CHAPTER / 05

Direct Current Circuits

Topics Covered

- DC Circuit
- Cells
- Combination of Resistors
- Grouping of Cells
- Kirchhoff's Laws
- Wheatstone Bridge
- Meter Bridge
- Potentiometer

DC Circuit

Electrical circuit in which the direction of current does not change with the passage of time is called direct current circuit or DC circuit. A simple DC circuit consists of electrical components like a source of emf, a resistor and a switch key. A closed and continous path through which electric current flows is known as electric circuit.

Cells

An electric cell is a source of energy that maintains a continuous flow of charge in a circuit. Electric cell changes chemical energy into electrical energy. An electric cell has two terminals: positive terminal and negative terminal.

Electromotive Force (emf) of a Cell (E)

Electric cell has to do some work in maintaining the current through a circuit. The work done by the cell in moving unit positive charge through the whole circuit (including the cell) is called the electromotive force (emf) of the cell.

If during the flow of C coulomb of charge in an electric circuit, the work done by the cell is W, then

$$\text{emf of the cell, } E = \frac{W}{q}$$

Its unit is joule/coulomb or volt.

Internal Resistance (r)

Internal resistance of a cell is defined as the resistance offered by the ions of the electrolyte of the cell to the flow of current through it. It is denoted by r. Its unit is ohm (Ω). Internal resistance of a cell depends on the following factors:

(i) It is directly proportional to the separation between the two plates of the cell.

(ii) It is inversely proportional to the plates area dipped into the electrolyte.

(iii) It depends on the nature, concentration and temperature of the electrolyte and increases with increase in concentration.

Terminal Potential Difference (V)

Terminal potential difference of a cell is defined as the potential difference between the two terminals of the cell in a closed circuit (i.e. when current is drawn from the cell).

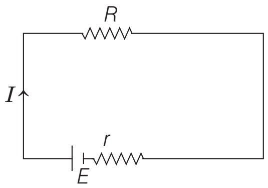
It is represented by V and its unit is volt. Terminal potential difference of a cell is always **less** than the emf of the cell.

Relation between Terminal Potential Difference, emf of the Cell and Internal Resistance of a Cell

(i) If no current is drawn from the cell, i.e. the cell is in open circuit, then emf of the cell will be equal to the terminal potential difference of the cell.

when $\qquad I = 0$ or $V = E$

(ii) Consider a cell of emf E and internal resistance r is connected across an external resistance R as shown in the figure below.



Current drawn from the cell, $I = \dfrac{E}{R + r}$

Terminal potential difference of cell is

$$V = E - Ir$$

Note During charging of the cell, the terminal potential difference of cell becomes greater than the emf of cell.

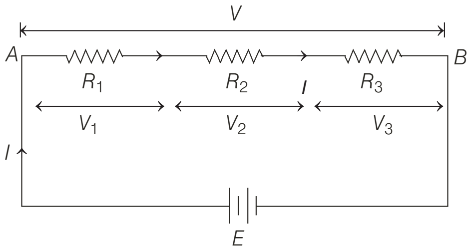
Difference between emf and terminal potential difference of a cell

emf	Terminal potential difference
The emf of a cell is the maximum potential difference between the two electrodes of a cell when the cell is in the open circuit.	The potential difference between the two points is the difference of potential between those two points in a closed circuit.
It is independent of the resistance of the circuit and depends upon the nature of electrodes and the nature of electrolyte of the cell.	It depends upon the resistance between the two points of the circuit and current flowing through the circuit.
The term emf is used for the source of electric current.	The potential difference is measured between any two points of the electric circuit.
It is a cause.	It is an effect.

Combination of Resistors

Series Grouping

Resistors are said to be connected in series, if the same current is flowing through each resistor when potential difference is applied across the combination. In this combination, resistors are connected end-to-end.



Equivalent resistance of series combination of resistances is given by

$$R_s = R_1 + R_2 + R_3$$

In series combination,

(i) The current in the circuit is independent of the relative positions of the various resistors.

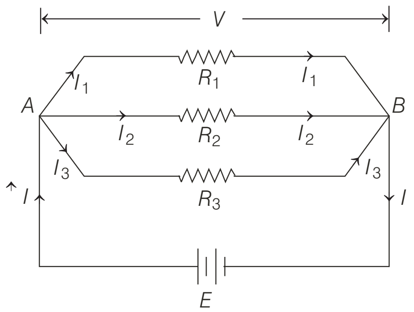
(ii) The voltage across any resistor is directly proportional to the resistance of that resistor.

(iii) Applied voltage across the series combination is equal to the sum of individual voltages across each resistor.

(iv) The total resistance in the series combination is more than the greatest resistance in the circuit.

Parallel Grouping

Resistors are said to be connected in parallel, if the potential difference across each resistance is same and sum of individual currents flowing through each resistance is equal to the total current drawn from the battery.



Equivalent resistance of parallel combination of resistances is given by

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

In parallel combination,

(i) The current through each resistor is inversely proportional to the resistance of that resistor.

(ii) The voltage in circuit is independent of relative positions of various resistors.

(iii) The total current in the circuit is equal to the sum of currents in individual resistances.

(iv) The total resistance in parallel combination is less than the least resistance of the circuit.

Mixed Grouping

In this grouping, some resistors in a circuit are combined in parallel and some others are combined in series.

Equivalent resistance of the grouping can be calculated as follows:

(i) First of all equivalent resistance (R_p) of all the resistors which are in parallel is calculated.

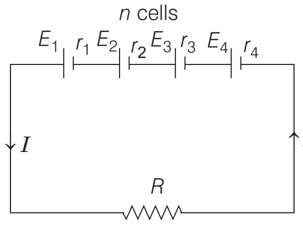
(ii) Now equivalent resistance of the mixed grouping is calculated by adding R_p with all other resistances in series.

Grouping of Cells

Cells can be combined in series as well as parallel grouping as discuss below:

Series Grouping of Cells

When n identical cells each of emf E and internal resistance r are connected to the external resistor of resistance R as shown in the figure below, the cells are said to be connected in series.



The equivalent emf of a series combination of n cells is equal to the sum of their individual emfs.

Equivalent emf of n cells in series,

$$E_{\text{eq}} = E_1 + E_2 + \ldots + \text{up to } n \text{ terms} = nE$$

Equivalent internal resistance of n cells in series, if all cells have same emf and internal resistance.

$$r_{\text{eq}} = r_1 + r_2 + \ldots + \text{up to } n \text{ terms} = nr$$

Total resistance of the circuit = $nr + R$

$\therefore$ Current in the resistance R is given by

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

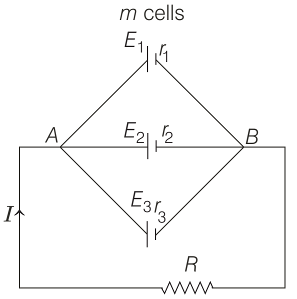
When cells are of different emfs and internal resistances

i.e. $$I = \frac{E_1 + E_2 + \ldots}{R + (r_1 + r_2 + \ldots)}$$

The maximum current can be drawn from the series combination of cell, if the value of external resistance is very high as compared to the total internal resistance of the cells.

Parallel Grouping of Cells

When m cells each of emf E and internal resistance r are connected in parallel, so that current passes through the external resistance R. Then, the cells are connected in parallel.



The equivalent emf of parallel combination of cells of same emfs is equal to emf of one cell.

$$E = E_1 = E_2 = E_3$$

The equivalent internal resistance of parallel combination of cells is

$$\therefore \quad \frac{1}{r_P} = \frac{1}{r_1} + \frac{1}{r_2} + \ldots + \text{up to } m \text{ terms} = \frac{m}{r}$$

or $$r_P = \frac{r}{m} \qquad [\text{if } r = r_1 = r_2 = r_3]$$

As R and r_P are in series, so total resistance in the circuit = $R + \frac{r}{m}$.

$\therefore$ Current in the resistance R is given by

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

When cells are of different emfs and different internal resistances, then

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

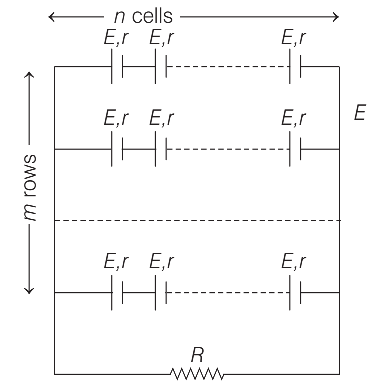
where, $$\frac{1}{r'} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \ldots + \frac{1}{r_n}$$

The maximum current can be drawn from the parallel combination of cells if the external resistance is very low as compared to the total internal resistance of the cells.

