical energy into electrical form. The main purpose of a cell is to maintain potential difference across the ends of a circuit or circuit element. This ensures flow of steady state current (direct current).

(c) A cell has two electrodes of different materials which are dipped in electrolyte solution. Due to electrochemical reactions positive charge accumulates at the electrode called anode, while negative charge at the cathode.



Cell



Equivalent Circuit

(d) When an external resistance (or load) is connected between the electrodes + ve charge flows from anode to cathode in the external resistance. However as charge is conserved, it must flow from cathode to anode in the internal circuit of the cell.

(e) The internal circuit current flows as +ve and –ve ions. But in the external circuit it depends on the circuit element. (metal, semi conductor or gas etc.)

✦ Cell Terminology

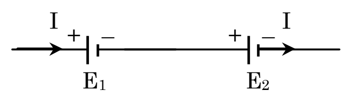
(a) Electromotive force : (EMF) :

It refers to the work done by the cell in moving unit + ve charge in the whole circuit including the cell once. So $E = \dfrac{W}{q}$

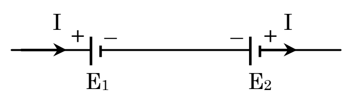
(i) It is measured in joule / coulomb or volt.

(ii) The emf of a cell depends only on the nature of electrodes and electrolyte and is constant for a given electrode electrolyte combination, e.g. for Lechlanche cell emf is 1.45 while emf of dry cell is 1.5 V. It is independent of size and shape of the cell.

(iii) If a cell is connected in a circuit such that current flows from anode to cathode then its emf is considered to be positive, otherwise negative. (see figure)



$E = E_1 + E_2$



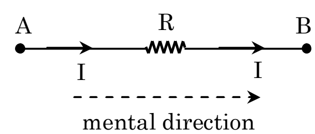
$E = E_1 - E_2$

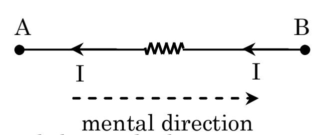
(b) Potential Difference : (V)

(i) In reference to an electric circuit potential difference between any two points is defined as the work done in moving unit + ve charge from one point to the other point of the circuit. It is equal to the product of resistance R between the two points and current (I) flowing through it.

i. e., $V = I R$

(ii)





While calculating potential difference between two points say A and B we travel mentally in any direction. If the current flows in the direction of travel then the products is considered positive (+ I R). If current flows opposite to the direction of travel then it is taken negative (– I R). As shown above.

$V_A - I\,R = V_B$

$\Rightarrow \quad V_A - V_B = I\,R$

[I flows along mental direction]

$V_A + I\,R = V_B$

$\Rightarrow \quad V_A - V_B = -\,I\,R$

[I flows opposite to mental direction]

(c) Internal resistance (r) :

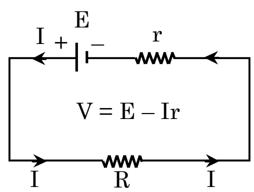
(i) Internal resistance of a cell depends on the distance between electrodes ($r \propto d$) area of electrodes $\left(r \propto \frac{1}{A}\right)$ concentration of electrolyte ($r \propto c$) and its temp $\left(r \propto \frac{1}{T}\right)$.

NOTE If two cells are of same emf, the internal resistance of reversible (secondary) cell is lower than that of irreversible (primary) cell.

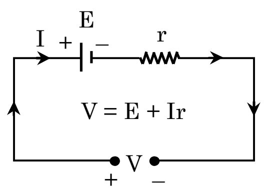
(ii) The internal resistance of an ideal cell is zero. But for real cell it is non-zero and is always connected in series with the cell.

(d) Relation between E, V and r

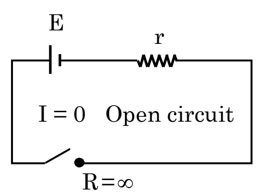
If a resistance R is connected between the terminals of a cell of emf E and internal resistance r (see fig.) the current in the circuit by ohm's law will be



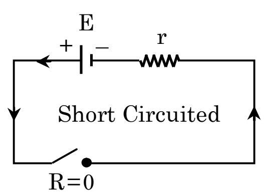
(A)



(B)



(C)



(D)

$$I = \frac{E}{R+r} \quad \text{or} \quad E = I\,R + I\,r$$

Here the quantity I R is called terminal voltage (V) and I r is called internal drop (X). Therefore

$$E = V + X$$

$$\frac{E}{V} = 1 + \frac{X}{V} = \left[1 + \frac{r}{R}\right] \Rightarrow r = R\left[\frac{E}{V} - 1\right]$$

From this expression it is clear that :

(i) If the cell is ideal ($r = 0$), then $E = V$

i.e. for ideal cell the terminal voltage is equal to the emf of the cell.

(ii) When the cell is discharging or when current is drawn from the cell then (see fig. A)

$E = V + X$

$V = E - X$

$V = E - I\,r \Rightarrow V < E \quad (\text{if } I \neq 0,\ r \neq 0)$

i.e. for a real discharging cell the terminal voltage must be lesser than it e.m.f.

When the cell (reversible) is charging or when current in flowing into the cell (see fig B)

$V = E + X$

$V = E + I\,r \Rightarrow V > E \ (\text{if } I \neq 0,\ r \neq 0)$

i.e. when a real cell is being charged the terminal voltage must be greater than the emf of the cell.

(iii) When the cell is in open circuit or when external resistance is infinite ($R = \infty$) then, (see fig. C)

$$I = \frac{E}{(r+\infty)} = 0 \quad \text{so} \quad V = E - I\,r = E$$

Thus when a real cell is in open circuit no current flows cell in the circuit and hence terminal voltage of cell is equal to its emf.

(iv) When the cell is short circuited or when external resistance is zero ($R = 0$), then, (see fig. D)

$$I = \frac{E}{(0+r)} = \frac{E}{r} = \text{max},$$

$$V = I \times 0 = 0$$

When a real cell is short circuited the current drawn from cell is maximum & terminal voltage is zero.

(v) When the cell has become old : In this case the internal resistance of the cell increases and its emf decreases. This is why a fresh cell gives more current as compared to old one.

(vi) Current capacity : Current capacity of a cell depends upon the amount of electrolyte. A bigger cell contains more electrolyte and so has greater capacity than a smaller one.

Current capacity is measured in ampere hour.

✦ Power Transfer

It is defined as the time rate of energy transferred by a cell to the load. It is given by

$$W = qV$$

$$W = I^2 R\, t \qquad [q = It,\ \&\ V = I\,R]$$

therefore $\frac{W}{t} = P = I^2 r$

$$\Rightarrow \quad P = \frac{E^2 R}{(R+r)^2} \qquad \left[\because I = \frac{E}{R+r}\right].$$

From the equations it is clear that power transferred to the load will be maximum when

$$\frac{dP}{dR} = 0$$

$$\frac{d}{dR}\left[\frac{E^2 R}{(R+r)^2}\right] = 0$$

on solving it we get $R = r$.

This shows that power transferred by a cell to the load will be maximum when external load is equal to internal resistance of the cell, i.e. R = r. This rule is know as **maximum power transfer theorem** and the power transferred to the load (R) in this condition is

$$P_{max} = \frac{E^2 R}{(R+r)^2} = \frac{E^2}{4r}$$

> **NOTE** It is common misconception that "current will be maximum when power consumed by the load is maximum".
>
> Actually, $I_{max} = \dfrac{E}{0+r}$,
>
> when R = 0 and not when R = r

Example Based on

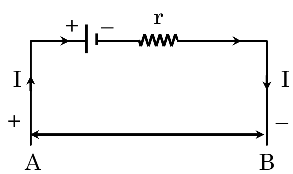
Cell

Example. 21

A battery of emf 2V and r = 0.1 Ω is being charged with a current of 5 ampere. In what direction will the current flow inside the battery ? What is the terminal voltage between two terminals of the battery ?

Solution.

In changing a battery (reversible) current inside should flow from anode to cathode (see figure)



From figure we can say

$V_A + E + Ir = V_B$

$|V_A - V_B| = E + Ir = 2 + 5 \times 0.1$

$|V_A - V_B| = 2.5$ V

Example. 22

An accumulator is first connected to load R, and then to another load R_2 for the same time. In both cases the time rate of heat generation across the loads is same. Calculate internal resistance of the accumulator.

Solution.

According given problem $\dfrac{H_1}{t} = \dfrac{H_2}{t}$

$$\frac{E^2 R_1}{(R_1+r)^2} = \frac{E^2 R_2}{(R_2+r)^2},$$

solving it we get $r = \sqrt{R_1 R_2}$

Example. 23

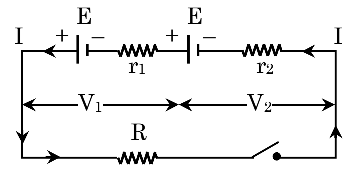
Two batteries of same emf E but different internal resistance r_1 and r_2 ($< r_1$) are connected in series to an external resistance R.

(a) Find value of R that makes potential difference zero across the terminals of one battery.

(b) Which battery is it ?

Solution.

As both the batteries are being discharged, current drawn



$$I = \frac{E+E}{R+r_1+r_2} = \left[\frac{\text{Total emf}}{\text{Total resistance}}\right] \quad \ldots(1)$$

Also $V_1 = E - Ir_1$ and $V_2 = E - Ir_2$

But as $r_1 > r_2 \Rightarrow V_1 < V_2$

So if potential difference across any one of the batteries is to become zero it should be V_1 (i.e. across the one which has higher internal resistance).

$V_1 = E - Ir_2 = 0$

$$\Rightarrow \quad I = \frac{E}{r_2} \quad \ldots(2)$$

Hence from eq. (1) and (2)

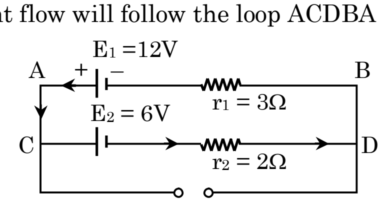
$$\frac{2E}{R+r_1+r_2} = \frac{E}{r_1} \Rightarrow R = r_1 - r_2$$

Example. 24

What is the potential difference between the points M and N for the circuit shown below.

Solution.

As + ve terminals of both cells are connected at junction C, therefore the cell $E_1 = 12V$ will discharge while the cell E_2 = 6V will be charged. Hence the current flow will follow the loop ACDBA or



$$I = \frac{|E_1 - E_2|}{r_1 + r_2} = \frac{12-6}{3+2} = 1.2A$$

For the cell E_1 (which is being discharged)

$V_A - V_B = E_1 - Ir_1 = 12 - 1.2 \times 3 = 12 - 3.6 = 8.4$ V

Similar for the cell E_2 (which is being charged)

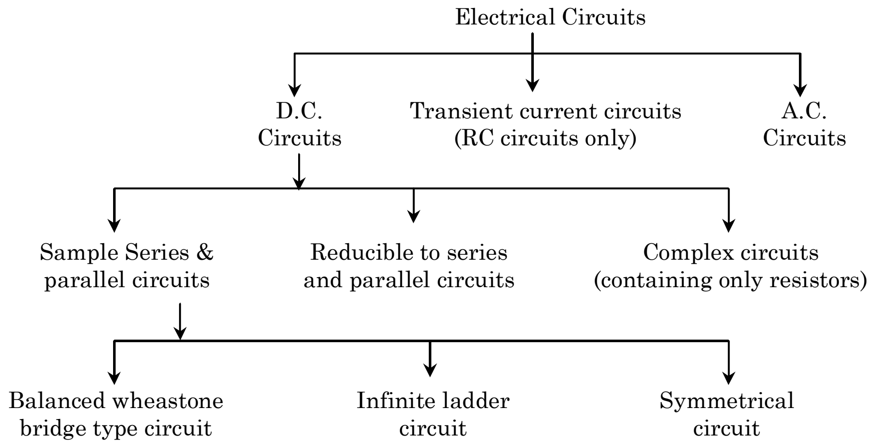
$V_C - V_D = E_2 + Ir_2 = 6 + 1.2 \times 2 = 8.4$ V

So $V_A - V_B = V_C - V_D = V_M - V_N = 8.4$ V

8. CIRCUIT ANALYSIS

As mentioned in the preface of this booklet we have followed a very innovative and simplified approach towards circuit analysis. After a thorough study of all possible resistor, capacitor and inductor networks, we have grouped them in a certain number of categories as given below. There is a technique for solving a network falling in a particular category or sub category. As an aspirant of JEE you are advised to conduct a deep study of each group and its underlying principles there in.

Once your have mastered the techniques for solving each and every category the analysis of electrical circuits will become amazingly easy.



In this booklet we will not study A.C. circuits. It will be dealt in the chapters coming later.

Before going into details of each category let's first understand the principle behind grouping of resistances.

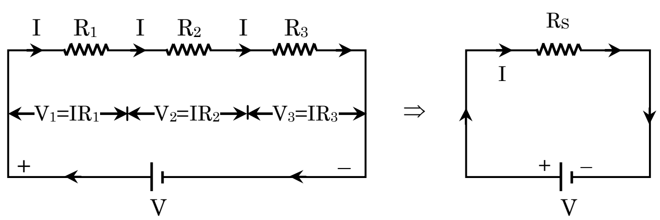
9. SIMPLE SERIES AND PARALLEL CIRCUITS

Replacing a combination of resistances by an equivalent resistance is called grouping of resistances. It is divided into three types namely series, parallel and mixed grouping.

✦ Resistances in 'Series'

(a) The principal of series combination can be remembered in the form of abbreviation CUPD.

(b) The term CUPD means "Current Undivided Potential difference Divided. This implies that in series combination of resistances current through each resistor flows undivided but the potential drop provided by the source is divided in direct proportion to the resistances ($V \propto R$)



From the figure it is clear that

$I = I_1 = I_2 = I_2 = I_4 = \cdots\cdots\cdots\cdots$, and

$V_1 = IR_1$, $V_2 = IR_2$ & $V_3 = IR_3$ $\cdots\cdots$, and

$V = V_1 + V_2 + V_3 + \cdots\cdots\cdots\cdots$

If equivalent resistance is R_s then

$V = IR_s$

Therefore $R_S = R_1 + R_2 + R_3 + \cdots\cdots\cdots\cdots$

i.e. $V_1 = \dfrac{R_1}{R_1 + R_2 + R_3} V$ and

$V_2 = \dfrac{R_2}{R_1 + R_2 + R_3} V$ and

$V_3 = \dfrac{R_3}{R_1 + R_2 + R_3} V$

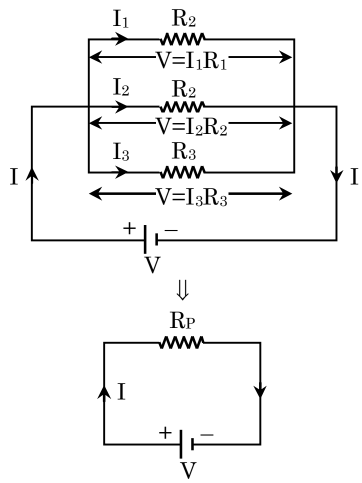
(c) Since in series combination potential is divided according to $V \propto R$, hence is case of three resistors in series

$V_1 : V_2 : V_3 = R_1 : R_2 : R_3$ and $V = V_1 + V_2 + V_3$

✦ Resistances in Parallel

(a) We can remember the principle of parallel combination in the abbreviated form PUCD - i.e. Potential Undivided & Current Divided.

(b) This implies that in parallel combination potential difference across each resistance is same, but total current from the source is divided in the inverse proportion of the resistance $\left(I \propto \frac{1}{R}\right)$.



From the figure we can say that

$V = V_1 = V_2 = V_3 =$ ...., and

$I_1 = \frac{V}{R_1}$, $I_2 = \frac{V}{R_2}$, $I_3 = \frac{V}{R_3}$;

..... and $I = I_1 + I_2 + I_3 + \cdots\cdots$

If equivalent resistance is R_P then $I = \frac{V}{R_P}$,

therefore $\frac{V}{R_P} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}$

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots\cdots$$

(c) In case of three resistance in parallel

$I_1 : I_2 : I_3 = \frac{1}{R_1} : \frac{1}{R_2} : \frac{1}{R_3}$ and $I = I_1 + I_2 + I_3$

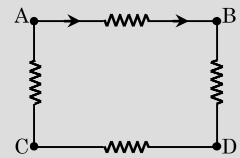
Hence $I_1 = \frac{1/R_1}{1/R_1 + 1/R_2 + 1/R_3} I$,

$$I_2 = \frac{1/R_2}{1/R_1 + 1/R_2 + 1/R_3} I$$

and so on

NOTE (1) In case of parallel grouping the equivalent resistance is lower than the value of lowest resistance in the combination. If n resistance are connected in series and parallel respectively the ratio of their resultants will be $\frac{nR}{R/n} = n^2$.

(2) While determining equivalent resistance of a circuit, one must select the terminals (or points) across which the equivalent resistance is to be calculated. This is because in a given network equivalent resistance would be different across different sets of terminals, e.g. as shown in the figure below equivalent resistance R_{AB} and R_{AD} will be different.



$\Rightarrow \quad R_{AB} = \frac{3R.R}{3R + R} = \frac{3}{4}R$

$\Rightarrow \quad R_{AD} = \frac{2R.2R}{2R + 2R} = R$

Example Based on

Simple series and parallel circuits

Example. 25

Resistance R, (R + 1), (R + 2) .... (R + n) are connected in series. Calculate equivalent resistance.

Solution.

As in series combination

$R_S = R_1 + R_2 + R_3 + \ldots\ldots\ldots\ldots R_n$

$= R + (R + 1) + (R + 2) + \ldots\ldots\ldots (R + n)$

This is an arithmetic progression with

no. of terms = n + 1

first term a = R

common difference d = 1

Therefore $R_s = S_n = \frac{n}{2}[2a + (n - 1)d]$

$= \frac{n+1}{2}[2R + \{2(n + 1) - 1\} 1]$

$= \frac{n+1}{2}[2R + n]$

$R_s = (n + 1)\left(R + \frac{n}{2}\right)$

Example. 26

Resistances R, 2R, 4R, 8R .... ∞ are connected in parallel. Calculate equivalent resistance.

Solution.

As in parallel combination

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots\ldots\ldots \infty$$

$$= \frac{1}{R} + \frac{1}{2R} + \frac{1}{4R} + \frac{1}{8R} + \frac{1}{\infty} = \frac{1}{R}\left[1 + \frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \ldots\ldots\ldots 0\right]$$

(Geometric progression)

$$\frac{1}{R_P} = \frac{1}{R}\left[\frac{a}{1-r}\right] = \frac{1}{R}\left[\frac{1}{1-\frac{1}{2}}\right]$$

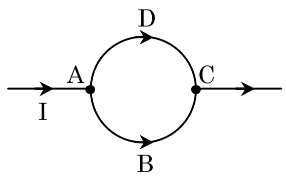
$$\because \quad \frac{1}{R_P} = \frac{2}{R} \Rightarrow R_P = \frac{R}{2}$$

Example. 27

A wire of resistance 10 Ω is bent to form a complete circle. Find the resistance between two diametrically opposite points (in Ω).

Solution.

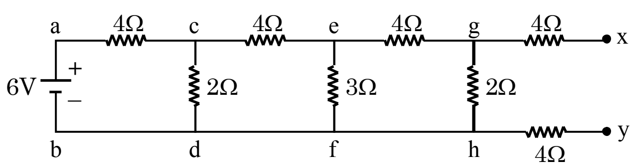
As shown in the figure, the equivalent resistance between the points A & C (R_{AC}) is equivalent to parallel combination of arms ADC and ABC, each of which is equal to 5Ω.



Thus $R_{AC} = \frac{5 \times 5}{5+5} = 2.5\ \Omega$

Example. 28

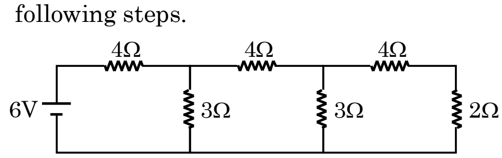
Find the equivalent resistance and current supplied by the battery in the network given below.



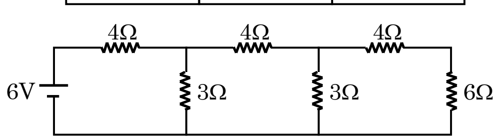
Solution.

To find the current supplied by the battery first we must calculate equivalent resistance. In such types of network the student must always start from the side lying farthest from the battery.

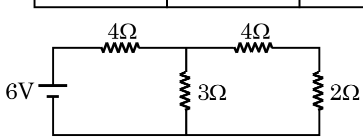
Note that no current shall flow through the resistances (g – x) and (h – y). Hence removing them from the network will not change its equivalent resistance. Thus, the network can be reduced in following steps.

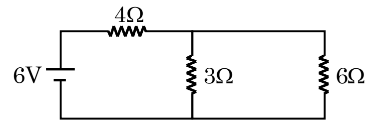


⇒

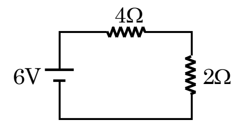


⇒





⇒



$\therefore \quad R_{eq} = 6\Omega$

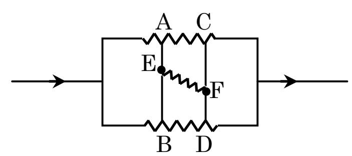
and $\quad I = \frac{V}{R_{eq}} = \frac{6}{6} = 1\ A$

Example. 29

Two conductors AB and CD are connected between two parallel resistors in such a way that no current flow through them (see figure). Then a wire is connected between E and F. Explain whether any current flows between points E & F or not ? If yes then explain the direction of current flow.

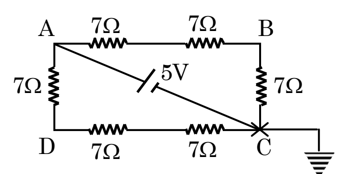
Solution.

As no current flows through the wire AB, thus every point of this wire must be at same potential (say V_E) similarly every point on the wire CD should also be at same potential (say V_F). But the direction of current in the network shows that wire AB must be at higher potential than wire CD. Thus $V_E > V_F$. Hence current should from point E to point F.



Example. 30

In the adjoining figure find the p.d. between the points A and B and the potential of point B. The point C is earthed.



Solution.

(a) The arms ABC and ADC are connected parallel to each other.

Therefore

$$\frac{1}{R_{eq}} = \frac{1}{R_{ABC}} + \frac{1}{R_{ADC}}$$

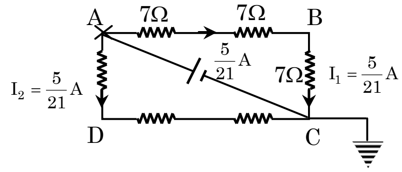
$$R_{eq} = \frac{21 \times 21}{21+21} = \frac{21}{2}\ \Omega$$

So the current drawn from the cell

$$I = \frac{V}{R_{eq}} = \frac{5}{\frac{21}{2}} = \frac{10}{21}\ A.$$

It will be divided equally between branches R_{ABC} and R_{ADC} hence current in the branches will be $\frac{5}{21}$ A each. (see figure).

Therefore from ohm's law



$V_{AB} = I_1\ (7\Omega + 7\Omega)$

$$= \frac{5}{21} \times 14 \text{ volt} = \frac{10}{3} \text{ volt}$$

(b) Since the point C is earthed hence $V_C = 0$. Therefore from ohm's law

$$\frac{V_B - V_C}{R_{BC}} = I_1 = \frac{V_B - 0}{7\Omega} = \frac{5}{21} \text{A}$$

$$V_B = \frac{5}{3} \text{ volt.}$$

10. NETWORKS REDUCIBLE TO SIMPLE SERIES AND PARALLEL CIRCUITS

There are a large number of networks which on first look, appear rather complicated. But on close observation we can reduce such networks into simple series & parallel circuits. In this chapter this category has been dealt, in three separate subcategories namely.

(a) Balanced Wheatstone bridge type circuits.

(b) Symmetrical circuits.

(c) Infinite circuits.

But before we go into details of each of these, let's first understand a very simple yet effective method of reducing complicated networks. It is known as **Point Potential Technique**.

✦ Point Potential Technique

This method is based on the fact that in an electrical circuit potential of every points is unique. Therefore if any two or more points are joined by connecting wire they will be at same potential and as such can be treated as a single point. This technique can be applied in following steps

(a) Assign number to each and every junction of a circuit.

(b) Identify all the junctions joined by zero resistance connecting wires. These junctions must be at same potential and can be treated as single point.

(c) Identify the terminals / points across which equivalent resistance is to be calculate.

Mark these points far away from each other. Note that a single point may represent more than one junctions (if several junctions correspond to same potential). Now mark the remaining junctions as separate points.

(d) Rewrite the circuit an go on reducing it till final result is achieved.

Example Based on

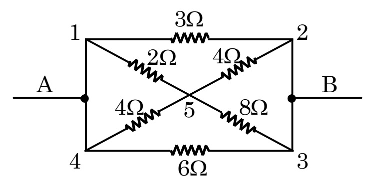
Point potential technique

Example. 31

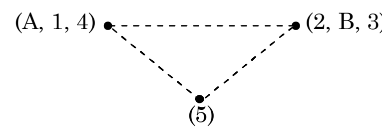
From the figure given below determine net resistance a cross the junction A and B.

Solution.

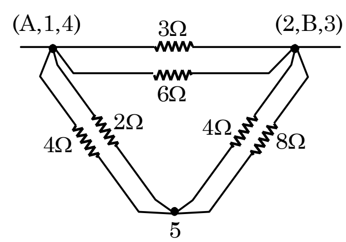
Step (i) Mark each junction 1 to 5 as shown.



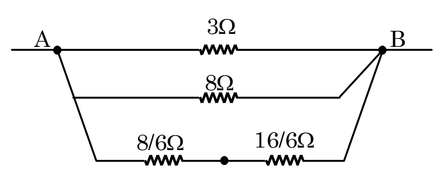
Step (ii) The junction groups (A, 1, 4) (2, B, 3) and (5) can be each treated as points as they are at same potentials. Mark these groups as points shown below.



Step (iii) Now we can connect these points with corresponding junctions as shown.



Step (iv) Reducing the network further we get.

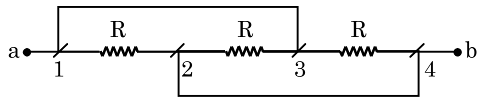


$$\frac{1}{R_{AB}} = \frac{1}{3} + \frac{1}{6} + \frac{6}{24}$$

$$\Rightarrow R_{AB} = \frac{24}{8+4+6} = \frac{24}{18} = \frac{4}{3}\,\Omega$$

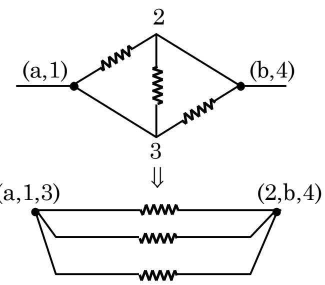
Example. 32

Find the equivalent resistance across the points a & b for the networks shown in the figure.



Solution.

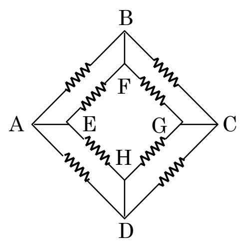
The network given in figure can be reduced according to point potential technique in following steps



$R_{ab} = R/3$

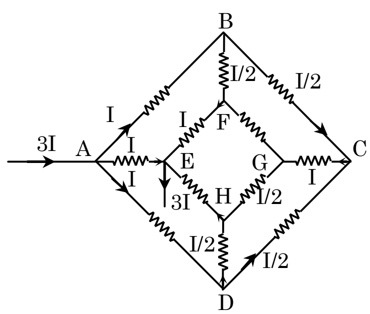
Example. 33

The equivalent resistance of the network shown below (each resistor has value r) between the junctions A & E.



Solution.

This network can also be solved using Kirchhoff's Laws. However we will solve it using point potential technique. Let's first connect the junctions A and E with (+) and (–) terminals of a battery. Also, we assume that a current of magnitude 3I enters the junction A. The division of this current is shown in the figure.



It become clear that potential drops

$V_A - V_B = V_A - V_D = I\,r$

$\therefore \quad V_B = V_D$

Thus the junctions B and D can be treated as a single point. Similarly

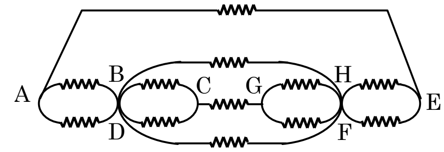
$$V_E - V_F = V_E - V_H = \frac{I}{2}.r.$$

$V_F = V_H$

The junctions F and H can also be treated as a single point.

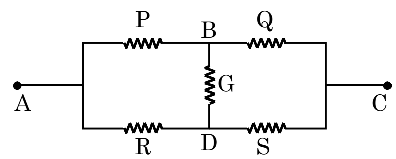
Since R_{eq} is to be calculated between points. A and E, mark them far from each other. Rewrite the network using point potential technique as given below.

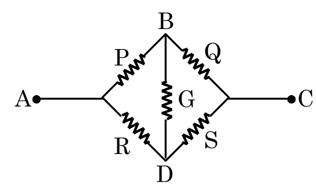
Solving this network we will get $R_{AE} = \frac{7}{12}R$

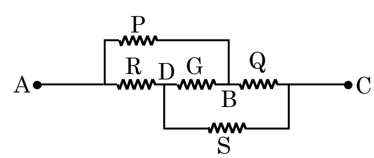


✦ Balanced Wheatstone bridge type circuits

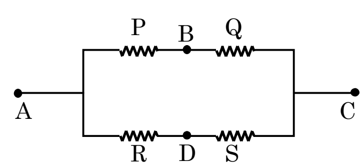
If in a network, resistance are arranged as in the circuit shown below, the network is called **balanced Wheatstone bridge** and is said to be balanced If $\frac{P}{Q} = \frac{R}{S}$







Details of Wheatstone bridge will be dealt later. Here it is sufficient to know that in a balanced Wheatstone bridge certain points are at same potential (see points B and D) and so no current flows through the resistor connected between such points (as the resistor G in above figures.) Therefore removing such resistors will have no effect on net resistance. Thus in a balanced Wheatstone bridge equivalent circuit resistance can be calculated as follows :



$$\frac{1}{R_{AC}} = \frac{1}{(P+Q)} + \frac{1}{(R+S)}$$

NOTE If the Wheatstone bridge is not balanced or equivalent resistance is to be calculated between the points other than A and C, the above method will not be useful. In such cases the circuit must be solved by applying **Kirchhoff's - Laws** or otherwise.

Example Based on

Balanced Wheatstone bridge

Example. 34

Calculate effective resistance between points A and B for the networks shown in fig. A and Fig. B.

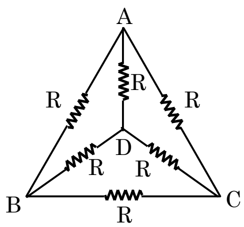


Fig. (A)

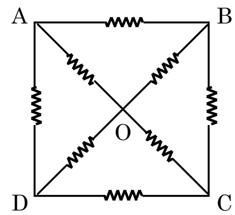


Fig. (B)

Solution.

In the Figure (A) the points B and D are equipotential. Therefore the resistor R_{BD} can be removed. Hence net resistance between points A and C will be

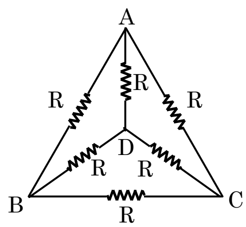


Fig. (A)

$$\frac{1}{R_{AC}} = \frac{1}{2R} + \frac{1}{2R} + \frac{1}{R} = \frac{2}{R} \Rightarrow R_{AC} = \frac{R}{2}$$

Similarly in the figure (B) since hence $V_B = V_D = V_O$ thus we can remove the resistors R_{OB} and R_{OD} therefore the equivalent resistance will be

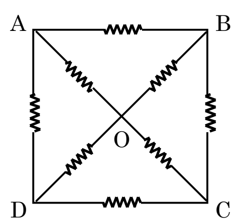
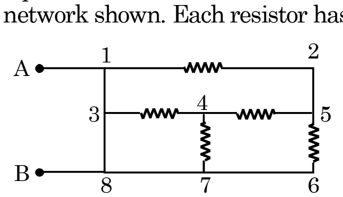


Fig. (B)

$$\frac{1}{R_{AC}} = \frac{1}{2R} + \frac{1}{2R} + \frac{1}{2R} \Rightarrow R_{AC} = \frac{2}{3}R$$

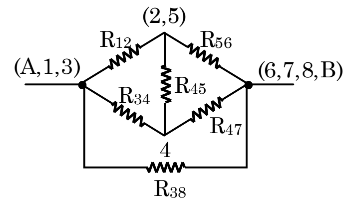
Example. 35

Find the equivalent resistance between the points A and B for the network shown. Each resistor has value R.



Solution.

First Let's rewrite the circuit using point potential method. Note that junction groups [A, 1, 3], [2, 5], [4] and [6,7, 8, B] can be each treated as separate points. More over since resistance is to be calculated between points A and B, these should be marked farther as shown.



As we can see, the resistor R_{45} = R can be removed as the junctions (2,5) and 4 are at same potential.

Hence $$\frac{1}{R_{eq}} = \frac{1}{2R} + \frac{1}{2R} + \frac{1}{R}$$

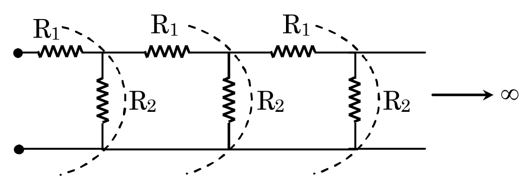
$$\therefore \quad \frac{1}{R_{eq}} = \frac{R}{2}$$

✦ Infinite Circuits

There are two types of infinite circuits which have been popular with the examiners. In the first type a network consists of infinite number of links connected with each other. In the second type you may be given a network in the form of an infinite wire grid. Here we are discussing these two types separately.

(A) Network with infinite number of links :

Such networks are in the form of a long chain of infinite links, with each link containing two or more resistors (see figure).



The equivalent resistance of such networks can be easily determined if we apply a simple theory that there will be no appreciable change in the net resistance of the chain even if we remove or add one link from the network. Also keep in your mind that in such cases you will always get answer in the form of a quadratic equation.

(B) Infinite wire grid networks :

Such networks are in the form of an infinite wire grid consisting of triangular, square, pentagonal or even hexagonal cells.

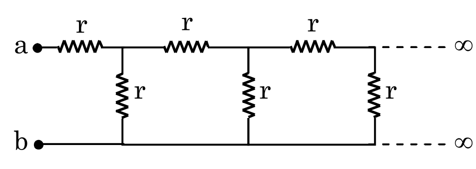
The net resistance of these type of girds can also be determined by using the principles of symmetry of current distribution and their super position.

Example Based on

Infinite circuits

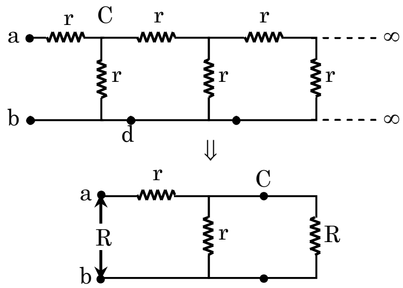
Example. 36

Find the equivalent resistance of the network between the points a and b as shown in the figure.



Solution.

Let the equivalent resistance between a and b is R. As the ladder is infinite, R is also the equivalent resistance of the ladder to the right of the points c and d. Thus, we can replace the part to the right of cd by a resistance R and Redraw the circuit as shown below.



This gives

$R = r + \frac{r.R}{r+R}$, read just this equation in the quadratic form of variable R.

or $R^2 - r\,R - r^2 = 0$

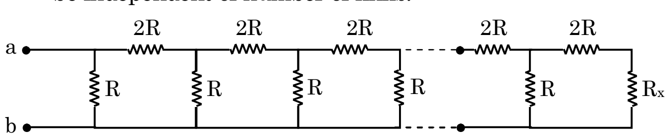
or $R = \frac{r \pm \sqrt{r^2 + 4r^2}}{2}$

[omit –ve quantity as resistance can not be negative].

$$R = \frac{1+\sqrt{5}}{2}.r.$$

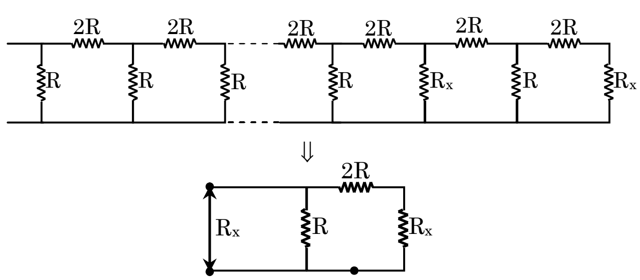
Example. 37

At what value of resistance R_x in the circuit shown below will the total resistance between points A and B be independent of number of links.



Solution.

In the given network if we add one more link and terminate it by R_x, the net resistance will remain same. Thus, we can reduced the circuit as shown below.



Therefore $R_x = \frac{R(R_x + 2R)}{R + (R_x + 2R)}$

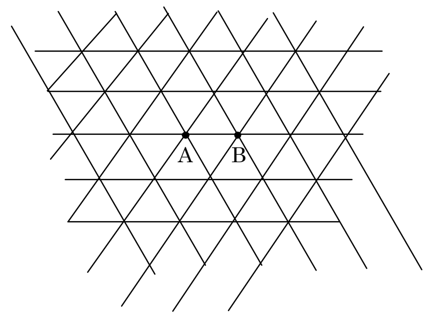
simplifying it in the form of quadratic equation of R_x.

