

Date: 01/02/2026



# Aakash

Medical | IIT-JEE | Foundations

Corporate Office : AESL, 3rd Floor, Incuspaze Campus-2, Plot-13, Sector-18,  
Udyog Vihar, Gurugram, Haryana-122015

## Answers & Solutions

Time : 3 Hrs.

for

M.M. : 180

# Indian National Junior Science Olympiad (INJSO)-2026

Indian Association of Physics Teachers (IAPT)

### IMPORTANT INSTRUCTIONS

- The answer-sheet must be returned to the invigilator. You can carry this question paper with you.
- Section I of this question paper has 15 questions (45 marks).
  - For each question in this section, **only one** of the four options is a correct answer.
  - For each question, a correct answer will earn 3 marks, a wrong answer will earn (-1) mark, and an un-attempted question will earn 0 marks.
  - If you mark more than one option, it would be treated as a wrong answer.
- Section II contains 9 questions worth 5 marks each. There is no negative marking (45 marks).
  - For each of these questions one or more option(s) may be correct.
  - You will get full credit for each question only if you mark all correct options and no wrong option. There are no partial marks for these 9 questions.
- Section III contains 11 questions (90 marks).
  - For all the questions in this section, the process involved in arriving at the solution is as important as the final answer. Valid assumptions / approximations are perfectly acceptable. Please write your method clearly, explicitly stating all the reasonings/ assumptions / approximations.

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**SECTION I:**  
**(Only one of the four options is correct)**

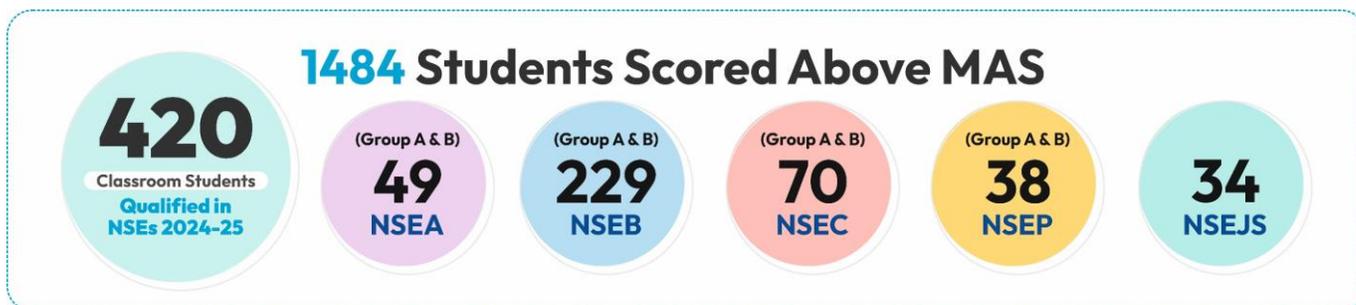
1. Which of the following statements are correct with respect to nerve impulse conduction in a brain slice cultured in an artificial medium?
- I. Conduction relies on electrical signals
  - II. Conduction is driven by sodium-potassium pump activity
  - III. Myelin slows down the conduction
  - IV. Conduction requires ATP hydrolysis
- (A) I and II only  
(B) I, III and IV only  
(C) II and IV only  
(D) I, II and IV only

**Answer (D)**

- Sol.** • Nerve impulse conduction occurs due to electrical changes along the neuronal membrane caused by ion movement.
- Conduction of impulse is driven by activity of sodium-potassium pump.
  - Myelin increases the speed of conduction.
  - ATP is required indirectly to restore ionic gradients through the  $\text{Na}^+/\text{K}^+$  pump, especially in a cultured brain slice. The overall process of nerve signalling is energy-intensive.
2. Nucleic acids can be resolved on an agarose gel by their electrophoretic mobility. They are visualised by a dye that binds quantitatively to the bases when they are paired (double stranded). Only in the bound form does the dye fluoresce brightly under UV light. What unique advantage does fluorescent dyes (Fds) impart in the detection of nucleic acids, compared to chromogenic dyes (Cds, like methylene blue or safranin), to visualize DNA on an agarose gel?
- (A) Fds enable visualization by binding specifically to DNA based on molecular weight.  
(B) Fds are inert and do not diffuse into the gel matrix, unlike Cds.  
(C) Fds provide a better signal-to-noise ratio compared to Cds.  
(D) Fds do not alter the structure of DNA as much as Cds.

**Answer (C)**

- Sol.** Fluorescent dyes emit strong fluorescence under UV light only when bound to dsDNA. This provides high sensitivity, high contrast and low background noise, making even small amounts of DNA visible. Chromogenic dyes give weak, diffuse staining and poor sensitivity.





4. For the formation of human gametes, the primordial germ cells in ovaries undergo meiotic division. Considering this, which of the following combination of cell types and chromatid number are correct?

	Cell 1	Cell 2	Chromatid number per cell
1.	Oogonium	Primary polar body	46
2.	Secondary oocyte	Ootid	23
3.	Primary oocyte	Primary polar body	46
4.	Primary polar body	Secondary polar body	23
5.	Oogonium	Primary oocyte	46
6.	Secondary oocyte	Oogonium	46
7.	Primary oocyte	Secondary oocyte	92
8.	Secondary polar body	Ovum	23

- (A) 1, 3, 5  
(B) 2, 3, 4  
(C) 1, 6, 8  
(D) 3, 4, 8

**Answer (C)**

**Sol.** The correct rows are:

**Row 1.**

Cell 1: Oogonium → 46 chromatids

Cell 2: Primary polar body → 46 chromatids

**Row 6 :**

Cell 1: Secondary oocyte → 46 chromatids

Cell 2: Oogonium → 46 chromatids

**Row 8:**

Cell 1: Secondary polar body → 23 chromatids

Cell 2: Ovum → 23 chromatids

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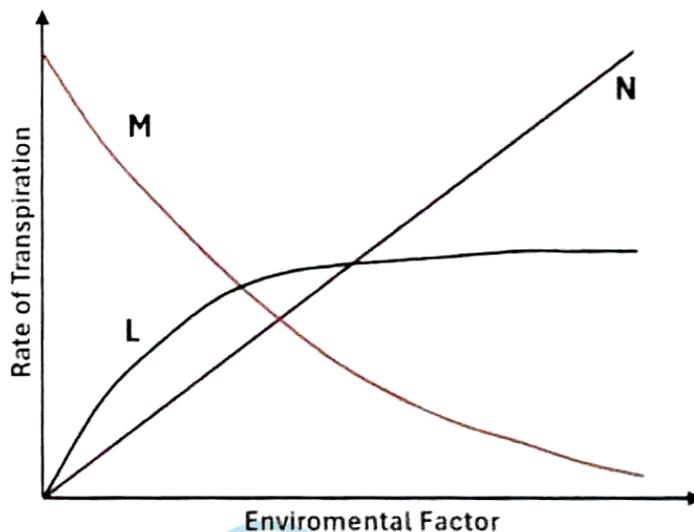
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5. Transpiration is the process by which water is lost from the aerial parts of plants, primarily through the stomata. The rate of transpiration is influenced by several environmental factors some of which are enlisted in the table below. The graph below shows three factors-L, M and N which affect the rate of transpiration in plants. Identify the correct combinations of L, M and N based on the patterns as seen in the graph.



	L	M	N
(A)	Humidity	Light intensity	Wind speed
(B)	Temperature	Wind speed	Humidity
(C)	Wind speed	Temperature	Light intensity
(D)	Light intensity	Humidity	Temperature

**Answer (D)**

- Sol.** • Higher the humidity, lesser the water vapour gradient, hence transpiration reduces. So, curve M represents humidity.
- Transpiration rate increases initially, then becomes constant during high light intensity. So, curve L represents light intensity.
  - As the temperature increases, evaporation becomes faster, thus leading to higher rate of transpiration, so curve N represents temperature.

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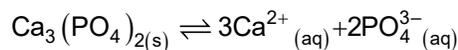
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6. When a slightly soluble ionic compound is added to water, some of it dissolves to form a solution, establishing equilibrium between the pure solid and a solution of its ions.

For the dissolution of calcium phosphate, one main component of kidney stones, the equilibrium can be written as follows, with the solid salt on the left:



The equilibrium constant for the dissolution of a sparingly soluble salt like calcium phosphate, is the **solubility product** ( $K_{\text{sp}}$ ) of the salt. The activity of pure  $\text{Ca}_3(\text{PO}_4)_2$  is a constant at given salt concentration. The solubility product expression for calcium phosphate is:

$$K_{\text{sp}} = [\text{Ca}^{2+}]^3 [\text{PO}_4^{3-}]^2$$

At 25°C and pH 7.00,  $K_{\text{sp}}$  for calcium phosphate is  $2.07 \times 10^{-33}$ , indicating that the concentrations of  $\text{Ca}^{2+}$  and  $\text{PO}_4^{3-}$  ions in solution that are in equilibrium with solid calcium phosphate are very low.