Mixed Grouping of Cells

Let the cells be connected as shown in figure. Let there be n cells in series in one row and m rows of cells are in parallel. Suppose all the cells are identical.

Let each cell be of emf E and internal resistance r.



Equivalent emf of each row = nE

Equivalent internal resistance of each row = $n\,r$

Total emf of combination = nE

Total internal resistance of combination

$$\frac{1}{r_1} = \frac{1}{nr} + \frac{1}{nr} + \ldots + \text{ up to } m \text{ times}$$

$$\frac{1}{r_1} = \frac{m}{nr} \quad \text{or} \quad r_1 = \frac{nr}{m}$$

Total resistance of the circuit = $\dfrac{nr}{m} + R$

Current in the resistance R is given by

$$I = \frac{n\,E}{\dfrac{nr}{m} + R}$$

Thus, we get the maximum current in mixed grouping of cells if the value of external resistance is equal to the total internal resistance of all the cells.

$$R = \frac{nr}{m}$$

Kirchhoff's Laws

Kirchhoff in 1842, put forward the following two rules to solve the complicated electrical circuits. These rules are basically the expressions of conservation of electric charge and energy.

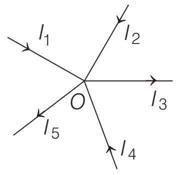
These rules were stated as follows:

First Law (Junction Rule KCL)

This law states that the algebraic sum of the currents meeting at a point in an electrical circuit is always zero. It is also known as junction rule.

$$I_1 + I_2 + I_4 = I_3 + I_5$$

So, junction rule can also be stated as the sum of currents entering the junction is equal to the sum of currents leaving the junction.

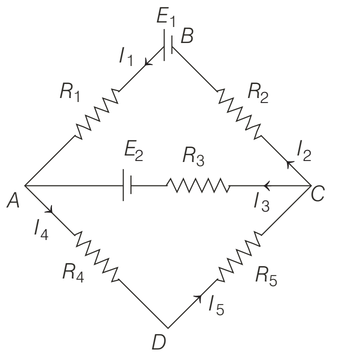


Sign Convention For Kirchhoff's First Law

The current flowing towards the junction of conductor is considered as positive and the current flowing away from the junction is taken as negative.

Second Law
(Kirchhoff's Voltage Rule KVL)

It states that in any closed part of an electrical circuit, the algebraic sum of the emfs is equal to the algebraic sum of the products of the resistances and currents flowing through them. It is also known as **loop rule**.



$\therefore$ According to second law, for closed part $ABCA$,

$$E_1 - E_2 = I_1R_1 + I_2R_2 - I_3R_3$$

Similarly, for closed part $ACDA$,

$$E_2 = I_3R_3 + I_4R_4 + I_5R_5$$

Sign Convention For Kirchhoff's Second Law

While traversing a loop, emf of a cell is taken negative, if negative pole of the cell is encountered first, otherwise positive.

Applications of Kirchhoff's Laws

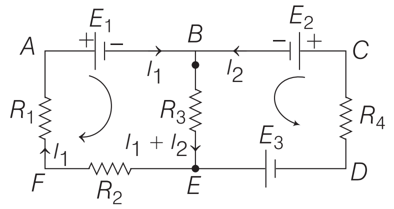
The Kirchhoff's law can be used to calculate the unknown quantities like current, potential difference, emf, resistance, etc. While using these rules to calculate the potential difference, the following points should be considered:

(i) Start from a point on the loop and go along the loop, either anti-clockwise or clockwise, to reach the same point again, but balance currents at junction as per KCL.

(ii) If moving along the direction of the current, there will be potential drop across a resistance and if moving in the opposite direction, there will be potential gain.

(iii) The net sum of all these potential differences should be zero, using the KVL rule.

Now, let us consider a circuit as shown in figure.



From point A to point D,

(i) Path $ABCD, V_A - E_1 + E_2 + I_2R_4 = V_D$

(ii) Path $ABED, V_A - E_1 - (I_1 + I_2)R_3 - E_3 = V_D$

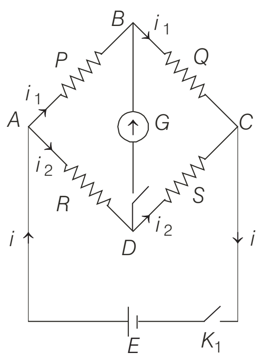
(iii) Path $AFED, V_A + I_1R_1 + I_1R_2 - E_3 = V_D$

Wheatstone Bridge

It is an arrangement of four resistances used to measure any one of them in terms of the other three. It makes use of KCL and KVL to deduce the unknown resistance.

Consider four resistances P, Q, R and S connected in the four arms of a quadrilateral.

The galvanometer G and a tapping key K_2 are connected between points B and D. The cell of emf E and one way key K_1 are connected between points A and C as shown in figure apart.



Resistances P and Q are called ratio arms, resistance R is a variable resistance and S is unknown resistance.

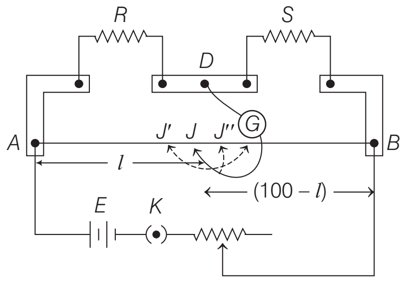
The bridge is said to be balanced when the galvanometer gives zero deflection. Thus, we have balance condition as

$$\frac{P}{Q} = \frac{R}{S}$$

Meter Bridge

A meter bridge is also known as slide wire bridge. It is called meter bridge because length of wire used in it is one meter.

It is an electrical device used to determine the resistance and hence specific resistance of material of given wire/conductor.



It is based on the principle of balanced Wheatstone bridge. For a uniform cross-section wire,

Resistance of wire $\propto$ Length of conductor

At balanced condition of bridge,

$$\frac{P}{Q} = \frac{R}{S} \text{ or } \frac{l}{100 - l} = \frac{R}{S} \Rightarrow S = \left(\frac{100 - l}{l}\right) \times R$$

where, l is the balancing length.

Potentiometer

It is an electrical device which can

(i) measure the potential difference with greater accuracy.

(ii) measure the emf of a cell.

(iii) compare the emfs of two cells.

(iv) be used to determine the internal resistance of a primary cell.

Working Principle

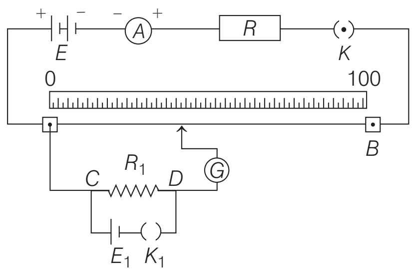
The potentiometer works on the principle that potential difference across any two points of uniform current carrying conductor is directly proportional to the length between the two points.

i.e. $V \propto l$

Applications of Potentiometer

There are following applications of potentiometer:

(i) Measurement of Potential Difference Using Potentiometers



If r is the resistance of potentiometer wire of length L, then current through potentiometer wire is

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

Potential drop across the entire potentiometer wire $= Ir = \left(\frac{E}{R + r}\right) r$

Potential gradient of potentiometer wire,

$$K = [E/(R + r)]\, r/L \;\Rightarrow\; V = Kl = [E/\,(R + r)]\, r/L\,(l)$$

where, V is potential drop across length l.

The potentiometer is a better device to measure potential difference than a voltmeter as null point method is used. Hence, it can measure even the emf of cell which a voltmeter cannot. It measures potential difference with greater accuracy.

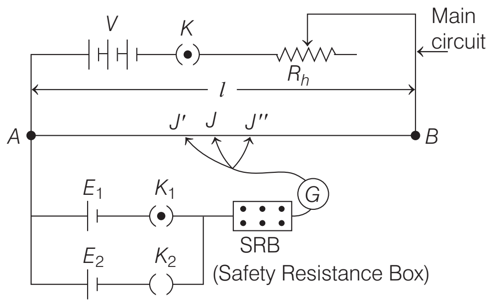
(ii) Comparing EMFs of Two Cells

The emfs of two primary cells can be compared using potentiometer using

$$E_1/E_2 = l_1/l_2$$

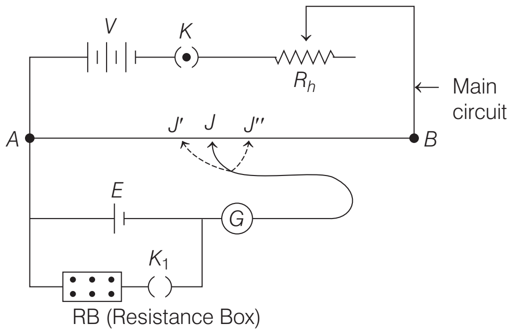
where, l_1 and l_2 are the balancing lengths corresponding to cells of emfs E_1 and E_2, respectively.