We get $R_x^2 + 2R.R_x - 2R^2 = 0$

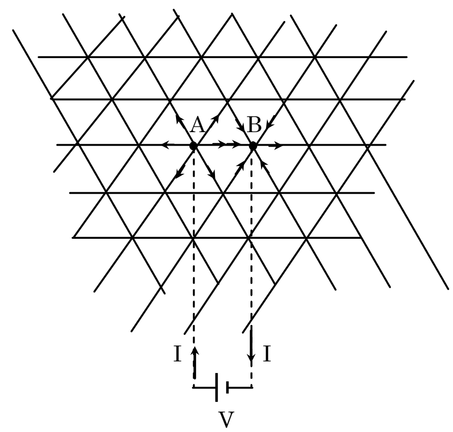
$$R_x = \frac{-2R + \sqrt{4R^2 + 8R^2}}{2} = (\sqrt{3} - 1)R$$

Example. 38

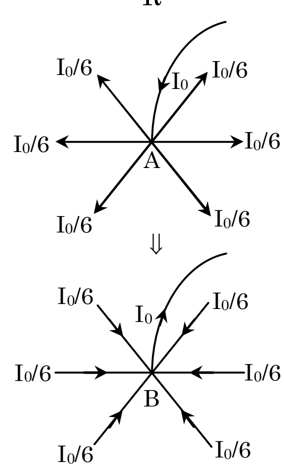
There is an infinite grid with hexagonal cells. (See figure). The resistance of each wire between neighbouring joints is equal to R_o. Find the resistance R of the whole grid between points A and B.



Solution.



Let's connect the joints A and B with a battery of emf V. If R is the resistance of grid , then the current entering at junction A (from battery) and leaving from junction B will be $I_o = \frac{V_o}{R}$



we can say that total current entering the junction A will leave this junction in six equal parts. Therefore current in the wire AB going away from A will be $\frac{I_0}{6}$.

By the principle of symmetry we can also say that the total current leaving the junction B will be I_o if each of the six wires connected to B supplies current equal to $I_0 / 6$.

Thus total current in wire AB = current leaving from junction A + Current entering into B = $\frac{I_0}{6} + \frac{I_0}{6}$

$$I = \frac{I_o}{3}$$

Now by ohm's law

$V = I.\ R_o$ resistance of wire AB.

$$V = \frac{I_o}{3}.R_o \Rightarrow V = \left(\frac{R_o}{3}\right) I_o$$

Since I_o is total current drawn from battery of emf V, hence resistance of grid across AB will be

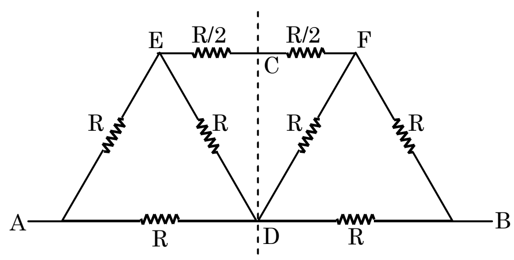
$$R = \frac{V}{I_o} = \frac{R_o}{3} \Rightarrow R = \frac{R_o}{3}$$

✦ Symmetric Circuits

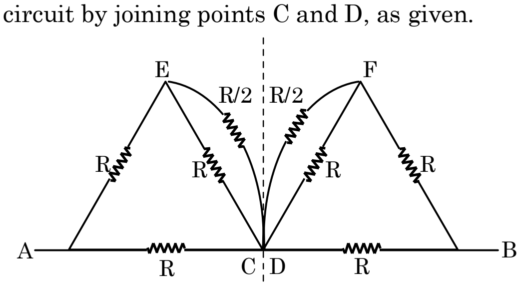
If distribution of resistors in a network is such that it is identical about any hypothetical line, then the circuit is said to be symmetrical. In other words if a symmetric circuit is broken in two parts about a given line, then one part will be a mirror image of the other.

In such cases the points of the circuit lying on the line of symmetry will be equipotential and therefore can be joined at a single point.

Let us understand the application of this theory with an illustration.



In this circuit the part left to the line of symmetry is identical to the part lying right. Therefore point C and D will be equipotential. Thus we can rewrite the circuit by joining points C and D, as given.



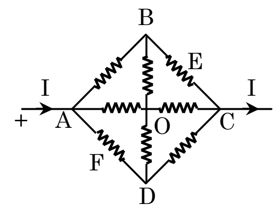
Now we can determine the resistance of any one part. Net resistance will be double the resistance of that part i. e, $R_{AB} = 2\left[\frac{4}{7}R\right] = \frac{8}{7}R$

Example Based on

Symmetrical circuits

Example. 39

In the network shown each resistor is equal to R. Find the equivalent resistance of the network between the points (i) A and C (ii) E and F. The points E and F are mid points of the side BC and AD respectively.

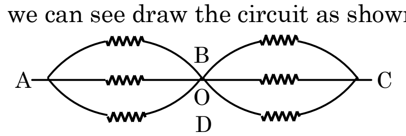


Solution.

(i) Suppose a current I enters the junction A and leaves from C.

For the terminals, A and C, the line BOD will be the line of symmetry. Therefore no current will flow through resistors BO and OD (as the line BOD is equipotential line)

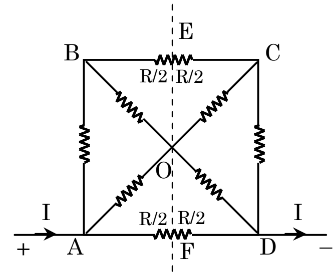
Thus we can see draw the circuit as shown:



$$\therefore\ R_{AC} = 2\left[\frac{R}{3}\right] = \frac{2}{3}R$$

(ii) Similarly if the current I enters at A and leaves from D, the circuit will be symmetric about the line EOF, [BE = FC = R/2 and AF = FD = R/2]

Proceeding similarly we can get



$$R_{AD} = 2\left[\frac{4}{15}R\right] = \frac{8}{15}R$$

11. COMPLEX CIRCUIT

The circuits which do not fall under the category of the previous categories, may be solved by using Kirchhoff's law.

✦ Kirchhoff's Laws

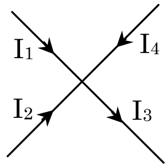
There are two laws

(a) Kirchhoff's Junction Law :

(i) This law is based on the principle of conservation of charges.

(ii) It states that the algebraic sum of currents coming at a junction is equal to zero. I = 0

(iii) **Sign convention :** Current reaching a junction is taken as positive and current leavig the junction is negative



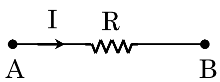
Here $I_1 + I_2 - I_3 + I_4 = 0$

(b) Kirchhoff's Loop Law

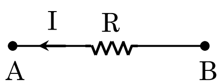
(i) This is based on conservation of energy.

(ii) It states that in an electric circuit the sum of the potential drop across different components is equal to zero.

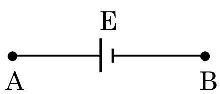
(iii) Sign convention

(1) 

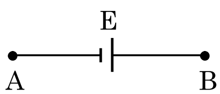
$V_A - B_B = + IR$

(2) 

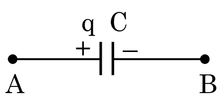
$V_A - V_B = - IR$

(3) 

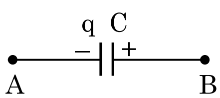
$V_A - V_B = + E$

(4) 

$V_A - B_B = - E$

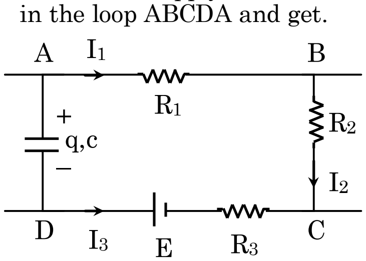
(5) 

$V_A - V_B = + \frac{q}{c}$

(6) 

$V_A - V_B = - \frac{q}{c}$

Here we can apply the Kirchhoff's second law in the loop ABCDA and get.



$$+ I_1R_1 + I_2R_2 - I_3 R_3 - E - \frac{q}{c} = 0$$

(c) The following points must be taken into consideration in applying the Kirchhoff's Law.

(i) Show the direction of current in each branch.

(ii) In showing the currents in different branches, use Kirchhoff's junction law.

(iii) Select the loops such a way that each new loop must have at least one new branch not considered previously.

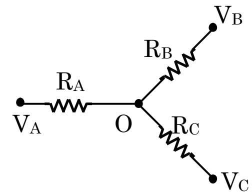
(iv) The number of loops must be equal to the number of variables.

Example Based on

Kirchhoff's Law

Example. 40

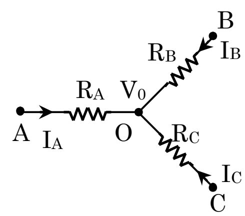
Three resistances are joined at a point O and their ends are at potentials V_A, V_B and V_C as shown. Find the potential of the junction O.



Solution.

Let V_0 be the potential of the point O.

From Kirchhoff's Junction Law



$I_A + I_B + I_C = 0$

$$\Rightarrow \frac{V_A - V_0}{R_A} + \frac{V_B - V_0}{R_B} + \frac{V_C - V_0}{R_C} = 0$$

$$\Rightarrow V_0 = \frac{V_A / R_A + V_B / R_B + V_C / R_C}{1/R_A + 1/R_B + 1/R_C}$$

Example. 41

Three 4V batteries of internal resistance 0.1, 0.2 and 0.3 are connected in parallel and in series with a 2.045 ohm resistor. Find

(a) equivalent resistance for the current

(b) equivalent voltage

(c) current in the circuit

(d) the terminal voltage of equivalent cells

(e) the terminal voltage of each cell.

Solution.

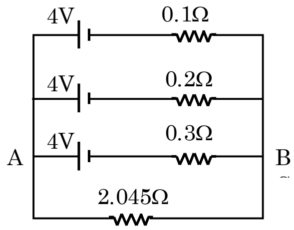
The circuit arrangement is shown in fig.

As the batteries are connected in parallel, hence total emf of the circuit = 4V.

The effective resistance R_{AB} between A and B is given by

$$\frac{1}{R_{AB}} = \frac{1}{0.1} + \frac{1}{0.2} + \frac{1}{0.3} = \frac{110}{6}$$

$$R_{AB} = \frac{6}{110} = 0.055 \text{ ohm.}$$



(a) Equivalent resistance of the circuit
$R = R_{AB} + 2.045 = 0.055 + 2.045 = 2.1$ ohm,

(b) Equivalent voltage = 4volt

(c) Current in the circuit $= \frac{4}{2.1} = 1.9$ amp.

(d) Terminal voltage of equivalent cell
$= 4 - i\,R_{AB} = 4 - 1.9 \times 0.55$
$= 4 - 0.1045 = 3.8955$ V

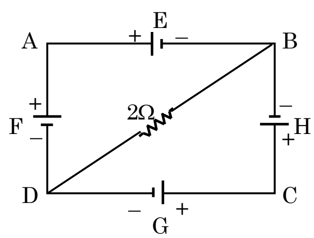
(e) Batteries are in parallel hence terminal voltage for each cell is 3.8955 V.

Example. 42

In the circuit shown in fig. E, F, G and H are cells of emf 2, 1, 3 and 1 volts and their internal resistances are 2, 1, 3 and 1 ohm respectively. Calculate

(i) the potential difference between B and D and

(ii) the potential difference across the terminals of each of the cells G and H.



Solution.

Fig. shows the current distribution

Applying Kirchhoff's first law at point D,

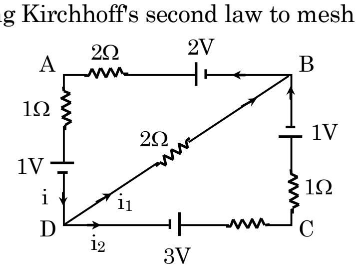
we have $i = i_1 + i_2$ ... (1)

Applying Kirchhoff's second law to mesh ADBA,

we have $2i + 1i + 2i_1 = 2 - 1 = 1$

or $3i + 2i_1 = 1$ ... (2)

Applying Kirchhoff's second law to mesh DCBD,



we get $3i_2 + 1i_2 - 2i_1 = 3 - 1$

or $4i_2 - 2i_1 = 2$ ...(3)

Solving eqs. (1), (2) and (3), we get

$$i_1 = \frac{1}{13} \text{ amp.}, \ i_2 = \frac{6}{13} \text{ amp., and } i = \frac{5}{13} \text{ amp.}$$

(i) Potential difference between B and D

$$= 2\,i_1 = 2\left(\frac{1}{13}\right) = \frac{2}{13} \text{ volt.}$$

(ii) Potential difference across G

$$= E - i_2 R = 3 - \frac{6 \times 3}{13} = 1.61 \text{ V.}$$

Potential difference across H

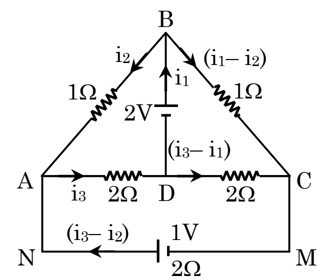
$$= 1 - \left(\frac{-6}{13}\right)(1) = 1.46 \text{ V.}$$

Example. 43

AB, BC, CD and DA are resistors of 1, 1, 2 and 2 ohms respectively connected in series. Between A and C is a 1 volt cell of resistance 2 ohms, A being positive. Between B and D is a 2 volt cell of 1 ohm resistance, B being positive. Find the current in each branch of the circuit.

Solution.

The circuit arrangement and the current distribution is shown in fig.



Applying Kirchhoff's law to meshes BADB, BCDB and ADCMNA, we have

$i_2 + 2i_3 + 1.i_1 = 2$

or $i_1 + i_2 + 2\,i_3 = 2$ ... (1)

$1(i_1 - i_2) - 2\,(i_3 - i_1) + i_1 = 2$

or $4i_1 - i_2 - 2i_3 = 2$ ... (2)

& $2i_3 + 2(i_3 - i_1) + 2\,(i_3 - i_2) = 1$

or $-2i_1 - 2i_2 + 6i_3 = 1$ ... (3)

Solving eqs. (1) and (2) (3), we get

$i_1 = 0.8$ amp. $i_2 = 0.2$ amp and $i_3 = 0.5$ amp.

∴ Current in AB branch = 0.2 amp.
Current in BC branch = 0.6 amp.
Current in CD branch = 0.3 amp.
Current in AD branch = 0.5 amp.
Current in MN branch = 0.3 amp.

12. JOULE HEATING

(a) When current pass through a resistor, heat is generated.

(b) The heat developed per unit time is equal to I^2R_0.

(c) If current through the resistor is constant, heat generated in time t is $H = I^2 Rt$

(d) If current through the resistor is variable, heat generated in time t is $H = \int I^2 R\, dt$

Example Based on

Joule heating

Example. 44

A varying current $I = I_0 \sin \omega t$ is passed through a resistor R. Here I_1 and ω are constants. Find the heat generated in the resistor in time t = 0 to t = $2\pi/\omega$.

Solution.

Heat generated,

$$H = \int_{t=0}^{2\pi/\omega} I^2 R\ dt = \int_{t=0}^{2\pi/\omega} I^2 \sin^2 \omega t.R.dt = \frac{\pi I_0{}^2 R}{\omega}$$

Example. 45

One kilowatt electric heater is to be used with 220 V, DC supply.

(i) What is the current in the heater ?

(ii) What is its resistance ?

(iii) What is the power dissipated in the heater ?

(iv) How much heat in calories is produced per second ?

(v) How may grams of water at 100°C will be converted per minute into steam at 100° C with the heater ?

Assume that the heat losses due to radiation are negligible Latent heat of steam = 540 cal/gm.

Solution.

Here P = 1 kW = 1000 W and V = 220 volt.

(i) Current in the heater

$$i = \frac{P}{V} = \frac{1000\,W}{220\,V} = 4.55\ A$$

(ii) Resistance of heater coil

$$R = \frac{V^2}{P} = \frac{220 \times 220}{1000} = 48.4\ \text{ohm}$$

(iii) Power dissipated in heater = 1000 W

(iv) Heat produced in second

$$H = \frac{V\,i\,t}{J} = \frac{\text{Power} \times \text{time}}{J}$$

$$\therefore \quad H = \frac{1000 \times 1}{4.2} = 240\ \text{cal/second}$$

(v) Heat produced in one minute

= 240 × 60 = 14400 cal.

We know that 540 cal are required to convert 1 gm of water at 100°C into steam at 100°C.

∴ Amount of water at 100° C converted into steam at 100° C by 14400 cal. of heat

$$= \frac{14400}{540} = 26.8\ \text{gm}$$

Example. 46

Three equal resistors connected in series across a source of emf together dissipate 10 watts of power. What would be the power dissipated if the same resistors are connected in parallel across the same source of emf ?

Solution.

Let R be the resistance of each resistor. When they are connected in series, the total resistance = R + R + R = 3R ohm.

∴ Power dissipated $W_1 = E^2/3R$,

Where E = emf of the source.

When the resistors are connected in parallel, their effective resistance is given by

$$\frac{1}{R'} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} = \frac{3}{R} \text{ or } R' = \frac{R}{3}$$

$$\therefore \text{ Power dissipated } W_2 = \frac{E^2}{R/3} = \frac{3E^2}{R}$$

$$\text{Now, } \frac{W_2}{W_1} = \frac{3E^2}{R} \times \frac{3R}{E^2} = 9$$

or $W_2 = 9\,W_1 = 9 \times 10$

$$= 90 \text{ watt. or } \frac{1}{10} = \frac{1}{P} + \frac{1}{P} + \frac{1}{P}$$

or P = 30

Now, $P_{parallel} = P + P + P = 30 + 30 + 30 = 90$ watt

Example. 47

A fuse of lead wire has an area of cross-section 0.2 mm^2. On short circuiting, the current in the fuse wire reaches 30 A. How long after the short-circuiting, will the fuse being to melt ? for lead, specific heat = 0.032 cal g^{-1} (°C^{-1}), melting point = 327°C, density = 11.34 gm cm^{-3} and the resistivity = 22×10^{-6} ohm-cm. The initial temperature of wire is 20°C. Negative heat losses.

Solution.

Let ℓ be the length of the fuse wire then its resistance R is given by $R = \rho\ell/A$

Here $\rho = 22 \times 10^{-6}$ ohm-cm, A = 0.2 mm^2

$= 0.2 \times 10^{-2}\ cm^2$

$$\therefore \quad R = \frac{22 \times 10^{-6}\,\ell}{0.2 \times 10^{-2}} \qquad \text{... (1)}$$

Let t seconds be the time taken for melting the fuse wire, then

$$\text{Heat produced } H = \frac{i^2 R t}{4.2} \text{ cals.}$$

$$\text{Here} \quad I = 30 \text{ amp. and } R = \frac{22 \times 10^{-6}\,l}{0.2 \times 10^{-2}}$$

$$\therefore \quad H = \frac{(30)^2 \times 22 \times 10^{-6} \times / \times t}{4.2 \times 0.2 \times 10^{-2}} \text{ cals} \qquad ...(2)$$

Again $\quad H = msT$

Here $\quad m$ = volume × density = A × ℓ × density

$= (0.2 \times 10^{-2}) \times \ell \times 11.34$

$\therefore H = (0.2 \times 10^{-2})\ \ell \times 11.34 \times 0.032 \times (327–20)$ ...(3)

From equations (2) and (3)

$(0.2 \times 10^{-2})\ \ell \times 11.34 \times 0.032 \times 307$

$$= \frac{(30)^2 \times 22 \times 10^{-6} \times \ell \times t}{4.2 \times 0.2 \times 10^{-2}}$$

solving we get, t = 0.095 second.

Example. 48

A copper wire having cross-sectional area 0.5 mm^2 and a length of 0.1 m is initially at 25°C and is thermally insulated from the surrounding. If a current of 10 amp. is set up in this wire,

(i) find the time in which the wire will start melting. The change of resistance with the temperature of the wire may be neglected.

(ii) what will be the time taken if length of the wire is doubled ?

Given for copper wire, density = 9×10^3 kgm^{-3}

specific heat = 9×10^2 Kcal kg^{-1} (°C)$^{-1}$,

melting point = 1075° C,

specific resistance = 1.6×10^{-8} ohm-meter.

Solution.

(i) The resistance R of copper wire is given by

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

Here $\rho = 1.6 \times 10^{-8}$ ohm-meter, ℓ = 0.1 m and $A = 0.5 \times 10^{-6}$ m^2

$$\therefore \ R = \frac{1.6 \times 10^{-8} \times 0.1}{0.5 \times 10^{-6}} = 0.00032 \text{ ohm.}$$

If H is the heat required to melt the copper wire then

$$H = \frac{i^2 Rt}{4.2} = \text{mass of copper wire} \times S \times T$$

Here i = current through the wire = 10 amp, R = 0.00032Ω

mass of the copper wire = volume × density

$= 0.5 \times 0.1 \times 10^{-6} \times 9 \times 10^3$ kg $= 45 \times 10^{-5}$ kg

s = 0.09 and T = (1075 – 25) = 1050

$$\therefore \ \frac{(10)^2 \times 0.00032 \times t}{4.2} = (45 \times 0^{-5})\ (0.09)\ (1050)$$

Solving we get t = 558 seconds.

(ii) When the length of the wire is doubled, its resistance is doubled. At the same time, the mass of the wire is also doubled. Using the expression

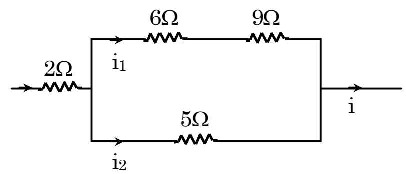
$$\frac{i^2 (2R) t}{4.2} = (2\ m)\ s\ T.$$

we can say that time t remains the same

$\therefore$ t = 558 seconds.

Example. 49

In the circuit shown in the fig. the 5 ohm resistance develops 10.23 cal s^{-1} due to the current flowing through it. Calculate



(i) the heat developed per second in the 2 ohm resistance and

(ii) the potential difference across 6 ohm resistance.

Solution.

(i) Let a current i flows through 2 ohm resistance. The current is divided into two parts. Let current i_1 flows through 6 ohm and 9 ohm and i_2 flows through 5 ohm. The effective resistance of 6 ohm and 9 ohm is 15 ohm. Now

$$i_1 = i \cdot \frac{5}{20} = \frac{i}{4} \text{ amp.}$$

and $\quad i_2 = i \cdot \dfrac{15}{20} = \dfrac{3i}{4}$ amp.

$\therefore$ Heat developed in 5 ohm resistor in one second

$$H = \frac{i^2\ R\ t}{4.2} \text{ cal.} = \frac{(3i/4)^2 \times 5 \times 1}{4.2}$$

But according to the problem,

H = 10.24 cal s^{-1}

$$\therefore \ \frac{(3i/4)^2 \times 5 \times 1}{4.2} = 10.24$$

Solving we get i = 3.92 A.

$\therefore$ Heat developed in 2 ohm resistor in one second

$$= \frac{i^2\ R\ t}{4.2} \text{ cal.} = \frac{(3.92)^2\ (2)(1)}{4.2} = 7.28 \text{ cal.}$$

(ii) Potential difference across 6 ohm resistor

= current × resistance

$$= i_1 \times 6 = \frac{i \times 6}{4} = \frac{3.92}{4} \times 6 = 5.86 \text{ volt}$$

Example. 50

A galvanometer having a coil resistance of 100 ohms gives a full scale deflection when a current of one milli ampere is passed through it. What is the value of resistance which can convert this galvanometer into ammeter giving a full scale deflection for a current of 10 amperes ?

A resistance of the required value of is available but it will get burnt if the energy dissipated in it is greater than one watt. Can it be used for the above described conversion of the galvanometer?

When this modified galvanometer is connected across the terminals of battery, it shows a current 4 amp. The current drops to 1 amp., when the resistance of 1.5 ohm is connected in series with modified galvanometer. Find the emf and internal resistance of battery.

Solution.

(i) In this case a shunt S should be connected in parallel with galvanometer. Now

$$\frac{S}{S+G} = \frac{10^{-3}}{10} \quad \text{or} \quad \frac{S}{S+100} = \frac{1}{1000}$$

$$S = \frac{1}{99.99} \text{ ohm}$$

(ii) Power dissipated in the shunt

$$= i^2 S = (9.999)^2 \times \frac{1}{99.99}$$

($\therefore$ Current in the shunt = 10 – 0.001 = 9.999 amp.)

$\therefore$ P = 0.9999 Watt

This is less than one watt. Hence the above shunt can be safely used.

(iii) Let E be the e.m.f. and r be the internal resistance of the cell. If R be the combined resistance of shunted galvanometer, then

$$\frac{1}{R} = \frac{1}{100} + \frac{9999}{100}$$

$\therefore$ R = 0.01 ohm.

The current $i = \dfrac{E}{R+r}$

$$\therefore \quad 4 = \frac{E}{0.01+r} \quad \text{...(i)}$$

$$\text{and} \quad 1 = \frac{E}{0.01+r+1.5} \quad \text{...(ii)}$$

Solving eqs. (i) and (ii), we get

E = 2 volt and r = 0.49 ohm

Example. 51

Two bulbs rated at 25 watts, 110 volts of 100 watts, 110 volts are connected in series to 220 volts electric supply. Perform the necessary calculations to find out which of the two bulbs, if any, will fuse. What would happen if the two bulbs were connected in parallel to the same supply.

Solution.

Let i_1 and i_2 be the currents which can flow through the two lamps safely, then

$$i_1 = \frac{25}{110} = 0.227 \text{ amp.}$$

$$\text{and} \quad i_2 = \frac{100}{110} = 0.909 \text{ amp.}$$

The resistance of two bulbs are given by

$$R_1 = \frac{E}{i_1} = \frac{110}{0.227} \text{ ohm}$$

$$\text{and} \quad R_2 = \frac{110}{0.909} \text{ ohm}$$

When the two bulbs are connected in series, their total resistance

$$R = R_1 + R_2 = \frac{110}{0.227} + \frac{110}{0.909} = 605 \text{ ohm}$$

When these two lamps are connected in series to 220 volts, the current passing through then is given by

$$i = \frac{220}{605} = 0.363 \text{ amp.}$$

Thus the first bulb will fuse because the current passing through it i,e., 0.363 is more than i_1(0.227)

When the two bulbs are connected in parallel, the effective resistance R' is given by

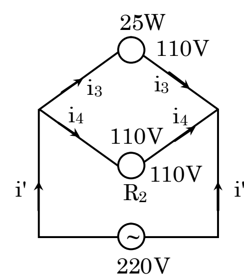
$$\frac{I}{R'} = \frac{I}{R_1} + \frac{I}{R_2} = \frac{0.227}{110} + \frac{0.909}{110} = \frac{1.136}{110}$$

$$R' = \frac{110}{1.136} \text{ ohm}$$

Current flowing through circuit

$$i' = \frac{220}{R'} = \frac{220 \times 1.136}{110} \text{ amp.}$$

Let i_3 and i_4 be the currents passing through the two bulbs as shown in fig.



Now the potential difference across the two bulbs is the same.

Hence, $i_3 R_1 = i_4 R_2$

$$i_3 \frac{110}{0.227} = i_4 \frac{110}{0.909}$$

$$\text{or} \quad 4i_3 = i_4 \quad \text{...(1)}$$

$$\text{again} \quad i_3 + i_4 = i' = \frac{220 \times 1.136}{110} \quad \text{...(2)}$$

Solving eqs. (1) and (2) , get

i_3 = 0.454 amp. and i_4 = 1.816 amp.

Thus both the bulbs will fuse.

Example. 52

An ammeter and a voltmeter are connected in series to a battery with an e.m.f. E = 6.0 V. When a certain resistance is connected in parallel with the voltmeter, the reading of the latter decrease η = 2.0 times, whereas the readings of the ammeter increase the same number of times. Find the voltmeter readings after the connection of the resistance.

Solution.

Let the initial readings of ammeter be I and that of voltmeter, V. When R' is connected in parallel with the voltmeter, let I' be the reading of ammeter and V_1', that of voltmeter.

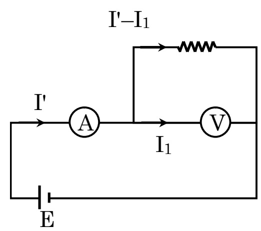
Now given that $I' = \eta I$ and $V' = \frac{V}{\eta}$. If in figure, I_1 is the current entering voltmeter,

then $V' = (I' - I_1)R$.

Now for the main circuit,

$E = I' R_A + (I' - I_1) R = 0$

$\Rightarrow E = I' R_A + V'$



$\Rightarrow R_A = \frac{E - V'}{I'}$ ...(i)

When no resistance is connected,

$E = I R_A + V$

$\Rightarrow R_A = \frac{E - V}{I}$ ...(ii)

From equs (i) and (ii) .

$\frac{I}{I'} = \frac{E - V}{E - V'} \quad \Rightarrow \frac{1}{\eta} = \frac{E - \eta V'}{E - V'}$

$\Rightarrow E - V' = \eta E - \eta^2 \quad \Rightarrow V' = (\eta^2 - 1) = \eta (E - 1)$

$\Rightarrow V = \frac{\eta - 1}{\eta^2 - 1} E$.

With the given values,

$V' = \frac{(2-1)6.0}{2^2 - 1} = \frac{6}{3} = 2V$

13. ELECTRICAL INSTRUMENTS

✦ Bulbs

(a) Bulbs are rated to consume power at a given voltage. For example 100W, 220 Volt.

(b) Power consumption is a variable quantity whereas its resistance is definite.

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

(d) When bulbs with rating P_1, P_2, P_3 at same voltage V are connected in parallel and to a voltage V, they will consume power as specified.

$P = P_1 + P_2 + P_3 + \ldots\ldots$

(e) When bulbs with rating P_1, P_2, P_3 at same voltage V are connected in series, power consumed by all the bulbs are less than specified. Net power consumption P is given by

$$\frac{1}{P} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3} \ldots\ldots$$

(f) When the circuit is complex, replace the bulb by pure resistance and solve the circuit.

✦ Galvanometer

(a) Galvanometer is an instrument which is sensitive to current. Whenever current flows through it, it gives deflection, and hence one can measure the current.

(b) Voltmeter is an instrument which measures potential difference between two points.

(c) Ammeter is an instrument which measures the current flowing through a particular branch.

(d) Voltmeter and ammeter are basically made from Galvanometers only.

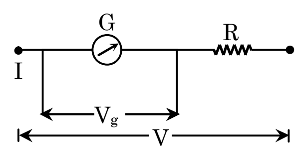
(A) Conversion of Galvanometer to Volt Meter or to Enhance the Range of Voltmeter :

Let, V_g = Potential difference applied across the voltmeter to give full scale deflection.

G = Galvanometer resistance.

V = The range of the voltmeter to be enhanced to

R = Resistance connected in series to the voltmeter to achieve the requirement.



$$R = G\left(\frac{V}{V_g} - 1\right)$$

DERIVATION

Since the galvanometer and the resistance R are connected in series, they will draw same current.

$\therefore I = \frac{V_g}{G} = \frac{V}{G + R} \Rightarrow R = G\left(\frac{V}{V_g} - 1\right)$

(B) Conversion of the Galvanometer to Ammeter or to Enhance the Range of the Ammeter:

Let, I_g = current required through the galvanometer to give full scale deflection.

G = Resistance of the galvanometer.

V = The range of the ammeter to be enhanced to

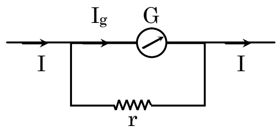
r = resistance connected in parallel to the galvanometer

$$r = \frac{G}{I/I_g - 1}$$

DERIVATION

Since galvanometer and the resistor are connected in parallel, potential difference across them will be same.

$\therefore \quad I_g \cdot G = (I - I_g) \cdot r$

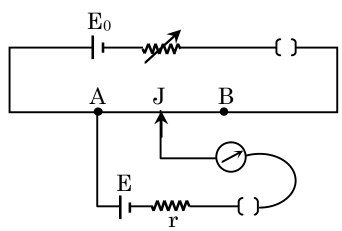


$$\Rightarrow \quad r = \frac{G}{I/I_g - 1}$$

NOTE (i) The resistance of ideal voltmeter is infinite.

(ii) The resistance of ideal ammeter is zero.

✦ Potentiometer



(a) Potentiometer is a device to measure the potential difference between two points.

(b) The instrument is a better device compared to voltmeter.

(c) A typical circuit of potentiometer is shown in the fig.

(d) The wire AB is called potentiometer wire. It is made of uniform cross-section so that resistance per unit length of the wire is uniform.

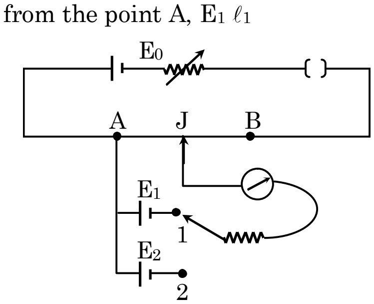
(e) The point J is moved such that there is no deflection in the galvanometer, hence potential difference across AJ is equal to E.

$\therefore \quad E \propto \ell$

(f) To get a null point or no deflection in the galvanometer, emf E_0 must be greater than E.

(A) Use of Potentiometer to Compare the Emf's of Two Cells :

When switch is in position (1), null point is obtained in the galvanometer at length ℓ_1 from the point A, E_1 ℓ_1



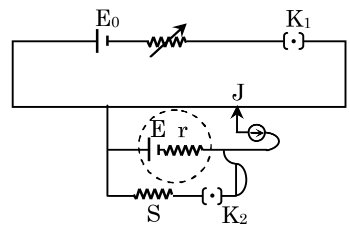
And when switch is in position (2), null point is obtained in the galvanometer at length ℓ_2.

$\therefore \quad E_2 \propto \ell_2$

Thus $\dfrac{E_1}{E_2} = \dfrac{\ell_1}{\ell_2}$

(B) Use of Potentiometer to Calculate the Internal Resistance of a Cell :

When switch K_1 is closed and K_2 is opened ; the null point is obtained at a length ℓ_1.



$\therefore \quad E_0 \propto \ell_1$ ...(i)

When switch K_2 is also closed, the null point is obtained at a length ℓ_2.

$\therefore \quad V \propto \ell_2$ ...(ii)

where V is the potential difference across the cell when switch K_2 is closed.

$$V = \frac{E}{r + R} \cdot R \qquad \text{...(iii)}$$

$$\therefore \quad \frac{E}{V} = \frac{\ell_1}{\ell_2}$$

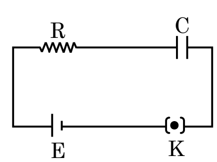
$$\Rightarrow \quad \frac{E}{E\frac{R}{r+R}} = \frac{\ell_1}{\ell_2} \Rightarrow r = R.\ \frac{\ell_1 - \ell_2}{\ell_1}$$

14.R–C CIRCUIT

When resistance and capacitor are connected in series with or without cell in an electric circuit, the circuit is called R– C circuit.

✦ Charging of a Capacitor

A resistor of resistance R and an uncharged capacitor of capacitance C are connected in series with a cell of emf E. The switch k is closed at t = 0.



(a) The current in the circuit at any instant t is given by

$$I(t) = \frac{E}{R} e^{-t/RC}$$

(b) The charge on the capacitor at any time t,

$q(t) = CE\,(1 - e^{-t/RC})$

(c) At $t = 0, I = \frac{E}{R}$

which is maximum and charge $q = 0$

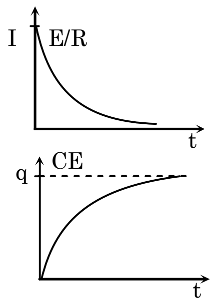
(d) Steady state is reached at $t = \infty$.

Steady state current,

$I (t = \infty) = 0$ and steady state charge

$q (t = \infty) = CE$

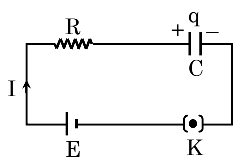
(e) Plot of I versus t Plot of q versus t



(f) $\tau = RC$ is called the time constant.

DERIVATION

Let I be the current in the circuit and q be the charge on the capacitor at any instant t.