The solubility of calcium phosphate gets changed in presence of other salts containing similar ions as in calcium phosphate. Adding a common cation or anion shifts solubility equilibrium in the direction predicted by Le Chatelier's principle.

The solubilities of calcium phosphate are measured in different solutions at 25°C.

Choose the **correct** option from the table given below:

	Solubility of $\text{Ca}_3(\text{PO}_4)_2$ in moles/litre			
	Aqueous solution	0.01 M calcium chloride solution	0.025 M calcium nitrate solution	0.05 M sodium phosphate solution
(A)	$1.14 \times 10^{-7}$	$1.97 \times 10^{-11}$	$4.38 \times 10^{-15}$	$1.11 \times 10^{-15}$
(B)	$1.14 \times 10^{-7}$	$1.11 \times 10^{-15}$	$4.38 \times 10^{-15}$	$1.97 \times 10^{-11}$
(C)	$1.14 \times 10^{-7}$	$4.38 \times 10^{-15}$	$1.11 \times 10^{-15}$	$1.97 \times 10^{-11}$
(D)	$1.14 \times 10^{-7}$	$4.38 \times 10^{-15}$	$1.11 \times 10^{-15}$	$1.97 \times 10^{-15}$

Answer (C)

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Sol. Given equilibrium



$$\Rightarrow K_{sp} = [\text{Ca}^{2+}]^3 [\text{PO}_4^{3-}]^2$$

At 25°C and pH = 7

$$K_{sp} = 2.07 \times 10^{-33}$$

(i) Solubility in pure water

$$[\text{Ca}^{2+}] = 3s, [\text{PO}_4^{3-}] = 2s$$

$$\Rightarrow K_{sp} = (3s)^3 (2s)^2 = 108s^5$$

$$\Rightarrow s^5 = \frac{2.07}{108} \times 10^{-33}$$

$$s \approx 1.14 \times 10^{-7}$$

(ii) 0.01 M CaCl<sub>2</sub> solution

$$[\text{Ca}^{2+}] = 0.01$$

$$K_{sp} = (0.01)^3 (2s)^2$$

$$\Rightarrow s = 2.37 \times 10^{-14}$$

(iii) 0.025 M Ca(NO<sub>3</sub>)<sub>2</sub> solution

$$[\text{Ca}^{2+}] = 0.025$$

$$s \approx 5.75 \times 10^{-15}$$

(iv) 0.05 M Na<sub>3</sub>PO<sub>4</sub> solution

$$[\text{PO}_4^{3-}] = 0.05$$

$$K_{sp} = (3s)^3 (0.05)^2$$

$$s \approx 3.13 \times 10^{-11}$$


  
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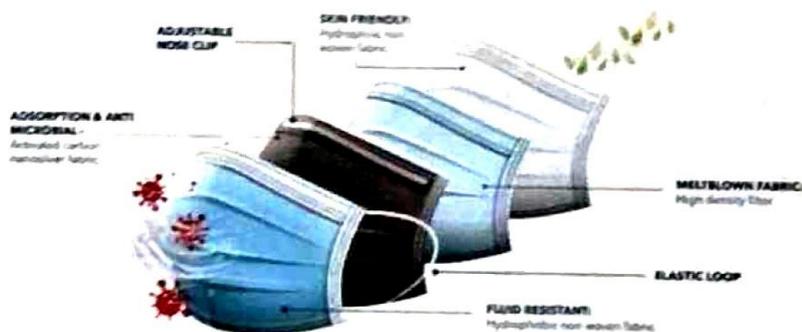
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Although the data is not matching but we can conclude the following:

- The solubility of calcium phosphate is maximum in pure water and decreases in solutions containing either  $\text{Ca}^{2+}$  or  $\text{PO}_4^{3-}$  ions, with the decrease becoming more pronounced as the concentration of the common ion increases.
  - Although both  $\text{Ca}^{2+}$  and  $\text{PO}_4^{3-}$  act as common ions, the addition of  $\text{Ca}^{2+}$  suppresses the solubility of calcium phosphate more strongly than  $\text{PO}_4^{3-}$  because  $\text{Ca}^{2+}$  appears with a higher power in the  $K_{sp}$  expression. Hence, the solubility in phosphate solution is slightly higher than in calcium nitrate solution.
7. After the last pandemic, masks have become an extended part of our body. If you ever try to cut open a pollution mask, you shall find it consists of two or more layers of fabric, and between the layers exist activated carbon granules or a filter sheet, which serve as a purifier. It allows clean air to reach our nostrils by adsorbing the dust and smoke particles. The activated carbon element or the filter sheet is the adsorbent, while the dust and smoke particles are adsorbates.



This process creates a film of the adsorbate on the surface of the adsorbent. The process of adsorption is distinctly a surface phenomenon. Adsorption is usually an exothermic process. And when molecules get adsorbed, they lose their freedom of motion. This adsorption process differs from absorption in which a fluid (the adsorbate) is dissolved by or permeates a liquid or solid (the absorbent).

Now, in view of the following thermodynamic parameters described below:

- Gibbs free energy change ( $\Delta G$ ) which is the criterion for determining whether a chemical reaction or physical transformation will occur on its own under constant temperature and pressure conditions.
- Enthalpy change ( $\Delta H$ ) which is a measure of the heat gained or lost by a system during a process under constant pressure.
- Entropy change ( $\Delta S$ ) a positive change in entropy indicates a system is becoming more disordered, while a negative change indicates a move toward greater order.

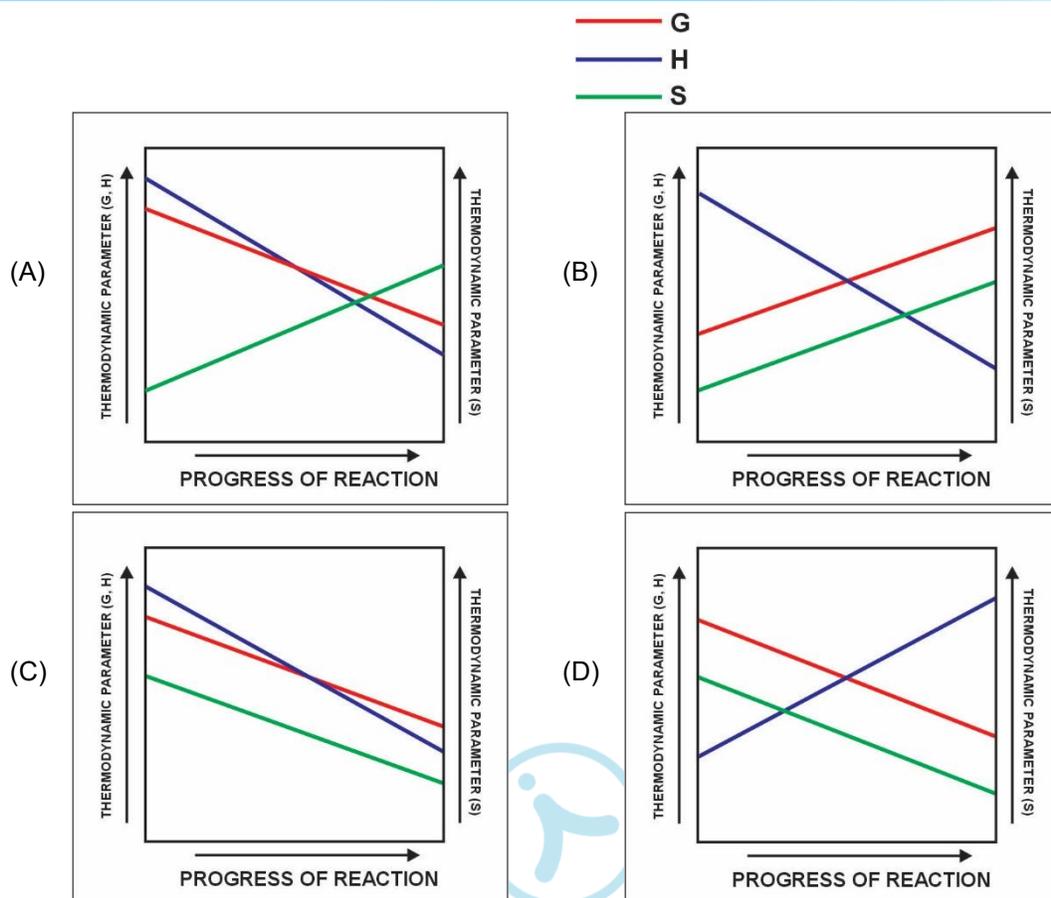
And they are also related by the equation:  $\Delta G = \Delta H - T\Delta S$

[where,  $T$  = absolute temperature];

Which of the following graphs represent the adsorption process on the system, where the following lines represent each thermodynamic property

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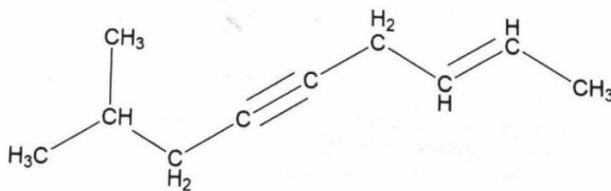
**Answer (C)**

**Sol. Given:** Exothermic process *i.e.*  $\Delta H < 0$ , so enthalpy decreases.

When molecules get absorbed, they lose their freedom of motion *i.e.*  $\Delta S < 0$ , so disorder/entropy decreases.