Circuit diagram for comparing the emfs of two primary cells.



(iii) To Measure Internal Resistance of a Cell

The internal resistance can be determined using the following circuit:



If l_1, l_2 are the balancing lengths when key K_1 is opened and closed respectively and resistance R is applied, then internal resistance of primary cell is given by

$$r = R\left(\frac{l_1}{l_2} - 1\right)$$

The potentiometer works only when

(i) the terminal voltage applied by driving cell is greater than the emf of primary cell.

(ii) the positive terminals of driving cell and primary cell are connected at the zero end of potentiometer wire.

PRACTICE QUESTIONS

Exam', Textbook's & Other Imp. Questions

1 MARK *Questions*

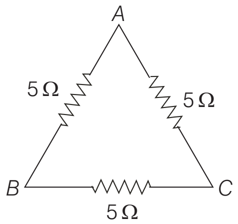
Exams' Questions

Q.1 Three resistances each of 5 Ω are connected to form a triangle. How much is the resistance between two ends of any arm of the triangle in this combination? (Write the answer only) **[2013 Instant]**

Or

Three resistances each of 5 Ω are connected to form a triangle. The resistance between any two terminals is .... (Fill in the blank) **[2011]**

Sol Consider the figure,



∵ Resistance R_{AB} and R_{AC} are connected in series.

So, $R_s = 5 + 5 = 10\,\Omega$

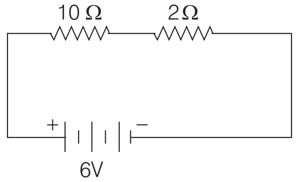
Also, R_s is connected in parallel with R_{BC}.

$$\therefore \quad R_P = \frac{R_s R_{BC}}{R_s + R_{BC}} = \frac{10 \times 5}{10 + 5} = \frac{10}{3} = 3.33\,\Omega$$

So, equivalent resistance between two ends (B and C) of triangle is 3.33Ω. **(1)**

Q.2 Draw the circuit diagram to measure the potential difference across a 10 Ω resistor when it is connected in series with a 20 Ω resistor and a 6 V source. **[2016]**

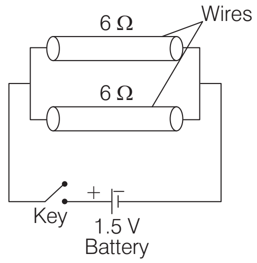
Sol



(1)

Q.3 You are given a cell of emf 1.5 V and two wires each of resistance 6 Ω and a key. Draw the circuit diagram to get the maximum current in the circuit using these. **[2015]**

Sol



(1)

Q.4 Three identical 3 V batteries are connected in parallel. The emf of the combination is **[2012 Instant]**

(a) 9 V (b) 3 V (c) 1 V (d) 6 V

Sol (*b*) Since, the batteries are connected in parallel. So, the potential drop will be same everywhere.

Hence, the correct option is (c). **(1)**

Q.5 Two electrical conducting wires are connected in parallel. The resultant resistance of the combination is 0.5 Ω. One of these has a resistance of 1Ω. The resistance of the other is **[2011 Instant]**

(a) 0.5 Ω (b) 1 Ω (c) 1.5 Ω (d) 2 Ω

Sol (*b*) As, $R_P = 0.5\,\Omega$, $R_1 = 1\,\Omega$

So, resistance, $\dfrac{1}{R_P} = \dfrac{1}{R_1} + \dfrac{1}{R_2}$

$$\Rightarrow \quad \frac{1}{R_2} = \frac{1}{R_P} - \frac{1}{R_1} = \frac{1}{0.5} - \frac{1}{1} = 2 - 1 = 1$$

$$\therefore \quad R_2 = 1\,\Omega$$ **(1)**

Q.6 A cell of emf E is connected across a conductor of resistance R. If the potential difference across the terminals of the conductor is found to be V, then the internal resistance of the cell is

(a) $RV(E - V)$ (b) $R\,(E - V)$

(c) $\left(\dfrac{E - V}{V}\right)R$ (d) $\left(\dfrac{E - R}{V}\right)V$ **[2010]**

Sol (*c*) ∵ $E = V + Ir$

So, $$r = \frac{E - V}{I} = \frac{E - V}{\dfrac{V}{R}}$$

$$\therefore \quad r = \left(\frac{E - V}{V}\right)R$$ **(1)**

Q.7 Three cells of emfs 2 V, 5 V and 7 V are connected in parallel. The effective emf of the combination is **[2009]**

(a) $\frac{70}{47}$ V (b) 14 V (c) 7 V (d) 2 V

Sol (*c*) As, the cells are connected in parallel, so the effective emf of the combination will be the maximum of 2 V, 5 V and 7 V.

i.e. $E_{eff} = 7$ V **(1)**

Q.8 A simple chemical cell has an emf of 2 V. When the circuit containing this cell is open, what is the potential difference between the two terminals? Neglect the internal resistance of the cell. (Write the answer only.) **[2008, Textbook]**

Sol 2 V;

In open circuit, the terminal potential difference will be equal to the emf of the cell. **(1)**

Q.9 What is the terminal potential difference of a cell when short-circuited? **[2007]**

Sol The terminal potential difference of a cell when its short-circuited is zero. **(1)**

Q.10 When is a Wheatstone bridge called balanced? **[2007]**

Sol A Wheatstone bridge is said to be balanced when the galvanometer shows zero deflection. **(1)**

Q.11 The potential difference across a cell of emf 4 V drops to 2 V when a current of 2 A is drawn from it. What is the internal resistance of the cell? **[2002]**

Sol Given, $E = 4$ V, $V = 2$ V, $I = 2$ A, $r = ?$

$\because$ emf, $E = V + Ir$

So, internal resistance,

$$r = \frac{E - V}{I} = \frac{4-2}{2} = 1\ \Omega$$ **(1)**

Important Questions

Q.12 In a simple DC circuit supplying current, the emf of a cell is **[Textbook]**

(a) always greater than its terminal potential difference
(b) always less than its terminal potential difference
(c) always equal to its terminal potential difference
(d) may be greater than or equal to the terminal potential difference

Sol (*d*) As we know that,

$$V = E - Ir \Rightarrow E = V + Ir \quad \text{...(i)}$$

where, V = terminal potential difference ,
E = emf of cell
and I = current drawn from cell.

When no current is drawn from the cell,

i.e. $I = 0$ then, $V = E$ ...(ii)

From Eqs. (i) and (ii), it is clear that in a simple DC circuit supplying current the emf of a cell is may be greater than or equal to the terminal potential difference. **(1)**

Q.13 During charging of a storage cell, its terminal potential difference becomes **[Textbook]**

(a) zero (b) greater than its emf
(c) less than its emf (d) equal to its emf

Sol (*b*) During charging of a cell the current flows from positive electrode to negative electrode of the cell. Thus, the terminal potential difference of cell becomes greater than the emf of the cell. **(1)**

Q.14 The current in electrolyte is due to **[Textbook]**

(a) positive ions only
(b) negative ions only
(c) Both positive and negative ions
(d) holes

Sol (*c*) The mobile ions (positive and negative) are used for carrying charge through the solution. An electrolyte solution conducts electricity because of movement of ions in the solution. **(1)**

Q.15 The smallest resistance that one can obtain with five $0.2\,\Omega$ resistors is **[Textbook]**

(a) 1Ω (b) $0.5\,\Omega$ (c) $0.25\,\Omega$ (d) $0.04\,\Omega$

Sol (*d*) To get the smallest resistance, we connect all the resistances in parallel combination.