Applying Kirchhoff's law in the loop.

$$E = IR + \frac{q}{c} \qquad \text{... (i)}$$

$$I = \frac{dq}{dt} \qquad \text{... (ii)}$$

On substituting for I in equation (i),

$$\frac{q}{c} + R\frac{dq}{dt} = E$$

On solving and putting the initial condition at $t = 0, q = 0$, we get

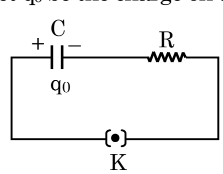
$$q = CE\,(1 - e^{-t/RC}) = CE\,(1 - e^{-t/\tau})$$

on differentiating

$$I = \frac{dq}{dt} = \frac{E}{R}\, e^{-t/RC} = \frac{E}{R}\, e^{-t/\tau}$$

✦ Discharging of a Capacitor

A charged capacitor is connected in series with a resistance R. Let q_0 be the charge on the capacitor at $t = 0$



(a) The current in the circuit at any instant t is given by

$$I = \frac{q_0}{RC}\, e^{-t/RC}$$

(b) The charge on the capacitor at any instant t is

$$q = q_0\, e^{-t/RC}$$

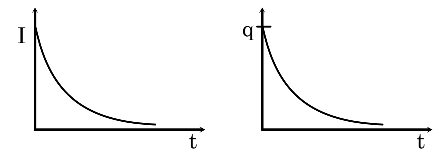
(c) at $t = 0$, $I (t = 0) = \frac{q_0}{RC}$

which is maximum and charge $q (t = 0) = q_0$

(d) at steady state $t = \infty$, $I (t = \infty) = 0$

and charge, $q (t = \infty) = 0$

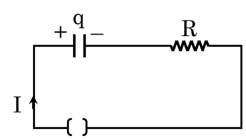
(e) Plot of I verses t Plot of q versus t



(f) $\tau = RC$ is called time constant. (Its dimension is equal to time)

DERIVATION

Let I be the current in the circuit and q be the charge on the capacitor at any instant. Applying Kirchhoff's law



$$\frac{q}{c} + IR = 0, \; I = \frac{dq}{dt}$$

$$\therefore \quad R\frac{dq}{dt} + \frac{q}{c} = 0$$

on solving and putting initial condition

$t = 0, q = q_0,$

We get, $q = q_0\, e^{-t/RC}$ and on differentiating,

$$I = \frac{dq}{dt} = -\frac{q_0}{RC}\, e^{-t/RC}$$

The minus sign signifies that the assumed current direction is opposite to the actual direction.

✦ Important Points Regarding R-C Circuit

(a) If capacitor is uncharged it behaves as zero resistance wire.

(b) If capacitor is fully charged, it behaves as infinite resistance wire. No current will flow in the branch having a fully charged capacitor.

(c) If charge on a capacitor is known at any instant, the current can be obtained by simplifying the circuit by replacing the capacitor by a cell of emf q/c with proper polarity.

(d) If a charged capacitor is discharged through a resistor, the heat produced in the resistor is equal to the energy stored on the capacitor.

$$H = \frac{1}{2} CV^2$$

The head produced in the resistor does not depend on the value of resistance. Even if a zero resistance wire is connected, the heat produced will be same.

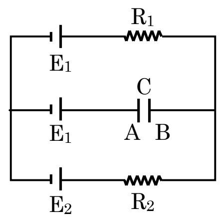
(e) In case of charging, the charge stored on a capacitor in one time-constant is 37% of the maximum charge.

(f) Similarly, in case of discharging, the current in the circuit is 37% of the maximum in one time constant.

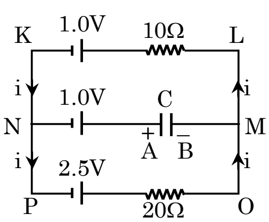
Example Based on
R - C Circuit

Example. 53

In the circuit shown in fig. the sources have e.m.f. s E_1 = 1.0 V and E_2 = 2.5 V and the resistance have the values $R_1 = 10\Omega$ and $R_2 = 20\Omega$. The internal resistances of the sources are negligible. Find the potential difference $V_A - V_B$ between the plates A and B of the capacitor C.



Solution.



The current flowing in the circuit is shown in fig. The current will not flow through the capacitor.

Applying Kirchhoff's law to mesh POLKP, we have

20i + 10i = 2.5 – 1.0 or 30 i = 1.5

$$\therefore \quad i = \frac{1.5}{30} = 0.05 \text{ amp.}$$

Applying Kirchoff's law to mesh POMNP, we have

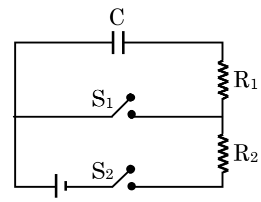
$$20i + \frac{q}{C} = 2.5 - 1$$

$$\text{or} \quad \frac{q}{C} = 1.5 - 20\,i = 1.5 - 20 \times 0.05$$

$$\text{or} \quad \frac{q}{C} = 0.5 \text{ volts}$$

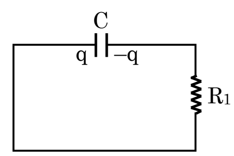
Example. 54

The capacitors shown in fig. has been charged to a potential difference of V volts so that it carries a charge CV with both the switches S_1 and S_2 remaining open,. Switch S_1 is closed at t = 0. At t = R_1 C switch S_1 is opened and S_2 is closed. Find the charge on the capacitor at. t = 2 R_1 C+ R_2 C



Solution.

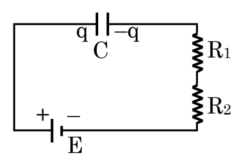
When the switch S_1 is closed and S_2 is open. The circuit now becomes as shown in fig.



Now $q = CVe^{-t/R_1C}$

At t = R_1C, the charge on the capacitor will be $q = CV\,e^{-1} = CV/e$

At this position, S_2 is closed and S_1 is opened. The circuit now becomes as shown in fig.



$R = R_1 + R_2$

$$\therefore \quad \frac{dq}{dt} = \frac{CE - q}{RC} \text{ or } \frac{dq}{CE - q} = \frac{dt}{RC}$$

Integrating within proper limits, we have

$$\int_{CV/e}^{q_f} \frac{dq}{CE - q} = \int_{R_1C}^{2R_1C + R_2C} \frac{dt}{R_1C}$$

Solving we get

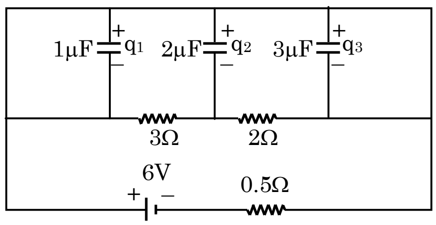
$$CE - q_f = \frac{CE}{e} - \frac{CV}{e^2}$$

$$q_f = CE - \frac{CE}{e} + \frac{CV}{e^2}$$

$$\text{or} \quad q_f = CE\left(1 - \frac{1}{e}\right) + \frac{CV}{e^2}$$

Example. 55

In the circuit shown in fig. e.m.f. and internal resistance of battery are 6V & 0.5 Ω respectively. Calculate charge on each capacitor in steady state.



Solution.

In steady state, no current flows through the capacitors The circuit in this state will be like shown in fig.

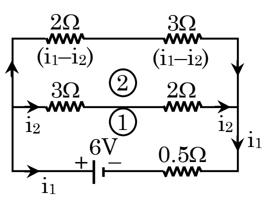
Applying Kirchoff's voltage law to mesh 1 and mesh 2 respectively, we have

$3i_2 + 2i_2 + 0.5\, i_1 = 6$ ...(i)

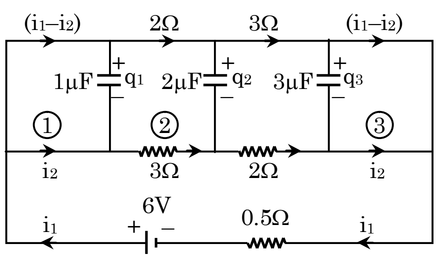
$2(i_1 - i_2) + 3(i_1 - i_2) - 2i_2 - 3i_2 = 0$ ...(ii)

Solving these equations, we get

i_1 = 2amp. and i_2 = 1 amp.



Let, in the steady state, the charges on capacitors of capacitances 1μF and 3μF be q_1, q_2 and q_3 respectively as shown in fig.



Applying KVL to mesh 1, we have

$$\frac{q_1}{1\times 10^{-6}} = 0 \text{ or } q_1 = 0$$

Applying KVL to mesh 2, we get

$$2(i_1 - i_2) + \frac{q_2}{2\times 10^{-6}} - 3\, i_2 - \frac{q_1}{1\times 10^{-6}} = 0$$

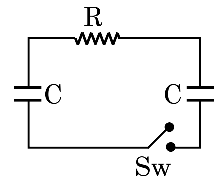
$q_2 = 2\times 10^{-6}$ C or $q_2 = 2\mu C$

Similarly, applying KVL to-mesh 3, we get

$$\frac{-q_3}{3\times 10^{-6}} = 0 \text{ or } q_3 = 0$$

Example. 56

In the circuit below, the capacitance of each capacitor is equal to C and the resistance R. One of the capacitors was connected to a voltage V_0 and then at the moment t = 0 was shorted by means of a switch Sw find :



(a) a current I in the circuit as a function of time ;

(b) the amount of heat generated provided a dependence I(t) is known.

Solution.

(a) At the instant, when the switch is closed, then the charge on one of the capacitors, $q_0 = CV_0$ will flow on closing the switch and the current flowing $I = \frac{dq}{dt}$.

From Kirchoff's Laws:

$$\frac{q}{C} + \frac{q}{C} + IR = V_0 \Rightarrow \frac{2q}{C} + R\frac{dq}{dt} = V_0$$

$$\Rightarrow \frac{dq}{CV_0 - 2q} = \frac{dt}{RC}$$

Integrating, $\log_e \dfrac{q - \frac{CV_0}{2}}{-\frac{CV_0}{2}} = -\dfrac{2t}{RC}$

or, $q = \dfrac{CV_0}{2}\left(1 - e^{-2t/RC}\right)$

and $I = \dfrac{dq}{dt} = \dfrac{V_0}{R} e^{-2t/RC}$

(b) Heat generated Q = Initial energy of the capacitors :

$$Q = \frac{1}{2}\left(\frac{C}{2}\right) V_0^2 = \frac{CV_0^2}{4}$$

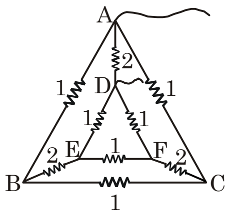
or from a knowledge of I(t)

$$Q = \int_0^\infty I^2(t)\, R\, dt = \frac{V_0^2}{R}.R \int_0^\infty e^{-4t/RC} dt$$

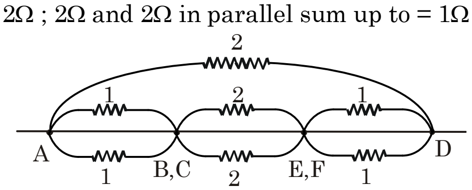
$$= \frac{1}{4} CV_0^2$$

SOLVED EXAMPLES

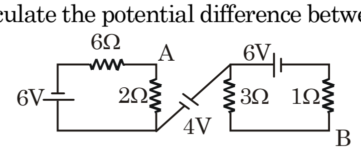
Ex.1 A network of nine conductors connects six points A, B, C, D, E and F as shown. The figures denote resistances in ohms. The equivalent resistance between A and D is



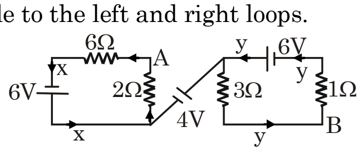
Sol. B and c are equipotential points and so are E and F. Here the circuit can be redrawn as shown in Figure. 1Ω and 1Ω in parallel sum up to 1/2W ; 2W and 2W in parallel sum up to 1 W ; 1/2W, 1 W, 1/2W in series sum up to 1/2 + 1 + 1/2 = 2Ω ; 2Ω and 2Ω in parallel sum up to = 1Ω .



Ex.2 In the network shown in the figure below, calculate the potential difference between A and B.



Sol. The distribution of current is shown in Fig., keeping in view that the inflow and outflow of current in a cell must be the same. Applying the loop rule to the left and right loops.



$2x + 6x = 6$

or $x = 0.5$ A

and $3y + 1y = 6$

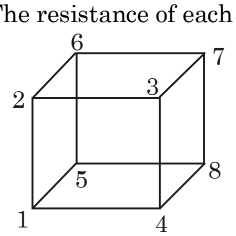
or $y = 1.5$ A

$V_{AB} = \Sigma ir - \Sigma e = (-2 \times 0.5 + 3 \times 1.5) - 4 = -0.5$ V

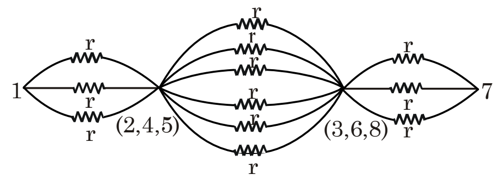
The minus sign shows that B is at a higher potential than A. Thus

$V_{BA} = -1$ V

Ex.3 Find the resistance of a wire frame shaped as a cube when measured between points.
1 and 7 The resistance of each edge is r.



Sol. Symmetry about entrance point 1 and exit point 7 shows that 2, 4, 5 are equipotential points and 5,6, and 8 are equipotential points. Hence the circuit can be redrawn as shown in Figure. The resistance r, r and r in parallel sum up to r/3.



r, r, r, r, r, r in parallel sum up to r/6 and r, r, r in parallel sum up to r/3. Next r/3. r/6, r/3 in series sum up to 5r/6.

Ex.4 Two resistors with temperature coefficients of resistance α_1 and α_2 have resistances R_{01} and R_{02} at 0°C .Find the temperature coefficient of the compound resistor consisting of the two resistors connected in parallel.

Sol. $R_1 = R_{01}(1+\alpha_1 t)$

and $R_2 = R_{02}(1+\alpha_2 t)$

Also $R = \dfrac{R_1R_2}{R_1 + R_2} = R_0(1 + \alpha t)$

and $R_o = \dfrac{R_{01}R_{02}}{R_{01} + R_{02}}$

$$\therefore \quad \frac{R_{01}R_{02}}{R_{01}+R_{02}}(1+\alpha t)$$

$$= \frac{R_{01}R_{02}(1+\alpha_1 t)(1+\alpha_2 t)}{R_{01}+R_{02}+(R_{01}\alpha_1+R_{02}\alpha_2)t}$$

$$\Rightarrow (1+\alpha t) = \frac{(1+(\alpha_1+\alpha_2)t)}{1+\dfrac{R_{01}\alpha_1+R_{02}\alpha_2}{R_{01}+R_{02}}t}$$

$$= (1+(\alpha_1+\alpha_2)t)\left(1-\frac{R_{01}\alpha_1+R_{02}\alpha_2}{R_{01}+R_{02}}t\right)$$

$$\Rightarrow \quad 1 = \alpha t$$

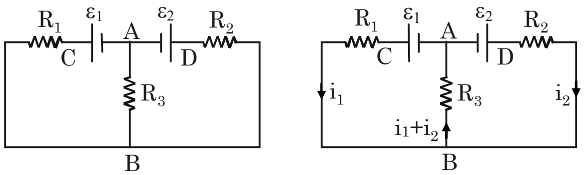
$$= 1 + 1+(\alpha_1+\alpha_2)t - \frac{R_{01}\alpha_1+R_{02}\alpha_2}{R_{01}+R_{02}}t$$

$$=1+\frac{R_{01}\alpha_1+R_{02}\alpha_1+R_{01}\alpha_2+R_{02}\alpha_2-R_{01}\alpha_1-R_{02}\alpha_2}{R_{01}+R_{02}}t$$

$$= 1+\frac{R_{02}\alpha_1+R_{01}\alpha_2}{R_{01}+R_{02}}\times t$$

$$\alpha = \frac{R_{02}\alpha_1+R_{01}\alpha_2}{R_{01}+R_{02}}$$

Ex.5 Find the currents going through the three resistors R_1, R_2 and R_3 in the circuit of figure.



(a) (b)

Sol. Let us take the potential of the point. A to be zero. The potential at C will be ε_1 and that at D will be ε_2. Let the potential at B be V. The currents through the three resistors are i_1, i_2 and $i_1 + i_2$ as shown in figure. Note that the current directed towards B equals the current directed away from B.

Applying Ohm's law to the three resistors R_1, R_2 and R_3 we get

$$\varepsilon_1 - V = R_1 i_1 \quad \text{...(i)}$$

$$\varepsilon_2 - V = R_2 i_2 \quad \text{...(ii)}$$

and $$V - 0\ R_2\ (i_1 + i_2) \quad \text{...(iii)}$$

Adding (i) and (iii),

$$\varepsilon_1 = R_1 i_1 + R_3 (i_1 + i_2)$$
$$= (R_1 + R_3)\, i_1 + R_3 i_2 \quad \text{...(iv)}$$

and adding (ii) and (iii),

$$\varepsilon_2 = R_2 i_2 + R_3 (i_1 + i_2)$$
$$= (R_2 + R_3)\, i_2 + R_3 i_1 \quad \text{...(v)}$$

Equations (iv) and (v) may be directly written from Kirchhoff's loop law applied to the left half and the right half of the circuit.

Multiply (iv) by $(R_2 + R_3)$, (v) by R_3 and subtract to eliminate i_2. This gives

$$i_1 = \frac{\varepsilon_1 (R_2 + R_3) - \varepsilon_2 R_3}{(R_1 + R_3)(R_2 + R_3) - R_3^2}$$

$$i_1 = \frac{\varepsilon_1 (R_2 + R_3) - \varepsilon_2 R_3}{R_1 R_2 + R_2 R_3 + R_3 R_1}$$

Similarly eliminating i_1 from (iv) and (v) we obtain,

$$i_2 = \frac{\varepsilon_2 (R_1 + R_3) - \varepsilon_1 R_3}{R_1 R_2 + R_2 R_3 + R_3 R_1}$$

And so,

$$i_1 + i_2 = \frac{\varepsilon_1 R_2 + \varepsilon_2 R_1}{R_1 R_2 + R_2 R_3 + R_3 R_1}$$

Ex.6 A capacitor is connected to a 12 V battery through a resistance of 10 Ω.It is found that the potential difference across the capacitor rises to 4.0 V in 1μs. Find the capacitance of the capacitor (given ℓn (3/4) = 0.405).

Sol. The charge on the capacitor during charging is given by

$$Q = Q_0 (1 - e^{-t/RC})$$

Hence, the potential difference across the capacitor is

$$V = Q/C = Q_0 / C\ (1 - e^{-t/RC})$$

Here at t = 1 μs, the potential difference is 4 V whereas the steady state potential difference is

$$Q_0 / C = 12 \text{ V So,}$$

$$4V = 12\text{ V } (1 - e^{-t/RC})$$

or, $$1 - e^{-t/RC} = \frac{1}{3}$$

or, $$e^{-t/RC} = \frac{2}{3}$$

or, $$\frac{t}{RC} = \text{In}\left(\frac{3}{2}\right) = 0.405$$

or, $$RC = \frac{t}{0.405} = \frac{1\mu s}{0.405} = 2.469\,\mu s$$

or, $$C = \frac{2.469\ \mu s}{10\,\Omega} = 0.25\,\mu F$$

Ex.7 All the edges of a block with parallel faces are unequal. Its longest edge is twice its shortest edge. The ratio of the maximum to minimum resistance between parallel faces is

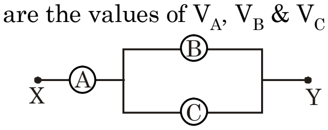
Sol. Let the edges be 2ℓ, a and ℓ, in decreasing order.

$$R_{max} = \rho \frac{2\ell}{a\ell}$$

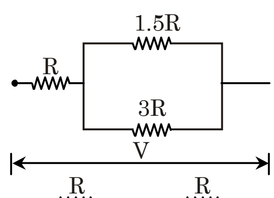
$$R_{min} = \rho \frac{\ell}{2\ell a} = \frac{\rho}{2a}$$

$$\frac{R_{max}}{R_{min}} = 4$$

Ex.8 A, B and C are voltmeters of resistances R, 1.5 R and 3 R respectively. When some potential difference say V is applied between X and Y, the voltmeter readings are V_A, V_B and V_C respectively. What are the values of V_A, V_B & V_C?



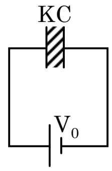
Sol.



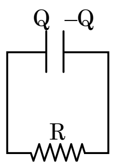
$$V_A = V_B = V_C = \frac{V}{2}$$

Ex.9 A parallel-plate capacitor of capacitance C, filled with a dielectric of dielectric constant k, and charged to a potential V_0. It is now disconnected from the cell and the slab is removed. If it now discharges, with time constant τ, through a resistance, the potential difference across it will be V_0 after what time.

Sol.



$$Q = KCV_0$$



$$q = Qe^{-t/\tau}$$

$$\Rightarrow \quad \frac{q}{C} = \frac{Q}{C}e^{t/\tau}$$

$$V_0 = \frac{KCV_0}{C}e^{-t/\tau}$$

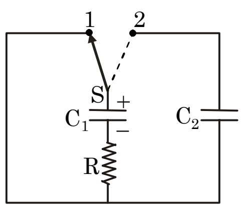
$$\Rightarrow \quad V_0 = KV_0e^{-t/\tau}$$

$$\frac{1}{K} = e^{-t/\tau}$$

or $$\log K = \frac{t}{\tau}$$

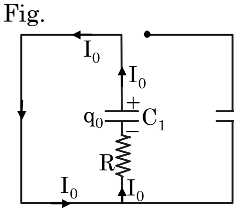
$$t = \tau \log_e K$$

Ex.10 A charged capacitor C_1 is discharged through a resistance R by putting switch S in position 1 of circuit shown in Fig. when discharge current reduces to I_0, the switch is suddenly shifted to position 2.



Calculate the amount of heat liberated in resistor R starting from this instant. Calculate also, current I through the circuit as a function of time.

Sol. Let charge on capacitor C_1 be q_0 when switch was shifted from position 1 to position 2. Just before shifting of switch, circuit was as shown in fig. Applying Kirchoff's voltage law on the circuit Fig.



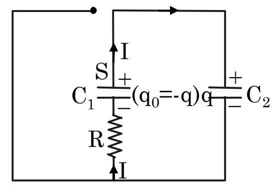
$$\frac{q_0}{C_1} - I_0 R = 0 \quad \text{or} \quad q_0 = I_0 RC_1$$

When switch is shifted from position 1 to position 2, capacitor C_1 continues to be discharged while C_2 starts charging.

Let at time t after shifting of switch to position 2, charge on capacitor C_2 be q and let current through the circuit be I.

$\therefore$ Charge remaining on C_1 is equal to $(q_0 - q)$ as shown in Fig.

Applying Kirchoff's voltage law on the circuit shown in fig.



$$\frac{q}{C_2} + IR - \frac{(q_0 - q)}{C_1} = 0$$

or $$I\,R = \frac{q_0 - q}{C_1} - \frac{q}{C_2} = \frac{(q_0C_2 - qC_2) - qC_1}{C_1C_2}$$

But current, $I = \frac{dq}{dt}$ (Rate of increase of charge on C_2)

$$\therefore \quad R\frac{dq}{dt} = \frac{q_0C_2 - q(C_1 + C_2)}{C_1C_2}$$

or $$\frac{dp}{q_0C_2 - q(C_1 + C_2)} = \frac{dt}{RC_1C_2}$$

But at t = 0, q = 0

$$\therefore \quad \int_0^q \frac{dp}{q_0C_2 - q(C_1 + C_2)} = \int_0^1 \frac{dt}{RC_1.C_2}$$

From above equation,

$$q = \left(\frac{q_0C_2}{C_1 + C_2}\right)\left[1 - e^{-\left(\frac{C_1+C_2}{RC_1C_2}\right)t}\right]$$

Substituting $q_0 = I_0 RC_1$,

$$q = I_0 . \frac{RC_1C_2}{C_1 + C_2}\left[1 - e^{-\left(\frac{C_1+C_2}{RC_1C_2}\right)t}\right]$$

But current, $$I = \frac{dq}{dt}$$

$$I = I_0 . e^{-\left(\frac{C_1+C_2}{RC_1C_2}\right)t}$$

In steady state common potential difference across capacitors is given by

$$V = \frac{q_0 + 0}{C_1 + C_2} \left(\text{using } V = \frac{C_1V_1 + C_2V_2}{C_1 + C_2}\right)$$

or $$V = \frac{I_0RC_1}{C_1 + C_2}$$

Initially energy stored in C_1 was

$$U_1 = \frac{q_0^2}{2C_1} = \frac{1}{2}I_0^2 R^2 C_1$$

In steady state, energy stored in two capacitors is

$$U_2 = \frac{1}{2}C_1V^2 + \frac{1}{2}C_2V^2$$

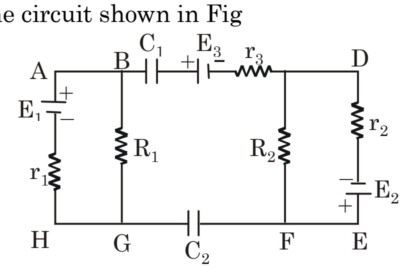
$$= \frac{1}{2}(C_1+C_2)\,\frac{I_0^2\,R^2\,C_1^2}{(C_1+C_2)^2}$$

$$= \frac{I_0^2\,R^2\,C_1^2}{2(C_1+C_2)}$$

Heat generated across resistor R = Loss of energy stored in capacitors during redistribution of charge = $U_1 - U_2$

$$= \frac{I_0^2\,R^2\,C_1C_2}{2(C_1+C_2)}$$

Ex.11 In the circuit shown in Fig



$R_1 = 8\Omega$, $R_2 = 5\Omega$, $C_1 = 6\mu F$, $C_2 = 3\mu F$, $E_1 = 5V$, $r_1 = 2\Omega$, $E_2 = 24V$, $r_2 = 3\Omega$, $E_3 = 14V$ and $r_3 = 2\Omega$.

Calculate charge on capacitors C_1 and C_2 in steady state.

Sol. In steady state, no current flows through capacitors, therefore, there are four unknown quantities in the given circuit :

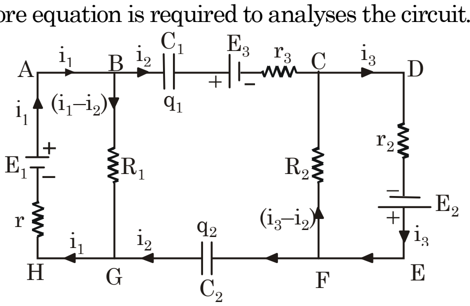
(i) current in left mesh ABGHA,

(ii) current in right mesh CDEFC.

(iii) charge q_1 on capacitor C_1 and

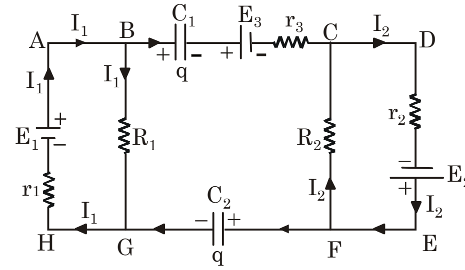
(iv) charge q_2 on capacitor C_2.

But by applying Kirchhoff's voltage law three unique equations can be formed. It means that one more equation is required to analyses the circuit.



Considering the circuit at an instant when steady state was not reached and charges on capacitors were increasing. By applying Kirchoff's current law at junctions, it is found that currents through two capacitors were always identical as shown in fig. Hence, magnitudes q_1 and q_2 of charges on two capacitors are equal. Let it be q.

From directions of current in fig, it is clear that if left plate of capacitor C_1 is positively charged then right plate of capacitor C_2 will be of the same polarity. Considering this fact, in steady state, circuit will be as shown in fig.



Applying Kirchhoff's voltage law on mesh ABGHA,

$I_1R_1 + I_1r_1 - E_1 = 0$ or $I_1 = 0.5$ A

For mesh, CDEFC, $I_1r_2 - E_2 + I_2R_2 = 0$

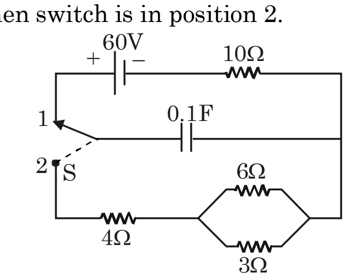
or $I_2 = 3A$

Now applying Kirchoff's voltage law on mesh BCFGB,

$$+\frac{q}{C_1} + E_3 - I_2R_2 + \frac{q}{C_2} - I_1R_1 = 0,\ q = 10\mu C \quad \textbf{Ans.}$$

Ex.12 A two way switch S is used in the circuit shown in fig. First, the capacitor is charged by putting the switch in position 1.

Calculate heat generated across each resistor when switch is in position 2.



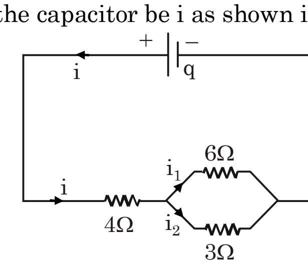
Sol. Initially the switch was in position 1. Therefore, initially potential difference across capacitors was equal to emf of the battery i.e. 60 volt

∴ Initially energy stored in the capacitor was

$$U = \frac{1}{2}CV^2 = \frac{1}{2} \times 0.1 \times 60^2 \text{ J} = 180 \text{ J}$$

When switch is shifted to position 2, capacitor begins to discharge and energy stored in it is dissipated in the form of heat across resistances.

Let at some instant discharging current through the capacitor be i as shown in fig.



According to Kirchoff's laws,

$i_1 + i_2 = i$ ...(1)

$6i_1 - 3i_2 = 0$

or $i_2 = 2i_2$ ...(2)

From above two equations,

$$i_1 = \frac{i}{3}$$

and $$i_2 = \frac{2}{3}i$$

But thermal power generated in a resistance R is $P = i^2 R$ where is current flowing through it. Therefore, heat generated P_1, P_2 and P_3 across 4Ω, 6Ω and 3Ω resistances is in ratio

$$4i^2 : 6i_1^2 : 3i_2^2$$

or $$P_1 : P_2 : P_3 = 4 : \frac{2}{3} : \frac{4}{3} = 6 : 1 : 2$$

But total heat generated is

$$P_1 + P_2 + P_3 = U$$

∴ Heat generated across 4Ω is

$P_1 = 120$ J **Ans.**

Heat generated across 6Ω is

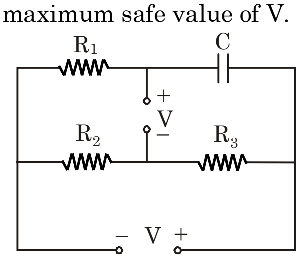
$P_2 = 20$ J **Ans.**

Heat generated across 3Ω is

$P_3 = 40$ J **Ans.**

Since, during discharging, no current flows through 10Ω, therefore heat generated across it is equal to zero. **Ans.**

Ex.13 In the circuit shown in fig., C is a parallel plate air capacitor having plates of area $A = 50\ cm^2$ each and a distance d = 1 mm apart. R_1 : R_2 and R_3 are resistors having resistances 3Ω, 2Ω and 1Ω respectively. Two identical sources each of emf V and of negligible internal resistance are connected as shown in fig. If dielectric strength of air is $E_0 = 3 \times 10^6\ Vm^{-1}$, calculate maximum safe value of V.



Sol. Due to sources, currents flow through resistance R_1, R_2 and R_3 and capacitor gets charged. Due to charge, an electric field is established in the capacitor whose magnitude can not exceed di-electric strength E_0 of air.

Maximum safe value of V corresponds to maximum possible charge on capacitor. let maximum possible charge on capacitor be q_0

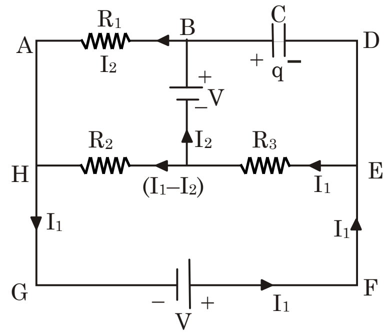
Then electric field inside the capacitor,

$$E_0 = \frac{q_0}{A\varepsilon_0}$$

or $$q_0 = A\varepsilon_0 E_0 = 15000\ \varepsilon_0 \text{ coulomb}$$

and capacitance $C = \frac{\varepsilon_0 A}{d} = 5\varepsilon_0$ Farad

Since, in steady state no current flows through capacitor, therefore, current through various parts of the circuit will be as shown in fig.



Now analysing the circuit in steady state,

First, applying Kirchoff's voltage law on mesh ABJHA,

$$-I_2R_1 + V + R_2(I_1 - I_2) = 0$$

or $2I_1 - 5I_2 = -V$ ....(1)

For mesh HJEFGH,

$$-R_2(I_1 - I_2) - R_3 I_1 + V = 0$$

or $3I_1 - 2I_2 = V$ .....(2)

From equations (1) and (2) ,

$$I_1 = \frac{7V}{11}$$

and $$I_2 = \frac{5V}{11}$$

Now, applying Kirchhoff's voltage law on mesh BDEJB,

$$\frac{q}{C} + I_1 R_3 - V = 0$$

or $$q = \frac{4CV}{11} = \frac{20}{11}\varepsilon_0 V$$

But maximum possible value of q is

$$q_0 = 1500\ \varepsilon_0$$

∴ Maximum safe value of $V = \frac{11q_0}{20\varepsilon_0}$

= 8250 volts = 8.25 kV

Ans.

Ex.14 A variable capacitor is adjusted in position of its lowest capacitance C_0 and is connected with a source of constant voltage V for a long time. Resistance of connecting wires is R. At t = 0, its capacitances starts to increase so that a constant current I starts to flow through the circuit, Calculate at time t

(i) power supplied by the source,

(ii) thermal power generated in the connecting wires and

(iii) rate of increase of electrostatic energy stored in capacitor.

(iv) What do you infer from above three results?

Sol. Since, voltage V of the source is constant and circuit draws a constant current I from it, therefore, power supplied by the source is

P = V **Ans (i)**

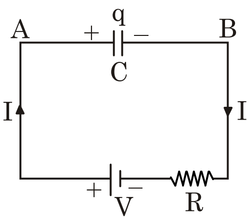
Thermal power generated in connecting wires,

$H = I^2 R$ **Ans (ii)**

Since, initial capacitance of the capacitor was equal to C_0 and it was connected with the source for long time, therefore, initial charge on capacitor was equal to $q_0 = C_0 V$

Since a constant I starts to flow at t = 0 there fore, at time t, charge on capacitor becomes equal to $q = (C_0 V + It)$

At time t, circuit will be as shown in fig.



Potential difference across the capacitor is

$$V_C = V_A - V_B \ (V - IR)$$

∴ Electronic energy in capacitor at this instant is

$$U = \frac{1}{2} qV_C$$

Rate of increase of electrostatic energy

$$= \frac{dU}{dt} = \frac{1}{2} V_C \frac{dq}{dt} = \frac{1}{2} (V - IR)$$

$$= \frac{1}{2} (VI - I^2 R)$$

Ans. (iii)

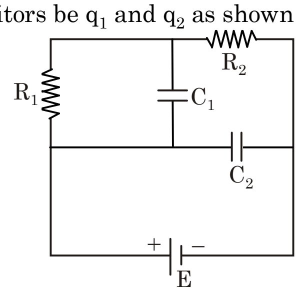
But power acting across the capacitor at this instant is $P_C = P - H = (VI - I^2R)$ while rate. of increase of electrostatic energy in capacitor is half of it.

In fact, a force of attraction exists between surfaces of the capacitor. When these surfaces move towards each other capacitance increases. Hence, remaining part of the power acting across capacitor is used to increase kinetic energy of surfaces (plates) of the capacitor.

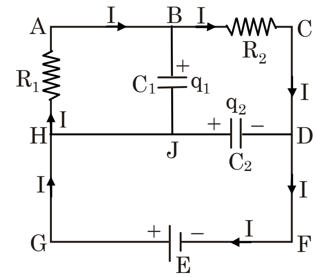
Ans. (iv)

Ex.15 In the circuit shown in fig. $R_1 = 1\Omega$, $R_2 = 2\Omega$, $C_1 = 1\ \mu F$, $C_2 = 2\mu F$ and $E = 6V$. Calculate charge on each capacitor in steady state.

Sol. In steady state no current flows through capacitors. Therefore charge on each capacitor remains constant. Let, in steady state circuit draw a current I from battery and let charge on capacitors be q_1 and q_2 as shown in fig.



Applying Kirchoff's voltage law on mesh ABCDFGHA,



$$IR_2 - E + IR_1 = 0$$

or $$I = \frac{E}{R_1 + R_2} = 2A$$

Now applying KVL on mesh ABJHA,

$$+\frac{q_1}{C_1} + IR_1 = 0$$

or $$q_1 = -2\mu C$$

(Negative sign indicates that the polarity of charge on capacitor C_1 is opposite to assume polarity. It means upper plate of the capacitor is negative while lower plate is positive).

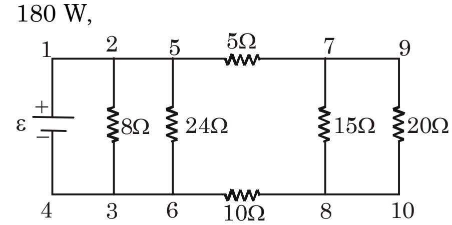
Hence, magnitude of charge on $C_1 = 2\mu C$.