Absorption happens spontaneously, so  $\Delta G < 0$ .

8. Hydrogenation of alkenes and alkynes is executed by exposing them to excess hydrogen gas in presence of a metal catalyst like Nickel. The molecule below was exposed to excess gas H-D in presence of nickel catalyst. How many unique products are formed? [D = deuterium. Assume reaction goes to completion. Ignore formation of stereoisomers]



- (A) 3  
(C) 6

- (B) 4  
(D) 8

**Answer (C)**

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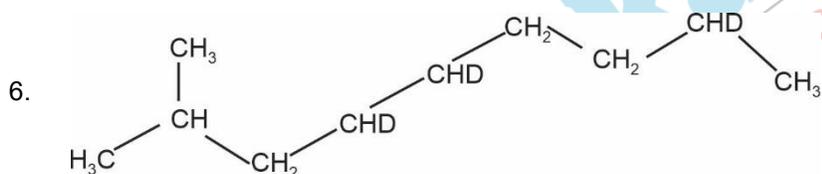
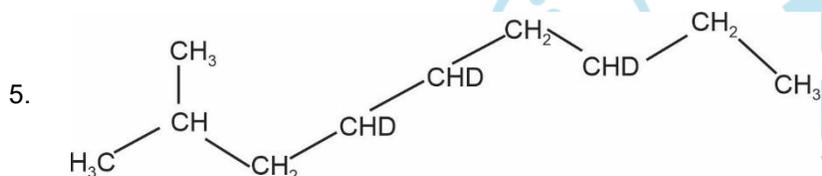
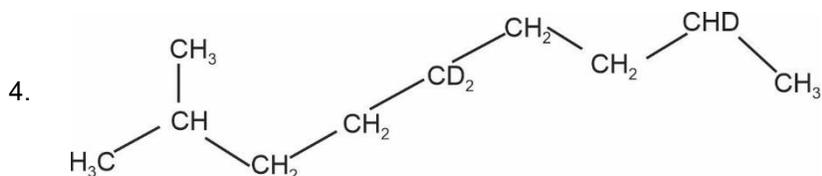
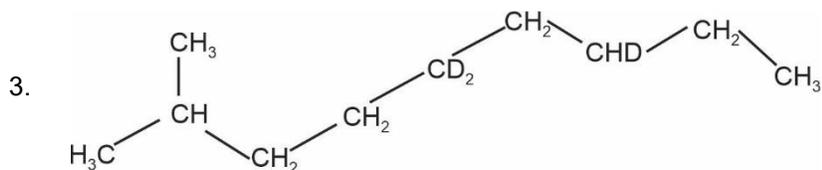
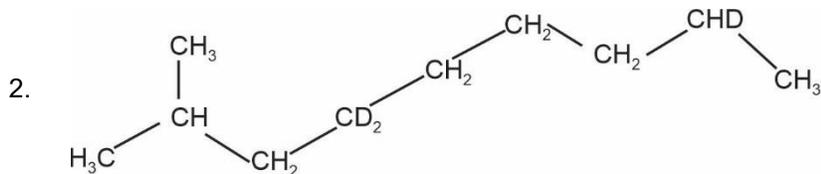
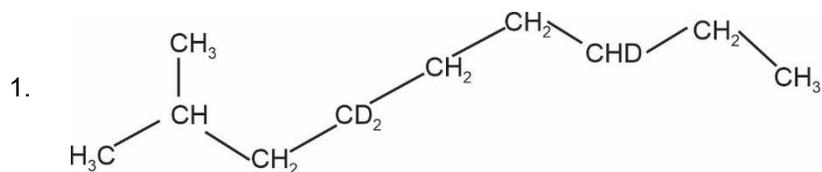
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Sol. The unique products can be



9. One day in a university chemistry laboratory, Priya was preparing an aqueous urea solution for her experiment. She carefully weighed out exactly 900 grams of water and added the required amount of urea to achieve a mole fraction of 0.05. As she observed the clear solution, she wondered about its concentration. Checking her notes, Priya found that the density of the solution was noted as  $1.03 \text{ gdm}^{-3}$ . What is the molarity of her freshly prepared urea solution?

- (A) 2.64 (B) 2.56  
(C) 3.27 (D) 3.01

Answer (B)

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**Sol.** Given: Mass of water = 900 g

Mole fraction of urea = 0.05

Density of solution = 1.03 g dm<sup>-3</sup> or 1.03 gL<sup>-1</sup>

Molar mass of urea = 60 g mol<sup>-1</sup>

$$\text{Moles of water} = \frac{900}{18} = 50$$

$$\chi_{\text{urea}} = \frac{\eta_{\text{urea}}}{\eta_{\text{urea}} + \eta_{\text{water}}}$$

$$0.05 = \frac{\eta_{\text{urea}}}{\eta_{\text{urea}} + 50}$$

$$\eta_{\text{urea}} = 2.63$$

Mass of urea = 2.63 × 60 = 157.8 g

Mass of solution = 900 g + 157.8 g = 1057.8 g

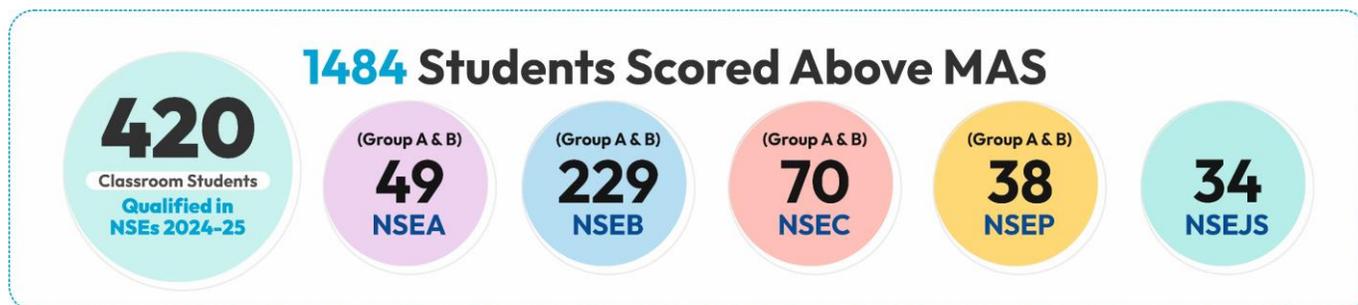
$$\begin{aligned} \text{Volume of solution} &= \frac{\text{Mass of solution}}{\text{Density of solution}} = \frac{1057.8 \text{ g}}{1.03 \text{ gL}^{-1}} \\ &\approx 1027 \text{ L} \end{aligned}$$

$$\begin{aligned} \text{Molarity of solution} &= \frac{\text{Moles of urea}}{\text{Volume of solution (in L)}} \\ &= \frac{2.63}{1027} = 2.56 \times 10^{-3} \text{ M} \end{aligned}$$

\*If density is taken as 1.03 gcm<sup>-3</sup> then molarity will be 2.56 M.