Now, $\frac{1}{R_{eq}} = \frac{1}{0.2} + \frac{1}{0.2} + \frac{1}{0.2} + \frac{1}{0.2} + \frac{1}{0.2}$

$$\frac{1}{R_{eq}} = \frac{5}{0.2} \Rightarrow R_{eq} = \frac{0.2}{5} = 0.04\,\Omega$$ **(1)**

Q.16 In order to get a resistance of $0.1\ \Omega$, the number of $1\ \Omega$ resistor to be connected in parallel is **[Textbook]**

(a) 1 (b) 10 (c) 100 (d) 1000

Sol (*b*) If n resistors of each resistance R are connected in parallel, then their equivalent resistance is

$$R_{eq} = \frac{R}{n}$$

Given, $R_{eq} = 0.1\,\Omega$ and $R = 1\Omega$

$$n = \frac{R}{R_{eq}} = \frac{1}{0.1} = 10$$ **(1)**

Q.17 Three cells each of emf 1.5 V and internal resistance $1\ \Omega$ are connected in parallel. The combination will have an emf of **[Textbook]**

(a) 4.5 V (b) 3 V (c) 1.5 V (d) 0.5 V

Sol (c) In the parallel combination of the cell, potential difference remains same. Hence, the emf of the combination is 1.5 V. **(1)**

Q.18 A primary cell has an emf of 2 V. When short circuited, it gives a current of 4 A. Its internal resistance is **[Textbook]**

(a) $0.5\,\Omega$ (b) $2\,\Omega$ (c) 6Ω (d) $8\,\Omega$

Sol (*a*) Given, $E = 2$ V and $i_{sc} = 4$

Short circuit current, $i_{sc} = \dfrac{E}{r}$ [as $R = 0$]

$$4 = \frac{2}{r} \Rightarrow r = \frac{2}{4} = 0.5\,\Omega \qquad \textbf{(1)}$$

Q.19 A wire has a resistance of $12\,\Omega$. It is bent to form a circle. The effective resistance between the ends of any of its diameter is **[Textbook]**

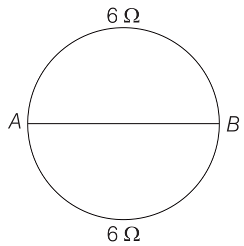
(a) $24\,\Omega$ (b) $12\,\Omega$ (c) $6\,\Omega$ (d) $3\,\Omega$

Sol (*d*) Given, resistance of wire,

$R = 120\,\Omega$

After bending of the wire total resistance will be $12\,\Omega$.

Now, along any diameter, we can say that the whole circle is divided into two segments. So, the resistance of each segment is half, i.e. $6\,\Omega$.



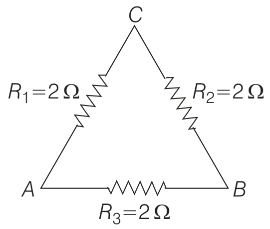
Now, these two segments are connected in parallel. So, the effective resistance is

$$\frac{1}{R_{eq}} = \frac{1}{6} + \frac{1}{6} \Rightarrow \frac{1}{R_{eq}} = \frac{2}{6} \Rightarrow R_{eq} = 3\Omega \qquad \textbf{(1)}$$

Q.20 Three $2\,\Omega$ resistors are arranged in a triangle. The resistance between any two corners of the triangle is **[Textbook]**

(a) $6\,\Omega$ (b) $2\,\Omega$ (c) $4/3\,\Omega$ (d) $3/4\,\Omega$

Sol (*c*) According to the question,



In the above circuit, between terminals A and B.

R_1 and R_2 are connected in series combination and its equivalent resistance is parallel with R_3.

Now, $R' = R_1 + R_2 = 2 + 2 = 4\Omega$

$$\frac{1}{R_{eq}} = \frac{1}{R'} + \frac{1}{R_3} \Rightarrow \frac{1}{R_{eq}} = \frac{1}{4} + \frac{1}{2}$$

$$\frac{1}{R_{eq}} = \frac{1+2}{4} \Rightarrow \frac{1}{R_{eq}} = \frac{3}{4} \Rightarrow R_{eq} = \frac{4}{3}\Omega \qquad \textbf{(1)}$$

Q.21 A 50 V battery is connected across a $10\,\Omega$ resistor. The current obtained is 4.5 A. The internal resistance of the battery is **[Textbook]**

(a) zero (b) $0.5\,\Omega$ (c) 1.1Ω (d) $5\,\Omega$

Sol (*c*) Given, $E = 50$ V, $R = 10\,\Omega$ and $i = 4.5$ A

As we know that, $i = \dfrac{E}{R + r}$

$$4.5 = \frac{50}{10 + r} \Rightarrow 4.5(10 + r) = 50$$

$$10 + r = 11.11 \Rightarrow r = 11.11 - 10 = 1.1\Omega \qquad \textbf{(1)}$$

Q.22 Kirchhoff's first law is based on the principle of **[Textbook]**

(a) conservation of charge (b) conservation of energy

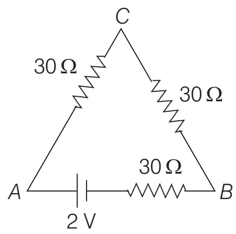
(c) separation of charge (d) separation of energy

Sol (*a*) Kirchhoff's first law is based on the principle of conservation of charge. According to this law, the sum of currents flowing into a junction or node is equal to the sum of the currents flowing out of it. **(1)**

Q.23 Three resistors each of resistance $30\,\Omega$ are arranged to form an equilateral triangle. A battery of emf 2V and negligible internal resistance is connected between any two vertices of the triangle. The current delivered by the arrangement is **[Textbook]**

(a) 0.2 A (b) 0.1 A (c) 0.067 A (d) 0.033 A

Sol (*b*) Here two $30\,\Omega$ resistances are connected in series combination and its equivalent is in parallel with third $30\,\Omega$ resistance. Hence, equivalent resistance



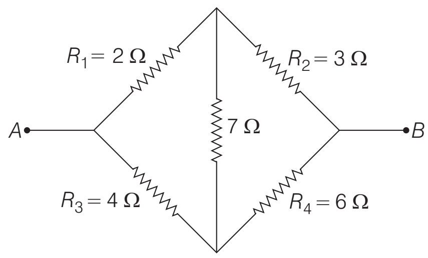
$$R_s = R_1 + R_2 = 30 + 30 = 60\Omega$$

$$R_{eff} = \frac{R_s \times R_3}{R_s + R_3}$$

$$R_{eff} = \frac{60 \times 30}{60 + 30} = 20\Omega$$

Current, $I = \dfrac{V}{R_{eff}} = \dfrac{2}{20} = 0.1$ A **(1)**

Q.24 Five resistances are connected to form a bridge as shown in the circuit diagram given below. The effective resistance between the points A and B is nearly **[Textbook]**



(a) $3.33\,\Omega$ (b) $6\,\Omega$

(c) $6.67\,\Omega$ (d) $15\,\Omega$

Sol (a) Given, $R_1 = 2\Omega$, $R_2 = 3\Omega$, $R_3 = 4\Omega$ and $R_4 = 6\Omega$

In the given circuit diagram, the 4 resistors satisfy the Wheatstone bridge balance condition. Hence, 7Ω resistance becomes inactive.

Now, equivalent resistance between A and B,

$$R_{AB} = (R_1 + R_2) \,||\, (R_3 + R_4)$$

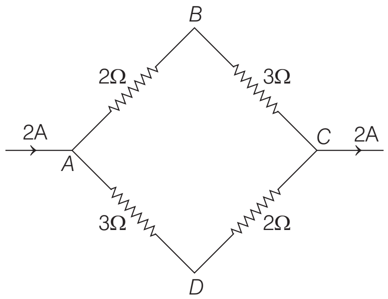
$$\Rightarrow \quad R_{AB} = (2+3) \,||\, (4+6)$$

$$\Rightarrow \quad R_{AB} = \frac{5 \times 10}{5 + 10}$$

$$= \frac{50}{15} = 3.33\Omega$$

(1)

Q.25 A current of 2A enters into the arrangement of resistors given below at A and leaves it at C.



The potential difference between the points B and D, i.e. $V_B - V_D$ will be **[Textbook]**

(a) + 2V (b) +1V (c) −1V (d) −2 V

Sol (b) From given figure,

Current through each arm ABC and $ADC = 1$ A

[$\because$ resistance of each arm is equal to current divides equally in both arms.]

$$V_A - V_B = 2 \quad \text{...(i)}$$

and $$V_A - V_D = 3 \quad \text{...(ii)}$$

From Eqs. (i) and (ii), we get

$$V_A - V_B = IR_{AB} = 1 \times 2 = 2\text{V} \quad \text{...(iii)}$$

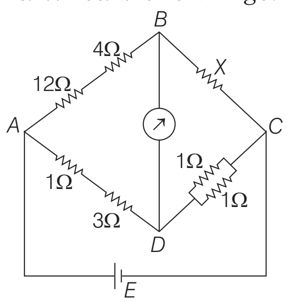
$$V_A - V_D = IR_{AD} = 1 \times 3 = 3\text{V} \quad \text{...(iv)}$$

Now, subtracting Eq. (iii) from Eq. (iv), we get

$$V_B - V_D = +1\text{ V}$$

(1)

Q.26 Given below is an arrangement of resistors in the form of a Wheatstone bridge.