Now applying KVL on mesh HJDFGH,

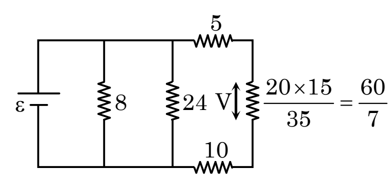
$$+\frac{q_2}{C_2} - E = 0$$

or $q_2 = C_2 E = 12\ \mu C$ **Ans.**

Ex.16 Determine the value of ε, for which the power supplied to the 20 Ω resistance in the figure is 180 W,



Sol.



$$V = \frac{\frac{60}{7} \times \varepsilon}{5 + \frac{60}{7} + 10};$$

$$V = \frac{60 \times \varepsilon}{1.5}$$

Heat $$-\frac{V^2}{20} = 180$$

or $$V = \sqrt{3600} = 60$$

$$\frac{60}{165} \varepsilon = 60$$

or $$\varepsilon = 165\ V$$

EXERCISE (Level-1)

Questions based on Current & Resistance definition

Q.1 In copper, each copper atom releases one electron. If a current of 1.1 A is flowing in the copper wire of uniform cross-sectional area of diameter 1 mm, then drift velocity of electrons will approximately be-
(Density of copper = 9×10^3 kg /m^3, Atomic weight of copper = 63)
(A) 10.3 mm/s (B) 0.1 mm/s
(C) 0.2 mm/s (D) 0.2 cm/s

Q.2 A current of 5A exists in a 10 Ω resistance for 4 minutes. The number of electrons and charge in coulombs passing through any section of the resistor in this time are -
(A) 75×10^{20}, 600C (B) 75×10^{21}, 600C
(C) 75×10^{20}, 1200C (D) 75×10^{19}, 1200C

Q.3 A potential difference V exists between the ends of a metal wire of length ℓ. The drift velocity will be doubled if -
(A) V is doubled
(B) ℓ is doubled
(C) The diameter of the wire is doubled
(D) The temperature of the wire is doubled

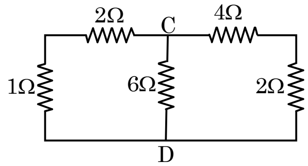
Q.4 The current in a conductor varies with time t is $I = 2t + 3t^2$ where I is in ampere and t in seconds. Electric charge flowing through a section of conductor during t = 2 sec to t = 3 sec. is -
(A) 10 C (B) 24 C (C) 33 C (D) 44 C

Q.5 The current in a copper wire is increased by increasing the potential difference between its end. Which one of the following statements regarding n, the number of charge carriers per unit volume in the wire and v the drift velocity of the charge carriers is correct -
(A) n is unaltered but v is decreased
(B) n is unaltered but v is increased
(C) n is increased but v is decreased
(D) n is increased but v is unaltered

Q.6 Consider two conducting wires of same length and material, one wire is solid with radius r. The other is a hollow tube of outer radius 2r while inner r. The ratio of resistance of the two wires will be -
(A) 1 : 1 (B) 1 : 2 (C) 3 : 1 (D) 1 : 4

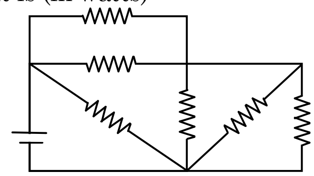
Questions based on Series & parallel combination of Resistance

Q.7 Equivalent resistance between point C and D in the combination of resistance shown is –



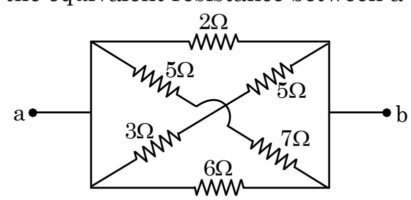
(A) 3 Ω (B) 1 Ω (C) 1.5 Ω (D) 0.5 Ω

Q.8 In the figure shown each resistor is of 20 Ω and the cell has emf 10 volt with negligible internal resistance. Then rate of joule heating in the circuit is (in watts) -



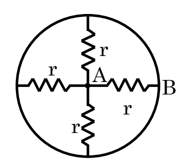
(A) 100/11 (B) 10000/11
(C) 11 (D) None of these

Q.9 Find the equivalent resistance between a & b



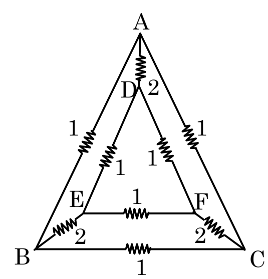
(A) $\frac{7}{8}$ Ω (B) $\frac{8}{7}$ Ω
(C) $\frac{6}{7}$ Ω (D) $\frac{7}{6}$ Ω

Q.10 The equivalent resistance between point A and B is -



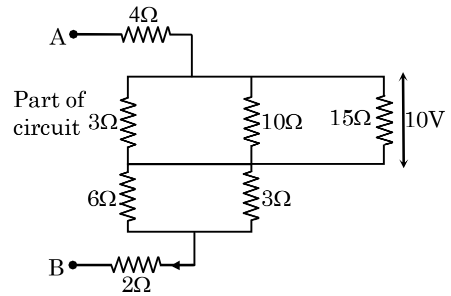
(A) 4 r (B) 2r (C) r (D) $\frac{r}{4}$

Q.11 A network of nine conductors connects six points A, B, C, D, E and F as shown below. The digits denote resistances in Ω. Find the equivalent resistance between B and C-



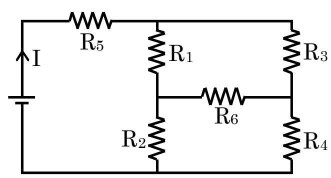
(A) $\frac{2}{15}$ Ω (B) $\frac{7}{12}$ Ω
(C) $\frac{5}{12}$ Ω (D) $\frac{11}{12}$ Ω

Q.12 Calculate the potential difference between points A and B and current flowing through the 10 Ω resistor in the part of the network below -



(A) 20 V, 2A (B) 50 V, 1A
(B) 40 V, 1A (D) 30 V, 1A

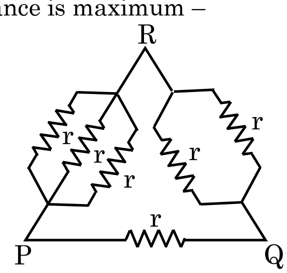
Q.13 In the given circuit, it is observed that the current I is independent of the value of the resistance R_6. Then the resistance values must satisfy -



(A) $R_1R_2R_5 = R_3R_4R_6$
(B) $\frac{1}{R_5} + \frac{1}{R_6} = \frac{1}{R_1 + R_2} + \frac{1}{R_3 + R_4}$
(C) $R_1R_4 = R_2R_3$
(D) $R_1R_3 = R_2R_4 = R_5R_6$

Q.14 Two wires of equal diameters of resistivities ρ_1 and ρ_2 and lengths x_1 and x_2 are joined in series. The equivalent resistivity of the combination is -
(A) $\frac{\rho_1 x_1 + \rho_2 x_2}{x_1 + x_2}$ (B) $\frac{\rho_1 x_2 - \rho_2 x_1}{x_1 - x_2}$
(C) $\frac{\rho_1 x_2 + \rho_2 x_1}{x_1 + x_2}$ (D) $\frac{\rho_1 x_1 + \rho_2 x_2}{\rho_1 + \rho_2}$

Q.15 In the circuit shown in the figure, equivalent resistance is maximum –



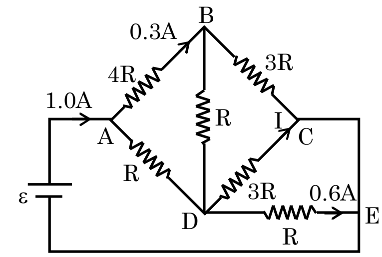
(A) Between P & Q
(B) Between P & R
(C) Between R & P
(D) Same between all the points

Q.16 The length of a given cylindrical wire is increased by 100%. Due to the consequent decrease in diameter the change in the resistance of the wire will be -
(A) 100% (B) 50% (C) 300% (D) 200%

Questions based on **Kirchoff Law : Power, Energy, Battery, EMF, Terminal voltage**

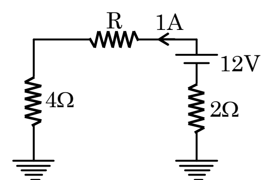
Q.17 For driving a current of 3 ampere for 5 minutes in an electrical circuit, 900 joule of work is to be done. Find the emf of the source in the circuit.
(A) 2 Volt (B) 3 Volt (C) 1 Volt (D) 5 Volt

Q.18 The current I in the circuit shown in the figure is -



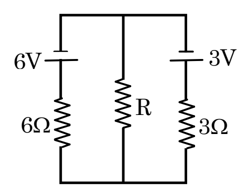
(A) 0 (B) 0.1 A (C) 0.4 A (D) 0.2 A

Q.19 In the circuit shown in figure the value of R is-



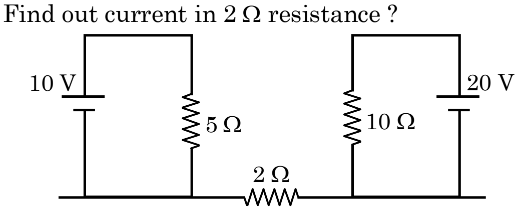
(A) 8 Ω (B) 6 Ω (C) 10 Ω (D) 12 Ω

Q.20 In the circuit, the value of R is so chosen that thermal power generated in it is maximum, then value of R is –



(A) 2 Ω (B) 3 Ω (C) 6 Ω (D) 9 Ω

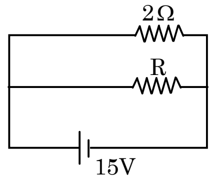
Q.21 Find out current in 2 Ω resistance ?



(A) 0 (B) 2 A (C) 3A (D) 5 A

Q.22 An electric kettle has two coils. When one coil is switched on it takes 15 minutes to boil water and when the second coil is switched on, it takes 30 minutes. How long will it take to boil water when both the coils are used in (i) series and (ii) parallel ?
(A) 10 min, 45 min (B) 45 min, 10 min
(C) 30 min, 10 min (D) 20 min, 45 min

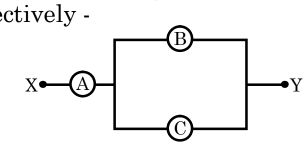
Q.23 If energy consumption of this circuit is 150 watt then find the value of resistance –



(A) 2 Ω (B) 4 Ω (C) 6 Ω (D) 8 Ω

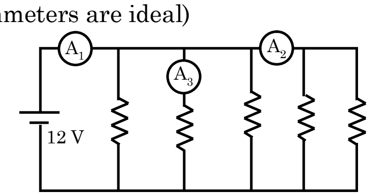
Questions based on Instruments

Q.24 A, B and C are voltmeters of resistances R, 1.5R and 3R respectively. When some potential difference is applied between X and Y, the voltmeter readings are V_A, V_B and V_C respectively -



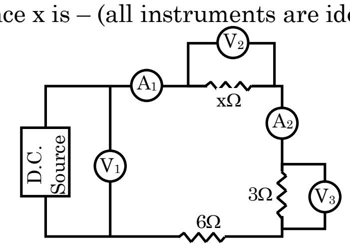
(A) $V_A = V_B = V_C$ (B) $V_A \neq V_B = V_C$
(C) $V_A = V_B \neq V_C$ (D) $V_B \neq V_A = V_C$

Q.25 In the circuit, each resistance is 20 Ω. The readings of A_1, A_2 and A_3 are respectively – (all ammeters are ideal)



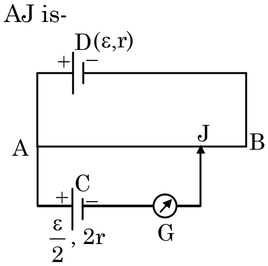
(A) 3A, 1.8A, 1.2 A (B) 3A, 1.2 A, 0.6A
(C) 3A, 0.6 A, 1.2 A (D) 3A, 0.6 A, 0.6 A

Q.26 In the electric circuit shown in figure, the reading of voltmeter V_1 is 26 volt, and the reading of ammeter A_1 is 2 ampere. The value of resistance x is – (all instruments are ideal)



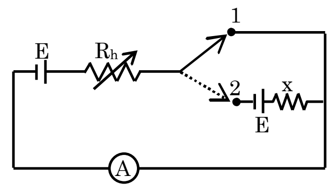
(A) 2 Ω (B) 4 Ω (C) 6 Ω (D) 8 Ω

Q.27 In the figure, the potentiometer wire AB of length L and resistance 9r is joined to the cell D of emf ε and internal resistance r. The cell C's emf is ε/2 and its internal resistance is 2r. The galvanometer G will show no deflection when the length AJ is-



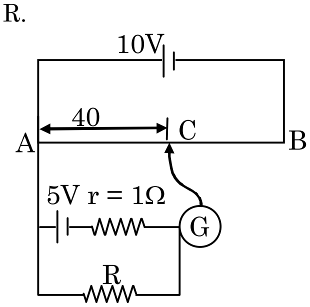
(A) $\frac{4L}{9}$ (B) $\frac{5L}{9}$ (C) $\frac{7L}{18}$ (D) $\frac{11L}{18}$

Q.28 In the circuit shown the variable resistance R_h is so adjusted that ammeter reads the same in both positions of the key. The reading of ammeter is I. The emf of the cell in series with x is E, the value of x is –



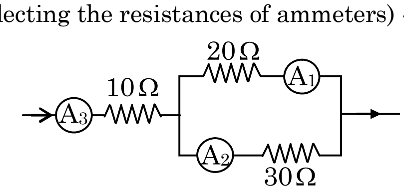
(A) $\frac{2E}{I}$ (B) $\frac{E}{I}$ (C) EI (D) 2EI

Q.29 A potentiometer wire AB is 100 cm long and has a total resistance of 10 ohm. If the galvanometer shows zero deflection at the position C, then find the value of unknown resistance R.



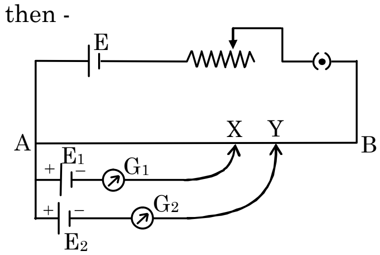
(A) 2Ω (B) 4Ω (C) 6 Ω (D) 8 Ω

Q.30 If the reading of ammeter A_1, in figure is 2.4 A, what will the ammeter A_2 and A_3 read? (Neglecting the resistances of ammeters) -



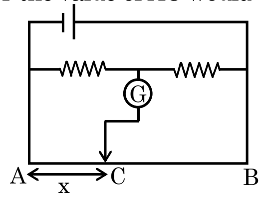
(A) 1.6 A, 2.3 A (B) 1.6 A, 4.0 A
(C) 4.0 A, 1.6 A (D) 2.3 A, 1.6 A

Q.31 A potentiometer experiment is setup as shown in figure. If both the galvanometer shows null deflections for the sliding contacts at x and y as shown then -



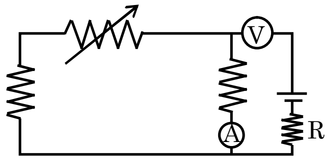
(A) $E_1 = E_2$ (B) $E_1 > E_2$
(C) $E_1 < E_2$ (D) none of the above

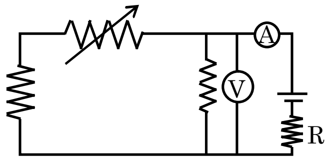
Q.32 In this given circuit, no current is passing through the galvanometer. If the cross-sectional diameter of the wire AB is doubled then for null point of galvanometer the value of AC would –

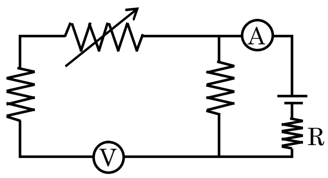


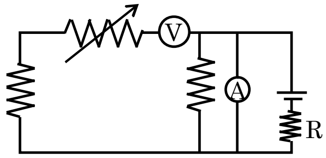
(A) x/4 (B) 4x (C) 2x (D) x

Q.33 Which of the following circuit is correct for verification of ohms law -

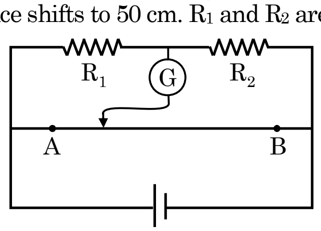
(A)


(B)


(C)


(D)


Q.34 In the figure shown for gives of R_1 and R_2 the balance point for Jockey is at 40 cm from A. When R_2 is shunted by a resistance of 10 Ω, balance shifts to 50 cm. R_1 and R_2 are (AB = 1 m)-



(A) $\frac{10}{3}$ Ω, 5 Ω (B) 20 Ω, 30 Ω

(C) 10 Ω, 15 Ω (D) 5 Ω, $\frac{15}{2}$ Ω

Questions based on — Standard rating / Heat generation definition

Q.35 A bulb is made using two filaments. A switch selects whether the filaments are used individually or in parallel. When this bulb is used with a 15 volt battery, the bulb can developed 5W, 10W, or 15W power. Then resistances of filaments should be -

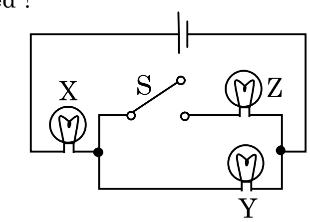
(A) 10Ω, 20 Ω (B) 22.5 Ω, 22.5 Ω
(C) 22.5 Ω, 45 Ω (D) 45 Ω, 90 Ω

Q.36 A cell of constant emf produces the same amount of heat during the same time in two independent resistors R_1 and R_2 when they are separately connected across the terminals of the cell, one after another. The internal resistance of the cell is -

(A) $\frac{R_1 + R_2}{2}$ (B) $\sqrt{R_1 R_2}$

(C) $\frac{|R_1 - R_2|}{2}$ (D) $\frac{R_1 R_2}{R_1 + R_2}$

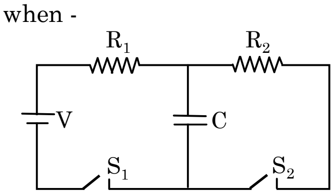
Q.37 If X, Y, and Z in figure are identical lamps, which of the following changes to the brightnesses of the lamps occur when switch S is closed ?



(A) X stays the same, Y decreases
(B) X increases, Y decreases
(C) X increases, Y stays the same
(D) X decreases, Y increases

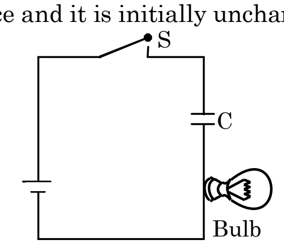
Questions based on — Capacitor in circuit

Q.38 A battery of emf V volt, resistance R_1 and R_2, a capacitance C and switches S_1 and S_2 are connected in an electrical circuit as shown in figure. The capacitor C gets fully charged to V volt when -



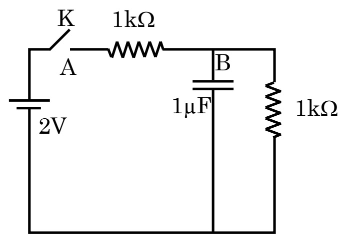
(A) S_1 and S_2 are both closed
(B) S_1 and S_2 are both open
(C) S_1 closed and S_2 open
(D) S_2 closed and S_1 open

Q.39 In the circuit shown in figure, how does brightness of the bulb change with time after the switch S is closed ? Assume that the capacitance and it is initially uncharged -



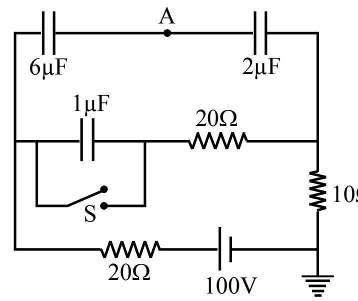
(A) brightness increases with time and becomes constant after a certain time
(B) brightness decreases with time and reduces to zero after some time
(C) brightness increases, becomes constant and then again increases due to the discharging of capacitor
(D) brightness is constant till the capacitor is fully charged and then it increases because the whole current is now available to the bulb

Q.40 When the key K is pressed at time t = 0 which of the following statements about the current I in the resistor AB of the given circuit is true -



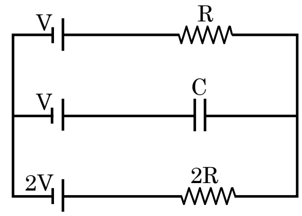
(A) I = 2 mA at all t
(B) I oscillates between 1 mA and 2 mA
(C) I = 1 mA at all t
(D) At t = 0, I = 2 mA and with time it goes to 1 mA

Q.41 In fig. shown, when switch S is closed, what will be the voltage across capacitor 2 μF and 1 μF capacitor. (consider steady state condition)



(A) 20V, 0
(B) 40V, 0
(C) 30V, 0
(D) 10V, 0

Q.42 In the given circuit, with steady current, the potential drop across the capacitor must be -



(A) V (B) V/2 (C) V/3 (D) 2V/3

EXERCISE (Level-2)

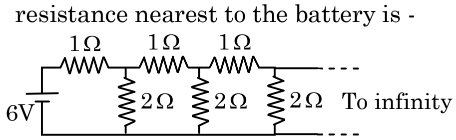
Single correct answer type questions

Q.1 A carbon and an aluminium wire connected in series. If the combination has resistance of 30 ohm at 0°C, what is the resistance of carbon and aluminium wire at 0°C so that the resistance of the combination does not change with temperature - [$\alpha_c = -0.5 \times 10^{-3}\,(C°)^{-1}$ and $\alpha_{Al} = 4 \times 10^{-3}\,(C°)^{-1}$]

(A) $\frac{10}{3}\Omega, \frac{80}{3}\Omega$ (B) $\frac{80}{3}\Omega, \frac{10}{3}\Omega$

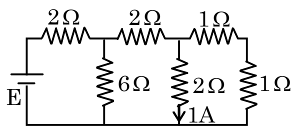
(C) 10 Ω, 80 Ω (D) 80 Ω, 10 Ω

Q.2 An infinite ladder network of resistance is constructed with 1 Ω and 2 Ω resistance. The 6V battery between A and B has negligible internal resistance. The current that passes through 2 Ω resistance nearest to the battery is -



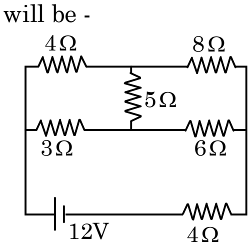
(A) 1A (B) 1.5 A (C) 2 A (D) 2.5 A

Q.3 The emf of the battery shown in the figure is given by -



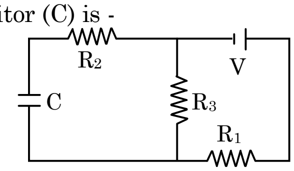
(A) 6 V (B) 12 V (C) 18 V (D) 8 V

Q.4 In the given figure the ratio of current in 8Ω and 3Ω will be -



(A) $\frac{8}{3}$ (B) $\frac{3}{8}$ (C) $\frac{4}{3}$ (D) $\frac{3}{4}$

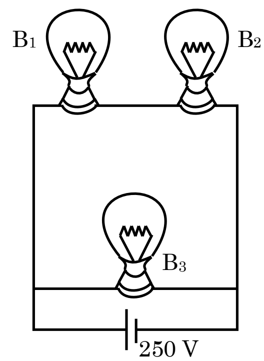
Q.5 In figure the steady state voltage drop across capacitor (C) is -



(A) V (B) $\frac{VR_1}{\left[R_3\left(\frac{R_1.R_3}{R_1+R_3}\right)\right]}$

(C) $\frac{VR_3}{R_1+R_3}$ (D) $\frac{VR_1}{R_1+R_3}$

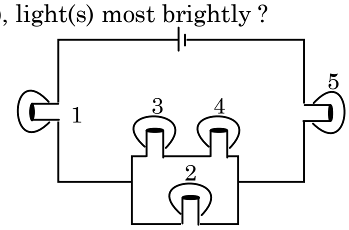
Q.6 A 100 W bulb B_1, and two 60 W bulbs B_2 and B_3, are connected to a 250 V source, as shown in the figure. Now W_1, W_2 and W_3 are the output powers of the bulbs B_1, B_2 and B_3, respectively. (Rated potential of each bulb is 250 V) select correct alternative -



(A) $W_1 > W_2 = W_3$ (B) $W_1 > W_2 > W_3$

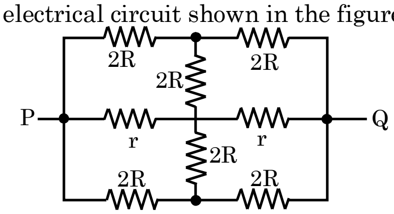
(C) $W_1 < W_2 = W_3$ (D) $W_1 < W_2 < W_3$

Q.7 In the fig below the bulbs are identical, which bulb(s), light(s) most brightly ?



(A) 1 only (B) 4 only (C) 2 and 3 (D) 1 and 5

Q.8 The effective resistance between points P and Q of the electrical circuit shown in the figure is -



(A) 2Rr / (R + r) (B) 8R (R + r) / (3 R + r)

(C) 2r + 4R (D) 5R / 2 + 2r

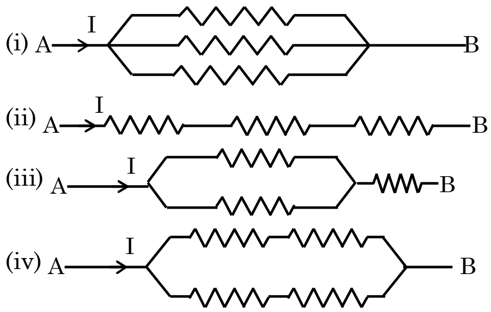
Q.9 A long resistance wire is divided into 2n parts. Then n parts are connected in series and the other n parts in parallel separately. Both combinations are connected to identical supplies. Then the ratio of heat produced in series to parallel combinations will be -

(A) 1 : 1 (B) 1 : n^2 (C) 1 : n^4 (D) n^2 : 1

Q.10 In a potentiometer experiment it is found that no current pass through the galvanometer when the terminals of the cell are connected across 125 cm of potentiometer wire. On shunting the cell by a 2Ω resistance the balancing length reduces to half. The internal resistance of the cell is –

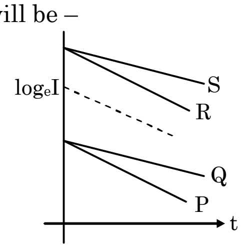
(A) 4 Ω (B) 2Ω (C) 1Ω (D) 0.5Ω

Q.11 Arrange the order of power dissipated in the given circuits, if the same current is passing through all the circuits. The resistance of each resistor is 'r' -



(A) $P_2 > P_3 > P_4 > P_1$ (B) $P_1 > P_4 > P_2 > P_3$
(C) $P_3 > P_1 > P_4 > P_2$ (D) $P_2 > P_4 > P_1 > P_3$

Q.12 A capacitor is charged using an external battery with a resistance x in series. The dashed line shows the variation of $\log_e I$ with respect to time. If the resistance is changed to 2x, the new graph will be –



(A) P (B) Q (C) R (D) S

Q.13 The length of a wire of a potentiometer is 100 cm, and the e.m.f. of its standard cell is E volt. It is employed to measure the e.m.f. of battery whose internal resistance is 0.5 Ω. If the balance point is obtained at ℓ = 30 cm from the positive end the e.m.f. of the battery is -

(A) $\dfrac{30\,E}{(100-0.5)}$

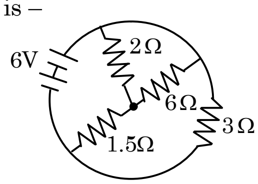
(B) $\dfrac{30\,(E-0.5\,i)}{(100)}$, where i is the current in the potentiometer wire

(C) $\dfrac{30\,E}{100}$

(D) $\dfrac{30\,E}{100.5}$

Q.14 An ammeter reads upto 1 ampere. Its internal resistance is 0.81 ohm. To increase the range to 10A the value of the required shunt is -
(A) 0.3 Ω (B) 0.9 Ω (C) 0.09 Ω (D) 0.03 Ω

Q.15 The total current supplied to the circuit by the battery is –



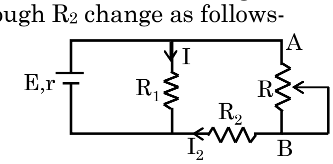
(A) 1 A (B) 2 A (C) 4 A (D) 6 A

Q.16 The resistance of the series combination of two resistance is S. When they are joined in parallel the total resistance is P. If S = n P then the minimum possible value of n is -
(A) 4 (B) 3 (C) 2 (D) 1

Q.17 An electric current is passed through a circuit containing two wires of the same material, connected in parallel. If the lengths and radii of the wires are in the ratio of 4/3 and 2/3, then the ratio of the currents passing through the wires will be -
(A) 3 (B) 1/3 (C) 8/9 (D) 2

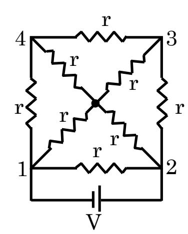
Q.18 When a galvanometer is shunted with a 4Ω resistance, the deflection is reduced to one-fifth. If the galvanometer is further shunted with a 2Ω wire, the deflection will be (The main current remains the same) -
(A) (8/13) of the original deflection only
(B) (5/13) of the original deflection
(C) (3/4) of the deflection when shunted with 4 Ω only
(D) (5/13) of the deflection when shunted with 4 Ω only

Q.19 In the circuit shown in figure, the emf and internal resistance of the battery are E and r. R_1 and R_2 are two resistance of fixed resistance. As the side of variable resistor R moves towards A, the current I_1 through R_1 and current I_2 through R_2 change as follows-



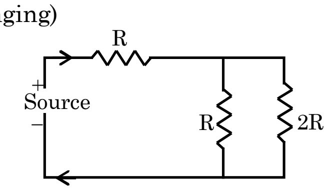
(A) I_1 increases, I_2 decreases
(B) I_1 increases, I_2 increases
(C) I_1 decreases, I_2 increases
(D) I_1 decreases, I_2 decreases

Q.20 For the circuit shown in figure the ratio of the amounts of heat liberated per unit time in conductors 1-2 and 3-4 is -



(A) 1 : 16 (B) 16 : 1 (C) 8 : 1 (D) 1 : 8

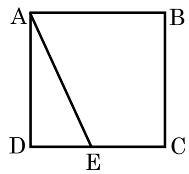
Q.21 The charge supplied by source varies with time t as $Q = at - bt^2$. The total heat produced in resistor 2R is : (Assume direction of current is not changing)



(A) $\dfrac{a^3R}{6b}$ (B) $\dfrac{a^3R}{27b}$

(C) $\dfrac{a^3R}{3b}$ (D) None of these

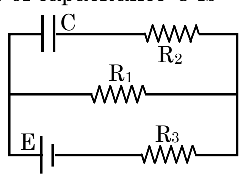
Q.22 ABCD is a square of side 1 metre where each side is a uniform wire of resistance 1Ω. A point E lies on CD such that if a uniform wire of resistance 1Ω is connected across AE and constant potential difference is applied across A and C then B and E are equipotential then select correct option B -



(A) $\frac{CE}{ED} = 1$ (B) $\frac{CE}{ED} = 2$

(C) $\frac{CE}{ED} = \frac{1}{\sqrt{2}}$ (D) $\frac{CE}{ED} = \sqrt{2}$

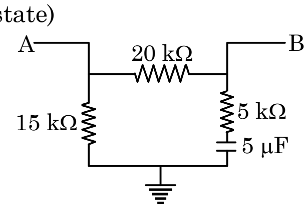
Q.23 The magnitude of saturation charge on capacitor of capacitance C is –



(A) CE (B) $\frac{CER_1}{R_1 + R_3}$

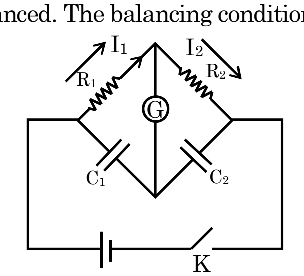
(C) $\frac{CER_2}{R_1 + R_3}$ (D) $\frac{CER_1}{R_2 + R_3}$

Q.24 The value of resistance as measured across terminals A and B in figure would be : (Assume steady state)



(A) 20 kΩ (B) 10 kΩ (C) 15 kΩ (D) 5 kΩ

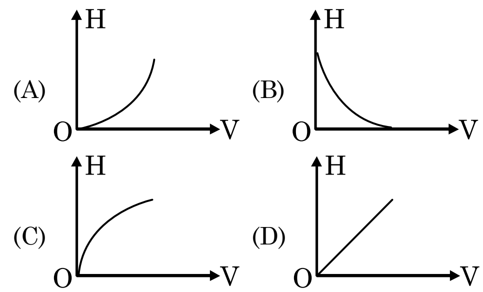
Q.25 In circuit, if no current flows through the galvanometer when the key K is closed, the bridge is balanced. The balancing condition for bridge is -



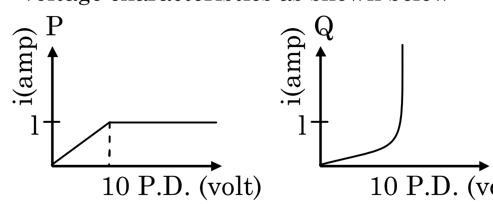
(A) $\frac{C_1}{C_2} = \frac{R_1}{R_2}$ (B) $\frac{C_1}{C_2} = \frac{R_2}{R_1}$

(C) $\frac{C_1^2}{C_2^2} = \frac{R_1^2}{R_2^2}$ (D) $\frac{C_1^2}{C_2^2} = \frac{R_2^2}{R_1^2}$

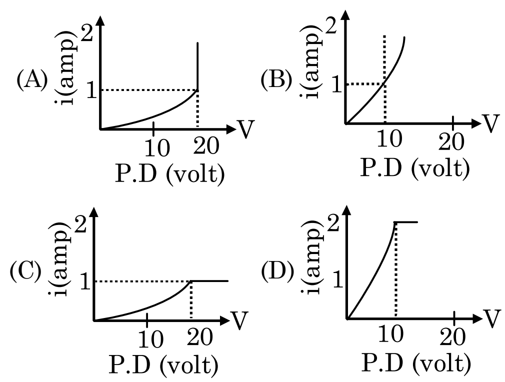
Q.26 A capacitor is charged by connecting a battery of emf E and internal resistance r, at t = 0. If at an instant t, potential difference across the capacitor be V and heat generated upto that instant be H, then which of the following graphs is correct -



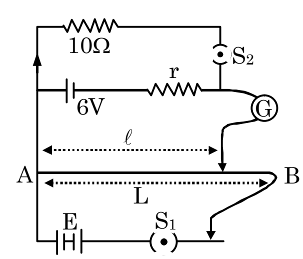
Q.27 Two current elements P and Q have current voltage characteristics as shown below -



Which of the graphs given below represents current voltage characteristics when P and Q are in series-



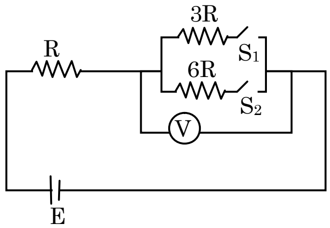
Q.28 In the arrangement shown in figure when the switch S_2 is open, the galvanometer shows no deflection for $\ell = L/2$. When the switch S_2 is closed, the galvanometer shows no deflection for $\ell = 5L/12$. The internal resistance (r) of 6 V cell, and the emf E of the other battery are respectively-



(A) 3Ω, 8V (B) 2Ω, 12V

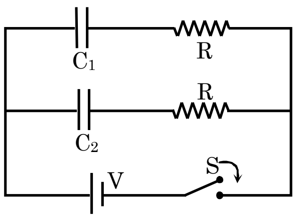
(C) 2Ω, 24V (D) 3Ω, 12V

Q.29 In the circuit shown in figure reading of ideal voltmeter is V_1 when only S_1 is closed, reading of ideal voltmeter is V_2 when only S_2 is closed and reading of this voltmeter is V_3 when both S_1 and S_2 are closed. Then -



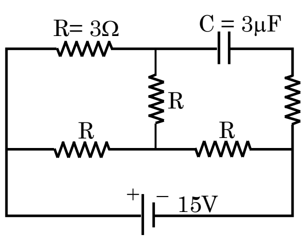
(A) $V_3 > V_2 > V_1$ (B) $V_2 > V_1 > V_3$
(C) $V_3 > V_1 > V_2$ (D) $V_1 > V_2 > V_3$

Q.30 In the circuit shown in figure $C_1 = 2C_2$. Switch S is closed at time t = 0. Let i_1 and i_2 be the currents flowing through C_1 and C_2 at any time t, then the ratio i_1/i_2 -



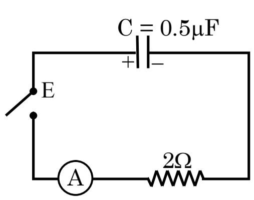
(A) is constant
(B) increases with increase in time t
(C) decreases with increase in time t
(D) first increases then decreases

Q.31 In the circuit shown, the cell is ideal, with emf = 15 V. Each resistance is of 3Ω. The potential difference across the capacitor is -



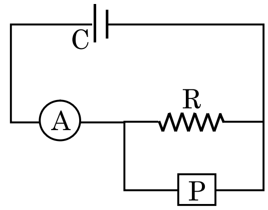
(A) zero (B) 9 V (C) 12 V (D) 15 V

Q.32 A charged capacitor is allowed to discharge through a resistor by closing the key at the instant t = 0. At the instant t = (ln 4) μs, the reading of the ammeter falls half the initial value. The resistance of the ammeter is equal to –



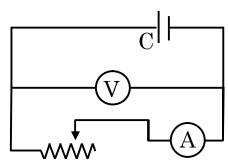
(A) 1 MΩ (B) 1 Ω (C) 2 Ω (D) 2 MΩ

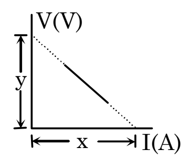
Q.33 An ammeter A of finite resistance, and a resistor R are joined in series to an ideal cell C. A potentiometer P is joined in parallel to R. The ammeter reading is I_0 and the potentiometer reading is V_0. P is now replaced by a voltmeter of finite resistance. The ammeter reading now is I and the voltmeter reading is V –



(A) $I > I_0$, $V < V_0$ (B) $I > I_0$, $V = V_0$
(C) $I = I_0$, $V < V_0$ (D) $I < I_0$, $V = V_0$

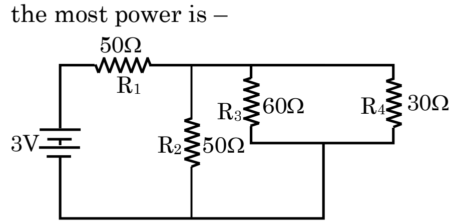
Q.34 The diagram beside shows a circuit used in an experiment to determine the emf and internal resistance of the cell C. A graph was plotted of the potential difference V between the terminals of the cell against the current I, which was varied by adjusting the rheostat. The graph is shown on the right; x and y are the intercepts of the graph with the aces as shown. What is the internal resistance of the cell ?