10. A large number of different proteins contain nearly the same percentage of nitrogen (N). The factor for conversion of weight of N to weight of protein is 6.25, (proteins contain about 16% nitrogen). A sample of protein is heated with excess sulphuric acid in a closed container. The nitrogen atoms in it are converted to soluble ammonium salt. The solution is cooled, and concentrated sodium hydroxide is added to make the solution alkaline. This liberates a colourless pungent gas which is passed through excess of acid of known concentration. The unreacted acid is titrated with sodium hydroxide of known concentration to obtain the amount of nitrogen present in the protein sample. A 3.00 g sample of health supplement is analysed for its protein content by the above method. The colourless gas was passed through 100.0 mL of 0.1 M HCl. After completion of the reaction, the remaining acid required 35.0 mL of 0.05 M NaOH solution. The percent of protein in the sample and the sequence of reactions are
- (A) 72% -- {decomposition, displacement, neutralisation, neutralisation}
- (B) 24% -- {decomposition, displacement, neutralisation, neutralisation}
- (C) 72% -- {decomposition, neutralisation, displacement, neutralisation, neutralisation}
- (D) 24% -- {decomposition, neutralisation, displacement, neutralisation, neutralisation}

**Answer (B)**



**Sol.** Given:

Mass of protein sample = 3 g

Volume of HCl used = 100 mL of 0.1 M

Remaining acid is neutralised by 35 mL of 0.05 M NaOH

Conversion factor, weight of protein = 6.25 × Weight of nitrogen

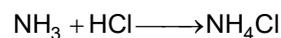
Now,

Moles of HCl initially = 0.1 × 0.1 = 0.01

Moles of NaOH used = 0.05 × 0.035 = 0.00175

⇒ Remaining HCl = 0.00175 mol

Now,



Moles of HCl consumed by  $\text{NH}_3$

$$= 0.01 - 0.00175$$

$$= 0.00825$$

Each mole of  $\text{NH}_3$  contains 1 mole of N

⇒ Moles of N = 0.00825

$$\text{Mass of N} = 0.00825 \times 14 = 0.1155 \text{ g}$$

⇒ Mass of protein = 0.1155 × 6.25

$$= 0.72 \text{ g}$$

$$\therefore \text{Percentage of protein} = \frac{0.72}{3} \times 100 = 24\%$$

Reaction sequence :

- (i) Decomposition (Protein to ammonium salt)
- (ii) Displacement ( $\text{NH}_3$  liberation by NaOH)
- (iii) Neutralisation ( $\text{NH}_3 + \text{HCl}$ )
- (iv) Neutralisation (Remaining HCl + NaOH)

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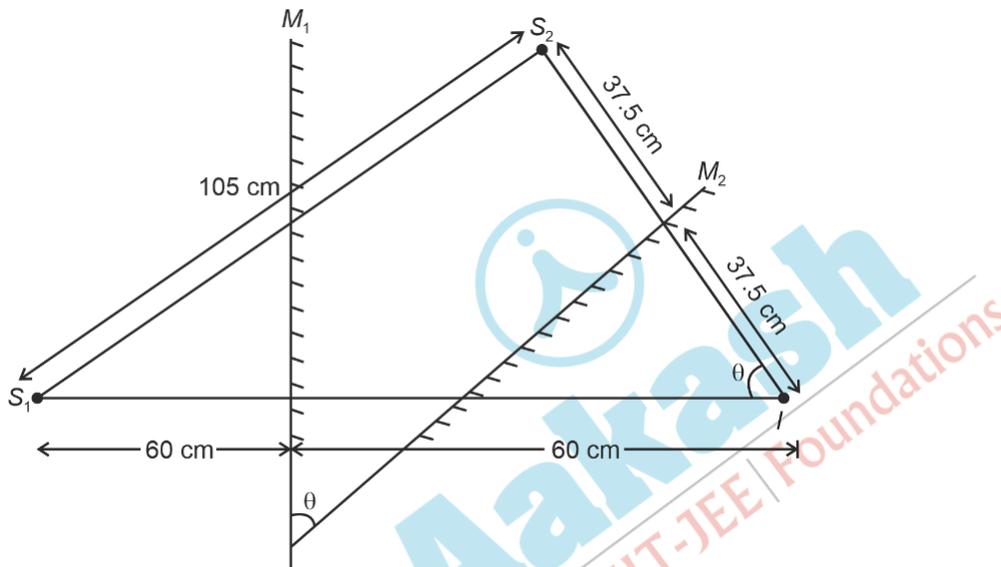
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11. Two point-sources of light lying on a plane of the paper are separated by 105 cm. Two plane mirrors are placed at a perpendicular distance of 60 cm and 37.5 cm respectively from the two sources. The mirrors are oriented in such a way that the images of the two light sources of light formed by them coincide with each other. The angle included by the two non-reflecting faces of the mirrors is.

- (A)  $90^\circ$
- (B)  $120^\circ$
- (C)  $60^\circ$
- (D)  $0^\circ$

**Answer (B)**

**Sol.**



In  $\Delta S_1S_2I$ , using law of cosine

$$(105)^2 = (120)^2 + (75)^2 - 2 \times 120 \times 75 \times \cos\theta$$

$$\Rightarrow \cos\theta = \frac{(75)^2 + (120)^2 - (105)^2}{2 \times 120 \times 75} = 0.5$$

$$\Rightarrow \theta = 60^\circ$$

The angle between non-reflecting surface

$$= 180^\circ - \theta = 180^\circ - 60^\circ = 120^\circ$$

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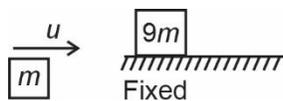
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12. A bullet of mass  $m$  is fired horizontally into a fixed wooden block of mass  $9m$ . It pierces through a distance  $S_0$  in the block and stops. In another case, an identical block that is free to move on a smooth horizontal surface is hit by an identical bullet fired into the block horizontally. The bullet covers distance  $S$  into the block and after that, they travel with common velocity. Assuming same masses, same initial velocity of the bullet and same constant resistive force, determine  $\frac{S_0}{S}$ .

- (A)  $\frac{3}{4}$  (B)  $\frac{10}{9}$   
(C)  $\frac{19}{10}$  (D)  $\frac{4}{3}$

**Answer (B)**

**Sol.** In case-I

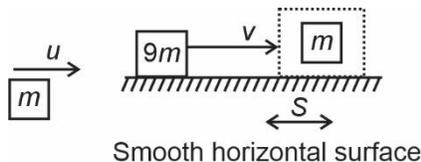


Let the resistive force be  $F$ , then using

Work - Energy theorem

$$F \times S_0 = \frac{1}{2} mu^2 \quad \dots(i)$$

In case-II



Applying law of conservation of linear momentum

$$mu + 9m(0) = (m + 9m)v$$

$$\Rightarrow v = \frac{u}{10} \quad \dots(ii)$$

Now, using Work-Energy theorem

$$F \times S = \frac{1}{2} mu^2 - \frac{1}{2} \times 10mv^2$$

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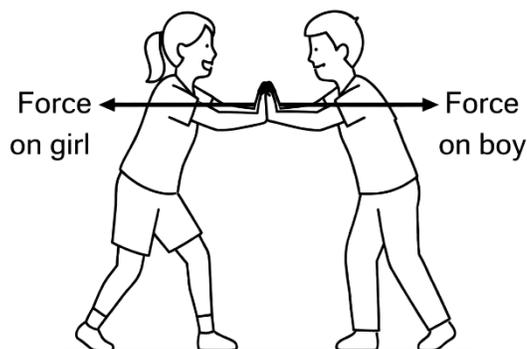
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14. Two ice skaters, a boy of mass 60 kg and a girl of mass 45 kg are initially at rest on a flat ice bed. They push each other to gain some velocity. As a result, the boy picks a speed of 1.5 m/s.



Consider the following statements.

**Statement 1:** The speed of girl is  $1.5 \text{ m/s}^{-1}$ .

**Statement 2:** The speed of girl is  $2.0 \text{ m/s}^{-1}$ .

**Statement 3:** Work done by the boy while pushing the girl is 90 J.

**Statement 4:** Work done by the girl while pushing the boy is less than work done by the boy pushing the girl.

**Choose the correct options**

- (A) Statements 1, 3 and 4 are only correct.  
 (B) Statements 1 and 4 only correct.  
 (C) Statements 2,3 and 4 only correct.  
 (D) Statements 2 and 3 only correct.