For the bridge to be balanced, the unknown resistance X should be **[Textbook]**

(a) $4\,\Omega$ (b) $3\,\Omega$ (c) $2\,\Omega$ (d) 1Ω

Sol (c) From given figure,

The equivalent resistance of each arm of bridge,

$$R_{AB} = 12 + 4 = 16\Omega$$

$$R_{BC} = X$$

$$R_{AD} = 1 + 3 = 4\Omega$$

$$R_{CD} = \frac{1 \times 1}{1 + 1} = \frac{1}{2} = 0.5\Omega$$

From the balanced condition of Wheatstone bridge,

$$\frac{R_{AB}}{R_{BC}} = \frac{R_{AD}}{R_{CD}}$$

$$\frac{16}{X} = \frac{4}{0.5}$$

$$X = \frac{16 \times 0.5}{4}$$

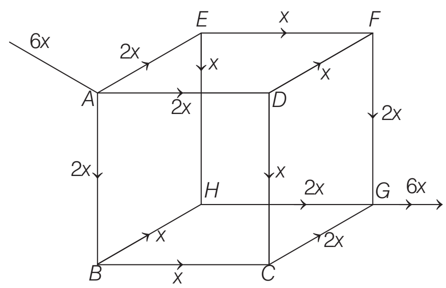
$$X = 2\,\Omega$$

(1)

Q.27 Twelve identical resistors each having resistance R are joined to form a skeleton cube. The equivalent resistance between any two diagonally opposite ends will be **[Textbook]**

(a) $12R$ (b) $3R$ (c) $\left(\frac{6}{5}\right)R$ (d) $\left(\frac{5}{6}\right)R$

Sol (d)



Here 12 resistance are arranged such that they form a cube. Now, each of the 12 wires represents a resistor of value R.

Let assume that we have attached a voltage source (or emf V) across the end A and G and thus current starts to flow in the network as shown in above figure.

Applying KVL in loop $ABCGA$

$$V = 2xR + xR + 2xR$$

$$V = 5xR \quad \text{...(i)}$$

According to Ohm's law,

$$V = 6xr$$

(where, r is resistance in external circuit) ...(ii)

From Eqs. (i) and (ii), we get

$$5xR = 6xr \Rightarrow r = \left(\frac{5}{6}\right)R$$

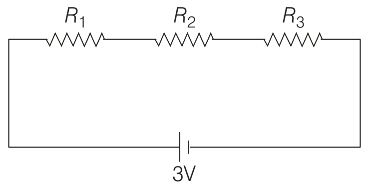
(1)

Q.28 A cell having an emf of 3 V and negligible internal resistance is connected across a series combination of three resistances of value 3 Ω, 4 Ω and 5 Ω. The potential difference across the 4 Ω resistor is **[Textbook]**

(a) 0.5V (b) 1V (c) 1.5 V (d) 3 V

Sol (*b*) According to the question,

$R_1 = 3\,\Omega$, $R_2 = 4\,\Omega$, $R_3 = 5\,\Omega$ and $E = 3$ V



Equivalent resistance of circuit,

$$R_{eq} = R_1 + R_2 + R_3 = 3 + 4 + 5 = 12\Omega$$

As we know that, $V = IR_{eq}$

$$I = \frac{V}{R_{eq}} = \frac{3}{12} = \frac{1}{4}\text{ A}$$

The potential difference across the 4Ω resistor is

$$V = IR_2 = \frac{1}{4} \times 4 = 1\text{ V}$$ **(1)**

Q.29 An electrician has only two resistances. By using them he is able to obtain resistances of 3Ω, 4Ω, 12 Ω and 16 Ω. The two resistances are **[Textbook]**

(a) 3Ω and 13 Ω (b) 4 Ω and 12Ω

(c) 6 Ω and 10Ω (d) 7 Ω and 9Ω

Sol (b) The two resistances are 4Ω and 12Ω. When we will use it individually, we get equivalent resistance of 4Ω and 12Ω. When both resistances are connected in series combination, then its equivalent resistance will be 16Ω and in the parallel combination the equivalent resistance will be

$$\frac{1}{R_{eq}} = \frac{1}{4} + \frac{1}{12}$$

$$\frac{1}{R_{eq}} = \frac{3+1}{12} \Rightarrow R_{eq} = 3\Omega$$ **(1)**

Q.30 A total number of 24 cells each of emf 1.5V and internal resistance 0.5 Ω are combined in mixed grouping to deliver maximum current in an external resistor of 12 Ω. There are *m* rows of such cells in parallel combination with *n* cells in series in each row. Then, the values of *m* and *n* are **[Textbook]**

(a) $n = 12, m = 2$ (b) $n = 8, m = 3$

(c) $n = 6, m = 4$ (d) $n = 4, m = 6$

Sol (*a*) Given,

Total number of cells, $nm = 24$ ...(i)

Emf of each cell = 1.5 V

Internal resistance of each cell, $r = 2\Omega$

External resistance of the circuit = 12 Ω

Resistance of each row = $2n\Omega$

Total internal resistance due to all cells = R

$$\frac{1}{R} = \frac{1}{2n} + \frac{1}{2n} + \ldots\ldots m \text{ times}$$

$$\frac{1}{R} = \frac{m}{2n} \Rightarrow R = \frac{2n}{m}$$

We know that, the maximum amount of current passes through the circuit when the internal resistance of cells equal the external resistance.

$$\frac{2n}{m} = 12$$

$$\frac{n}{m} = 6 \quad \ldots\text{(ii)}$$

Multiplying the Eqs. (i) and (ii), we get

$$nm \times \frac{n}{m} = 24 \times 6$$

$$n^2 = 144$$

$$n = 12$$

Now, putting the value of *n* in Eq. (i), we get

$$12 \times m = 24 \Rightarrow m = 2$$ **(1)**

Q.31 Three resistances 2Ω, 3Ω and 6Ω are connected in parallel. The effective resistance is .... (Fill in the blank) **[Textbook]**

Sol Equivalent resistance of combination,

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_{eq}} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6}$$

$$\frac{1}{R_{eq}} = \frac{3+2+1}{6} \Rightarrow R_{eq} = 1\Omega$$ **(1)**

Q.32 Kirchhoff's second law is based on the principle of conservation of energy. (True or False) **[Textbook]**

Sol True;

According the Kirchhoff's second law, in any closed part of an electrical circuit, the algebraic sum of the emfs is equal to the algebraic sum of the products of the resistances and currents flowing through them. Hence, it is based on principle of conservation of energy. **(1)**

Q.33 Three resistors each of 1 Ω are connected in parallel. The effective resistance is 3 Ω. (True or False) **[Textbook]**

Sol False;

When three resistors of 1Ω are connected in the parallel combination, then its equivalent resistance is given by

$$R_{eq} = \frac{1 \times 1 \times 1}{1+1+1} = \frac{1}{3}\Omega$$ **(1)**

Q.34 Define electromotive force (emf) of a cell. **[Textbook]**

Sol The potential difference between two ends of the cell in an open circuit (when no current is drawn from the cell) is called the electromotive force (emf) of the cell. **(1)**

Q.35 Define internal resistance of a cell. **[Textbook]**

Sol The resistance offered by the electrolyte of the cell when the electric current flows through it is known as the internal resistance of the cell. **(1)**

Q.36 Why are resistances connected in series?

Sol The resistances are connected in series to increase the resistance of the circuit. **(1)**

Q.37 Mention the factor on which the internal resistance of cell depends? **[Textbook]**

Sol Internal resistance of a cell depends up on the following factors:

(i) The nature of electrolyte.
(ii) Distance between the electrodes.
(iii) Area of electrodes inside the electrolyte. **(1)**

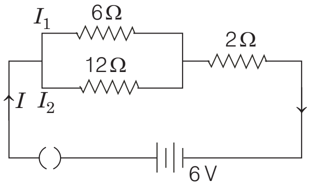
2 MARKS *Questions*

Exams' Questions

Q.38 Three resistances, each of $5\,\Omega$ are connected to form a triangle. Calculate the resistance between two ends of any arm. **[2019]**

Sol Refer to solution 1. **(2)**

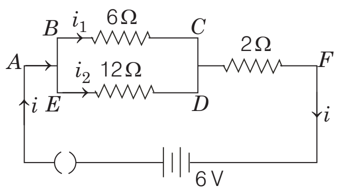
Q.39 Calculate i in the given circuit applying Kirchhoff's laws.