(A) x (B) y (C) x/y (D) y/x

Q.35 In the circuit shown, the resistance are given in ohms and the battery is assumed ideal with emf equal to 3.0 volts. The resistor that dissipates the most power is –



(A) R_1 (B) R_2 (C) R_3 (D) R_4

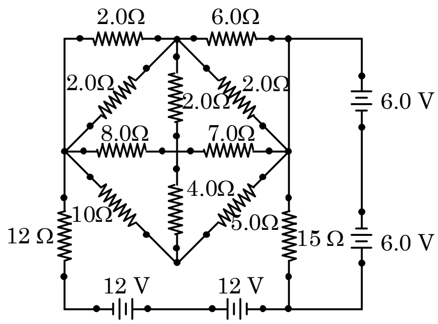
Q.36 The length of a potentiometer wire is l. A cell of emf E is balanced at a length $l/3$ from the positive end of the wire. If the length of the wire is increased by $l/2$. At what distance will the same cell give a balance point -

(A) $\frac{2l}{3}$ (B) $\frac{l}{2}$ (C) $\frac{l}{6}$ (D) $\frac{4l}{3}$

Q.37 A heater A gives out 300 W of heat when connected to a 200 V d.c. supply. A second heater B gives out 600 W when connected to a 200 V d.c. supply. If a series combination of the two heaters is connected to a 200 V d.c. supply the heat output will be -

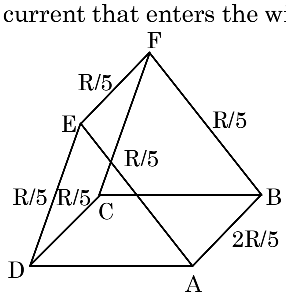
(A) 100 W (B) 450 W (C) 300 W (D) 200 W

Q.38 The current through the 8Ω resistor (shown in fig.) is -



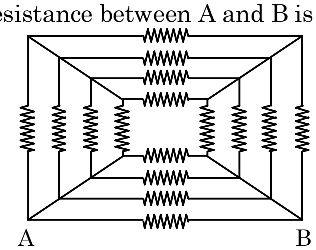
(A) 4A (B) 2A
(C) zero (D) 2.5 A

Q.39 The current enters at A and comes out at D. Some of the resistances are shown. What should be resistance of wire CB so that it draws double of the current that enters the wire BF.



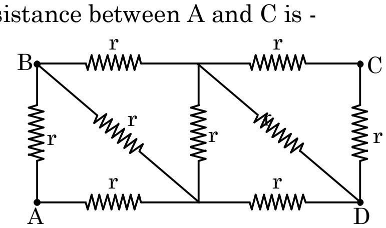
(A) $\left(\frac{9}{10}\right)$R (B) $\left(\frac{8}{9}\right)$R
(C) $\left(\frac{7}{9}\right)$R (D) $\left(\frac{3}{20}\right)$R

Q.40 Sixteen resistor, each of resistance 16Ω, are connected in the circuit as shown in figure. The net resistance between A and B is -



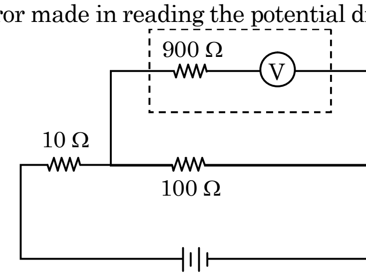
(A) 1Ω (B) 2Ω (C) 3Ω (D) 4 Ω

Q.41 For the circuit shown in figure, the equivalent resistance between A and C is -



(A) $\frac{12}{11}$r (B) $\frac{13}{11}$r (C) $\frac{14}{11}$r (D) $\frac{15}{11}$r

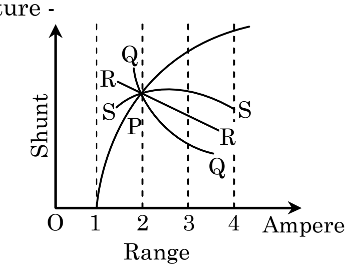
Q.42 The potential difference across the 100 Ω resistance in the following circuit is measured by a voltmeter of 900 Ω resistance. The percentage error made in reading the potential difference is -



(A) $\frac{10}{9}$ (B) 0.1 (C) 1.0 (D) 10.0

Q.43 Two resistances of 400 Ω and 800 Ω are connected in series with 6 V battery of negligible internal resistance. A voltmeter of resistance 10000 Ω is used to measure the potential difference across 400 Ω. The error in the measurement of potential difference in volts approximately is -
(A) 0.01 (B) 0.02 (C) 0.03 (D) 0.05

Q.44 The ammeter has range I ampere without shunt. The range can be varied by using different shunt resistance. The graph between shunt resistance and range will have the nature -

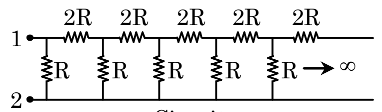


(A) P (B) Q (C) R (D) S

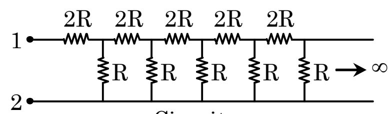
EXERCISE (Level-3)

Part-A : Multiple correct answer type questions

Q.1 Two circuits (as shown in figure) are called circuit A and circuit B. The equivalent resistance of circuit A is x and that of circuit B is y between 1 and 2.



Circuit

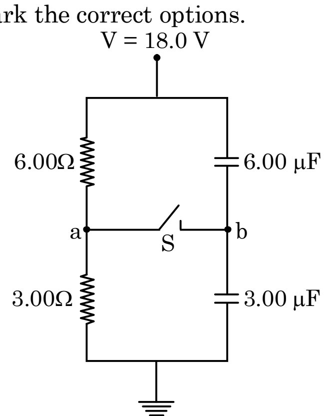


Circuit

(A) y > x (B) $y = (\sqrt{3} + 1)\,R$

(C) $xy = 2R^2$ (D) y – x = 2R

Q.2 Study the following circuit diagram in figure and mark the correct options.



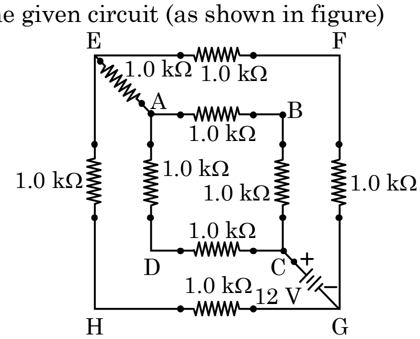
(A) The potential of point a with respect to point b in the figure when switch S is open is –6V.

(B) The points a and b are at the same potential, when S is opened.

(C) The charge flowing though switch S when it is closed is 54 μC.

(D) The final potential of b with respect to ground when switch S is closed is 8 V.

Q.3 In the given circuit (as shown in figure)



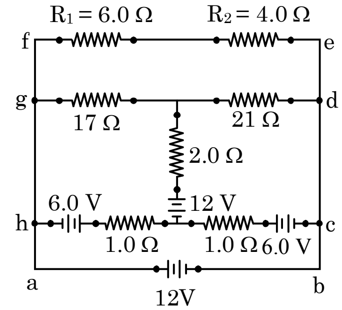
(A) the equivalent resistance between C and G is 3 kΩ.

(B) the current provided by the source is 4 mA

(C) the current provided by the source is 8 mA

(D) voltage across points G and E is 4 V

Q.4 In the circuit shown in figure, mark the correct option.



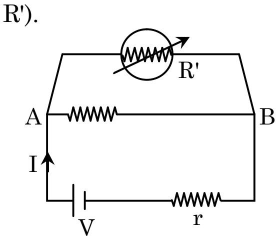
(A) potential drop across R_1 is 3.2 V

(B) Potential drop across R_2 is 5.4 V

(C) Potential drop across R_1 is 7.2 V

(D) Potential drop across R_2 is 4.8 V

Q.5 Consider a simple circuit shown in figure stands for a variable resistance R'. R' can vary from R_0 to infinity, r is internal resistance of the battery (r << R << R').



(A) Potential drop across, AB is nearly constant as R' is varied

(B) Current through R' is nearly a constant as R' is varied

(C) Current I depends sensitively on R'

(D) $I \geq \dfrac{V}{r + R}$ always

Q.6 When no current is passed through a conductor–

(A) the free electrons do not move

(B) the average speed of free electrons over a large period of time is zero

(C) the average velocity of free electrons over a large period of time is zero

(D) the average of the velocities of all the free electrons at an instant is zero

Q.7 A current passes through a wire of non-uniform cross-section. Which of the following quantities are independent of the cross-section –

(A) the charge crossing in a given time interval

(B) drift velocity

(C) current density

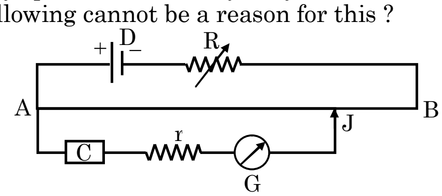
(D) free-electron density

Q.8 Two resistors having equal resistances are joined in series and a current is passed through the combination. Neglect any variation of resistance as a temperature change. In a given time interval–
(A) equal amounts of thermal energy must be produced in the resistors
(B) unequal amounts of thermal energy may be produced
(C) the temperature must rise equally in the resistors
(D) the temperature may rise equally in the resistors

Q.9 Two fuse wire of rating 10 A and 20 A are connected in different type. Then –
(A) In parallel combination works as a fuse of 30 A
(B) In parallel combination works as a fuse of 10 A
(C) In series combination works as a fuse of 10 A
(D) In series combination works as a fuse of 20 A

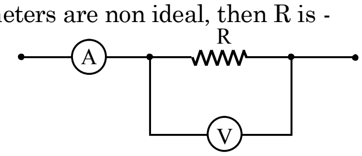
Q.10 In a potentiometer wire experiment the emf of a battery in the primary circuit is 20 Volt and its internal resistance is 5 Ω. There is a resistance box (in series with the battery and the potentiometer wire) whose resistance can be varied from 120 Ω to 170 Ω. Resistance of the potentiometer wire is 75 Ω. The following potential difference can be measured using this potentiometer-
(A) 5V (B) 6V (C) 7V (D) 8V

Q.11 In the given potentiometer circuit, the resistance of the potentiometer wire AB is R_0. C is a cell of internal resistance r. The galvanometer G does not give zero deflection for any position of the jockey J. Which of the following cannot be a reason for this ?



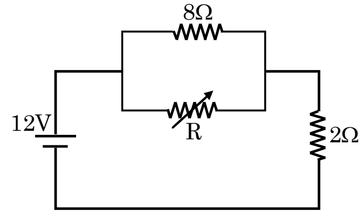
(A) $r > R_0$
(B) $R >> R_0$
(C) emf of C > emf of D
(D) The negative terminal of C is connected to A

Q.12 In the circuit shown the readings of ammeter and voltmeter are 4 A and 20 V respectively. The meters are non ideal, then R is -



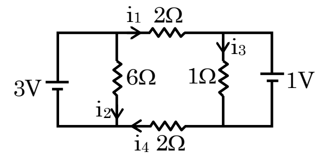
(A) 5 Ω (B) less than 5 Ω
(C) greater than 5 Ω (D) between 4 Ω & 5Ω

Q.13 The value of the resistance R in figure is adjusted such that power dissipated in the 2Ω resistor is maximum. Under this condition -



(A) R = 0
(B) R = 8 Ω
(C) Power dissipated in the 2 Ω resistor is 72 W
(D) Power dissipated in the 2 Ω resistor is 8 W

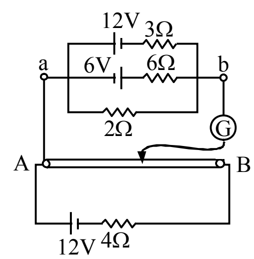
Q.14 In the circuit shown, current in different branches are marked. Select the correct alternatives -



(A) $i_1 = \frac{1}{2}$ A (B) $i_4 = \frac{1}{2}$ A

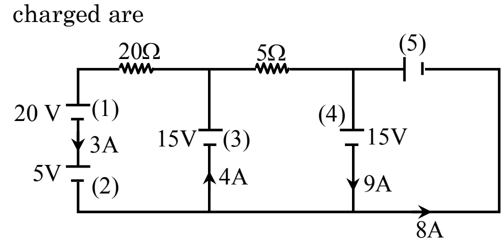
(C) $i_2 = \frac{1}{2}$ A (D) i_3 = 1A

Q.15 In a potentiometer circuit, a uniform wire of 10 m having resistance 20 Ω is fixed between A and B as shown in fig. Neglecting resistance of connecting wires, select the correct options



(A) distance of null point from A is 5m.
(B) distance of null point from A is 3m
(C) at null point, current through 4 Ω is 0.5 A
(D) at null point, current through 3Ω resistor is 3A

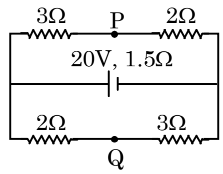
Q.16 In the given networks, the batteries getting charged are



(A) 1 & 3 (B) 1, 3 & 5
(C) 1 & 4 (D) 1, 2 & 5

Q.17 The emf of a cell is :
(A) the potential difference across its terminals
(B) the potential difference across its terminals when no current is passing through it
(C) the heat produced when the cell is connected across a one ohm resistance
(D) the total work done per coulomb of electricity taken in a circuit in which the cell is connected

Q.18 In the given circuit :



(A) the current through the battery is 5.0 amp
(B) P and Q are at the same potential
(C) P is 2.5 V higher than Q
(D) Q is 2.5 V higher than P

Part-B : Assertion Reason type Questions

The following questions consists of two statements each, printed as Assertion and Reason. While answering these questions you are to choose any one of the following four responses.

(A) If both Assertion and Reason are true and the Reason is correct explanation of the Assertion.
(B) If both Assertion and Reason are true but Reason is not correct explanation of the Assertion.
(C) If Assertion is true but the Reason is false.
(D) If Assertion is false but Reason is true.

Q.19 **Assertion :** If the length of the conductor is doubled, the drift velocity will become half of the original value (keeping potential difference unchanged).
Reason : At constant potential difference, drift velocity is inversely proportional to the length of the conductor.

Q.20 **Assertion :** In a chain of bulbs, 50 bulbs are joined in series. One bulb is fused now. If the remains 49 bulbs are again connected in series across the same supply then light gets increased in the room.
Reason : The resistance of 49 bulbs will be less than 50 bulbs.

Q.21 **Assertion :** Current is passed through a metallic wire, heating it red. When cold water in poured on half of its portion, then rest of the half portion becomes more hot.
Reason : Resistance decreases due to decrease in temperature and then current through wire increases.

Q.22 **Assertion:** A domestic electrical appliance, working on a three pin, will continue working even if the top pin is removed.
Reason : The third pin is used only as a safety device.

Q.23 **Assertion :** In parallel combination of electrical appliances, in home circuit total power consumption is equal to the sum of the rated powers of the individual appliances.
Reason : In parallel combination, in home circuit the voltage across each appliance is the same, as required for the proper working of electrical appliance.

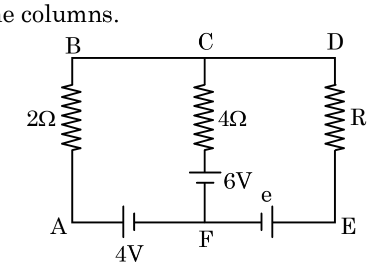
Q.24 **Assertion :** When the cell is in the open circuit there is no force on a test charge inside the electrolyte of the cell.
Reason : There is no electric field inside the cell, when the cell is in open circuit.

Q.25 **Assertion :** The emf of the driver cell in the potentiometer experiment should be greater than the e.m.f. of the cell to be determined.
Reason : The fall of potential across the potentiometer wire should not be less than the e.m.f. of the cell to be determined.

Q.26 **Assertion :** A potentiometer of longer length is used for accurate measurement.
Reason : The potential gradient for a potentiometer of longer length with a given source of e.m.f. becomes small.

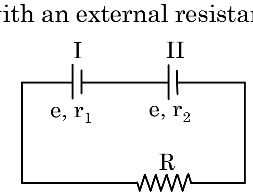
Part-C : Column Matching type Questions

Q.27 A circuit is shown in figure R is a nonzero variable but finite resistance. e is some unknown emf with polarities as shown. Match the columns.



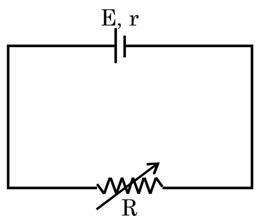
Column-I	**Column-II**
(A) Current passing through 4Ω resistance can be zero.	(P) possible if e = 6V
(B) Current passing through 4Ω resistance can be from F to C.	(Q) possible if e > 6 V
(C) Current passing through 4Ω resistance can be from C to F.	(R) possible if e < 6 V
(D) Current passing through 2Ω resistance will be from B to A.	(S) possible for any value of e from zero to infinity

Q.28 Two cells of the same emf 'e' but different internal resistances, r_1 & r_2 are connected in series with an external resistance R.



Column I	Column II
(A) value of current through R	(P) potential drop across second cell is zero
(B) when external resistance R is $r_1 - r_2$	(Q) $\dfrac{2e}{R + r_1 + r_2}$
(C) when external resistance R is $r_1 + r_2$	(R) potential drop across first cell is zero
(D) when external resistance R is $r_2 - r_1$	(S) maximum power output across resistance R

Q.29 Referring to the circuit shown in figure for different values of R effect on various things are given in column-I. Then match Column-I with Column-II.

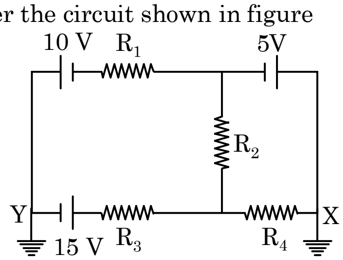


Column I	Column II
(A) Terminal potential difference across the cell will be maximum	(P) r > R
(B) Power transferred to resistance R is less than the maximum possible	(Q) r < R
(C) Power dissipated in the cell is maximum	(R) R = ∞
(D) Fastest drift of ions in the electrolyte in the cell will be for	(S) R = 0

Part-D : Passage based objective questions

Passage # 1 (Q.30 to 32)

Consider the circuit shown in figure



Q.30 Current through R_2 is zero if $R_4 = 2\Omega$ and $R_3 = 4\Omega$. In this case -
(A) current through R_3 = 2.5 A
(B) current through R_4 = 3A
(C) both (a) and (b) are correct
(D) both (a) and (b) are wrong

Q.31 Assuming $R_1 = 2\Omega$, current passing through resistance R_1 is -
(A) 2A (B) 2.5 A (C) 3.5 A (D) zero

Q.32 Assuming $R_1 = 2\Omega = R_4$, $R_3 = 4\Omega$, current passing through the circuit if resistance R_2 is removed is (remove ground connection at point X)
(A) 2A (B) 3A (C) 1A (D) 2.5A

Passage # 2 (Q. 33 to 37)

In the laboratory, the voltage across a particular circuit element can be measured by a voltmeter. A voltmeter has a very high resistance and should be connected in parallel to the circuit element whose voltage is being measured. Connected improperly, the voltmeter will affect the circuit, interrupting it and preventing current from flowing through the circuit element that it is meant to measure.

An experiment is conducted in which a voltmeter is used to investigate voltages in a circuit containing a capacitor and a light bulb. The bulb and the capacitor are connected in series with a battery and the voltmeter is placed in different positions : in the first case across the capacitor, in the second case across the light bulb, and in the third case across the battery (see figure 1). The voltmeter reading is recorded every 10 seconds. The voltage for Case 1 as a function of time is shown in figure 2.

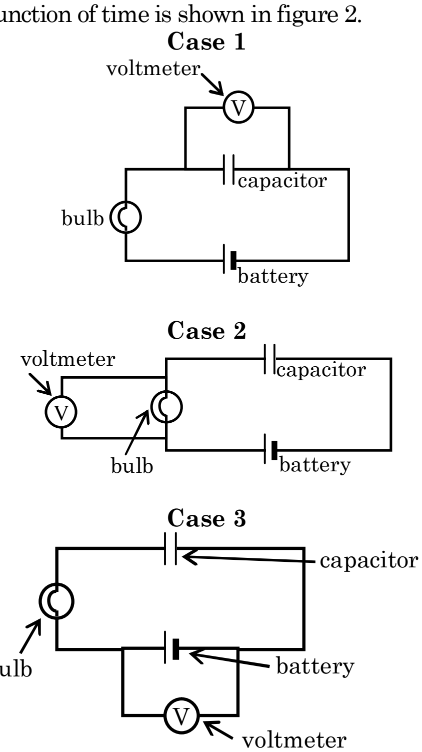


Figure – 1

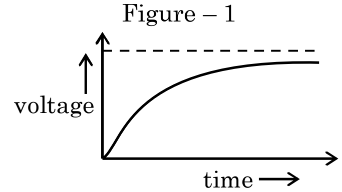


Figure – 2

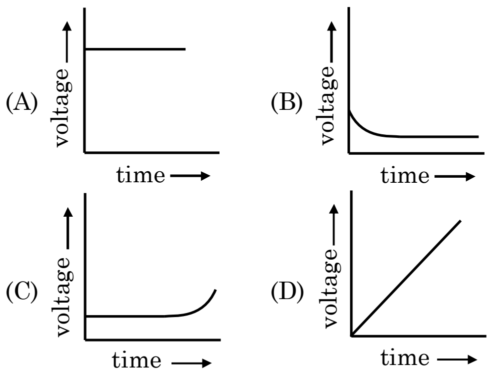
(**Note :** Assume that the battery has no internal resistance and that the resistance of the light bulb is constant)

Q.33 In the circuit shown in figure 1, which of the following conditions would indicate that the capacitor was fully charged –

I. A voltmeter connected across the capacitor reads a constant voltage.
II. The light bulb in the circuit stops shining.
III. The voltage across the bulb equals the voltage across the battery

(A) I only (B) III only
(C) I and II only (D) I, II, and III

Q.34 Which one of the following graphs could correctly represent the voltage across the battery as a function of time during the experiment described in the passage ?



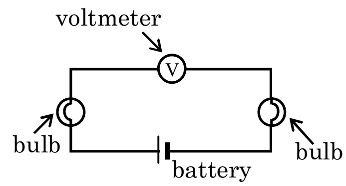
Q.35 How will the voltage across the light bulb vary with time as the capacitor is charging–

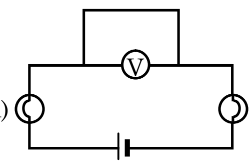
(A) It will decrease, because as the capacitor plates fill with charge, they will impede further charge, which will decrease the current and the voltage across the bulb
(B) It will remain the same, because as the capacitor plates fill with charge and impede the current, the voltage output of the battery will increase to keep the current constant
(C) It will increase, because as the capacitor plates fill with charge, they will induce further charge, which will create a greater voltage across the bulb
(D) It will increase, because as the capacitor plates fill with charge, the voltage across the capacitor will decrease, and therefore the voltage across the light bulb will increase

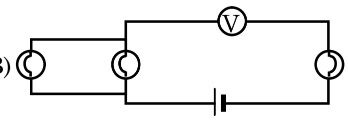
Q.36 The light bulb shown in figure 1 is replaced first with two identical resistors in series, and then with the same two resistors in parallel. The total time taken for the capacitor to charge is measured in both cases, and found to be longer for the first case. It can be deduced that –

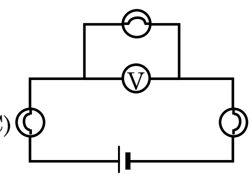
(A) When the resistance of the circuit is increased, the capacitance of the capacitor increases
(B) the presence of resistors affects the final voltage across the capacitor plates
(C) more charge is absorbed by the resistors as the resistance of the circuit increases
(D) the presence of resistors hinders the flow of charge, thus reducing the current in the circuit

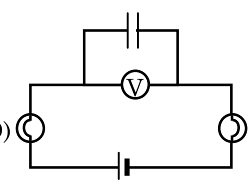
Q.37 In the diagram below, a voltmeter is connected in series to a circuit that includes a battery and two bulbs in series. The bulbs, which had been shining in the absence of the voltmeter immediately stop shining. How might the circuit be modified in order to make the bulbs shine steadily again with their former brilliance without removing the voltmeter ?



(A)


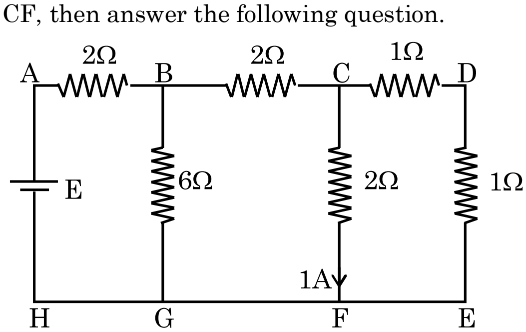
(B)


(C)


(D)


Passage # 3 (Q.38 to 40)

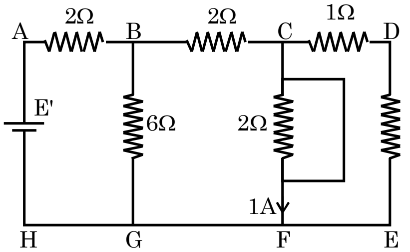
Figure shows a network of resistors and a battery. If 1A current flows through the branch CF, then answer the following question.



Q.38 The current through –

(A) Branch DE is 1A
(B) Branch BC is 2A
(C) Branch BG is 4A
(D) A & B both

Q.39 In the above circuit if a zero resistance wire is connected in parallel to branch CF. Then the current through -



(A) Branch DE is 0.5A (B) Branch BC is 1A
(C) Branch BG is 0.5A (D)Branch AB is1.5A

Q.40 The emf E' of the battery in the **question 39.**

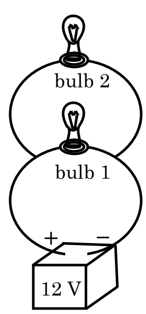
(A) 9 V (B) 12 V (C) $\frac{14}{3}$ V (D) 16 V

Passage # 4 (Q.41 to 43)

A 12-volt battery is connected to two light bulbs as drawn in fig. I light bulb 1 has resistance 3 ohms, while light bulb 2 has resistance 6 ohms. The battery has essentially no internal resistance, and all the wires are essentially resistanceless, too.

When a light bulb is unscrewed, no current flows through that branch of the circuit. For instance, if light bulb 2 is unscrewed, current flows only around the lower loop of the circuit, which consists of the battery and light bulb 1. The more current flows through a light bulb, their equivalent resistance is $R_{eq} = R_1 + R_2$. By contrast, when two resistors are wired in parallel, their net resistance is given by.

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$



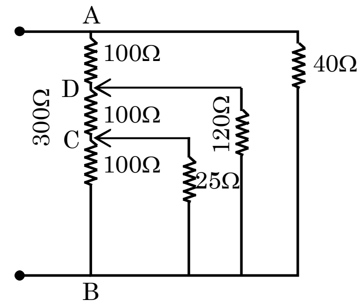
Q.41 With only light bulb 1 screwed in, a 12-volt battery goes dead in 24 days. With both light bulbs screwed in, a 12-volt battery goes dead in
(A) 12 days (B) 14 days
(C) 16 days (D) 18 days

Q.42 Bulb 2 is now screwed in As a result, bulb 1
(A) turns off
(B) becomes dimmed
(C) stays about the same brightness
(D) becomes brighter

Q.43 With both light bulbs screwed in, the current through the battery is
(A) 1.2 amperes (B) 2 amperes
(C) 4 amperes (D) 6 amperes

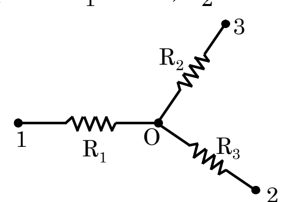
Part-E : Numerical Response/Subjective Type Qs.

Q.44 A long resistor between A and B as shown in fig. has resistance of 300 Ω and is tapped at one-third points.

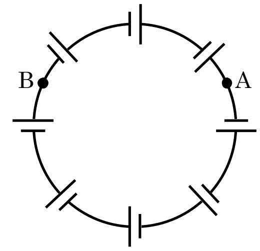


(a) What is the equivalent resistance between points A and B ?
(b) If the p.d. between A and B is 320 V, what will be the p.d. between B and C ?
(c) Will the answer of part (b) change if the 40Ω resistor is disconnected ?

Q.45 Find the value of n if current flowing through the resistance R_1 of the circuit shown in fig is n × 10^{-1} if the resistance are equal to R_1 = 10 Ω, R_2 = 20 Ω and R_3 = 30 Ω and potentials of points 1, 2 and 3 are equal to V_1 = 10 V, V_2 = 6 V and V_3 = 5 V.



Q.46(a) N sources of current with different emf's are connected as shown in fig. The emfs of the sources are proportional to their internal resistances, i.e. E = αR, where α is an assigned constant. The lead wire resistance is negligible, find:

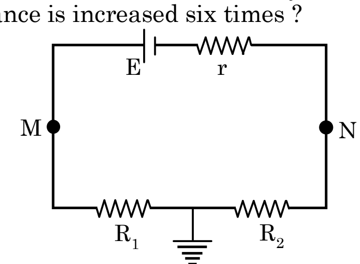


(i) the current in the circuit;
(ii) the potential difference between points A and B dividing the circuit in n and N - n links.

(b) The internal resistance of an accumulator battery of emf 6 V is 10 Ω when it is fully discharged. As the battery gets charged up, its internal resistance decreases to 1 Ω. The battery in its completely discharged state is connected to a charger which maintains a constant potential difference of 9 V. Find the current through the battery (a) just after the connections are made and (b) after a long time when it is completely charged.

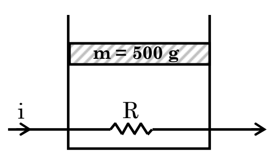
Q.47(a) In the given figure, calculate the potential of the points M and N if $E = 12V$, $R_1 = 3\Omega$, $R_2 = 2\Omega$ and $r = 1\Omega$.

(b) The efficiency of a cell whose internal resistance is 1Ω when connected to a external resistance R is 60%. What will be its efficiency if the external resistance is increased six times ?



Q.48 An electric kettle used to prepare tea, takes 2 minutes to boil 4 cups of water (1 cup contains 200 cc of water) if the room temperature is 25°C. (a) If the cost of power consumption is Rs. 1.00 per unit (1 unit = 1000 watt-hour), calculate the cost of boiling 4 cups of water. (b) What will be the corresponding cost if the room temperature drops to 5°C ?

Q.49 A resistance coil, connected to an external battery, is placed inside an adiabatic cylinder fitted with a frictionless piston and containing an ideal gas. A current i = 2A flows through the coil, which has a resistance R = 10Ω. At what speed v (in m/s) must the piston move upward in order that the temperature of the gas may remain unchanged. (Assume atmosphere pressure is to be zero). $g = 10\ m/s^2$



Q.50 There are several cells each of e.m.f. 2V and internal resistance 0.5 Ω. It is desired to obtain a maximum current of 8 A from their combination in an external resistance of 5 Ω.

(a) Calculate the minimum no. of cells required for this purpose, and

(b) How they should be grouped.

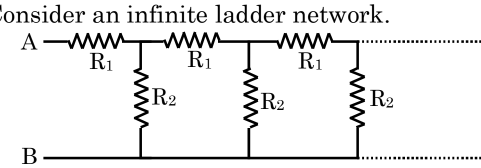
Q.51(a) A conductor has a temperature-independent resistance R and a total heat capacity C. At the moment t = 0 it is connected to a dc voltage V. Find the time dependence of the conductor's temperature T, assuming the thermal power dissipated into surrounding space to vary as $q = K(T - T_0)$, where K is a constant, T_0 is the environmental temperature (equal to the conductors temperature at the initial moment).

(b) A resistance R carries a current I. At steady state the rate of heat loss to the surroundings is $\lambda (T - T_0)$ where λ is a constant. T is the temperature of the resistance and T_0 is the temperature of the atmosphere. If the coefficient of linear expansion is α, then find strain in the resistance at steady state.

(strain = $\dfrac{\text{change in length}}{\text{original length}}$)

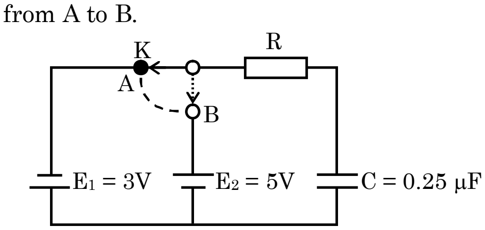
Q.52 A battery consists of twelve cells in series, each cell having an e.m.f. E and internal resistance. Some of the cells in the battery are connected with wrong polarity. This battery is connected to another source of e.m.f. 2E and internal resistance 2r. An ammeter in the circuit reads 3 amp when battery and the source aid each other and
2 amp in the same direction when they oppose each other. Find how many cells in the battery are connected with wrong polarity.

Q.53 Consider an infinite ladder network.

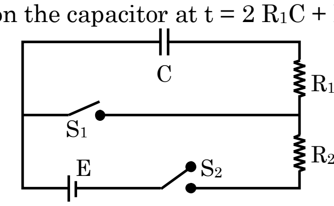


A voltage is applied between points A & B. If the voltage is halved after each section. Find the ratio R_2/R_1.

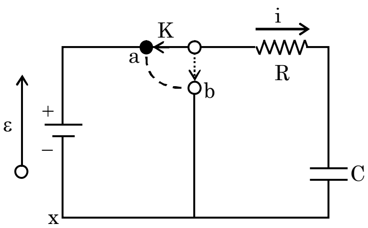
Q.54 Two batteries of emf E_1 and E_2 a capacitor of capacitance C, and a resistor of resistance R are connected in a circuit as shown in Fig. Determine the amount of heat Q (in μJ) liberated in the resistor after shifting the key K from A to B.



Q.55 The capacitor shown in fig. has been charged to a p.d. of V volt so that it carries a charge CV with both the switches S_1 and S_2 remaining open. Switch S_1 is closed at t = 0. At $t = R_1C$, switch S_1 is opened and S_2 is closed. Find the charge on the capacitor at $t = 2R_1C + R_2C$.



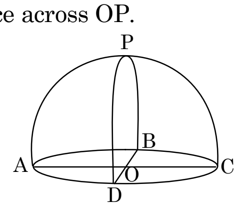
Q.56 If key K is shifted from a to b then after how many time constants will the energy stored in the capacitor in Fig. reach $\frac{1}{e^4}$ times of its equilibrium value ?



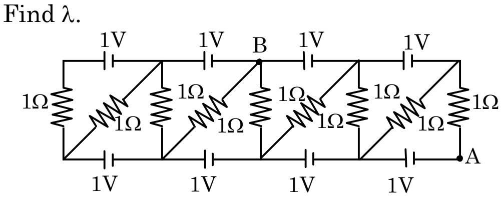
Q.57 A voltmeter coil has resistance 50.0 Ω and a resistor of 1.15 kΩ is connected in series. It can read potential differences upto 12 volts. If this same coil is used to construct an ammeter which can measure currents upto 260 mA, what should be the resistance of the shunt used ? If it is 0.5 × n. Find n.

Q.58 A voltmeter of resistance R_V and an ammeter of resistance R_A are connected in series across a battery of emf E and of negligible internal resistance. When a resistance R is connected in parallel to voltmeter, reading of ammeter increases to three times while that of voltmeter reduces to one-third. If $R_V = \lambda R_A$. Find value of λ.

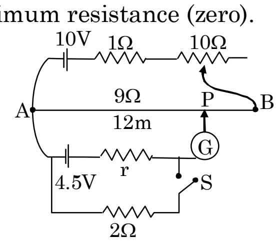
Q.59 A hemisphere network of radius a = 2 cm is made by using a conducting wire of resistance per unit length r = 0.8 Ω/cm. Find the equivalent resistance across OP.



Q.60 Potential difference $V_B - V_A$ for the circuit shown in the figure, is given by $\frac{22}{3\lambda}$ V. Find λ.



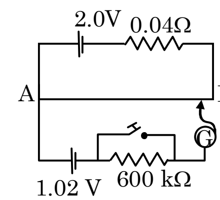
Q.61 In the primary circuit of potentiometer the rheostat can be varied from 0 to 10 Ω. Initially it is at minimum resistance (zero).



(a) Find the length AP of the wire such that the galvanometer shows zero deflection.