**Answer (C)**

**Sol.** By conservation of momentum

$$m_g v_g = m_B v_B$$

$$v_g = \frac{60 \times 1.5}{45}$$

$$= 2 \text{ m/s}$$

Work done by boy = change in kinetic energy of girl

$$= \frac{1}{2} m_g v_g^2$$

$$= \frac{1}{2} \times 45 \times (2)^2$$

$$= 90 \text{ J}$$

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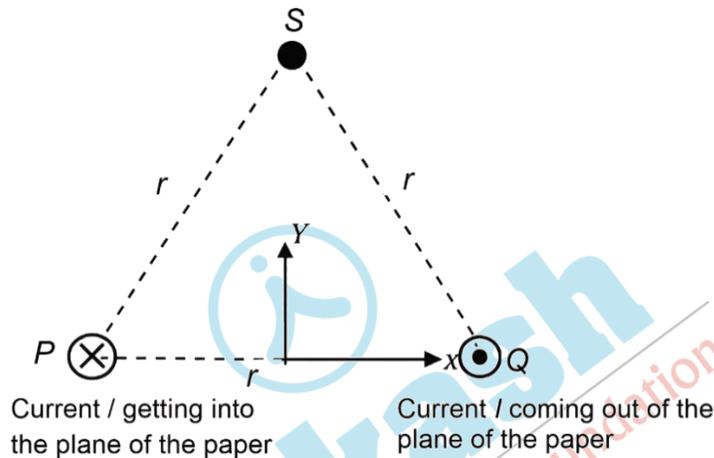
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Work done by girl = Change in kinetic energy of boy

$$\begin{aligned}
 &= \frac{1}{2} m_B v_B^2 \\
 &= \frac{1}{2} \times 60 \times (1.5)^2 \\
 &= 67.5 \text{ J}
 \end{aligned}$$

15. Two long conducting wires carry equal currents but in opposite direction. These are separated by distance  $r$ . The wire at  $P$  carries current into plane of the paper and that at  $Q$  carries current coming out of the plane of the paper.  $S$  is a point in the plane of the paper at an equidistance ( $r$ ) from both the wires. Select the correct statements from the following.



**Statement 1:** The directions of magnetic fields produced at  $S$  by the two wires are at  $120^\circ$  with each other.

**Statement 2:** The net magnetic field at  $S$  is towards negative  $y$  - direction.

**Statement 3:** If the current in the wire at  $P$  is reversed, then the magnetic field at  $S$  will be along positive  $x$ - direction.

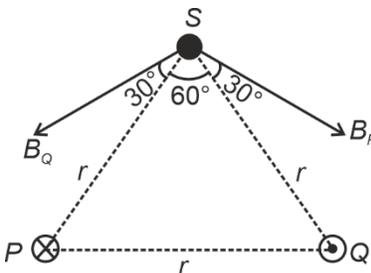
- (A) Statements 1, 2 and 3 are correct.  
 (B) Statements 1 and 3 only are correct.  
 (C) Statements 1 and 2 only are correct.  
 (D) Statements 2 and 3 only are correct.

**Answer (C)**

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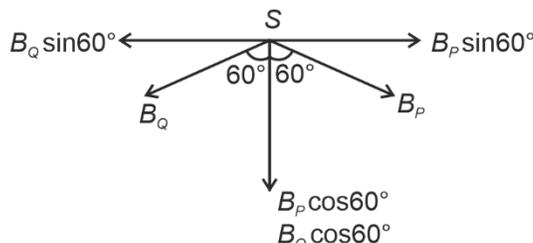
<p style="font-size: 2em; font-weight: bold;">420</p> <p>Classroom Students Qualified in NSEs 2024-25</p>	<p>(Group A &amp; B)</p> <p style="font-size: 2em; font-weight: bold;">49</p> <p>NSEA</p>	<p>(Group A &amp; B)</p> <p style="font-size: 2em; font-weight: bold;">229</p> <p>NSEB</p>	<p>(Group A &amp; B)</p> <p style="font-size: 2em; font-weight: bold;">70</p> <p>NSEC</p>	<p>(Group A &amp; B)</p> <p style="font-size: 2em; font-weight: bold;">38</p> <p>NSEP</p>	<p style="font-size: 2em; font-weight: bold;">34</p> <p>NSEJS</p>
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Sol. By the right hand thumb rule the direction of magnetic field is shown in the figure.



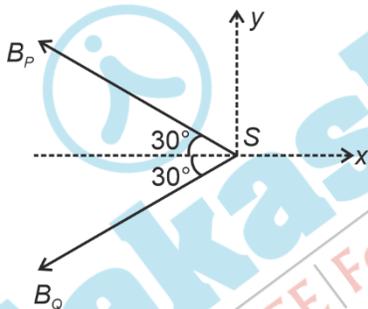
Hence  $B_P$  and  $B_Q$  are inclined at  $120^\circ$ .

The net magnetic field at 'S' is



Hence the direction of net magnetic field is in negative y-axis

If current  $P$  is reversed



The net magnetic field at 'S' will be toward negative x-directions.

## SECTION II:

(One or more than one option(s) may be correct)

16. During prolonged fasting in a healthy individual, the body tries to maintain blood glucose levels. If a healthy person fasts for longer than 18 hours, which of the following statement/s correctly describe the body's process(es) for maintaining optimum glucose levels?
- (A) Glycogen stores are depleted due to increased mobilisation.
  - (B) Adipose tissue is broken down, and free fatty acids are used for energy.
  - (C) The body shows reduced insulin sensitivity since there is no glucose.
  - (D) Fermentative metabolism begins in the liver.

Answer (A, B)

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- Sol.** Glycogen stores get depleted due to increased mobilisation, after 18 hours of fasting and the body shifts to fat breakdown, and free fatty acids are used for energy.
17. In the Western Ghats, farms with installed wind turbines were operated for using wind as a renewable energy source. The operation of wind turbines reduced the number of predatory birds in that area. Which of the following is likely to have happened due to the fall in number of predatory birds?
- (A) The lizard population will result in fewer beetles.  
 (B) The frog population will increase due to a decline in the number of snakes.  
 (C) Higher number of frogs will result in fewer beetles.  
 (D) Wind turbines will eventually result in fewer flowering plants.

**Answer (A)**

- Sol.** A decrease in predatory birds reduces predation on lizards so increase in lizards causes a decrease in beetle number. An increase in snake population would increase predation on frogs, reducing frog population.
18. The nitrogen cycle maintains the balance of nitrogen in the biosphere through several microbial transformations and human-induced alterations.

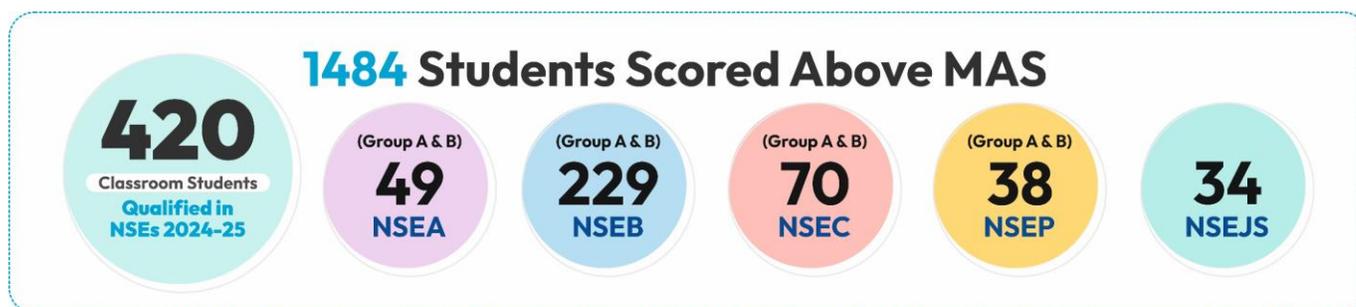
Which of the following statements most accurately describe these processes and their ecological consequences?

**Choose the correct statements:**

- (A) During nitrification, chemoautotrophic bacteria such as *Nitrosomonas* and *Nitrobacter* oxidize ammonia into nitrite and nitrate; under excessive fertilizer input, this step accelerates nitrate leaching and enhances the risk of eutrophication in aquatic systems.
- (B) Denitrification involves the reduction of nitrates by soil microbes into ammonium compounds that remain available for plant uptake, thereby preventing nitrogen loss and maintaining soil fertility even under limited oxygen conditions.
- (C) Ammonification releases ammonia from dead plants and animals through microbial decay. But when fossil fuels or plant matter are burned, this natural process is skipped, and instead nitrogen oxides (NO<sub>x</sub>) are released into the air, leading to acid rain and ozone formation near the ground.
- (D) Biological nitrogen fixation, mediated by *Rhizobium* in legume root nodules and by free-living bacteria such as *Azotobacter*, converts N<sub>2</sub> to ammonia; yet prolonged use of synthetic nitrogen fertilizers down-regulates this symbiotic process by reducing plant-bacterial signalling and altering soil microbial community structure.