[2017]

Sol Applying Kirchhoff's law, in closed loop *ABCFA*

$$6i_1 + 2i = 6 \quad \text{...(i)} \textbf{(1/2)}$$



Similarly, applying Kirchhoff's law in closed loop *AEDFA*

$$12i_2 + 2i = 6$$

or $\quad 12(i - i_1) + 2i = 6$ **(1/2)**

or $\quad 12i - 12i_1 + 2i = 6$

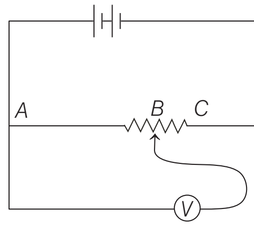
or $\quad -12i_1 + 14i = 6$ ...(ii)

Now, adding the Eqs. (i) × 2 and (ii), we get

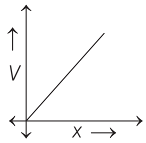
$$12i_1 + 4i - 12i_1 + 14i = 12 + 6$$

$$18i = 18 \Rightarrow i = 1\text{ A} \quad \textbf{(1)}$$

Q.40 The voltmeter reading in the given circuit as shown above can be changed by moving the sliding contact B from A to C. Plot a graph to show the variation of the voltmeter reading with the distance of the contact point B from A towards C. **[2015]**



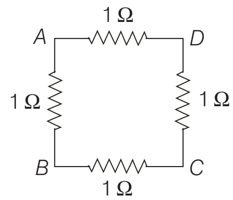
Sol



Here, x is distance between A and B as B is moved. **(2)**

Q.41 Four resistances each of $1\,\Omega$ are connected to form a square. Find the resistance across any one side of the square. **[2013]**

Sol Let us find the net resistance between B and C.



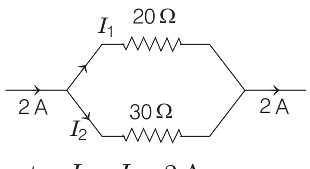
Here, R_{BA}, R_{AD} and R_{DC} are in series.

So, $\quad R_s = 1 + 1 + 1 = 3\ \Omega$ **(1)**

Since, R_s is in parallel with R_{BC}.

So, $\quad R_{\text{eq}} = R_P = \dfrac{R_s R_{BC}}{R_s + R_{BC}} = \dfrac{3 \times 1}{3 + 1} = \dfrac{3}{4} = 0.75\ \Omega$ **(1)**

Q.42 A current of 2 A gets divided into I_1 and I_2 through resistances $20\ \Omega$ and $30\ \Omega$, respectively connected as shown in the figure. Calculate I_1 and I_2. **[2013 Instant]**



Sol Given, curent, $\quad I_1 + I_2 = 2\text{ A}$ ...(i)

As two resistors are in parallel combination, so potential drop across them will be same.

i.e. $\quad V_1 = V_2 \quad \text{or} \quad I_1 \times 20 = I_2 \times 30$

$\therefore \quad I_1 = \dfrac{3}{2} I_2$ **(1)**

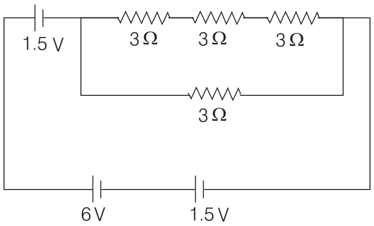
By substituting I_1 in Eq. (i), we get

$$\left(\frac{3}{2}+1\right) I_2 = 2$$

$$\therefore \quad I_2 = 2 \times \frac{2}{5} = \frac{4}{5} = 0.8 \text{ A}$$

$$\therefore \quad I_1 = 2 - 0.8 = 1.2 \text{ A} \qquad \textbf{(1)}$$

Q.43 Calculate the main current in the given circuit. **[2012]**



Sol From the circuit, $R_s = 3 + 3 + 3 = 9\,\Omega$

This R_s is in parallel with another $3\,\Omega$ resistor.

So, $$R_{eq} = \frac{R_s \times 3}{R_s + 3} = \frac{9 \times 3}{9+3} = \frac{9}{4} = 2.25\ \Omega \qquad \textbf{(1)}$$

Also, net emf $= E_{net} = 1.5 + 6 + (-1.5) = 6\text{ V}$

$$I = \frac{E_{net}}{R_{eq}} = \frac{6}{2.25} = \frac{24}{9} = 2.67 \text{ A} \qquad \textbf{(1)}$$

Q.44 State Kirchhoff's laws as applicable to electrical networks. **[2011, 2007, 2005 Instant]**

Sol **Kirchhoff's laws** Refer to text on page 73. **(2)**

Q.45 n number of resistances each of r, are connected in parallel to give an equivalent resistance of R. If these resistances are connected in series, express the equivalent resistance of the new combination in terms of n and R. **[2011 Instant]**

Sol Given, n = number of resistors

and r = resistance of each resistor.

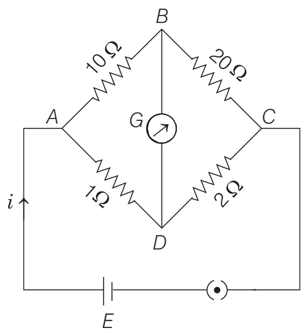
$$R = \frac{r}{n} \qquad \textbf{(1)}$$

If these resistances are connected in series, then

$$R_{eq} = nr = n\,(nR)$$

So, $$R_{eq} = n^2 R \qquad \textbf{(1)}$$

Q.46 What is the current through the arm BD in the circuit diagram given below? Answer with reason. **[2009]**

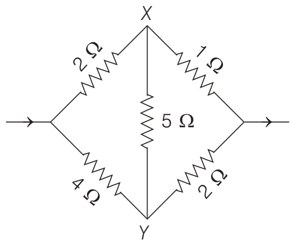


Sol As, it is clear from the diagram that

$$\frac{P}{Q} = \frac{R}{S} \qquad \left[\because \frac{10}{1} = \frac{20}{2}\right] \qquad \textbf{(1)}$$

So, the bridge is balanced and no current flows through the galvanometer. Hence, the current through arm BD is zero. **(1)**

Q.47 Find the equivalent resistance between points X and Y in combination of resistance as shown in figure. **[2008 Instant]**



Sol From the given diagram resistance,

$$R_{s_1} = 2 + 4 = 6\,\Omega$$

$$R_{s_2} = 1 + 2 = 3\,\Omega \qquad \textbf{(1)}$$

Now, R_{s_1}, R_{s_2} and $5\,\Omega$ are in parallel combination.

$$\therefore \quad \frac{1}{R_p} = \frac{1}{6} + \frac{1}{3} + \frac{1}{5} = \frac{5+10+6}{30} = \frac{21}{30} = \frac{7}{10}\Omega$$

Hence, equivalent resistance between X and Y is $\frac{10}{7}\Omega$. **(1)**

Q.48 Five cells each of internal resistance $0.2\,\Omega$ and emf 2 V are connected in series with a resistance of 4Ω. Find the current through the external resistance. **[2007]**

Sol Given, $n = 5, r = 0.2\,\Omega, E = 2\text{ V}, R = 4\,\Omega, I_{ext} = ?$

Total emf in the circuit $= nE = 5 \times 2 = 10$ V

Total resistance in the circuit $= R + 5r$

$= 4 + 5 \times 0.2 = 5\,\Omega$ **(1)**

So, current through the external resistance is the total current of circuit.

So, $$I_{ext} = \frac{10}{5} = 2 \text{ A} \qquad \textbf{(1)}$$

Q.49 (i) Two resistances of $10\,\Omega$ each are connected in series and again in parallel. What will be the ratio of their effective resistances in two cases?

(ii) The emf of a cell is 2 V. What is meant by it? **[2006 Instant]**

Sol (i) Given, $R_1 = R_2 = 10\ \Omega$ and $R_s = 20\ \Omega$

$$R_p = \frac{10 \times 10}{10 + 10} = 5\,\Omega \Rightarrow \frac{R_s}{R_p} = \frac{20}{5} = \frac{4}{1} \qquad \textbf{(1)}$$

(ii) Given, the emf of a cell is 2 V.

As the emf of cell is the energy gained by 1C of charge as it passes through it. So, the emf of a cell is 2 V if 2 J of work is done by the cell to drive 1C of charge round the circuit. **(1)**

Q.50 You are given 20 cells, each of emf 1.5 V and internal resistance of $0.3\,\Omega$. How would you arrange them to produce the maximum current in a circuit of $1.5\,\Omega$ resistance? **[2003]**

Sol Given, $n = 20$, $E = 1.5$ V, $r = 0.3\,\Omega$ and $R = 1.5\,\Omega$

In order to obtain maximum current, the cells should be mixed grouped in such a manner that the external resistance in the circuit is equal to the total internal resistance of the cells in the mixed group. **(1)**

Here, if we take $n = 10, m = 2$, then we get

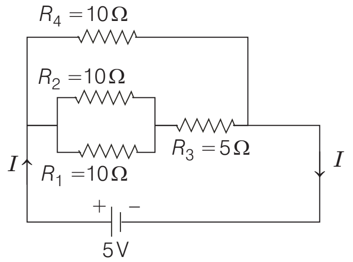
Total resistance,

$$R_T = \frac{nr}{m} = \frac{10}{2} \times 0.3 = 1.5\Omega \text{ (as given)}$$

This $\quad R_T = R_{\text{ext}}$

Thus, we should make 2 rows of 10 cells each. **(1)**

Q.51 Calculate the main current I in this circuits.