(b) Now the rheostat is put at maximum resistance (10 Ω) and the switch S is closed. New balancing length is found to 8 m. Find the internal resistance r of the 4.5V cell.

Q.62 Figure shows a potentiometer with a cell of emf 2.0 V and internal resistance 0.04 Ω maintaining a potential drop across the resistor wire AB. A standard cell which maintains a constant emf of 1.02 V (for very moderate currents up to a few ampere) gives a balance point of 67.3 cm length of the wire. To ensure very low currents drawn from the standard cell, a very high resistance of 600 kΩ is put is series with it which is shorted close to the balance point. The standard cell is then replaced by a cell of unknown emf E and the balance point found similarly turns out to be at 82.3 cm length of the wire.



(a) What is the value of E

(b) What purpose does the high resistance of 600 kΩ have?

(c) Is the balance point affected by this high resistance?

(d) Is the balance point affected by internal resistance of the driver cell?

(e) Would the method work in the above situation if the driver cell of the potentiometer had an emf of 1.0V instead of 2.0 V ?

Q.63 A resistor R placed in a circuit in series with the other resistor totaling 50 Ω alters the current in the circuit by 0.5 Ampere. When it is placed in parallel with the other resistors, the current alters by 1 amp, find the value of R.

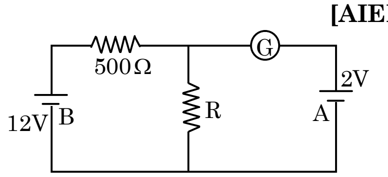
Q.64 A total charge Q flows across a resistor R during a time interval = T in such a way that the current versus time graph for 0 → T is like the loop of a sin curve in the range 0 → π. Find the total heat generated in the resistor.

EXERCISE (Level-4)
Old Examination Questions

Section-A [JEE Main]

Q.1 A moving coil galvanometer has 150 equal divisions. Its current sensitivity is 10 divisions per milliampere and voltage sensitivity is 2 divisions per millivolt. In order that each division reads 1 volt, the resistance in ohms needed to be connected in series with the coil will be - **[AIEEE-2005]**
(A) 10^3 (B) 10^5 (C) 99995 (D) 9995

Q.2 In the circuit, the galvanometer G shows zero deflection. If the batteries A and B have negligible internal resistance, the value of the resistor R will be- **[AIEEE-2005]**



(A) 200 Ω (B) 100 Ω (C) 500 Ω (D) 1000 Ω

Q.3 Two sources of equal emf are connected to an external resistance R. The internal resistances of the two sources are R_1 and R_2($R_2 > R_1$). If the potential difference across the source having internal resistance R_2 is zero, then - **[AIEEE-2005]**
(A) $R = R_2 \times (R_1 + R_2)/(R_2 - R_1)$
(B) $R = R_2 - R_1$
(C) $R = R_1R_2/(R_1 + R_2)$
(D) $R = R_1R_2/(R_2 - R_1)$

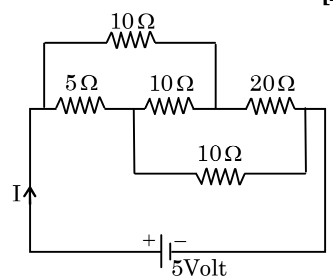
Q.4 An energy source will supply a constant current into the load if its internal resistance is - **[AIEEE-2005]**
(A) equal to the resistance of the load
(B) very large as compared to the load resistance
(C) zero
(D) non-zero but less than the resistance of the load

Q.5 In a potentiometer experiment the balancing with a cell is at length 240 cm. On shunting the cell with a resistance of 2 Ω, the balancing length becomes 120 cm. The internal resistance of the cell is - **[AIEEE-2005]**
(A) 1 Ω (B) 0.5 Ω (C) 4 Ω (D) 2 Ω

Q.6 A material 'B' has twice the specific resistance of 'A'. A circular wire made of 'B' has twice the diameter of a wire made of 'A'. Then for the two wires to have the same resistance, the ratio ℓ_B/ℓ_A of their respective lengths must be - **[AIEEE-2006]**
(A) $\frac{1}{4}$ (B) 2 (C) 1 (D) $\frac{1}{2}$

Q.7 The Kirchhoff's first law ($\sum i = 0$) and second law ($\sum iR = \sum E$), where the symbols have usual meanings, are respectively based on - **[AIEEE-2006]**
(A) conservation of momentum, conservation of charge
(B) conservation of charge, conservation of energy
(C) conservation of charge, conservation of momentum
(D) conservation of energy, conservation of charge

Q.8 The current I drawn from the 5 volt source will be – **[AIEEE-2006]**



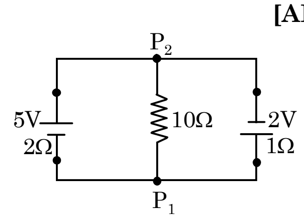
(A) 0.67 A (B) 0.17 A (C) 0.33 A (D) 0.5 A

Q.9 In a Wheatstone's bridge, three resistances P, Q and R are connected in the three arms and the fourth arm is formed by two resistances S_1 and S_2 connected in parallel. The condition for the bridge to be balance will be - **[AIEEE-2006]**
(A) $\frac{P}{Q} = \frac{R(S_1 + S_2)}{2S_1S_2}$ (B) $\frac{P}{Q} = \frac{R}{S_1 + S_2}$
(C) $\frac{P}{Q} = \frac{2R}{S_1 + S_2}$ (D) $\frac{P}{Q} = \frac{R(S_1 + S_2)}{S_1S_2}$

Q.10 An electric bulb is rated 220 volt – 100 watt. The power consumed by it when operated on 110 volt will be- **[AIEEE-2006]**
(A) 25 watt (B) 50 watt
(C) 75 watt (D) 40 watt

Q.11 The resistance of wire is 5 ohm at 50ºC and 6 ohm at 100ºC. The resistance of the wire at 0ºC will be – **[AIEEE-2007]**
(A) 2 ohm (B) 1 ohm (C) 4 ohm (D) 3 ohm

Q.12 A 5 V battery with internal resistance 2 Ω and a 2V battery with internal resistance 1Ω are connected to a 10Ω resistor as shown in the figure. **[AIEEE-2008]**



The current in the 10 Ω resistor is -
(A) 0.03 A P_1 to P_2 (B) 0.03 A P_2 to P_1
(C) 0.27 A P_1 to P_2 (D) 0.27 A P_2 to P_1

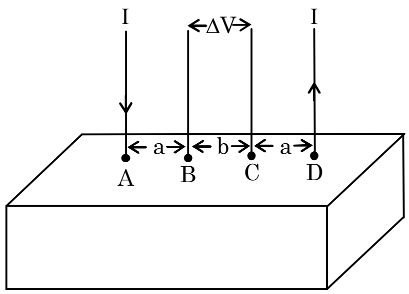
Passage : (Q.13 & 14)

Consider a block of conducting material of resistivity 'ρ' shown in the figure. Current 'I' enters at 'A' and leaves from 'D'. We apply superposition principle to find voltage 'ΔV' developed between 'B' and 'C'. The calculation is done in the following steps : **[AIEEE-2008]**

(i) Take current 'I' entering from 'A' and assume it to spread over a hemispherical surface in the block.

(ii) Calculate field E(r) at distance 'r' from A by using Ohm's law E = ρj, where j is the current per unit area at 'r'.

(iii) From the 'r' dependence of E(r), obtain the potential V(r) at r.



Q.13 For current entering at A, the electric field at a distance 'r' from A is -

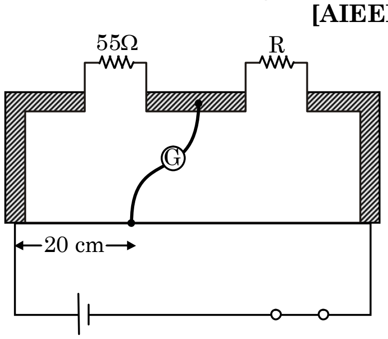
(A) $\frac{\rho I}{r^2}$ (B) $\frac{\rho I}{2\pi r^2}$ (C) $\frac{\rho I}{4\pi r^2}$ (D) $\frac{\rho I}{8\pi r^2}$

Q.14 ΔV measured between B and C is -

(A) $\frac{\rho I}{a} - \frac{\rho I}{(a+b)}$ (B) $\frac{\rho I}{2\pi a} - \frac{\rho I}{2\pi(a+b)}$

(C) $\frac{\rho I}{2\pi(a-b)}$ (D) $\frac{\rho I}{\pi a} - \frac{\rho I}{\pi(a+b)}$

Q.15 Shown in the figure below is a meter-bridge set up with null deflection in the galvanometer. **[AIEEE-2008]**



The value of the unknown resistor R is -

(A) 220 Ω (B) 110 Ω

(C) 55 Ω (D) 13.75 Ω

Q.16 **Statement-1:** The temperature dependence of resistance is usually given as $R = R_0(1 + \alpha\Delta t)$. The resistance of a wire changes from 100Ω to 150Ω when its temperature is increased from 27ºC to 227ºC. This implies that $\alpha = 2.5 \times 10^{-3}$/ºC.

Statement-2 : $R = R_0(1 + \alpha\Delta t)$ is valid only when the change in the temperature ΔT is small and $\Delta R = (R - R_0) << R_0$. **[AIEEE-2009]**

(A) Statement-1 is true, Statement-2 is true; Statement-2 is a correct explanation for Statement-1

(B) Statement-1 is true. Statement-2 is true; Statement-2 is not a correct explanation for Statement-1

(C) Statement-1 is true, Statement-2 is false.

(D) Statement-1 is false, Statement-2 is true.

Q.17 A resistance R and a capacitance C are connected in series to a battery of negligible internal resistance through a key. The key is closed at t = 0. If after t sec the voltage across the capacitance was seven times the voltage across R, the value of t is : **[JEE Main Online -2012]**

(A) 3 RC ℓn 7 (B) 3 RC ℓn 2

(C) 2 RC ℓn 2 (D) 2 RC ℓn 7

Q.18 Three resistance of 4Ω, 6Ω and 12 Ω are connected in parallel and the combination is connected in series with a 1.5 V battery of 1 Ω internal resistance. The rate of Joule heating in the 4 Ω resistor is : **[JEE Main Online -2012]**

(A) 0.86 W (B) 0.25 W (C) 0.33 W (D) 0.55 W

Q.19 Two electric bulbs marked 25 W - 220 V and 100 W - 220 V are connected in series to a 440 V supply. Which of the bulbs will fuse ? **[AIEEE-2012]**

(A) 100 W (B) 25 W

(C) neither (D) both

Q.20 The supply voltage to a room is 120 V. The resistance of the lead wires is 6Ω. 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 ? **[JEE-Main 2013]**

(A) 13.3 V (B) 10.04 V

(C) zero V (D) 2.9 V

Q.21 **Statement-I :** Higher the range, greater is the resistance of ammeter.

Statement-II : To increase the range of ammeter, additional shunt needs to be used across it. **[JEE-Main 2013]**

(A) If statement-I is true but statement-II is false.

(B) If statement-I is false but statement-II is true.

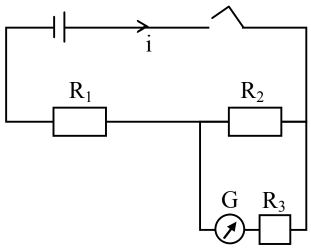
(C) If both statement-I and statement-II are true, and statement-II is the **correct** explanation of statement-I.

(D) If both statement-I and statement-II are true but statement-II is **not** the correct explanation of statement-I

Q.22 In a metre bridge experiment null point is obtained at 40 cm from one end of the wire when resistance X is balanced against another resistance Y. If X < Y, then the new position of the null point from the same end, if one decide to balance a resistance of 3X against Y, will be close to : **[JEE Main Online -2013]**

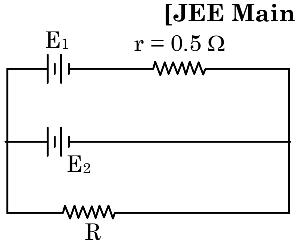
(A) 80 cm (B) 75 cm (C) 67 cm (D) 50 cm

Q.23 To find the resistance of a galvanometer by the half deflection method the following circuit is used with resistances $R_1 = 9970\ \Omega$, $R_2 = 30\ \Omega$ and $R_3 = 0$. The deflection in the galvanometer is d. With $R_3 = 107\ \Omega$ the deflection change to d/2. The galvanometer resistance is approximately-
[JEE Main Online-2013]



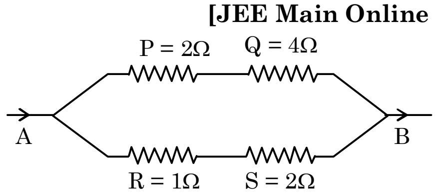
(A) 107 Ω (B) 137 Ω
(C) 107/2 Ω (D) 77 Ω

Q.24 A dc source of emf E_1 = 100 V and internal resistance r = 0.5 Ω, a storage battery of emf E_2 = 90 V and an external resistance R are connected as shown in figure. For what value of R no current will pass through battery -
[JEE Main Online -2013]



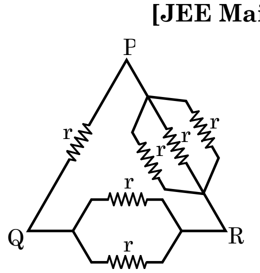
(A) 5.5 Ω (B) 3.5 Ω (C) 4.5 Ω (D) 2.5 Ω

Q.25 Which of the four resistances P, Q, R and S generate the greatest amount of heat when a current flows from A to B ?
[JEE Main Online -2013]



(A) Q (B) S (C) P (D) R

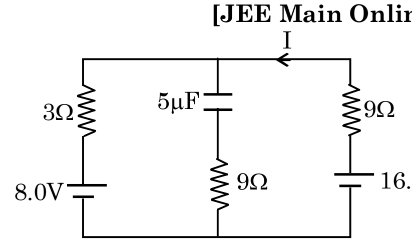
Q.26 Six equal resistance are connected between points P, Q and R as shown in figure. Then net resistance will be maximum between -
[JEE Main Online-2013]



(A) P and R (B) P and Q
(C) Q and R (D) Any two points

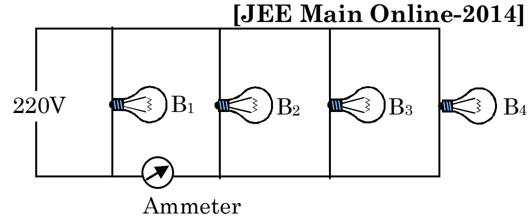
Q.27 A d.c. main supply of e.m.f 220 V is connected across a storage battery of e.m.f. 200 V through a resistance of 1 Ω. The battery terminals are connected to an external resistance 'R' .The minimum value of 'R', so that a current passes through the battery to charge it is :
[JEE Main Online-2014]
(A) 7 Ω (B) 9 Ω (C) 11 Ω (D) Zero

Q.28 The circuit shown here has two batteries of 8.0 V and 16.0 V and three resistors 3Ω, 9Ω and 9Ω and a capacitor 5.0 μF.
[JEE Main Online-2014]



How much is the current I in the circuit in steady state?
(A) 1.6 A (B) 0.67 A (C) 2.5 A (D) 0.25 A

Q.29 Four bulbs B_1, B_2, B_3 and B_4 of 100 W each are connected to 220V main as shown in the figure. The reading in an ideal ammeter will be :
[JEE Main Online-2014]

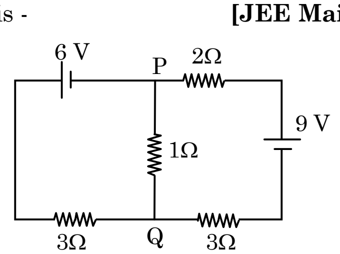


(A) 0.45 A (B) 0.90 A (C) 1.35 A (D) 1.80 A

Q.30 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 - **[JEE-Main 2014]**
(A) 10 A (B) 12 A (C) 14 A (D) 8 A

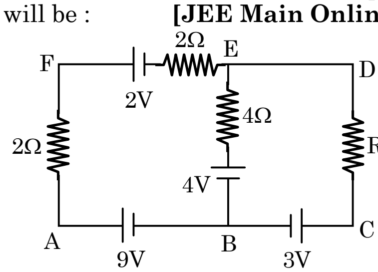
Q.31 When 5 V potential difference is applied across a wire of length 0.1 m, the drift speed of electrons is $2.5 \times 10^{-4}\ ms^{-1}$. If the electron density in the wire is $8 \times 10^{28}\ m^{-3}$, the resistivity of the material is close to –
[JEE Main -2015]
(A) $1.6 \times 10^{-8}\ \Omega m$ (B) $1.6 \times 10^{-7}\ \Omega m$
(C) $1.6 \times 10^{-6}\ \Omega m$ (D) $1.6 \times 10^{-5}\ \Omega m$

Q.32 In the circuit shown, the current in the 1 Ω resistor is - **[JEE Main -2015]**



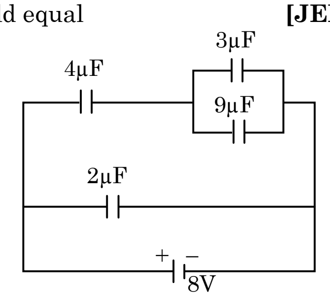
(A) 1.3 A, from P to Q (B) 0 A
(C) 0.13 A, from Q to P (D) 0.13 A, from P to Q

Q.33 In the electric network shown, when no current flows through the 4Ω resistor in the arm EB, the potential difference between the points A and D will be : **[JEE Main Online-2015]**



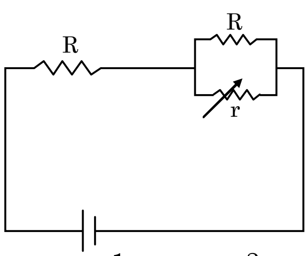
(A) 3 V (B) 5 V (C) 4 V (D) 6 V

Q.34 A combination of capacitors is set up as shown in the figure. The magnitude of the electric field, due to a point charge Q (having a charge equal to the sum of the charges on the 4 μF and 9 μF capacitors), at a point distant 30 m from it, would equal **[JEE Main-2016]**



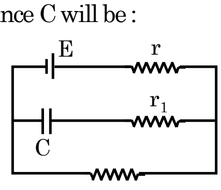
(A) 240 N/C (B) 360 N/C
(C) 420 N/C (D) 480 N/C

Q.35 In the circuit shown, the resistance r is a variable resistance. If for r = f R, the heat generation in r is maximum then the value of f is : **[JEE Main Online-2016]**



(A) $\frac{1}{4}$ (B) $\frac{1}{2}$ (C) $\frac{3}{4}$ (D) 1

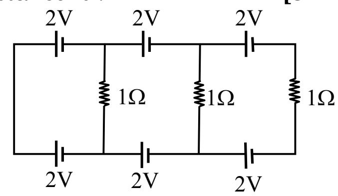
Q.36 In the given circuit diagram when the current reaches steady state in the circuit, the charge on the capacitor of capacitance C will be : **[JEE Main -2017]**



(A) CE (B) CE $\frac{r_1}{(r_2 + r)}$

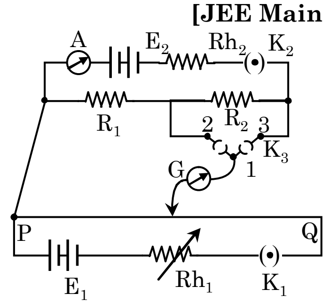
(C) CE $\frac{r_2}{(r + r_2)}$ (D) CE $\frac{r_1}{(r_1 + r)}$

Q.37 In the given circuit the current in each resistance is : **[JEE Main -2017]**



(A) 1A (B) 0.25 A (C) 0.5 A (D) 0 A

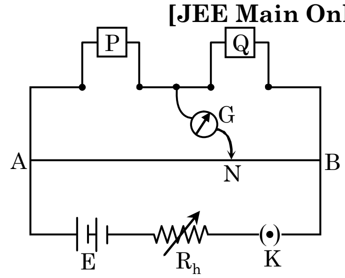
Q.38 A potentiometer PQ is set up to compare two resistances as shown in the figure. The ammeter A in the circuit reads 1.0 A when two way key K_3 is open. The balance point is at a length ℓ_1 cm from P when two way key K_3 is plugged in between 2 and 1, while the balance point is at a length ℓ_2 cm from P when key K_3 is plugged in between 3 and 1. The ratio of the two resistance $\frac{R_1}{R_2}$, is found to be - **[JEE Main Online-2017]**



(A) $\frac{\ell_1}{\ell_1 - \ell_2}$ (B) $\frac{\ell_2}{\ell_2 - \ell_1}$

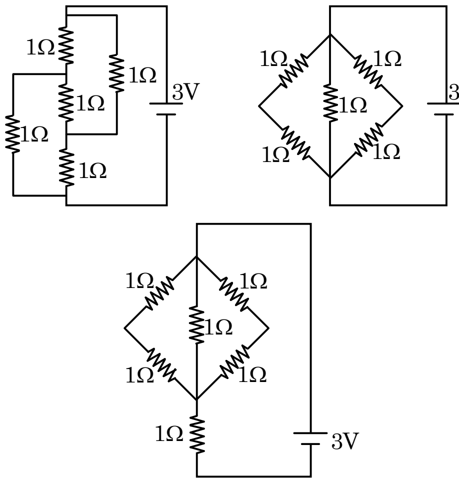
(C) $\frac{\ell_1}{\ell_1 + \ell_2}$ (D) $\frac{\ell_1}{\ell_2 - \ell_1}$

Q.39 In a meter bridge experiment resistances are connected as shown in the figure. Initially resistance $P = 4\Omega$ and the neutral point N is at 60 cm from A. Now an unknown resistance R is connected in series to P and the new position of the neutral point is at 80 cm from A. The value of unknown resistance R is - **[JEE Main Online-2017]**



(A) $\frac{33}{5}\Omega$ (B) $6\ \Omega$ (C) $\frac{20}{3}\Omega$ (D) $7\ \Omega$

Q.40 The figure shows three circuits I, II and III which are connected to a 3V battery. If the powers dissipated by the configuration I, II and III are P_1, P_2 and P_3 respectively, then – **[JEE Main Online-2017]**



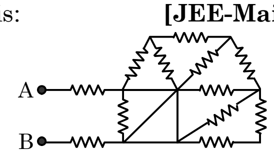
(A) $P_2 > P_1 > P_3$ (B) $P_1 > P_2 > P_3$
(C) $P_3 > P_2 > P_1$ (D) $P_1 > P_3 > P_2$

Q.41 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 : **[JEE Main - 2018]**
(A) 11.6 V and 11.7 V (B) 11.5 V and 11.6 V
(C) 11.4 V and 11.5 V (D) 11.7 V and 11.8 V

Q.42 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. **[JEE Main - 2018]**
(A) 1 Ω (B) 1.5 Ω (C) 2 Ω (D) 2.5 Ω

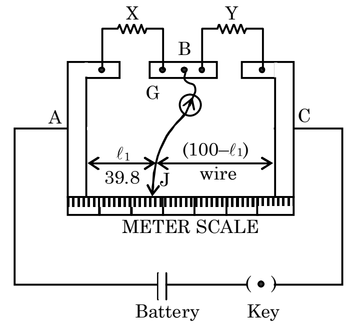
Q.43 On interchanging the resistances, the balance point of a meter bridge shifts to the left by 10 cm. The resistance of their series combination is 1 kΩ. How much was the resistance on the left slot before inter-changing the resistances ? **[JEE Main - 2018]**
(A) 990 Ω (B) 505 Ω (C) 550 Ω (D) 910 Ω

Q.44 In the given circuit all resistances are of value R ohm each. The equivalent resistance between A and B is: **[JEE-Main Online-2018]**



(A) 2 R (B) $\frac{5R}{2}$ (C) $\frac{5R}{3}$ (D) 3 R

Q.45 In a meter bridge, as shown in the figure, it is given that resistance Y=12.5 Ω and that the balance is obtained at a distance 39.5 cm from end A (by jockey J). After interchanging the resistances X and Y, a new balance point is found at a distance ℓ_2 from end A. What are the values of X and l_2 ? **[JEE-Main Online-2018]**



(A) 19.15 Ω and 39.5 cm (B) 8.16 Ω and 60.5 cm
(C) 19.15 Ω and 60.5 cm (D) 5.16 Ω and 39.5 cm

Q.46 A constant voltage is applied between two ends of metallic wire. If the length is halved and the radius of the wire is doubled, the rate of heat developed in the wire will be – **[JEE-Main Online-2018]**
(A) Increased 8 times (B) Doubled
(C) Halved (D) Unchanged

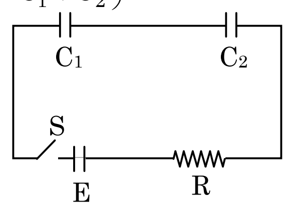
Q.47 A copper rod of cross-sectional area A carries a uniform current I through it. At temperature T, if the volume charge density of the rod is ρ, how long will the charges take to travel a distance d ? **[JEE-Main Online-2018]**

(A) $\frac{2\rho dA}{IT}$ (B) $\frac{2\rho dA}{I}$ (C) $\frac{\rho dA}{I}$ (D) $\frac{\rho dA}{IT}$

Q.48 A heating element has a resistance of 100Ω at room temperature. When it is connected to a supply of 220 V, a steady current of 2 A passes in it and temperature is 500ºC more than room temperature. What is the temperature coefficient of resistance of the heating element ? **[JEE-Main Online-2018]**
(A) 1×10^{-4} °C^{-1} (B) 5×10^{-4} °C^{-1}
(C) 2×10^{-4} °C^{-1} (D) 0.5×10^{-4} °C^{-1}

Q.49 In a circuit for finding the resistance of a galvanometer by half deflection method, a 6 V battery and high resistance of 11 kΩ are used. The figure of merit of the galvanometer 60μA/division. In the absence of shunt resistance, the galvanometer produces a deflection of θ = 9 divisions when current flows in the circuit. The value of the shunt resistance that can cause the deflection of θ/2, is closed to - **[JEE-Main Online-2018]**
(A) 55Ω (B) 110Ω (C) 220Ω (D) 550Ω

Q.50 In the following circuit, the switch S is closed at t = 0. The charge on the capacitor C_1 as a function of time will be given by $\left(C_{eq} = \frac{C_1C_2}{C_1 + C_2}\right)$ **[JEE-Main Online-2018]**



(A) $C_{eq}E[1 - \exp(-t/RC_{eq})]$ (B) $C_1E[1 - \exp(-tR/C_1)]$
(C) $C_2E[1 - ex(-t/RC_2)]$ (D) $C_{eq}E \exp(-t/RC_{eq})$

Q.51 A galvanometer with its coil resistance 25Ω requires at current of 1mA for its full deflection. In order to construct an ammeter to read up to a current of 2A, the approximate value of the shunt resistance should be- **[JEE-Main Online-2018]**

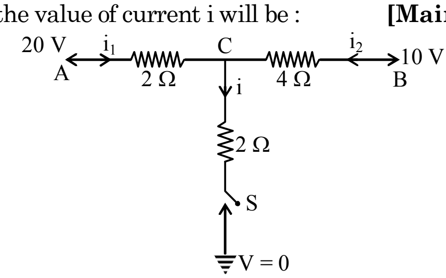
(A) $2.5 \times 10^{-2}\,\Omega$ (B) $1.25 \times 10^{-3}\,\Omega$

(C) $2.5 \times 10^{-3}\,\Omega$ (D) $1.25 \times 10^{-2}\,\Omega$

Q.52 Drift speed of electrons, when 1.5 A of current flows in a copper wire of cross section 5 mm^2, is v. If electron density in copper is $9 \times 10^{28}/m^3$ the value of v in mm/s is close to - (Take charge of electron to be = 1.6×10^{-19}C) **[Main-2019]**

(A) 0.02 (B) 0.2 (C) 3 (D) 2

Q.53 When the switch S, in circuit shown, is closed, then the value of current i will be : **[Main-2019]**



(A) 4 A (B) 5 A (C) 3 A (D) 2 A

Q.54 A copper wire is stretched to make it 0.5% longer. The percentage change in its electrical resistance if its volume remains unchanged is : **[Main-2019]**

(A) 0.5 % (B) 2.5 % (C) 2.0 % (D) 1.0 %

Q.55 A moving coil galvanometer, having a resistance G, produces full scale deflection when a current I_g flows through it. This galvanometer can be converted into (i) an ammeter of range 0 to $I_0(I_0 > I_g)$ by connecting a shunt resistance R_A to it and (ii) into a voltmeter of range 0 to V ($V = GI_0$) by connecting a series resistance R_V to it. Then, **[Main-2019]**

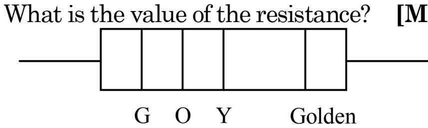
(A) $R_AR_V = G^2$ & $\frac{R_A}{R_V} = \frac{I_g}{(I_0 - I_g)}$

(B) $R_AR_V = G^2\left(\frac{I_g}{I_0 - I_g}\right)$ & $\frac{R_A}{R_V} = \left(\frac{I_0 - I_g}{I_g}\right)^2$

(C) $R_AR_V = G^2\left(\frac{I_0 - I_g}{I_g}\right)$ & $\frac{R_A}{R_V} = \left(\frac{I_g}{(I_0 - I_g)}\right)^2$

(D) $R_AR_V = G^2$ & $\frac{R_A}{R_V} = \left(\frac{I_g}{I_0 - I_g}\right)^2$

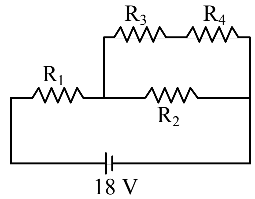
Q.56 A carbon resistance has a following colour code. What is the value of the resistance? **[Main-2019]**



(A) 5.3 MΩ ± 5% (B) 530 kΩ ± 5%

(C) 64 kΩ ± 10% (D) 6.4 MΩ ± 5%

Q.57 In the given circuit the internal resistance of the 18 V cell is negligible. If R_1 = 400 Ω, R_3 = 100 Ω and R_4 = 500 Ω and the reading of an ideal voltmeter across R_4 is 5 V, then the value of R_2 will be : **[Main-2019]**



(A) 550 Ω (B) 450 Ω (C) 230 Ω (D) 300 Ω

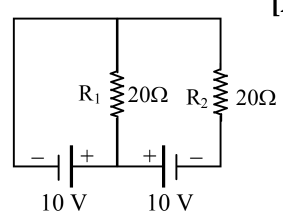
Q.58 A uniform metallic wire has a resistance of 18 Ω and is bent into an equilateral triangle. Then, the resistance between any two vertices of the triangle is – **[Main-2019]**

(A) 12 Ω (B) 2 Ω (C) 4 Ω (D) 8 Ω

Q.59 A 2 W carbon resistor is color coded with green, black, red and brown respectively. The maximum current which can be passed through this resistor is - **[Main-2019]**

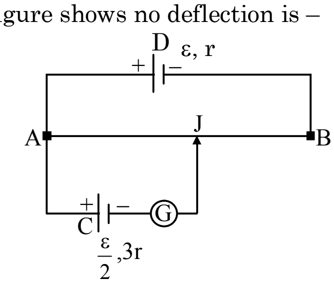
(A) 0.4 mA (B) 20 mA (C) 63 mA (D) 100 mA

Q.60 In the given circuit the cells have zero internal resistance. The currents (in Amperes) passing through resistance R_1 and R_2 respectively, are – **[Main-2019]**



(A) 0.5, 0 (B) 0, 1 (C) 1, 2 (D) 2, 2

Q.61 A potentiometer wire AB having length L and resistance 12 r is joined to a cell D of emf ε and internal resistance r. A cell C having emf ε/2 and internal resistance 3r is connected. The length AJ at which the galvanometer as shown in figure shows no deflection is – **[Main-2019]**



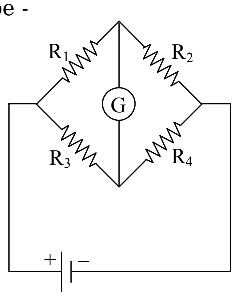
(A) $\frac{11}{12}L$ (B) $\frac{13}{24}L$

(C) $\frac{5}{12}L$ (D) $\frac{11}{24}L$

Q.62 A current of 2 mA was passed through an unknown resistor which dissipated a power of 4.4 W. Dissipated power when an ideal power supply of 11 V is connected across it is - **[Main-2019]**

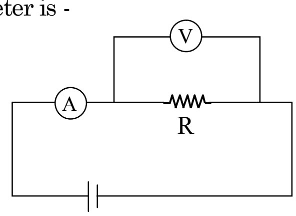
(A) 11×10^{-5} W (B) 11×10^{-3} W
(C) 11×10^{5} W (D) 11×10^{-4} W

Q.63 The Wheatstone bridge shown in figure, here, gets balanced when the carbon resistor used as R_1 has the colour code (Orange, Red, Brown). The resistors R_2 and R_4 are 80Ω and 40Ω, respectively. Assuming that the colour code for the carbon resistors gives their accurate values, the colour code for the carbon resistor, used as R_3, would be - **[Main-2019]**



(A) Brown, Blue, Brown (B) Grey, Black, Brown
(C) Red, Green, Brown (D) Brown, Blue, Black

Q.64 The actual value of resistance R, shown in the figure is 30Ω. This is measured in an experiment as shown using the standard formula $R = \frac{V}{I}$, where V and I are the readings of the voltmeter and ammeter, respectively. If the measured value of R is 5% less, then the internal resistance of the voltmeter is - **[Main-2019]**

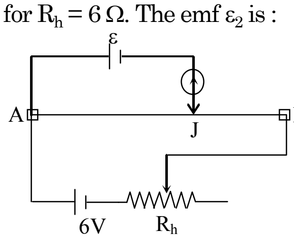


(A) 570 Ω (B) 600 Ω (C) 350 Ω (D) 35 Ω

Q.65 Two equal resistances when connected in series to a battery, consume electric power of 60 W. If these resistances are now connected in parallel combination to the same battery, the electric power consumed will be : **[Main-2019]**

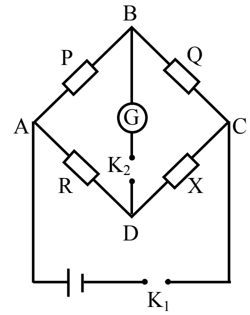
(A) 240 W (B) 60 W (C) 30 W (D) 120 W

Q.66 The resistance of the meter bridge AB in given figure is 4 Ω. With a cell of emf ε = 0.5 V and rheostat resistance R_h = 2 Ω the null point is obtained at some point J. When the cell is replaced by another one of emf $\varepsilon = \varepsilon_2$ the same null point J is found for R_h = 6 Ω. The emf ε_2 is : **[Main-2019]**



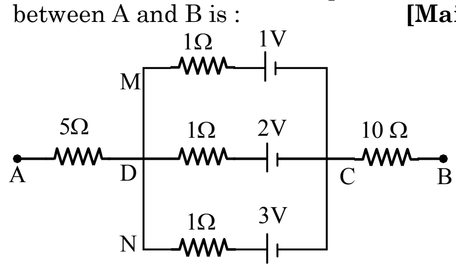
(A) 0.3 V (B) 0.6 V (C) 0.5 V (D) 0.4 V

Q.67 In a Wheatstone bridge(see fig.), Resistances P and Q are approximately equal. When R = 400 Ω, the bridge is balanced. On interchanging P and Q, the value of R, for balance, is 405 Ω. The value of X is close to: **[Main-2019]**



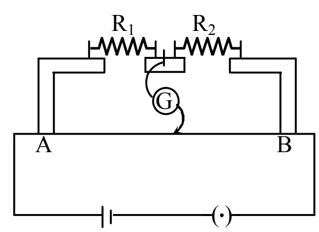
(A) 402.5 ohm (B) 401.5 ohm
(C) 403.5 ohm (D) 404.5 ohm

Q.68 In the circuit shown, the potential difference between A and B is : **[Main-2019]**



(A) 6 V (B) 3 V (C) 2 V (D) 1 V

Q.69 In the experimental set up of metre bridge shown in the figure, the null point is obtained at a distance of 40 cm from A. If a 10 Ω resistor is connected in series with R_1, the null point shifts by 10 cm. The resistance that should be connected in parallel with $(R_1 + 10)$ Ω such that the null point shifts back to its initial position is : **[Main-2019]**

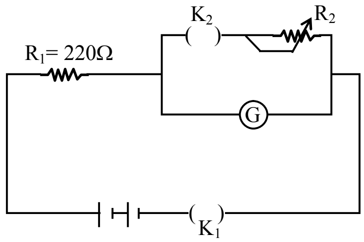


(A) 40 Ω (B) 30 Ω (C) 20 Ω (D) 60 Ω

Q.70 A galvanometer having a resistance of 20 Ω and 30 divisions on both sides has figure of merit 0.005 ampere/division. The resistance that should be connected in series such that it can be used as a voltmeter upto 15 volt, is : **[Main-2019]**

(A) 120 Ω (B) 125 Ω (C) 80 Ω (D) 100 Ω

Q.71 The galvanometer deflection, when key K_1 is closed but K_2 is open, equals θ_0 (see figure). On closing K_2 also and adjusting R_2 to 5Ω, the deflection in galvanometer becomes $\frac{\theta_0}{5}$. The resistance of the galvanometer is, then, given by [Neglect the internal resistance of battery] : **[Main-2019]**