**Answer (A, C, D)**

- Sol.**
- During nitrification, chemoautotrophic bacteria like *Nitrosomonas* and *Nitrobacter* oxidize ammonia into nitrite and then nitrate. Excessive nitrate leaches into water bodies and causes eutrophication.
  - Ammonification is the natural process where decomposers breakdown organic nitrogen from dead organisms and waste into ammonia / ammonium. The burning of fossil fuels releases nitrogen oxide (NO<sub>x</sub>), which contributes to acid rain.
  - Biological nitrogen fixation is indeed mediated by symbiotic bacterium (*Rhizobium*) in legume root nodules and free-living bacterium (*Azotobacter*) converting nitrogen into ammonia. Excessive synthetic nitrogen fertilizers reduce nodulation and fixation by suppressing plant-microbe signalling and altering soil microbial communities.



19. Oral rehydration salts (ORS) is a low-cost, simple mixture of sugar, salt, which when dissolved in water helps treat dehydration by replenishing fluids and electrolytes lost due to diarrhoea and vomiting. ORS works by enhancing the absorption of water and essential minerals like sodium and potassium in the small intestine, helping to restore the body's fluid balance. The mixture is provided in powder or tablet form and must be mixed with fresh drinking water before consumption.

An experiment is done by the students of Class X in the school laboratory under the supervision of a guide teacher to find out the percentage composition of sodium chloride and potassium chloride present in a very common branded powdered ORS which is readily available in the market.

A sachet of powdered ORS contains 21.80 g of powder. In this sachet, total quantity of sodium chloride and potassium chloride is 4.10 g. Whole sachet is dissolved in 250 mL of distilled water.

The solution is acidified with dilute nitric acid. In this solution, 170 mL of 0.495 M  $\text{AgNO}_3$  solution is added. The precipitate is filtered off, and a strip of copper weighing 50.0 g is dipped into the filtrate. After a given time interval, the strip weighs 51.5 g.

From the above experiment, find one or more correct result(s) which are obtained by the Class X students:

- (A) Percentage composition of sodium chloride present in ORS powder = 11.93% , quantity of deposited silver = 2.1246 g
- (B) Percentage composition of sodium chloride present in ORS powder = 6.88%, percentage composition of potassium chloride present in ORS powder = 11.93%.
- (C) Quantity of deposited silver = 2.1246 g, percentage composition of potassium chloride present in ORS powder = 6.88%.
- (D) Percentage composition of sodium chloride present in ORS powder = 6.88%, quantity of deposited silver = 2.1246 g.

**Answer (A, C)**

**Sol.** Given : Mass of ORS powder = 21.80 g

Mass of NaCl + KCl = 4.10 g

Volume of water = 250 mL

170 mL of 0.495 M  $\text{AgNO}_3$

Let mmol of KCl = x

NaCl = y

$74.5x + 58.5y = 4100$  ... (i)

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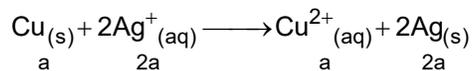
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Let mmol of copper dissolved = a



$$(2a \times 108) - a \times 63.5 = 1.5 \times 1000$$

$$a = 9.8 \text{ mmol}$$

Silver deposited = 2a mmol

$$= \frac{2 \times 9.8 \times 108}{1000} = 2.12 \text{ g}$$

$$\text{Ag}^+ (\text{used}) = 170 \times 0.495 - 2 \times 9.8 \approx 64.5 \text{ mmol}$$

$$x + y = 64.5 \quad \dots(\text{ii})$$

From equation (i) and (ii)

$$y = 44 \text{ mmol}$$

$$x = 20.5 \text{ mmol}$$

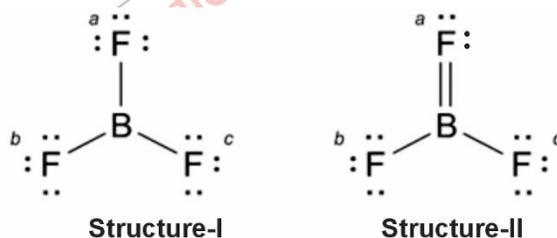
$$\text{Mass of NaCl} = \frac{44 \times 58.5}{1000} = 2.6 \text{ g}$$

$$\text{Mass of KCl} = \frac{20.5 \times 74.5}{1000} = 1.5 \text{ g}$$

$$\text{Percentage of NaCl} = \frac{2.6}{21.8} \times 100 = 11.93\%$$

$$\text{Percentage of KCl} = \frac{1.5}{21.8} \times 100 = 6.88\%$$

20. Two structures have been assigned to  $\text{BF}_3$ .



Formal charge of an atom in a molecule is the hypothetical charge the atom would have if we could redistribute the electrons in the bonds evenly between the atoms in the bond.

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Formal charge (F) of an atom in the molecule is determined using the formula

$$F = V - (S/2) - U$$

where V is valence electrons, S is shared electrons, and U is unshared electrons.

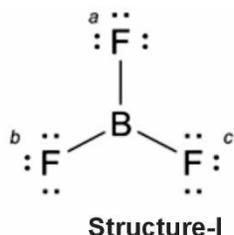
The oxidation number in small covalent molecules represents the hypothetical charge an atom would possess if all bonds were considered completely ionic, with electrons assigned to the more electronegative atom in each bond. Unlike formal charge, which assumes equal sharing of electrons, oxidation number helps in understanding electron transfer and chemical reactivity in compounds.

Choose the correct statements.

- (A) Formal charge and the oxidation number of boron in the  $\text{BF}_3$  in **Structure I** is 0 and +3 respectively, while formal charge and the oxidation number of boron in the  $\text{BF}_3$  in **Structure II** is  $-1$  and +3 respectively.
- (B) Formal charge and the oxidation number of fluorine atom *a* in **Structure I** is 0 and  $-1$  respectively, while formal charge and the oxidation number of fluorine atom *a* in **Structure II** is +1 and  $-1$  respectively.
- (C) Formal charge of fluorine atom *b* in **Structure I & II** is  $-1$  and  $-1$  respectively, while oxidation number of fluorine atom *b* in **Structure I & II** is  $-1$  and  $-1$  respectively.
- (D) **Structure-I** is a better representation of  $\text{BF}_3$ .

Answer (A, B, D)

Sol.

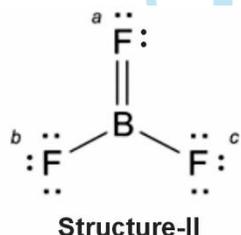


$$F(\text{B}) = 3 - \frac{6}{2} = 0$$

$$F(\text{F}_a) = 7 - \frac{2}{2} - 6 = 0$$

Similarly,

$$F(\text{F}_b) \text{ and } F(\text{F}_c) = 0$$



$$F(\text{B}) = 3 - \frac{8}{2} = -1$$

$$F(\text{F}_a) = 7 - \frac{4}{2} - 4 = +1$$

and

$$F(\text{F}_b) \text{ and } F(\text{F}_c) = 7 - \frac{2}{2} - 6 = 0$$

Oxidation number of boron and fluorine in both the structures are +3 and  $-1$  respectively. Structure I has no formal charge and is the accepted Lewis structure whereas structure II is only a resonance form.

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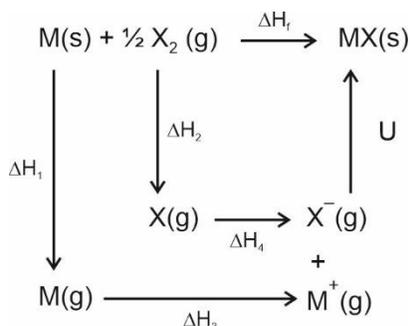
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21. The Born-Haber cycle is used to determine the lattice energy, which cannot be directly measured. Hess's law of constant heat summation is applied here. Hess's law states that the total enthalpy change in a chemical reaction remains the same, irrespective of the route taken, whether in a single step or in a series of steps. The Born-Haber cycle for formation of alkali metal halides may be represented as in the diagram below, where  $\Delta H_1$  is the enthalpy change for sublimation of the metal,  $\Delta H_2$  is enthalpy change for dissociation  $\frac{1}{2}X_2 \rightarrow X$ ,  $\Delta H_3$  is the ionisation energy for  $M \rightarrow M^+$ ,  $\Delta H_4$  is the electron affinity for  $X \rightarrow X^-$ ,  $U$  is the lattice energy for the formation of solid  $MX$  and  $\Delta H_f$  is enthalpy change for formation of  $MX$  directly from the elements.



By Hess's law,  $\Delta H_f = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + U$

Given the data below, what are the reasons for the high heat of formation of LiF over NaCl?