Or

What is the value of current I in given circuit? **[2002]**

Sol From the given diagram,

Resistance, $R_{P_1} = \dfrac{10 \times 10}{10 + 10} = 5\ \Omega$,

$$R_{S_1} = 5 + 5 = 10\ \Omega$$

$$R_{P_2} = \frac{10 \times 10}{10 + 10} = 5\ \Omega$$ **(1)**

So, $\quad R_{\text{eq}} = 5\ \Omega$

Given, $\quad E = 5$ V

$\therefore \quad I = \dfrac{E}{R_{\text{eq}}} = \dfrac{5}{5} = 1$ A **(1)**

Q.52 Determine the number of cells in series required to send a current of 0.5 A through a circuit having a resistance of 30Ω. Given that, the emf and internal resistance of each cell are 1.25 V and 0.5Ω, respectively? **[2001]**

Sol Given, $I = 0.5$ A, $R = 30\ \Omega$,

$$r = 0.5\ \Omega, E = 1.25 \text{ V}, n = ?$$

$\because$ Cells are in series combination.

So, $\quad E_{\text{eq}} = nE$

Also, current, $\quad I = \dfrac{nE}{R + nr}$ **(1)**

$$\frac{1}{2} = \frac{n \times \frac{5}{4}}{30 + \frac{n}{2}} = \frac{5n}{4} \times \frac{2}{60 + n}$$

$$\Rightarrow \quad \frac{1}{2} = \frac{5n}{120 + 2n} \Rightarrow 120 + 2n = 10n$$

$$\Rightarrow \quad 8n = 120 \Rightarrow n = \frac{120}{8} = 15$$

So, number of cells are 15. **(1)**

Important Questions

Q.53 A series combination of three resistors takes a current of 2 A from a 24 V supply. If the resistors are in the ratio 1 : 2 : 3, then find the values of unknown resistors.

Sol Given, $E = 24$ V, $I = 2$ A,

$$R_S = \frac{E}{I} = \frac{24}{2} = 12\,\Omega$$

Let R_1, R_2 and R_3 be the resistances of the three unknown resistors. **(1)**

As the resistance ratio $= 1:2:3$

So, $\quad R_1 = R, R_2 = 2R, R_3 = 3R$

Now, $\quad R_S = R + 2R + 3R = 6R$

Also, $\quad R_S = 12$

So, $\quad 6R = 12,\ R = 2\ \Omega$

$\therefore \quad R_1 = R = 2\,\Omega$

$R_2 = 2R = 4\,\Omega$

$R_3 = 3R = 6\,\Omega$ **(1)**

Q.54 Distinguish between emf and potential difference. **[Textbook]**

Sol **Difference between emf and terminal potential difference of a cell** Refer to text on page 71. **(2)**

Q.55 Give a sketch of Wheatstone bridge. **[Textbook]**

Sol **Wheatstone bridge** Refer to text on page 74. **(2)**

Q.56 A cell of emf 2 V and internal resistance $0.1\,\Omega$ is connected to a $3.9\,\Omega$ external resistance. What will be the potential difference across the terminals of cells?

Sol Given, $E = 2$V, $r = 0.1\ \Omega$, $R = 3.9\ \Omega$, $V = ?$

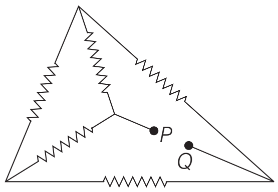
So, potential difference, $V = \dfrac{E}{R + r} R$

$$= \frac{2 \times 3.9}{3.9 + 0.1} = 1.95\,\Omega$$ **(2)**

3 MARKS *Questions*

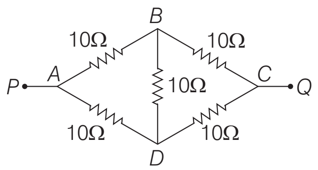
Exams' Questions

Q.57 Calculate the equivalent resistance between P and Q in the following circuit. Each resistance is of 10Ω. **[2018]**



Sol Resistance of each resistor is $10\ \Omega$.

Given, circuit is an example of balanced Wheatstone bridge. Therefore, no current will flows through BD.



(1)

AB and BC are in series and AD and DC are in series.

$\therefore \quad R_{ABC} = 10 + 10 = 20\,\Omega$

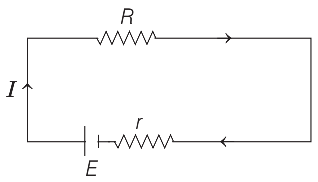
and $\quad R_{ADC} = 10 + 10 = 20\,\Omega$

Now, R_{ABC} and R_{ADC} are in parallel.

$$\therefore \quad \frac{1}{R_{PQ}} = \frac{1}{20} + \frac{1}{20} = \frac{2}{20} = \frac{1}{10}$$ **(2)**

Q.58 A battery of emf E and internal resistance r is connected to an external resistance R to complete the circuit. Show that the battery delivers the maximum power to R, when $R = r$. **[2015]**

Sol



Current through the circuit will be $I = \dfrac{E}{R + r}$ **(1)**

Power delivered $= VI$ **(1)**

Power will be maximum, when I will be maximum.

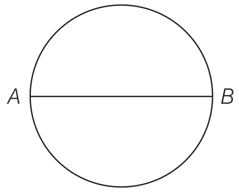
So, for maximum I, $r = R$ **(1)**

Q.59 Explain the relation between emf and potential difference with a circuit diagram. **[2013]**

Sol **Relation between potential difference, emf of the cell and internal resistance of a cell** Refer to text on page 71. **(3)**

Q.60 A wire has a resistance of $12\,\Omega$. It is bent to form a full circle. Calculate the effective resistance between two points on any diameter of the circle. **[2013 Instant]**

Sol As the resistance $12\,\Omega$ is divided in two halves.



So, $\quad R_1 = R_2 = \dfrac{12}{2} = 6\ \Omega$ **(2)**

Now, resistance between ends of diameter AB is

$$R_{\text{eq}} = \frac{R_1 R_2}{R_1 + R_2} = \frac{6 \times 6}{6 + 6} = 3\,\Omega$$ **(1)**

Important Questions

Q.61 Two wires of the same material having lengths in the ratio of 1 : 2 and diameters in the ratio of 2 : 3 are connected in series with an accumulator. Compute the ratio of the potential difference across the two wires.

Sol Let the lengths of the two wires 1 and 2 be $l_1 = l$ and $l_2 = 2l$ and their diameters be $D_1 = 2D$ and $D_2 = 3D$, respectively. Let ρ be resistivity of the material of the two wires.

Then, resistance of the wire 1,

$$R_1 = \rho_1 \frac{l_1}{A_1} = \rho \frac{l_1}{\pi r_1^2} = \rho \frac{l}{\pi\left(\frac{2D}{2}\right)^2} = \rho \frac{l}{\pi D^2}$$

The resistance of the wire 2,

$$R_2 = \rho_2 \frac{l_2}{A_2} = \rho \frac{l_2}{\pi r_2^2} = \rho \frac{2l}{\pi\left(\frac{3D}{2}\right)^2} = \rho \frac{8l}{9\pi D^2}$$ **(1)**

Then, total resistance of the series circuit, $R = R_1 + R_2$

or $$R = \rho \frac{l}{\pi D^2} + \rho \frac{8l}{9\pi D^2} = \rho \frac{17l}{9\pi D^2}$$

Let E be the emf of the accumulator. Then, current in the circuit, $I = \dfrac{E}{R} = \dfrac{E}{\rho} \dfrac{9\pi D^2}{17l}$ **(1)**

Now, potential difference across the wire 1,

$$V_1 = IR_1 = \frac{E}{\rho} \cdot \frac{9\pi D^2}{17l} \cdot \rho \frac{l}{\pi D^2} = \frac{9E}{17}$$

and potential difference across the wire 2,

$$V_2 = IR_2 = \frac{E}{\rho} \cdot \frac{9\pi D^2}{17l} \cdot \rho \frac{8\,l}{9\pi D^2} = \frac{8E}{17}$$

$$\therefore \quad \frac{V_1}{V_2} = \frac{9E}{17} \times \frac{17}{8E} = \frac{9}{8}$$ **(1)**

7 MARKS *Questions*

Exams' Questions

Q.62 State and explain Kirchhoff 's laws in electricity and apply these to obtain the balance condition of Wheatstone bridge. **[2019, 2014, 2012 Instant, 2010 Instant, 2008,2006,2004,2002]**