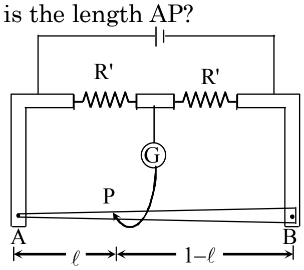


(A) 5 Ω (B) 25 Ω (C) 12 Ω (D) 22 Ω

Q.72 An ideal battery of 4 V and resistance R are connected in series in the primary circuit of a potentiometer of length 1 m and resistance 5 Ω. The value of R, to give a potential difference of 5 mV across 10 cm of potentiometer wire, is : **[Main-2019]**

(A) 480 Ω (B) 495 Ω (C) 490 Ω (D) 395 Ω

Q.73 In a meter bridge, the wire of length 1 m has a non-uniform cross-section such that, the variation $\frac{dR}{d\ell}$ of its resistance R with length ℓ is $\frac{dR}{d\ell} \propto \frac{1}{\sqrt{\ell}}$. Two equal resistances are connected as shown in the figure. The galvanometer has zero deflection when the jockey is at point P. What is the length AP? **[Main-2019]**



(A) 0.3 m (B) 0.25 m (C) 0.35 m (D) 0.2 m

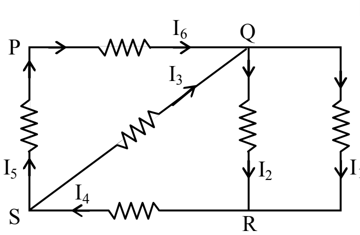
Q.74 Two electric bulbs, rated at (25 W, 220 V) and (100 W, 220 V), are connected in series across a 220 V voltage source. If the 25 W and 100 W bulbs draw powers P_1 and P_2 respectively, then : **[Main-2019]**

(A) P_1 = 4W, P_2 = 16 W (B) P_1 = 16W, P_2 = 4 W
(C) P_1 = 9W, P_2 = 16 W (D) P_1 = 16W, P_2 = 9 W

Q.75 A galvanometer, whose resistance is 50 ohm, has 25 divisions in it. When a current of 4×10^{-4} A passes through it, its needle (pointer) deflects by one division. To use this galvanometer as a voltmeter of range 2.5 V, it should be connected to a resistance of : **[Main-2019]**

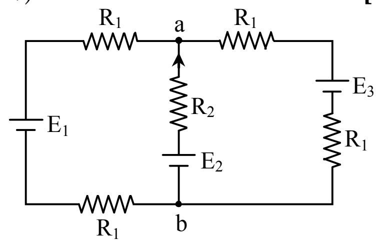
(A) 200 ohm (B) 250 ohm (C) 6200 ohm (D) 6250 ohm

Q.76 In the given circuit diagram, the currents, $I_1 = -0.3$ A, $I_4 = 0.8$ A and $I_5 = 0.4$ A, are flowing as shown. The currents I_2, I_3 and I_6, respectively, are : **[Main-2019]**



(A) 1.1 A, – 0.4 A, 0.4 A (B) – 0.4 A, 0.4 A, 1.1 A
(C) 0.4 A, 1.1 A, 0.4 A (D) 1.1 A, 0.4 A, 0.4 A

Q.77 For the circuit shown, with $R_1 = 1.0\ \Omega$, $R_2 = 2.0\ \Omega$, E_1 = 2V and $E_2 = E_3$ = 4V, the potential difference between the points 'a' and 'b' is approximately (in V) – **[Main-2019]**



(A) 3.7 (B) 2.7 (C) 2.3 (D) 3.3

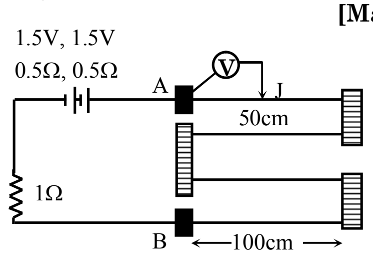
Q.78 A 200Ω resistor has a certain color code. If one replaces the red color by green in the code, the new resistance will be - **[Main-2019]**

(A) 100 Ω (B) 500 Ω (C) 400 Ω (D) 300 Ω

Q.79 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- **[Main-2019]**

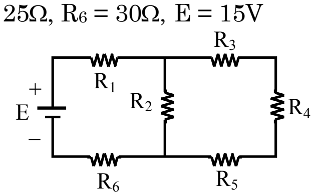
(A) R = 1000r (B) R = 0.001r
(C) R = 2r (D) R = r

Q.80 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 = 0.01Ω/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 - **[Main-2019]**



(A) 0.75 V (B) 0.25 V (C) 0.50 V (D) 0.20 V

Q.81 In the figure shown, what is the current (in Ampere) drawn from the battery? You are given – R_1 = 15Ω, R_2 = 10Ω, R_3 = 20Ω, R_4 = 5Ω, R_5 = 25Ω, R_6 = 30Ω, E = 15V **[Main-2019]**

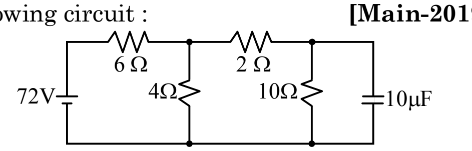


(A) 7/18 (B) 20/3 (C) 9/32 (D) 13/24

Q.82 A moving coil galvanometer has resistance 50Ω and it indicates full deflection at 4mA current. A voltmeter is made using this galvanometer and a 5kΩ resistance. The maximum voltage, that can be measured using this voltmeter, will be close to : **[Main-2019]**

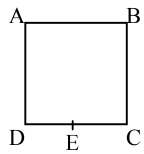
(A) 40 V (B) 10 V (C) 15 V (D) 20 V

Q.83 Determine the charge on the capacitor in the following circuit : **[Main-2019]**



(A) 200 μC (B) 10 μC (C) 60 μC (D) 2 μC

Q.84 A wire of resistance R is bent to form a square ABCD as shown in the figure. The effective resistance between E and C is : (E is mid-point of arm CD) **[Main-2019]**



(A) $\frac{3}{4}R$ (B) $\frac{1}{16}R$ (C) $\frac{7}{64}R$ (D) R

Q.85 One kg of water, at 20°C, heated in an electric kettle whose heating element has a mean (temperature averaged) resistance of 20 Ω. The rms voltage in the mains is 200 V. Ignoring heat loss from the kettle, time taken for water to evaporate fully, is close to :
[Specific heat of water = 4200 J/(kg °C), Latent heat of water = 2260 kJ/kg] **[Main-2019]**

(A) 10 minutes (B) 22 minutes
(C) 3 minutes (D) 16 minutes

Q.86 The resistance of a galvanometer is 50 ohm and the maximum current which can be passed though it is 0.002 A. What resistance must be connected to it in order to convert it into an ammeter of range 0–0.5 A ? **[Main-2019]**

(A) 0.2 ohm (B) 0.002 ohm
(C) 0.02 ohm (D) 0.5 ohm

Q.87 In a conductor, if the number of conduction electrons per unit volume is 8.5×10^{28} m^{-3} and mean free time is 25 *f*s (femto second), it's approximate resistivity is :
($m_e = 9.1 \times 10^{-31}$ kg) **[Main-2019]**

(A) 10^{-5} Ωm (B) 10^{-7} Ωm
(C) 10^{-8} Ωm (D) 10^{-6} Ωm

Q.88 A metal wire of resistance 3Ω is elongated to make a uniform wire of double its previous length. This new wire is now bent and the ends joined to make a circle. If two points on this circle make an angle 60° at the centre, the equivalent resistance between these two points will be : **[Main-2019]**

(A) $\frac{5}{2}\Omega$ (B) $\frac{5}{3}\Omega$ (C) $\frac{7}{2}\Omega$ (D) $\frac{12}{5}\Omega$

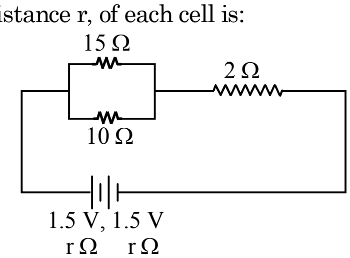
Q.89 A moving coil galvanometer allows a full scale current of 10^{-4} A. A series resistance of 2 MΩ is required to convert the above galvanometer into a voltmeter of range 0-5 V. Therefore the value of shunt resistance required to convert the above galvanometer into an ammeter of range 0-10 mA is : **[Main-2019]**

(A) 10 Ω (B) 500 Ω (C) 100 Ω (D) 200 Ω

Q.90 A current of 5 A passes through a copper conductor (resistivity = 1.7×10^{-8} Ωm) of radius of cross-section 5 mm. Find the mobility of the charges if their drift velocity is 1.1×10^{-3} m/s. **[Main-2019]**

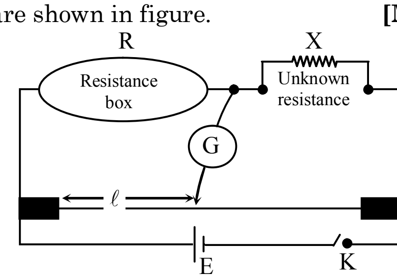
(A) 1.0 m^2/Vs (B) 1.8 m^2/Vs
(C) 1.5 m^2/Vs (D) 1.3 m^2/Vs

Q.91 In the given circuit, an ideal voltmeter connected across the 10 Ω resistance reads 2V. The internal resistance r, of each cell is: **[Main-2019]**



(A) 1 Ω (B) 0.5 Ω (C) 1.5 Ω (D) 0 Ω

Q.92 In a meter bridge experiment, the circuit diagram and the corresponding observation table are shown in figure. **[Main-2019]**

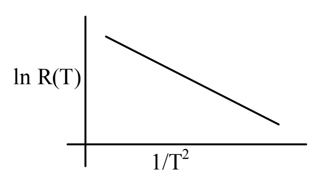


Sl. No.	R (Ω)	ℓ (cm)
1.	1000	60
2.	100	13
3.	10	1.5
4.	1	1.0

Which of the reading is inconsistent ?

(A) 3 (B) 4 (C) 2 (D) 1

Q.93 In an experiment, the resistance of a material is plotted as a function of temperature (in some range). As shown in the figure, it is a straight line. **[Main-2019]**



One may conclude that :

(A) $R(T) = R_0 e^{T^2/T_0^2}$ (B) $R(T) = \frac{R_0}{T^2}$

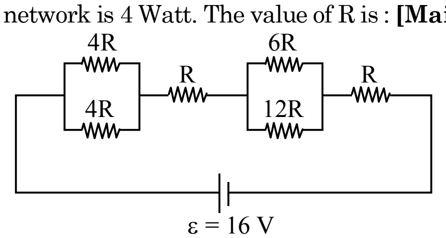
(C) $R(T) = R_0 e^{-T^2/T_0^2}$ (D) $R(T) = R_0 e^{-T_0^2/T^2}$

Q.94 Space between two concentric conducting spheres of radii a and b (b > a) is filled with a medium of resistivity ρ. The resistance between the two spheres will be - **[Main-2019]**

(A) $\frac{\rho}{2\pi}\left(\frac{1}{a}+\frac{1}{b}\right)$ (B) $\frac{\rho}{4\pi}\left(\frac{1}{a}+\frac{1}{b}\right)$

(C) $\frac{\rho}{2\pi}\left(\frac{1}{a}-\frac{1}{b}\right)$ (D) $\frac{\rho}{4\pi}\left(\frac{1}{a}-\frac{1}{b}\right)$

Q.95 The resistive network shown below is connected to a D.C. source of 16 V. The power consumed by the network is 4 Watt. The value of R is : **[Main-2019]**



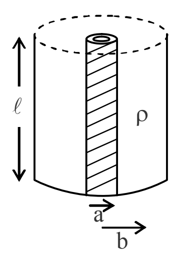
(A) 16 Ω (B) 1 Ω (C) 8 Ω (D) 6 Ω

Q.96 Consider four conducting materials copper, tungsten, mercury and aluminium with resistivity $\rho_C > \rho_T > \rho_M$ and ρ_A respectively. Then: **[JEE Main 2020]**

(A) $\rho_A > \rho_T > \rho_C$ (B) $\rho_C > \rho_A > \rho_T$

(C) $\rho_A > \rho_M > \rho_C$ (D) $\rho_M > \rho_A > \rho_C$

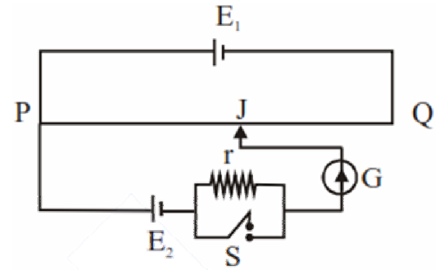
Q.97 Model a torch battery of length ℓ to be made up of a thin cylindrical bar of radius 'a' and a concentric thin cylindrical shell of radius 'b' filled in between with an electrolyte of resistivity ρ (see figure). If the battery is connected to a resistance of value R, the maximum Joule heating in R will take place for **[JEE Main 2020]**



(A) $R = \frac{2\rho}{\pi\ell}\ln\left(\frac{b}{a}\right)$ (B) $R = \frac{\rho}{\pi\ell}\ln\left(\frac{b}{a}\right)$

(C) $R = \frac{\rho}{2\pi\ell}\left(\frac{b}{a}\right)$ (D) $R = \frac{\rho}{2\pi\ell}\ln\left(\frac{b}{a}\right)$

Q.98 A potentiometer wire PQ of 1 m length is connected to a standard cell E_1. Another cell E_2 of emf 1.02 V is connected with a resistance 'r' and switch S (as shown in figure). With switch S open, the null position is obtained at a distance of 49 cm from Q. The potential gradient in the potentiometer wire is : **[JEE Main 2020]**



(A) 0.02 V/cm (B) 0.04 V/cm
(C) 0.01 V/cm (D) 0.03 V/cm

Q.99 Two resistors 400Ω and 800Ω are connected in series across a 6 V battery. The potential difference measured by a voltmeter of 10 kΩ across 400Ω resistor is close to : **[JEE Main 2020]**

(A) 2.05 V (B) 1.95 V (C) 2 V (D) 1.8 V

Q.100 A current through a wire depends on time $= \alpha_0 t + \beta t^2$ where α = 20 A/s and β = 8 As^{-2}. Find the charge crossed through a section of the wire in 15 s. **[JEE MAIN 2021]**

(A) 2250 C (B) 11250 C
(C) 2100 C (D) 260 C

Q.101 A wire of 1Ω has a length of 1m. It is stretched till its length increases by 25%. The percentage change in resistance to the neartest integer is : **[JEE MAIN 2021]**

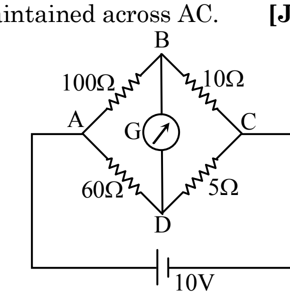
(A) 56% (B) 25% (C) 12.5% (D) 76%

Q.102 A conducting wire of length 'l', area of cross-section A and electric resistivity ρ is connected between the terminals of a battery. A potential difference V is developed between its ends, causing an electric current. If the length of the wire of the same material is doubled and the area of cross-section is halved, the resultant current would be : **[JEE MAIN 2021]**

(A) $\frac{1}{4}\frac{VA}{\rho\ell}$ (B) $\frac{3}{4}\frac{VA}{\rho\ell}$

(C) $\frac{1}{4}\frac{\rho\ell}{VA}$ (D) $4\frac{VA}{\rho\ell}$

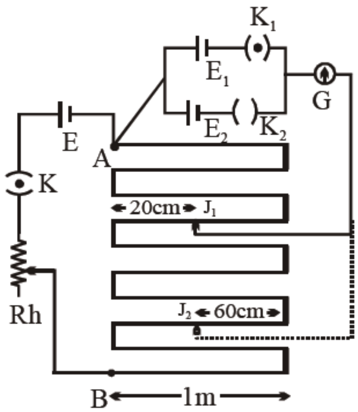
Q.103 The four arms of a Wheatstone bridge have resistance as shown in the figure. A galvanometer of 15 Ω resistance is connected across BD. Calculate the current through the galvanometer when a potential difference of 10 V is maintained across AC. **[JEE MAIN 2021]**



(A) 2.44 μA (B) 2.44 mA
(C) 4.87 mA (D) 4.87 μA

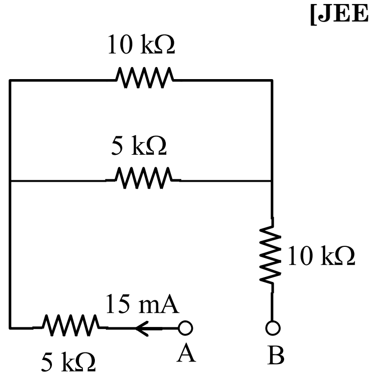
Q.104 In the given circuit of potentiometer, the potential difference E across AB (10 m length) is larger than E_1 and E_2 as well. For key K_1 (closed), the jockey is adjusted to touch the wire at point J_1 so that there is no deflection in the galvanometer. Now the first battery (E_1) is replaced by second battery (E_2) for working by making K_1 open and K_2 closed. The galvanometer gives then null deflection at J_2. The value of $\frac{E_1}{E_2}$ is $\frac{a}{b}$, where a = ______

[JEE MAIN 2021]



Q.105 A current of 15 mA flows in the circuit as shown in figure. The value of potential difference between the points A and B will be

[JEE Main 2022]



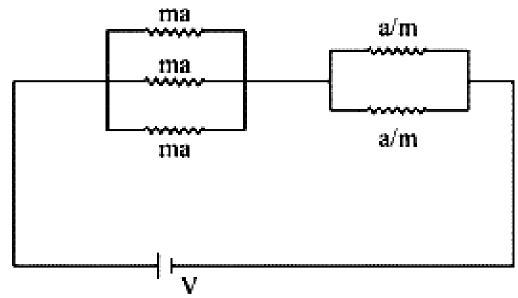
(A) 50 V (B) 75 V (C) 150 V (D) 275 V

Q.106 The current density in a cylindrical wire of radius r = 4.0 mm is 1.0×10^6 A/m^2. The current through the outer portion of the wire between radial distances $\frac{r}{2}$ and r is $x\pi$ A; where x is _________

[JEE Main 2022]

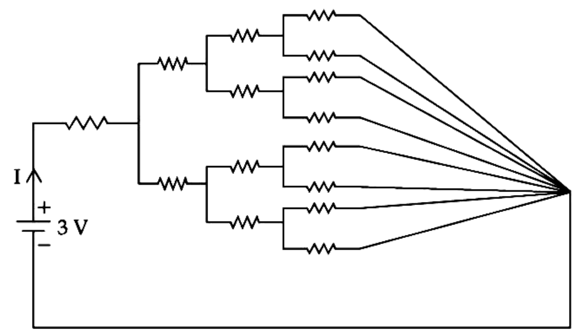
Q.107 In the given circuit 'a' is an arbitrary constant. The value of m for which the equivalent circuit resistance is minimum, will be $\sqrt{\frac{x}{2}}$. The value of x is ___________.

[JEE Main 2022]



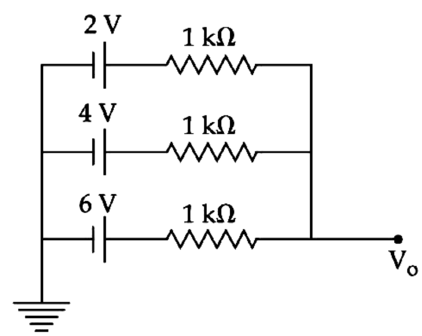
Q.108 All resistances in figure are 1 Ω each. The value of current 'I' is $\frac{a}{5}$ A. The value of a is ______

[JEE Main 2022]



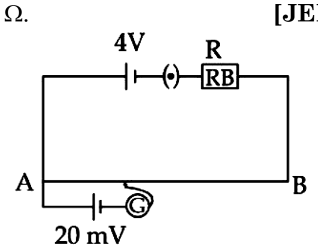
Q.109 In the given figure, the value of V_0 will be _________V.

[JEE Main 2022]



Q.110 As shown in the figure, a potentiometer wire of resistance 20 Ω and length 300 cm is connected with resistance box (R.B.) and a standard cell of emf 4 V. For a resistance 'R' of resistance box introduced into the circuit, the null point for a cell of 20 mV is found to be 60 cm. The value of 'R ' is Ω.

[JEE Main 2022]



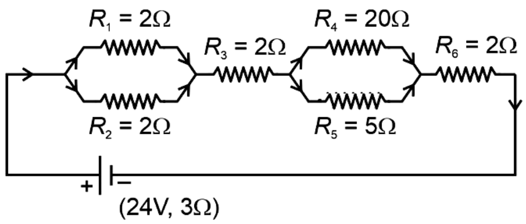
Q.111 An electrical bulb rated 220 V, 100 W, is connected in series with another bulb rated 220 V, 60 W. If the voltage across combination is 220 V, the power consumed by the 100 W bulb will be about ____ W. **[JEE Main 2022]**

Q.112 Equivalent resistance between the adjacent corners of a regular n-sided polygon of uniform wire of resistance R would be **[JEE Main 2023]**

(A) $\frac{(n-1)R}{(2n-1)}$ (B) $\frac{(n-1)R}{(n^2)}$

(C) $\frac{(n-1)R}{n}$ (D) $\frac{n^2R}{n-1}$

Q.113 As shown in the figure, a network of resistors is connected to a battery of 24V with an internal resistance of 3Ω. The currents through the resistors R_4 and R_5 are I_4 and I_5 respectively. The values of I_4 and I_5 are: **[JEE Main 2023]**



(A) $I_4 = \frac{8}{5}A$ and $I_5 = \frac{2}{5}A$

(B) $I_4 = \frac{24}{5}A$ and $I_5 = \frac{6}{5}A$

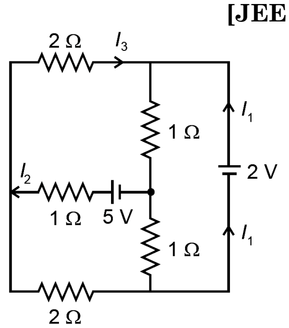
(C) $I_4 = \frac{2}{5}A$ and $I_5 = \frac{8}{5}A$

(D) $I_4 = \frac{6}{5}A$ and $I_5 = \frac{24}{5}A$

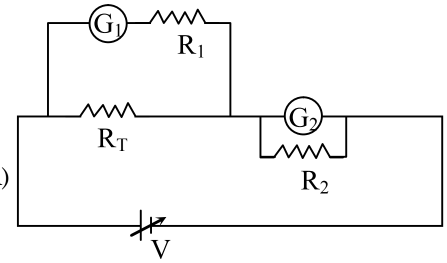
Q.114 A uniform metallic wire carries a current 2 A. When 3.4 V battery is connected across it. The mass of uniform metallic wire is 8.92×10^{-3} kg, density is 8.92×10^3 kg/m^3 and resistivity is 1.7×10^{-8} Ω–m. The length of wire is: **[JEE Main 2023]**

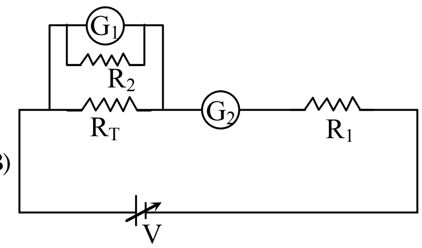
(A) $\ell = 100$ m (B) $\ell = 6.8$ m
(C) $\ell = 10$ m (D) $\ell = 5$ m

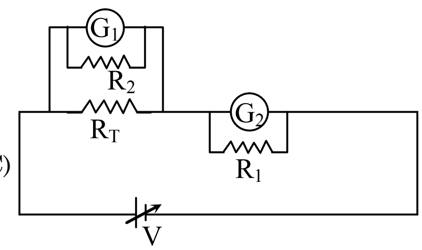
Q.115 In the following circuit, the magnitude of current I_1, is _______ A. **[JEE Main 2023]**

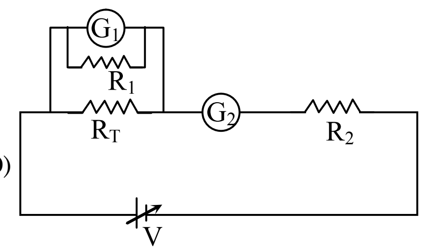


Q.116 A student is provided with a variable voltage source V, a test resistor $R_T = 10Ω$, two identical galvanometers G_1 and G_2 and two additional resistors, $R_1 = 10MΩ$ and $R_2 = 0.001$ Ω. For conducting an experiment to verify ohm's law, the most suitable circuit is : **[JEE Main 2023]**

(A)


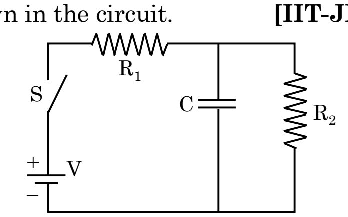
(B)


(C)


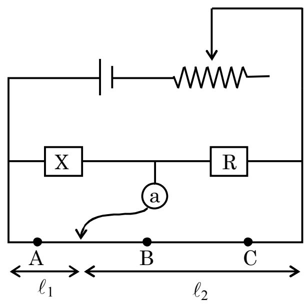
(D)


Section-B [JEE Advanced]

Q.1 In the given circuit the switch S is closed at time t = 0. The charge Q on the capacitor at any instant t is given by $Q(t) = Q_0(1 - e^{-\alpha t})$. Find the value of Q_0 and α in terms of given parameters as shown in the circuit. **[IIT-JEE 2005]**



Q.2 An unknown resistance is to be determined using resistance R_1, R_2, and R_3. If their corresponding null points are A, B and C. Which of the following will give most accurate reading ? **[IIT-JEE 2005]**



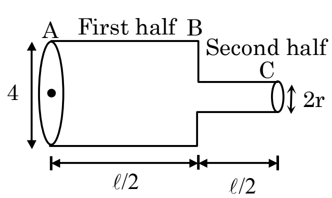
Q.3 A galvanometer having Resistance 100 Ω is used to form an ammeter with the help of resistance 0.1Ω. The maximum deflection of galvanometer is at 100 μA. Find the smallest current when Galvanometer shows maximum deflection- **[IIT-JEE 2005]**

(A) 100.1 mA (B) 1000.1 mA
(C) 10.01 mA (D) 1.001 mA

Q.4 A 4 μF capacitor, a resistance of 2.5 MΩ is in series with 12 V battery. Find the time after which the potential difference across the capacitor is 3 times the potential difference across the resistor
[Given ℓn (2) = 0.693] **[IIT-JEE 2005]**
(A) 13.86 s (B) 6.93 s (C) 7 s (D) 14 s

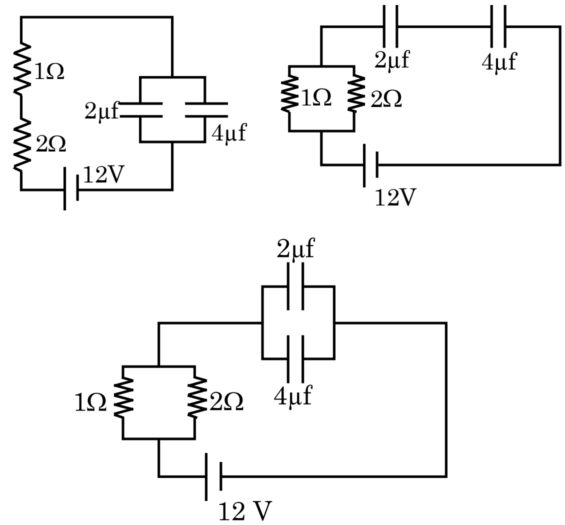
Q.5 An ideal gas is filled in a closed rigid and thermally insulated container. A coil of 100 Ω resistor carrying current 1A for 5 minutes supplies heat to the gas. The change in internal energy of the gas is - **[IIT-JEE 2005]**
(A) 10 kJ (B) 30 kJ (C) 20 kJ (D) 0 kJ

Q.6 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 - **[IIT-JEE 2006]**



(A) Power loss in second half is four times the power loss in first 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

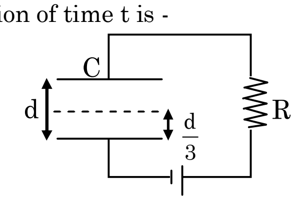
Q.7 Time constant for the given circuits are – **[IIT-JEE 2006]**



(A) 18 μs, $\frac{8}{9}$ μs, 4μs (B) 18 μs, 4 μs, $\frac{8}{9}$ μs

(C) 4μs, $\frac{8}{9}$ μs, 18 μs (D) $\frac{8}{9}$ μs, 18μs, 4μs

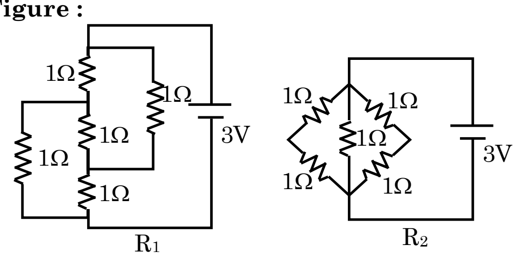
Q.8 A parallel plate capacitor C with plates of unit area and separation d is filled with a liquid of dielectric constant K = 2. The level of liquid is d/3 initially. Suppose the liquid level decreases at a constant speed V, the time constant as a function of time t is - **[IIT-JEE 2008]**

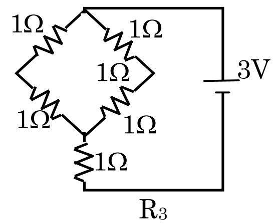


(A) $\dfrac{6\varepsilon_0 R}{5d + 3Vt}$ (B) $\dfrac{(15d + 9Vt)\varepsilon_0 R}{2d^2 - 3dVt - 9V^2t^2}$

(C) $\dfrac{6\varepsilon_0 R}{5d - 3Vt}$ (D) $\dfrac{(15d - 9Vt)\varepsilon_0 R}{2d^2 + 3dVt - 9V^2t^2}$

Q.9 Figure shows three resistor configurations R_1, R_2 and R_3 connected to 3V 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 **[IIT-JEE 2008]**
Figure :





(A) $P_1 > P_2 > P_3$ (B) $P_1 > P_3 > P_2$
(C) $P_2 > P_1 > P_3$ (D) $P_3 > P_2 > P_1$

Statement type Question : (Q.10 to 11)

(A) Statement-1 is True, Statement-2 is True; Statement-2 is a correct explanation for Statement-1
(B) Statement-1 is True, Statement-2 is True; Statement-2 is NOT a correct explanation for Statement-1
(C) Statement-1 is True, Statement-2 is False
(D) Statement-1 is False, Statement-2 is True

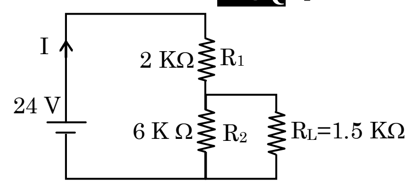
Q.10 **Statement-1 :** In a Meter Bridge experiment, null point for an unknown resistance is measured. Now, the unknown resistance is put inside an enclosure maintained at a higher temperature.
The null point can be obtained at the same point as before by decreasing the value of the standard resistance.
Statement-2 : Resistance of a metal increases with increase in temperature. **[IIT-JEE 2008]**

Q.11 **Statement-1 :** For practical purposes the earth is used as a reference at zero potential in electrical circuits.
Statement-2 : The electrical potential of a sphere of radius R with charge Q uniformly distributed on the surface is given by $\frac{Q}{4\pi\varepsilon_0 R}$. **[IIT-JEE 2008]**

Q.12 **Column II** gives certain systems undergoing a process. **Column I** suggests changes in some of the parameters related to the system. Match the statements in **Column I** to the appropriate process(es) from **Column II**. **[IIT-JEE 2009]**

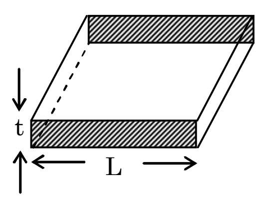
	Column I	Column II
(A)	The energy of the system is increased	(P) **System :** A capacitor, initially uncharged **Process :** it is connected to a battery
(B)	Mechanical energy is provided to the system, which is converted into energy of random motion of its parts	(Q) **System :** A gas in an adiabatic container fitted with an adiabatic piston. **Process :** The gas is compressed by pushing the piston
(C)	Internal energy of the system is converted into its mechanical energy	(R) **System :** A gas in a rigid container **Process :** The gas gets cooled due to colder atmosphere surrounding it
(D)	Mass of the system is decreased	(S) **System :** A heavy nucleus, initially at rest **Process :** The nucleus fissions into two fragments of nearly equal masses and some neutrons are emitted
		(T) **System :** A resistive wire loop **Process :** The loop is placed in a time varying magnetic field perpendicular to its plane

Q.13 For the circuit shown in the figure
MCQ **[IIT-JEE 2009]**



(A) the current I through the battery is 7.5 mA
(B) the potential difference across R_L is 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_1, will decrease by a factor of 9.

Q.14 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 – **[IIT-JEE 2010]**



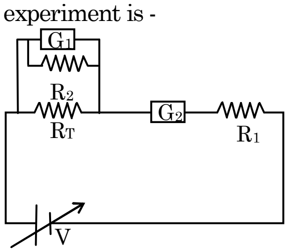
(A) directly proportional to L
(B) directly proportional to t
(C) independent of L
(D) independent of t

Q.15 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 R_{100}, R_{60} and R_{40}, respectively, the relation between these resistances is- **[IIT-JEE 2010]**

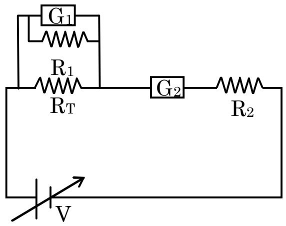
(A) $\frac{1}{R_{100}} = \frac{1}{R_{40}} + \frac{1}{R_{60}}$ (B) $R_{100} = R_{40} + R_{60}$
(C) $R_{100} > R_{60} > R_{40}$ (D) $\frac{1}{R_{100}} > \frac{1}{R_{60}} + \frac{1}{R_{40}}$

Q.16 To verify Ohm's law, 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 to carry out the experiment is - **[IIT-JEE 2010]**

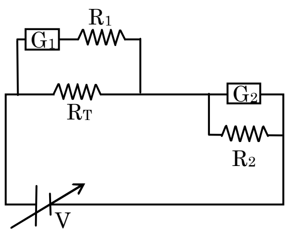
(A)



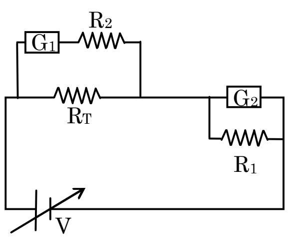
(B)



(C)

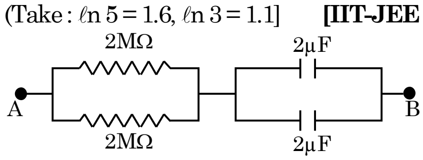


(D)

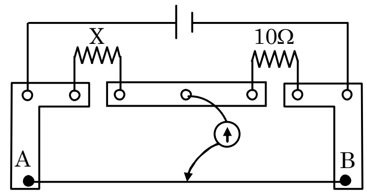


Q.17 When two identical batteries of internal resistance 1Ω each are connected in series across a resistor R, the rate of heat produced in R is J_1. When the same batteries are connected in parallel across R, the rate is J_2. If $J_1 = 2.25\ J_2$ then the value of R is Ω is ? **[IIT-JEE 2010]**

Q.18 At time t = 0, a battery of 10 V is connected across points A and B in the given circuit. If the capacitors have no charge initially, at what time (in seconds) does the voltage across them become 4 V? (Take : $\ell n\ 5 = 1.6$, $\ell n\ 3 = 1.1$] **[IIT-JEE 2010]**

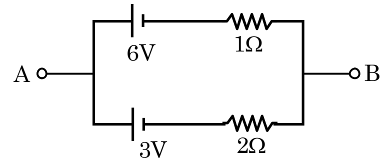


Q.19 A meter bridge is set-up as shown, to determine an unknown resistance 'X' using a standard 10 ohm resistor. The galvanometer show null point when tapping-key is at 52 cm mark. The end-corrections are 1 cm and 2 cm respectively for the ends A and B. The determine value of 'X' is - **[IIT-JEE 2011]**

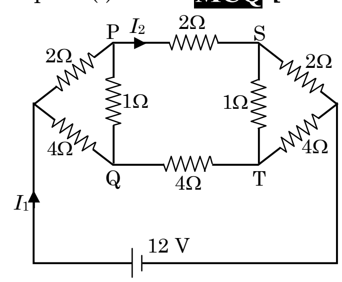


(A) 10.2 ohm (B) 10.6 ohm (C) 10.8 ohm (D) 11.1 ohm

Q.20 Two batteries of different emfs and different internal resistances are connected as shown. The voltage across AB in volts is - **[IIT-JEE 2011]**

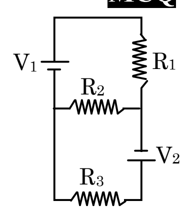


Q.21 For the resistance network shown in the figure, choose the correct option (s). **MCQ** **[IIT-JEE 2012]**



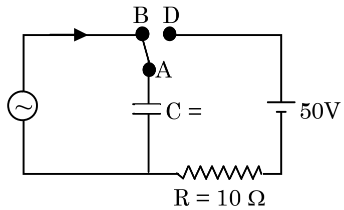
(A) The current through PQ is zero
(B) $I_1 = 3A$
(C) The potential at S is less than that at Q
(D) $I_2 = 2A$

Q.22 Two ideal batteries of emf V_1 and V_2 and three resistance R_1, R_2 and R_3 connected as shown in the figure. The current in resistance R_2 would be zero if **MCQ** **JEE-Advance-2014]**



(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 $2R_1 = R_2 = R_3$

Q.23 At time t = 0, terminal A in the circuit shown in the figure is connected to B by a key and an alternating current $I(t) = I_0 \cos(\omega t)$, with $I_0 = 1A$ and $\omega = 500\ rad\ s^{-1}$ starts flowing in it with the initial direction shown in the figure. At $t = 7\pi/6\omega$ the key is switched from B to D. Now onwards only A and D are connected. A total charge Q flows from the battery to charge the capacitor fully. If C = 20 μF, R = 10 Ω and the battery is ideal with emf of 50 V, identify the correct statement (s). **MCQ** **[JEE-Advance-2014]**



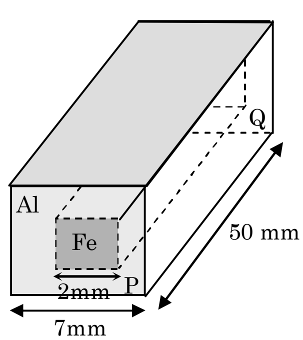
(A) Magnitude of the maximum charge on the capacitor before $t = 7\pi/6\omega$ is 1×10^{-3} C.
(B) The current in the left part of the circuit just before $t = 7\pi/6\omega$ is clockwise.
(C) Immediately after A is connected to D, the current in R is 10 A.
(D) $Q = 2 \times 10^{-3}$ C.