Reaction	Energy change (kJ mol <sup>-1</sup> )	Reaction	Energy change (kJ mol <sup>-1</sup> )
$Li(s) \rightarrow Li(g)$	161	$Na(s) \rightarrow Na(g)$	108
$Li(g) \rightarrow Li^+(g)$	$X_1$	$Na(g) \rightarrow Na^+(g)$	$X_2$
$\frac{1}{2}F_2(g) \rightarrow F(g)$	77	$\frac{1}{2}Cl_2(g) \rightarrow Cl(g)$	122
$F(g) \rightarrow F^-(g)$	$Y_1$	$Cl(g) \rightarrow Cl^-(g)$	$Y_2$
$Li^+(g) + F^-(g) \rightarrow LiF(s)$	-1047	$Na^+(g) + Cl^-(g) \rightarrow NaCl(s)$	-788
$Li(s) + \frac{1}{2}F_2(g) \rightarrow LiF(s)$	-617	$Na(s) + \frac{1}{2}Cl_2(g) \rightarrow NaCl(s)$	-411

- (A) It is easier to ionize sodium compared to lithium  
 (B) Electron affinity of fluorine is greater than that of chlorine  
 (C) LiF lattice energy is significantly higher than that of NaCl  
 (D) F-F bond is easier to break than Cl-Cl bond

**Answer (C, D)**

**Sol.** The much higher lattice energy of LiF is because  $Li^+$  and  $F^-$  ions are much smaller. The weaker F-F bond together make the heat of formation of LiF significantly more negative than that of NaCl.

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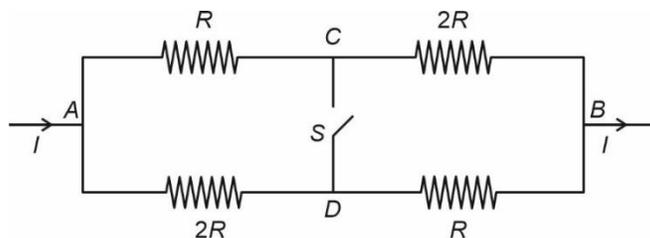
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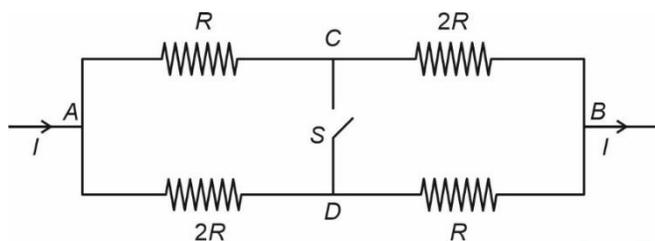
22. A current  $I$  is driven into a combination of resistors as shown in the figure. Initially switch is open then it is closed. Identify the correct statements.



- (A) Power consumed by  $R$  at the top left of the circuit before closing the switch is  $\frac{I^2 R}{2}$ .
- (B) Power consumed by  $R$  before closing the switch is  $\frac{I^2 R}{4}$ .
- (C) Power consumed by  $R$  after closing the switch is  $\frac{4I^2 R}{9}$ .
- (D) The current that flows through the key after closing the switch is  $\frac{I}{3}$ .

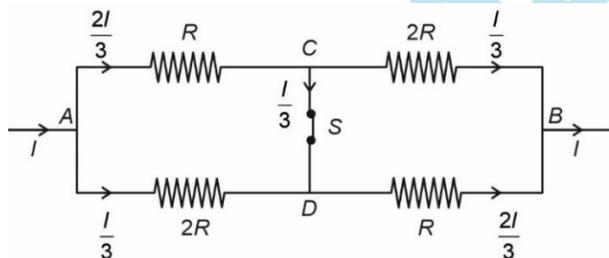
**Answer (B, C, D)**

**Sol.**



$$P_R = \left(\frac{I}{2}\right)^2 R = \frac{I^2 R}{4}$$

After the switch is closed



$$P'_R = \left[\frac{2I}{3}\right]^2 R = \frac{4I^2 R}{9}$$

After closing the switch current through the switch is  $\frac{I}{3}$ .

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23. A passenger gets down from a train compartment to have a cup of tea in a crowded shop on the platform just in front of the door of her compartment. When she is having tea, the train starts with an acceleration of  $0.03 \text{ m s}^{-2}$ . She starts running to catch the same door that she got down after finishing the tea. Assuming her speed of running to be uniform and neglecting the small distance between tea stall and door of the compartment, identify the correct possibilities
- (A) She can never catch the coach with a uniform speed. She must accelerate.
  - (B) If we assume that she runs with an average speed of  $3 \text{ m s}^{-1}$ , right from the beginning then she will have at least 50 s to finish the tea and run to reach the compartment door.
  - (C) The length of the platform should be at least 150 m from the tea shop for the passenger to safely reach the door of the compartment and catch the train.
  - (D) If she takes 60 s to finish her tea, the minimum speed required to catch the train by reaching the compartment door is  $3.6 \text{ m s}^{-1}$ .

**Answer (D)**

**Sol.** Distance cover by passenger = Distance travel by train.

$$v(t - T) = \frac{1}{2}at^2 \quad \text{[Here } T = \text{Time taken to finish tea]}$$

$$\frac{1}{2}at^2 - vt + vT_0 = 0$$

The roots of this quadratic equation must be real.

$$\therefore b^2 - 4ac \geq 0$$

$$(-v)^2 - 4\left(\frac{1}{2}a\right)vT \geq 0$$

$$v \geq 2aT$$

$$v_{\min} \geq 2aT$$

(A) Mathematically, catching the train at uniform speed is feasible as long as the speed meets  $v \geq 2aT$

(B)  $v = 3 \text{ m/s}$

$$3 \geq 2(0.03)T$$

$$T \leq 50 \text{ s}$$

This means, she has at most 50 s to finish the tea before starting to run and reaching the compartment door. Hence this is not possible

(C) It's incorrect, because the required platform length is scenario-specific, depending on exact speed  $v_p$  and wait time  $T$ , rather than a universal 150 m value.

(D)  $v \geq 2aT$

$$v_{\min} = 2 \times 0.03 \times 60$$

$$= 3.6 \text{ m/s}$$

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24. A square metal plate (of each side equal to  $10a$  and thickness  $a$ ) and a cube of wood (each side equal to  $10a$ ) are joined together with negligible amount of adhesive to form a cuboid. A liquid is taken in a sufficiently tall vessel with cross-sectional area marginally greater than  $100a^2$ . First, the cuboid is allowed to float with the metal surface at the top and the liquid level in the vessel is marked. The height of the submerged portion of the wood in this case is  $h_1$ . Now, the cuboid is taken out and floated again with metal plate lying at the bottom of the wooden block. The water level in the vessel is marked again. The height of the submerged portion of only the wood in this case is  $h_2$ . Use the following data to identify the correct statements.

The density of metal is  $8\rho$ .

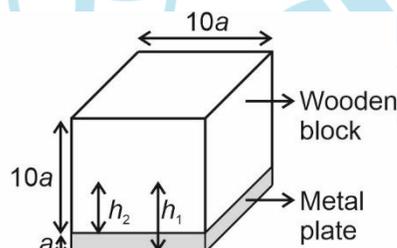
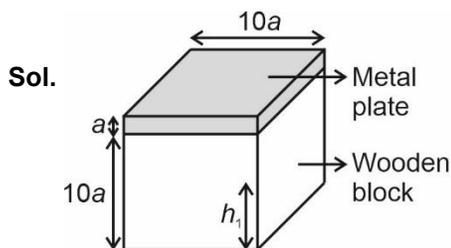
The density of wood is  $\rho$ .

The density of liquid is  $2\rho$ .

Walls of the vessel are smooth. Select correct statements.

- (A)  $h_1 - h_2$  is zero.
- (B)  $h_1 - h_2$  is  $a$ .
- (C) The water level in the vessel drops on flipping the cuboid.
- (D) The water level in the vessel remains the same on flipping the cuboid.

**Answer (B, D)**



From the diagram  $h_1 - h_2 = a$

In both cases.

$$Mg = \delta_L V_L g$$

$$A \times h_1 = \frac{M}{\delta_L}$$

$$h_1 = \frac{M}{\delta_L \times A} = \frac{M}{\delta_L \times 100a^2}$$

The volume of liquid displaced remains identical in both scenarios, keeping the water level unchanged.