Sol **Kirchhoff 's laws** Refer to text on pages 73 and 74. **(7)**

Q.63 State Kirchhoff's laws for the network of conductors. Use the laws to obtain the balanced condition of a Wheatstone's bridge. Verify if the condition remains the same, when the positions of the battery and galvanometer are interchanged in the bridge. **[2016]**

Or State Kirchhoff 's laws used for electrical networks. Explain what is Wheatstone bridge and find its condition of balance using those laws. Does the bridge remain balance when the battery and galvanometer interchange their positions? **[2008]**

Sol **Kirchhoff 's laws** Refer to text on pages 73 and 74. **(6)**

Yes, bridge remains balanced when the battery and galvanometer interchange their positions. **(1)**

Q.64 Sketch the combination of m number of cells connected in parallel through an external resistance R. Each cell has emf E and internal resistance r . Derive an expression for the electric current passing through the circuit. Indicate the usefulness of such combination in specific cases of $R >> \frac{r}{m}$ and $R << \frac{r}{m}$, separately. **[2013, 2008, 2005 Instant]**

Sol Refer to text on page 3. **(5)**

Case I When $R >> \frac{r}{m}$

Then, $I = \frac{E}{R}$

Case II When $R << \frac{r}{m}$

Then, $I = \frac{E}{r/m} = \frac{m\,E}{r}$ **(2)**

Q.65 (i) State Kirchhoff's rules for any electrical network and use those to obtain the balance condition of the Wheatstone bridge.

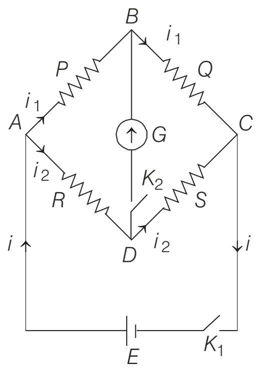
(ii) Use Kirchhoff's rules to obtain the formula for finding effective resistance in case of parallel combination of resistors. **[2012]**

Sol (i) **Statement of Kirchhoff's rules** Refer to text on pages 73 and 74. **(1)**

Wheatstone Bridge

Consider four resistances P, Q, R and S connected in four arms of a parallelogram $ABCD$.

One part i_1 flows in the arm AB and the other part i_2 flows in the arm AD.



The resistances P, Q, R and S are so adjusted that on pressing the key K_2 there is no deflection in the galvanometer G. That is, there is no current in the diagonal BD. Thus, the same current i_1 will flow in the arm BC as in the arm AB and the same i_2 will flow in the arm DC as in the arm AD.

Applying Kirchhoff's second law for the closed loop $BADB$, we have

$$-i_1P + i_2R = 0$$

$$Pi_1 = Ri_2 \quad \text{...(i)} \; \textbf{(1)}$$

Similarly, for the closed loop $CBDC$, we have

$$-i_1Q + i_2S = 0$$

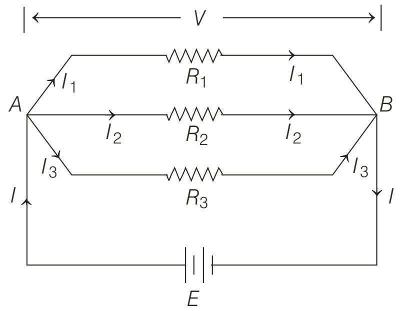
$$Qi_1 = Si_2 \quad \text{...(ii)} \; \textbf{(1)}$$

Dividing Eq. (i) by Eq. (ii), we have

$$\frac{i_1P}{i_1Q} = \frac{i_2R}{i_2S} \quad \text{or} \quad \frac{P}{Q} = \frac{R}{S}$$

This is the required formula of Wheatstone bridge. **(1)**

(ii) **Resistors in parallel** Consider three resistors with resistances R_1, R_2 and R_3 are connected in parallel. Let V be potential difference applied across A and B using battery E and I be main current in the circuit. Let I_1, I_2 and I_3 be the currents through three resistors.



On applying Kirchhoff's first law at point A, We have $I = I_1 + I_2 + I_3$ **(1)**

But, V across each resistor is given by

$$V = I_1R_1 = I_2R_2 = I_3R_3$$

So, $$I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \quad \textbf{(1)}$$

If R_p is equivalent resistance of given combination, then

$$V = IR_p$$

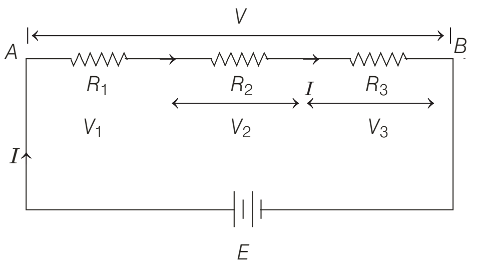
$$\therefore \quad \frac{V}{R_p} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \Rightarrow \frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad \textbf{(1)}$$

Q.66 Why do we use resistor in electrical circuit? Derive expression for equivalent resistance when three resistors are arranged in **[2011 Instant]**

(i) series combination, (ii) parallel combination.

Sol Resistors are used in electrical and electronic circuits for the controlled flow of current. **(1)**

(i) **Resistors in series**



Consider three resistors having resistances R_1, R_2 and R_3 are connected in series. Let V be the potential difference applied across A and B using the battery and the same current I be passing through each resistance. If V_1, V_2 and V_3 are the potential difference across R_1, R_2 and R_3 respectively, then **(1)**

$$V_1 = IR_1, \; V_2 = IR_2$$

and $V_3 = IR_3$ (Ohm's law)

But, $V = V_1 + V_2 + V_3 = IR_1 + IR_2 + IR_3$

$$V = I(R_1 + R_2 + R_3) \quad \textbf{(1)}$$

If R_s is the equivalent resistance of the given series combination of resistances.

Then, $V = IR_s$

$$\therefore \quad R_s = \frac{V}{I} = \frac{I}{I}(R_1 + R_2 + R_3)$$

$$\Rightarrow \quad R_s = R_1 + R_2 + R_3$$

Thus, the equivalent resistance of a number of resistors connected in series is equal to the sum of individual resistances. **(1)**

(ii) **Resistors in parallel** For parallel combination, refer to solution 65 (ii).

Thus, the reciprocal of equivalent resistance of a number of resistors connected in parallel is equal to the sum of the reciprocals of the individual resistances. **(3)**

Important Question

Q.68 Sketch the combination of n identical cells connected in series to an external resistor of resistance R. Each cell has emf E and internal resistance r. Derive an expression for electric current passing through circuit and deduce condition for maximum current.

Sol **Grouping of cells** Refer to text on page 72. **(7)**

Chapter Test

1 MARK *Questions*

1 What is the SI unit of emf of a cell?

2 How many resistance coil combined together can constitute a Wheatstone bridge?

3 Does a conductor becomes charged when a current is passed through it? **[Textbook]**

4 Write two factor on which the internal resistance of cell depends? **[Textbook]**

2 MARKS *Questions*

5 On what conservation principle is the
(i) Kirchhoff's first law based and
(ii) Kirchhoff's second law based?

6 What important conclusion can be drawn from Kirchoff's current law?

7 State the convention for the sign of electric current meeting at a point.

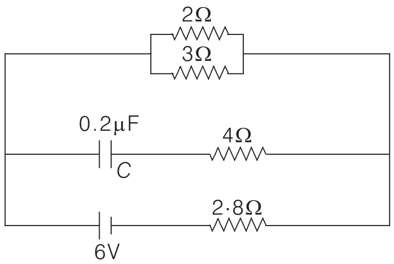
8 Two cells of emf 1.5 V and 2 V, respectively and internal resistances of 1 Ω and 2 Ω, respectively are connected in parallel to an external resistance of 5 Ω. Calculate the current in each of three branches.

3 MARKS *Questions*

9 Define emf of a source. Show that the emf of a source is equal to the maximum potential difference between its terminals when it is in the open circuit.

10 What is the internal resistance of a cell? Derive an expression for it.

11 Calculate the steady state current in 2Ω resistor shown in the circuit. So, no current in 4 Ω resistor. The internal resistance of cell is negligible.



7 MARKS *Questions*

12 A battery of n cells each of emf E and internal resistance r is connected across an external resistance R. Find the current in the circuit. Discuss the special case when
(i) $R >> nr$ and (ii) $R << nr$.

13 Describe a Wheatstone's bridge with a circuit diagram and obtain its condition of balance. Mention the importance of such bridge. **[Textbook]**

HINTS and ANSWERS

1. Volt

2. Any number

3. Yes

4. Conservation of charge, conservation of energy.

8. **Hint** $I = \dfrac{E}{R + r}$

[**Ans.** 1/34A, 9/34A]

11. **Hint** Capacitor blocks DC, now apply KVL

[**Ans.** 0.9A]