Q.24 A galvanometer gives full scale deflection with 0.006 A current. By connecting it to a 4990 Ω resistance, it can be converted into a voltmeter of range 0-30 V. If connected to a $\frac{2n}{249}$ Ω resistance, it becomes an ammeter of range 0-1.5 A. The value of n is. **[JEE-Advance-2014]**

Q.25 Heater of an electric kettle is made of a wire of length L and 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 2d. 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 ?
MCQ **[JEE-Advance-2014]**

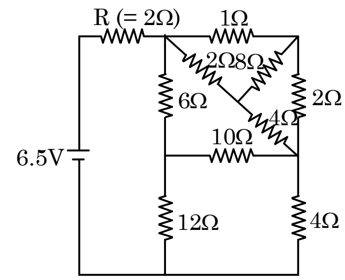
(A) 4 if wires are in parallel
(B) 2 if wires are in series
(C) 1 if wires are in the series
(D) 0.5 if wires are in parallel

Q.26 In an aluminum (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 2.7×10^{-8} Ωm and 1.0×10^{-7} Ωm, respectively. The electrical resistance between the two faces P and Q of the composite bar is **[JEE-Advance-2015]**

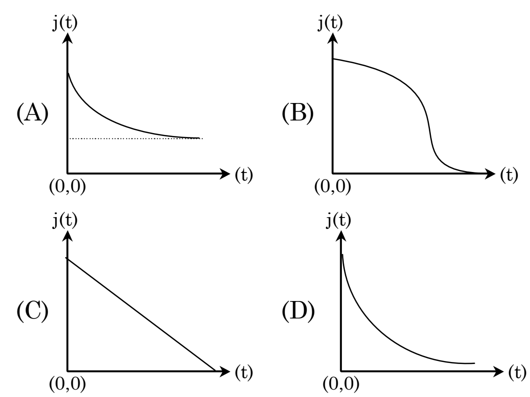


(A) $\frac{2475}{64}$ μΩ (B) $\frac{1875}{64}$ μΩ
(C) $\frac{1875}{49}$ μΩ (D) $\frac{2475}{132}$ μΩ

Q.27 In the following circuit, the current through the resistor R (= 2Ω) is I Amperes. The value of I is **[JEE-Advance-2015]**



Q.28 An infinite line charge of uniform electric charge density λ lies along the axis of an electrically conducting infinite cylindrical shell of radius R. At time t = 0, the space inside the cylinder is filled with a material of permittivity ε and electrical conductivity σ. The electrical conduction in the material follows Ohm's law. Which on the following graphs best describes the subsequent variation of the magnitude of current density j(t) at any point in the material . **[JEE-Advance-2016]**

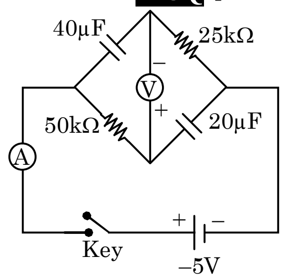


Q.29 An incandescent bulb has a thin filament of tungsten that is heated to high temperature by passing an electric current. The hot filament emits black-body radiation. The filament is observed to break up at random locations after a sufficiently long time of operation due to non-uniform evaporation of tungsten from the filament. If the bulb is powered at constant voltage, which of the following statement(s) is(are) true ? **MCQ** **[JEE-Advance-2016]**

(A) The temperature distribution over the filament is uniform
(B) The resistance over small sections of the filament decreases with time
(C) The filament emits more light at higher band of frequencies before it breaks up
(D) The filament consumes less electrical power towards the end of the life of the bulb

Q.30 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 ?
MCQ [JEE-Advance-2016]
(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

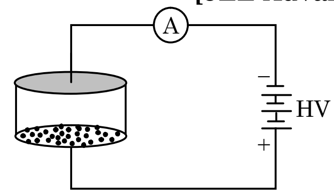
Q.31 In the circuit shown below, the key is pressed at time t = 0. Which of the following statement(s) is(are) true ? **MCQ [JEE-Advance-2016]**



(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 = ln 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

Passage Based Que. (Q.32 - 33)

Consider an evacuated cylindrical chamber of height h having rigid conducting plates at the ends and an insulating curved surface as shown in the figure.
A number of spherical balls made of a light weight and soft material and coated with a conducting material are placed on the bottom plate. The balls have a radius r << h. Now a high voltage sources (HV) is connected across the conducting plates such that the bottom plate is at $+ V_0$ and the top plate at $– V_0$. Due to their conducting surface, the balls will get charged, will become equipotential with the plate and are repelled by it. The balls will eventually collide with the top plate, where the coefficient of restitution can be taken to be zero due to the soft nature of the material of the balls. The electric field in the chamber can be considered to be that of a parallel plate capacitor. Assume that there are no collisions between the balls and the interaction between them is negligible. (Ignore gravity) **[JEE-Advance-2016]**



Q.32 Which one of the following statements is correct ?
(A) The balls will execute simple harmonic motion between the two plates
(B) The balls will bounce back to the bottom plate carrying the same charge they went up with
(C) The balls will stick to the top plate and remain there
(D) The balls will bounce back to the bottom plate carrying the opposite charge they went up with

Q.33 The average current in the steady state registered by the ammeter in the circuit will be
(A) proportional to V_0^2
(B) proportional to the potential V_0
(C) zero
(D) proportional to $V_0^{1/2}$

Passage Based Que. (Q.34 - 35)

Consider a simple RC circuit as shown in Figure 1.

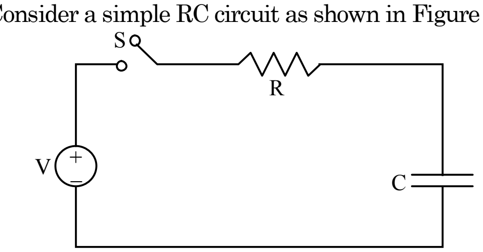


Figure 1

<u>Process 1</u> : In the circuit the switch S is closed at t = 0 and the capacitor is fully charged to voltage V_0 (i.e., charging continues for time T >> RC). In the process some dissipation (E_D) occurs across the resistance R. The amount of energy finally stored in the fully charged capacitor is E_C.

Process 2 : In a different process the voltage is first set to $\frac{V_0}{3}$ and maintained for a charging time T >> RC. Then the voltage is raised to $\frac{2V_0}{3}$ without discharging the capacitor and again maintained for a time T >> RC. The process is repeated one more time by raising the voltage to V_0 and the capacitor is charged to the same final voltage V_0 as in Process 1.

[JEE-Advance-2017]

These two processes are depicted in Figure 2.

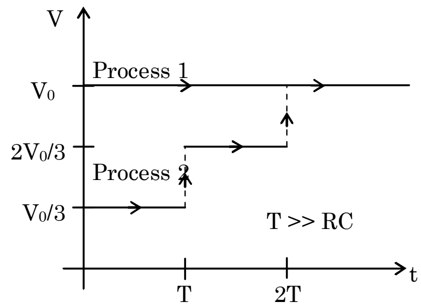


Figure 2

Q.34 In Process 1, the energy stored in the capacitor E_C and heat dissipated across resistance E_D are related by :

(A) $E_C = E_D \ln 2$ (B) $E_C = \frac{1}{2} E_D$

(C) $E_C = E_D$ (D) $E_C = 2E_D$

Q.35 In Process 2, total energy dissipated across the resistance E_D is :

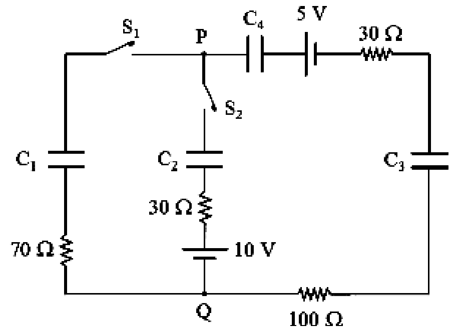
(A) $E_D = \frac{1}{3}\left(\frac{1}{2}CV_0^2\right)$ (B) $E_D = 3\left(\frac{1}{2}CV_0^2\right)$

(C) $E_D = \frac{1}{2}CV_0^2$ (D) $E_D = 3CV_0^2$

Q.36 A moving coil galvanometer has 50 turns and each turn has an area 2×10^{-4} m^2. The magnetic field produced by the magnet inside the galvanometer is 0.02 *T*. The torsional constant of the suspension wire is 10^{-4} *N m rad*$^{-1}$. When a current flows through the galvanometer, a full scale deflection occurs if the coil rotates by 0.2 *rad*. The resistance of the coil of the galvanometer is 50Ω. This galvanometer is to be converted into an ammeter capable of measuring current in the range 0 – 1.0 *A*. For this purpose, an shunt resistance is to be added in parallel to the galvanometer. The value of this shunt resistance, in *ohms*, is _______.

[JEE-Advanced-2018]

Q.37 In the circuit shown, initially there is no charge on capacitors and keys S_1 and S_2 are open. The values of the capacitors are $C_1 = 10\ \mu F$, $C_2 = 30\ \mu F$ and $C_3 = C_4 = 80\ \mu F$.



Which of the statement(s) is/are correct ?

MCQ **[JEE-Advanced-2019]**

(A) At time t = 0, the key S_1 is closed, the instantaneous current in the closed circuit will be 25 mA

(B) The key S_1 is kept closed for long time such that capacitors are fully charged. Now key S_2 is closed, at this time, the instantaneous current across 30 Ω resistor (between points P and Q) will be 0.2 A (round off to 1st decimal place)

(C) If key S_1 is kept closed for long time such that capacitors are fully charged, the voltage across the capacitor C_1 will be 4 V

(D) If key S_1 is kept closed for long time such that capacitors are fully charged, the voltage difference between points P and Q will be 10 V

Q.38 Two identical moving coil galvanometers have 10 Ω resistance and full scale deflection at 2 μA current. One of them is converted into a voltmeter of 100 mV full scale reading and the other into an Ammeter of 1 mA full scale current using appropriate resistors. These are then used to measure the voltage and current in the Ohm's law experiment with R = 1000 Ω resistor by using an ideal cell. Which of the following statement(s) is/are correct ?

MCQ **[JEE-Advanced-2019]**

(A) The resistance of the Ammeter will be 0.02 Ω (round off to 2nd decimal place)

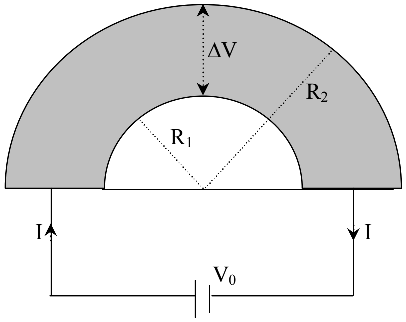
(B) The measured value of R will be 978 Ω < R < 982 Ω

(C) If the ideal cell is replaced by a cell having internal resistance of 5 Ω then the measured value of R will be more than 1000 Ω

(D) The resistance of the Voltmeter will be 100 kΩ

Q.39 Shown in figure is a semicircular metallic strip that has thickness t and resistivity ρ. Its inner radius is R_1 and outer radius is R_2. If a voltage V_0 is applied between its two ends, a current I flows in it. In addition, it is observed that a transverse voltage ΔV develops between its inner and outer surface due to purely kinetic effects of moving electrons (ignore any role of the magnetic filed due to the current). Then (figure is schematic and not drawn to scale)

[JEE Advanced 2020]



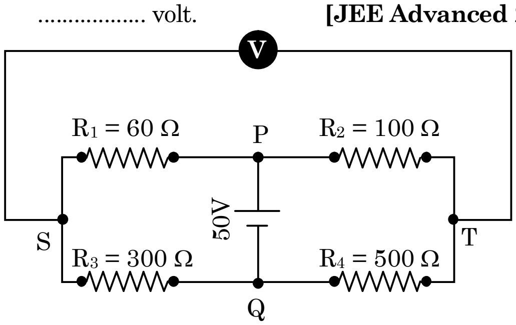
(A) $I = \frac{V_0 t}{\pi\rho}\ln\left(\frac{R_2}{R_1}\right)$

(B) the outer surface is at a higher voltage than the inner surface

(C) the outer surface is at a lower voltage than the inner surface

(D) $\Delta V \propto I^2$

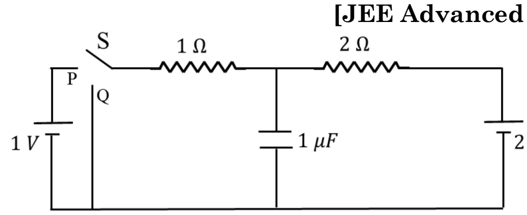
Q.40 In the balanced condition, the values of the resistances of the four arms of a Wheatstone bridge are shown in the figure below. The resistance R_3 has temperature coefficient 0.0004 C^{-1}. If the temperature of R_3 is increased by 100ºC, the voltage developed between S and ? T will be .... volt. **[JEE Advanced 2020]**



Question Stem for Question Nos.41 and 42

In the circuit shown below, the switch S is connected to position P for a long time so that the charge on the capacitor becomes q_1 μC. Then S is switched to position Q. After a long time, the charge on the capacitor is q_2 μC.

[JEE Advanced 2021]

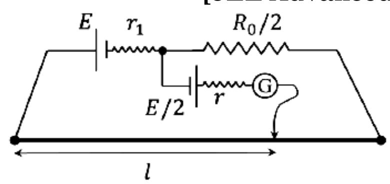


Q.41 The magnitude of q_1 is _____.

Q.42 The magnitude of q_2 is ______.

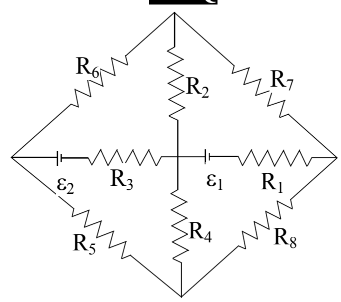
Q.43 In order the measure the internal resistance r_1 of a cell of emf E, a meter bridge of wire resistance R_0 = 50Ω, a resistance $R_0/2$, another cell of emf E/2 (internal resistance r) and a galvanometer G are used in a circuit, as shown in the figure. If the null point is found at l = 72 cm, then the value of r_1 = ____Ω.

[JEE Advanced 2021]



Q.44 The figure shows a circuit having eight resistances of 1 Ω each, labelled R_1 to R_8 , and two ideal batteries with voltages ε_1 = 12 V and ε_2 = 6 V.

MCQ **[JEE-Advanced-2022]**



Which of the following statement(s) is(are) correct?

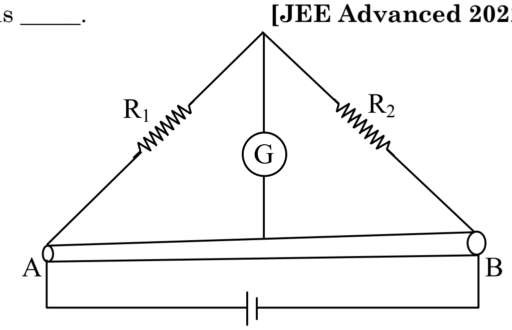
(A) The magnitude of current flowing through R_1 is 7.2 A.

(B) The magnitude of current flowing through R_2 is 1.2 A.

(C) The magnitude of current flowing through R_3 is 4.8 A.

(D) The magnitude of current flowing through R_5 is 2.4 A.

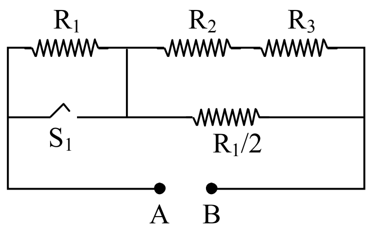
Q.45 Two resistances R_1 = X Ω and R_2 = 1 Ω are connected to a wire AB of uniform resistivity, as shown in the figure. The radius of the wire varies linearly along its axis from 0.2 mm at A to 1 mm at B. A galvanometer (G) connected to the center of the wire, 50 cm from each end along its axis, shows zero deflection when A and B are connected to a battery. The value of x is _____. **[JEE Advanced 2022]**



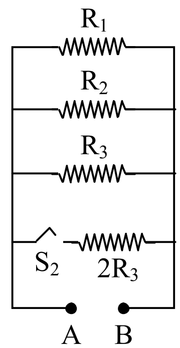
Q.46 In Circuit-1 and Circuit-2 shown in the figures, $R_1 = 1\Omega$, $R_2 = 2\Omega$ and $R_3 = 3\Omega$. P_1 and P_2 are the power dissipations in Circuit-1 and Circuit-2 when the switches S_1 and S_2 are in open conditions, respectively.

Q_1 and Q_2 are the power dissipations in Circuit-1 and Circuit-2 when the switches S_1 and S_2 are in closed conditions, respectively.

MCQ **[JEE-Advanced-2022]**



Circuit-1



Circuit-2

Which of the following statements (s) is (are) correct ?

(A) When a voltage source of 6V is connected across A and B in both circuits, $P_1 < P_2$

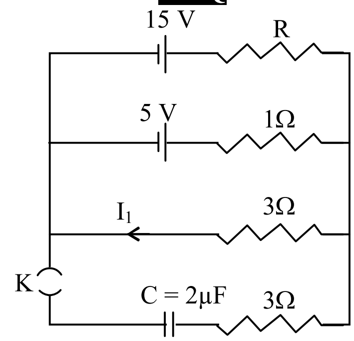
(B) When a constant current source of 2 Amp is connected across A and B in both circuits, $P_1 > P_2$

(C) When a voltage source of 6V is connected across A and B in Circuit-1, $Q_1 > P_1$.

(D) When a constant current source of 2 Amp is connected across A and B in both circuits, $Q_2 < Q_1$.

Q.47 In a circuit shown in the figure, the capacitor C is initially uncharged and the key K is open. In this condition, a current of 1 A flows through the 1 Ω resistor. The key is closed at time $t = t_0$. Which of the following statement(s) is(are) correct? [Given: $e^{-1} = 0.36$]

MCQ **[JEE-Advanced-2023]**



(A) The value of the resistance R is 3 Ω.

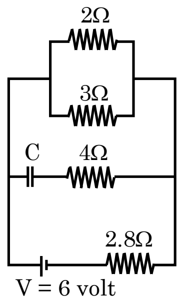
(B) For $t < t_0$, the value of current I_1 is 2 A.

(C) At $t = t_0 + 7.2$ μs, the current in the capacitor is 0.6 A.

(D) For $t \to \infty$, the charge on the capacitor is 12 μC.

EXERCISE (Level-5)
Review Exercise

Q.1 Calculate the steady state current in the 2Ω resistor shown in the circuit (see figure). The internal resistance of the battery is negligible and the capacitance of the condenser C is $0.2\ \mu F$. **[IIT-JEE 1982]**

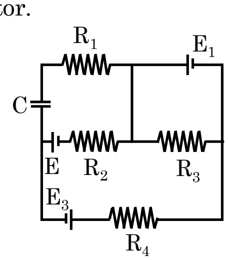


Q.2 Two resistors, $400\ \Omega$, and $800\ \Omega$ are connected in series with a 6 V battery. It is desired to measure the current in the circuit. An ammeter of $10\ \Omega$ resistance is used for this purpose. What will be the reading in the ammeter ? Similarly, if a voltmeter of $1000\ \Omega$ resistance is used to measure the potential difference across the $400\ \Omega$ resistor, what will be the reading in the voltmeter ? **[IIT-JEE 1982]**

Q.3 A wire of length L and 3 identical cells of negligible internal resistances are connected in series Due to the current the temperature of the wire is raised by ΔT in a time t. A number N of similar cells is now connected in series with a wire of the same material and cross-section but of length 2L. The temperature of the wire is raised by the same amount ΔT in the same time t. The value of N is - **[IIT-JEE 2001]**
(A) 4 (B) 6 (C) 8 (D) 9

Q.4 A piece of copper and another of germanium are cooled from room temperature to 80K. The resistance of - **[IIT-JEE 1988]**
(A) Each of them increases
(B) Each of them decreases
(C) Copper increases and germanium decreases
(D) Copper decreases and germanium increases

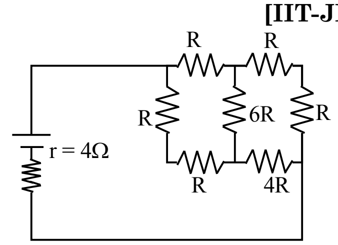
Q.5 In the given circuit –
$E_1 = 3$, $E_2 = 2$, $E_3 = 6$ volt,
$R_1 = 2\Omega$, $R_4 = 6$ ohm, $R_3 = 2\Omega$,
$R_2 = 4$ ohm, $C = 5\mu F$.
Find the current in R_3 and the energy stored in the capacitor. **[IIT-JEE 1998]**



Q.6 A micro ammeter has a resistance of $100\ \Omega$ and full scale range of $50\ \mu A$. It can be used as a voltmeter or as a higher range ammeter provided a resistance is added to it. Pick the correct range and resistance combinations - **MCQ** **[IIT-JEE 1991]**
(A) 50 V range with $10\ K\Omega$ resistance in series
(B) 10 V range with $200\ K\Omega$ resistance in series
(C) 5 mA range with $1\ \Omega$ resistance in parallel
(D) 10 mA range with $1\ \Omega$ resistance in parallel

Q.7 Read the following statements carefully -
Y : The resistivity of semiconductor decreases with increases of temperature.
Z : In a conducting solid, the rate of collisions between free electrons and ions increases with increase of temperature.
Select the correct statement (s) from the following **[IIT-JEE 1993]**
(A) Y is true but Z is false
(B) Y is false but Z is true
(C) Both Y and Z are true
(D) Y is true and Z is the correct reason for Y

Q.8 A battery of internal resistance $4\ \Omega$ is connected to the network of resistance as shown. In order that maximum power can be delivered to the network, the value of R in ohm should be - **[IIT-JEE 1995]**

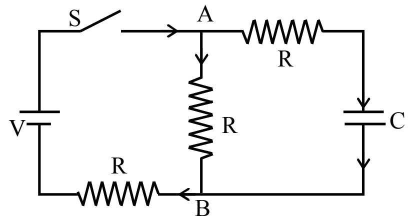


(A) $\frac{4}{9}$ (B) 2 (C) $\frac{8}{3}$ (D) 18

Q.9 A uniform copper wire of mass 2.23×10^{-3} kg carries a current of 1 A when 1.7 V is applied across it. Calculate its length and area of cross-section. If the wire is uniformly stretched to double its length, calculate the new resistance. Density of copper is $8.92 \times 10^3\ kg\ m^{-3}$ and resistivity is $1.7 \times 10^{-8}\ \Omega m$. **[Roorkee 95]**

Q.10 An electrical circuit is shown in figure. Calculate the potential difference across the resistor of 400 ohm, as will be measured by the voltmeter V of resistance 400 ohm, either by applying Kirchhoff's rules or otherwise. **[IIT-JEE 1996]**

Q.11 In the circuit shown in Fig., the battery is an ideal one, with emf V. The capacitor is initially uncharged. The switch S is closed at time t = 0.
(a) Find the charge Q on the capacitor at time t.
(b) Find the current in AB at time t. What is its limiting value at $t \to \infty$?
[IIT-JEE 1997]



Q.12 A steady current flows in a metallic conductor of non-uniform cross section. The quantity/quantities constant along the length of the conductor is – **[IIT-JEE 1997]**

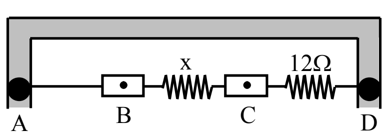
(A) current, electric field and drift speed
(B) drift speed only
(C) current and drift speed
(D) current only

Q.13 A series combination of 0.1 M Ω resistor and a 10 μF capacitor is connected across a 1.5 V source of negligible resistance. The time required for the capacitor to get charged up to 0.75 V is approximately (in seconds) **[IIT-JEE 1997]**

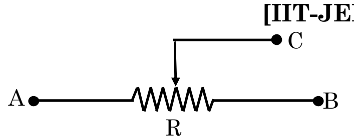
(A) ∞ (B) $\log_e 2$ (C) $\log_{10} 2$ (D) Zero

Q.14 A thin uniform wire AB of length 1m, an unknown resistance X and a resistance of 12Ω are connected by thick conducting strips, as shown in the figure. A battery and a galvanometer (with a sliding jockey connected to it) are also available. Connections are to be made to measure the unknown resistance X using the principle of Wheatstone bridge. Answer the following questions.

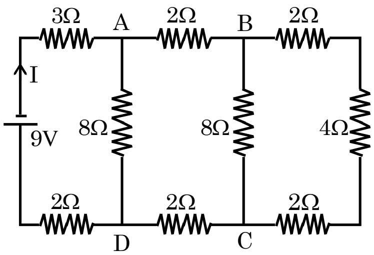
(a) Are there positive and negative terminals on the galvanometer ?
(b) Copy the figure in your answer book and show the battery and the galvanometer (with jockey) connected at appropriate points.
(c) After appropriate connections are made, it is found that no deflection takes place in the galvanometer when the sliding jockey touches the wire at a distance of 60 cm from A. Obtain the value of the resistance X. **[IIT-JEE 2002]**



Q.15 As shown in the figure a battery is to be connected so that the rheostat behaves like potential divider. Indicate how the battery should be connected. Also indicate the points about which output can be taken. **[IIT-JEE 2003]**

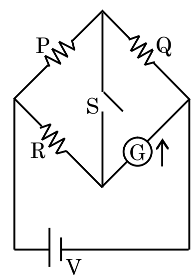


Q.16 In the circuit shown in figure, the current through - **[IIT-JEE 1998]**



(A) the 3Ω resistor is 0.50 A
(B) the 3Ω resistor is 0.25 A
(C) the 4Ω resistor is 0.50 A
(D) the 4Ω resistor is 0.25 A

Q.17 In the circuit P ≠ R, the reading of the galvanometer is same with switch S open or closed. Then - **[IIT-JEE 1999]**



(A) $I_R = I_G$ (B) $I_P = I_G$ (C) $I_Q = I_G$ (D) $I_Q = I_R$

Q.18 Draw the circuit diagram to verify Ohm's Law with the help of a main resistance of 100 Ω and two galvanometers of resistances 10^6Ω and 10^{-3} Ω and a source of varying emf. Show the correct positions of voltmeter and ammeter.
[IIT-JEE 2004]

Q.19 A parallel plate capacitor is charged to a potential difference of 50 V. It is discharged through a resistance. After 1 second, the potential difference between plates becomes 40 V. Then - **MCQ** **[REE-99]**

(A) fraction off stored energy after 1 second is 16/25
(B) potential difference between the plates after 2 second will be 32 V
(C) potential difference between the plates after 2 seconds will be 20 V
(D) fraction of stored energy after 1 second is 4/5

Q.20 A homogeneous proton beam accelerated by a potential difference V= 600 kV has a round cross-section of radius r = 5.0 mm. Find the electric field strength on the surface of the beam and the potential difference between the surface and the axis of the beam, if the beam current is equal to I = 50 mA.

ANSWER KEY

EXERCISE (Level-1)

1. (B)	**2.** (C)	**3.** (A)	**4.** (B)	**5.** (B)	**6.** (C)	**7.** (C)	**8.** (C)	**9.** (B)	**10.** (D)
11. (B)	**12.** (B)	**13.** (C)	**14.** (A)	**15.** (A)	**16.** (C)	**17.** (C)	**18.** (D)	**19.** (B)	**20.** (A)
21. (A)	**22.** (B)	**23.** (C)	**24.** (A)	**25.** (B)	**26.** (B)	**27.** (B)	**28.** (B)	**29.** (B)	**30.** (B)
31. (C)	**32.** (D)	**33.** (B)	**34.** (A)	**35.** (C)	**36.** (B)	**37.** (B)	**38.** (C)	**39.** (B)	**40.** (D)
41. (C)	**42.** (C)								

EXERCISE (Level-2)

1. (B)	**2.** (B)	**3.** (B)	**4.** (D)	**5.** (C)	**6.** (D)	**7.** (D)	**8.** (A)	**9.** (B)	**10.** (B)
11. (A)	**12.** (B)	**13.** (C)	**14.** (C)	**15.** (C)	**16.** (A)	**17.** (B)	**18.** (D)	**19.** (C)	**20.** (B)
21. (B)	**22.** (D)	**23.** (B)	**24.** (A)	**25.** (B)	**26.** (A)	**27.** (C)	**28.** (B)	**29.** (B)	**30.** (B)
31. (C)	**32.** (C)	**33.** (A)	**34.** (D)	**35.** (A)	**36.** (B)	**37.** (D)	**38.** (C)	**39.** (D)	**40.** (C)
41. (D)	**42.** (C)	**43.** (D)	**44.** (B)						

EXERCISE (Level-3)

Part-A

1. (A,B,C,D)	**2.** (A.C)	**3.** (A,B,D)	**4.** (C,D)	**5.** (A,D)	**6.** (C,D)	**7.** (A,D)
8. (A,D)	**9.** (A,C)	**10.** (A,B,C)	**11.** (A)	**12.** (C)	**13.** (A,C)	**14.** (A,B,C,D)
15. (B,C,D)	**16.** (C)	**17.** (B,D)	**18.** (A,D)			

Part-B

19. (A) **20.** (B) **21.** (A) **22.** (A) **23.**(A) **24.** (C) **25.** (A) **26.** (A)

Part-C

27. $A \to Q$; $B \to P,Q,R$; $C \to Q$; $D \to P,Q,R,S$

28. $A \to Q$; $B \to R$; $C \to S$; $D \to P$

29. $A \to R$; $B \to P, Q, R, S$; $C \to S$; $D \to S$

Part-D

30. (D)	**31.** (B)	**32.** (D)	**33.** (C)	**34.** (A)	**35.** (A)	**36.** (D)	**37.** (A)	**38.** (D)	**39.** (B)
40. (C)	**41.** (C)	**42.** (C)	**43.** (D)						

Part-E

44. [(a) 32 Ω (b) 20 V (c) 20 V]

45. 2

46.[(a) (i) I = α, (ii) $\phi_A - \phi_B = 0$, (b) (i) 0.3 A (ii) 3A]

47. [(a) 6 V and –4 V, (b) 90%]

48. [(A) 7 paisa, (b) 9 paisa]

49. 8

50. [160 cells, mixed grouping ⇒ 4 rows and each row will contain 40 cells]

51. **(a)** $[\frac{V^2}{KR}(1 - e^{-Kt/C})]$ **(b)** $\frac{a}{\lambda} i^2 R$

52. One

53. 2

54. 8

55. $EC\left(1 - \frac{1}{e}\right) + \frac{VC}{e^2}$

56. 2

57. 4

58. 3

59. 1

60. 3

61. (a) 6 m (b) 1Ω

62. (a) 1.25V

(b) The high resistance to kept the initial current low when null point is being located. This saves the standard cell from damage.

(c) This high resistance does not affect the balance point because then there is no flow of current through the standard cell branch.

(d) The internal resistance of driver cell affects the current through the potentiometer wire. Since potential gradient is changed, therefore, the balance point must be affected.

(e) No, It is necessary that the emf of the driver cell is more than the emf of the cells.

63. 50Ω or 25Ω **64.** $Q^2\pi^2R/8T$

EXERCISE (Level-4)

SECTION-A

1. (D)	**2.** (B)	**3.** (B)	**4.** (B)	**5.** (D)	**6.** (B)	**7.** (B)	**8.** (D)	**9.** (D)	**10.** (A)
11. (C)	**12.** (B)	**13.** (B)	**14.** (B)	**15.** (A)	**16.** (D)	**17.** (B)	**18.** (B)	**19.** (B)	**20.** (B)
21. (B)	**22.** (C)	**23.** (D)	**24.** (C)	**25.** (B)	**26.** (B)	**27.** (C)	**28.** (B)	**29.** (C)	**30.** (B)
31. (D)	**32.** (C)	**33.** (B)	**34.** (C)	**35.** (B)	**36.** (C)	**37.** (D)	**38.** (A)	**39.** (C)	40. (A)
41. (B)	**42.** (B)	**43.** (C)	44. (A)	**45.** (B)	**46.** (A)	**47.** (C)	**48.** (C)	**49.** (B)	**50.** (A)
51. (D)	**52.** (A)	**53.** (B)	**54.** (D)	**55.** (D)	**56.** (B)	**57.** (D)	**58.** (C)	**59.** (B)	**60.** (A)
61. (B)	**62.** (A)	**63.** (B)	**64.** (A)	**65.** (A)	**66.** (A)	**67.** (A)	**68.** (C)	**69.** (D)	**70.** (C)
71. (D)	**72.** (D)	**73.** (B)	**74.** (B)	**75.** (A)	**76.** (D)	**77.** (D)	**78.** (B)	**79.** (D)	**80.** (B)
81. (C)	**82.** (D)	**83.** (A)	**84.** (C)	**85.** (B)	**86.** (A)	**87.** (C)	**88.** (B)	**89.** (Drop by NTA)	**90.** (A)
91. (B)	**92.** (B)	**93.** (D)	**94.** (D)	**95.** (C)	**96.** (D)	**97.** (D)	**98.** (A)	**99.** (B)	**100.** (B)
101. (A)	**102.** (A)	**103.** (C)	**104.** 1	**105.** (D)	**106.** 12.00	**107.** 3.00	**108.** 8.00	**109.** 4.00	**110.** 780.00
111. 14.00	**112.** (B)	**113.** (C)	**114.** (C)	**115.** 01.50	**116.** (A)				

SECTION-B

1. $Q_0 = \dfrac{CVR_2}{R_1+R_2}$ and $\alpha = \dfrac{R_1+R_2}{R_1R_2C}$ **2.** The null point at B will give most accurate reading

3. (A)	**4.** (A)	**5.** (B)	**6.** (A)	**7.** (A)	**8.** (A)	**9.** (C)
10. (D)	**11.** (A)	**12.** $A \to P, Q, S, T; B \to Q; C \to S; D \to S$			**13.** (A)	**14.** (C)
15. (D)	**16.** (C)	**17.** 4	**18.** 2	**19.** (B)	**20.** 5 volt	**21.** (A,B,C,D)
22. (A, B,D)	**23.** (C,D)	**24.** 5	**25.** (B,D)	**26.** (B)	**27.** 1	**28.** (D)
29. (D)	**30.** (A,C)	**31.** (A,B,C,D)	**32.** (D)	**33.** (A)	**34.** (C)	**35.** (A)
36. 5.55	**37.** (A,C)	**38.** (A,B)	**39.** (A, C, D)	**40.** 0.26	**41.** 1.33 μC	**42.** 0.67 μC
43. 3	**44.** (A,B,C,D)	**45.** 5	**46.** (A,B,C)	**47.** (A,B,C,D)		

EXERCISE (Level-5)

1. 0.9 A **2.** 4.96 mA, 1.58 volt **3.** (B) **4.** (D)

5. 1.5 A from right to left and energy stored is 1.44×10^{-5} J **6.** (B, C) **7.** (C) **8.** (B)

9. ℓ = 5m, A = 5×10^{-8}, R_1 = 4 R = 6.8 Ω **10.** p.d. = $\dfrac{20}{3}$ V

11. (a) $Q = \frac{VC}{2}\left(1 - e^{-2t/3RC}\right)$ (b) $I_1 = \frac{V}{2R} - \frac{Ve^{-\frac{2t}{3RC}}}{6R}$, $\lim_{t \to \infty} I_1 = \frac{V}{2R}$ **12.** (D) **13.** (B)

14. (a) Galvanometer has no positive or negative terminals ; (c) 8Ω

15. Output terminals are [A, C] or [B, C] **16.** (D) **17.** (A) **19.** (A, B)

20. [$E = 32V/m$, $\Delta\phi = 0.8$ V]