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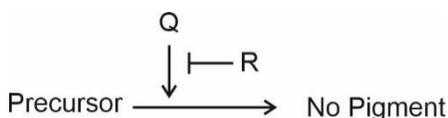
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### SECTION III: Long Answer/Theory Questions

25. In nature, some characters (phenotypes) observed in an organism are results of interactions of alleles of more than one gene. One such interaction is dominant suppression which occurs when a dominant allele of one gene completely suppresses the phenotypic expression of other gene.

This phenomenon is evident in chickens. There are two types of chickens, one with white feathers and the other with coloured ones. This trait is governed by interaction between the alleles of two genes, 'Q' and 'R'.

The dominant allele, 'Q' of one gene is responsible for coloured feathers; while the dominant allele, 'R' of the other gene, is responsible for controlling the expression of the first gene. Allele 'Q' is dominant over 'q' and the homozygous recessive genotype (qq) leads to growth of white feathers. Interestingly, the dominant allele, 'R' of the other gene has a suppressive effect on the colour-producing action of 'Q', but the recessive allele, 'r' has no such effect. The following figure depicts the actions of 'Q' and 'R'. [10 marks]



**Q1.** At a breeding centre, pure-breeding chickens of particular phenotypes were allowed to mate. Pure breeding organisms have identical alleles for a given gene(s). In an experimental setup, if pure breeding chickens with coloured feathers were allowed to mate with pure-breeding white chickens, the cross results in the production of all white-feathered dihybrid birds as the **F<sub>1</sub>** generation. When the white chickens of **F<sub>1</sub>** were interbred (selfing), the **F<sub>2</sub>** generation produced 629 birds. In the table given below, column A shows the most likely numbers of birds with coloured feathers, while column B shows the most likely numbers of birds with white feathers. Based on the information given, choose the correct pair of number of birds from column A with the one from column B and write it at the space given for writing the answer. [2 marks]

A	B
Birds with coloured feathers	Birds with white feathers
a. 118	w. 354
b. 158	x. 471
c. 275	y. 511
d. 40	z. 589

Answer: The correct matching pair from column A and B is \_\_\_\_\_

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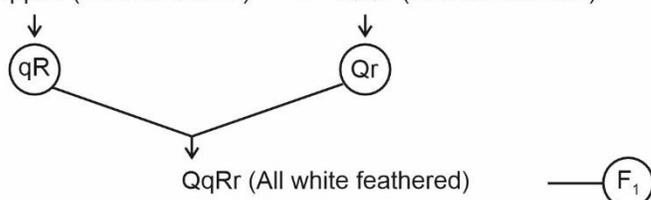
**Q2.** The breeding centre working with these birds has been meticulously keeping genotypic records of the birds from generation to generation. For a certain experiment, more white chickens than coloured ones are desired in  $F_2$ . Which genotype of the coloured birds will produce more white chickens than the coloured ones, when mated with white birds of  $F_1$  the experiment from the previous question?

Write down the cross(es) required and find out the correct genotype. All the conventions of writing crosses must be followed and the alphabets and symbols used must be clearly defined. The uppercase and lowercase letters must be clearly legible. **[4 Marks]**

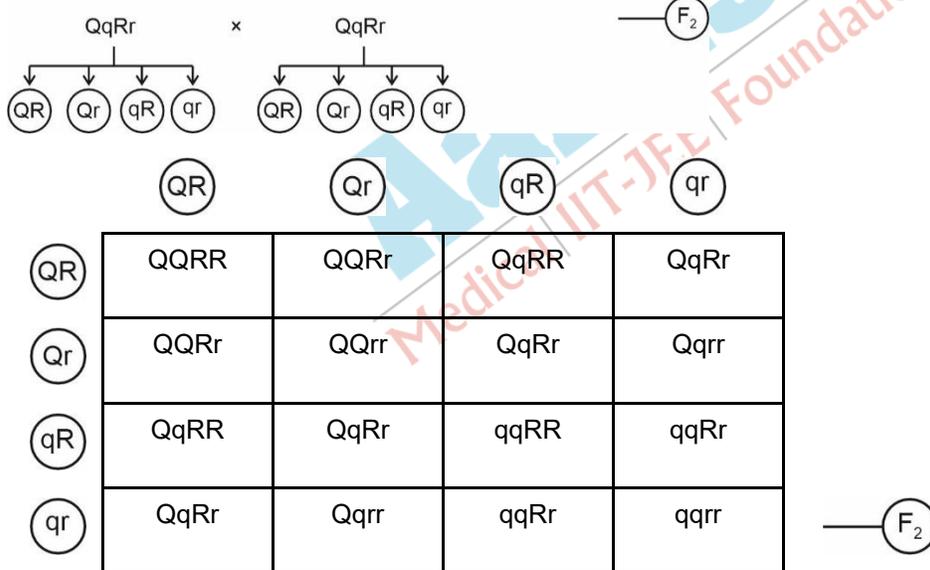
**Q3.** A private poultry farm requested the breeding centre for only coloured chickens in large quantities. The newly recruited personnel at the breeding centre formed mating pairs of only coloured birds. However, the progeny birds were comprised of both coloured and white ones. Find out the genotypes of male and female birds selected as mating pairs that resulted in the progeny with coloured and white birds.

Write down the details of the required cross(es) and find out the correct genotypes of male and female birds. All the conventions of writing crosses must be followed and the alphabets and symbols used must be clearly defined. The uppercase and lowercase letters must be clearly legible. **[4 Marks]**

**Sol. (1)**  $qqRR$  (white chickens)  $\times$   $QQrr$  (colored feathers)



Selling of  $F_1$  hybrids,



Hence, the ratio of white and colored in  $F_2$  generation is 13 : 3

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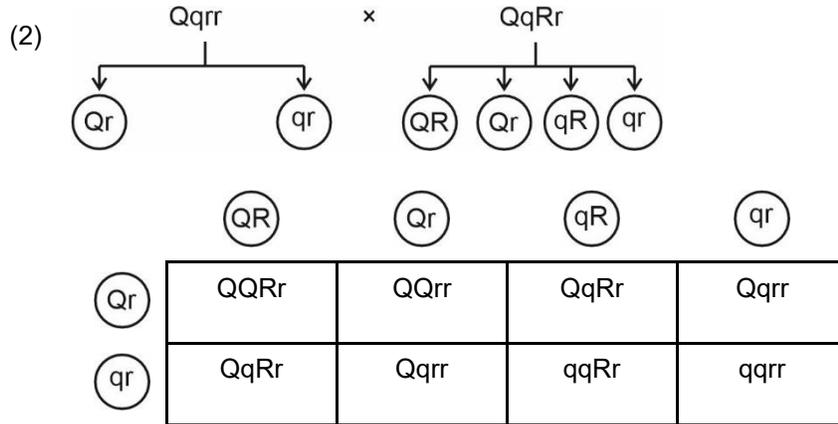
So, the number of white birds in F<sub>2</sub> generation will be  $\frac{13}{16} \times 629 = 511$

The number of colored birds in F<sub>2</sub> generation will be  $\frac{3}{16} \times 629 = 117.9 \approx 118$

Hence, A = 118,

B = 511

[2×1 Marks]



[2 Marks]

Genotypic ratios :

QQRr : QQrr : QqRr : Qqrr : qqRr : qqrr  
1 : 1 : 2 : 2 : 1 : 1

Hence, the ratio of white and colored feathers will be,

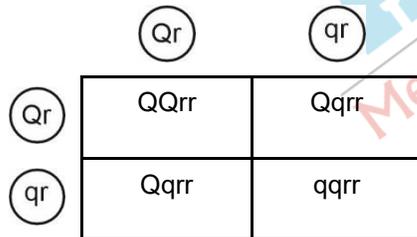
$$\frac{5}{8} : \frac{3}{8}$$

So, F<sub>1</sub> generation are Qqrr.

[2 Marks]

(3) Male : Qqrr

Female : Qqrr



Genotypic ratio = QQrr : Qqrr : qqrr  
1 : 2 : 1

Hence, the correct genotype of male & female would be Qqrr and Qqrr, respectively.

[4×1]

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26. Using several combinations of biochemical techniques, Zaira developed a multi-step strategy to purify the  $Mg^{2+}$  dependent *Taq* Polymerase enzyme to  $> 95\%$  purity, from the thermophilic bacterium, *Thermus aquaticus* (isolated from hot springs). Although these bacteria usually contain about  $10^7$  total number of protein molecules per cell (which include a mixture of structural proteins, enzymes of different metabolic pathways and recycling enzymes like nucleases and proteases) against only 100 copies of the *Taq* DNA polymerase enzyme per cell, they are still considered to be a great source of the thermostable polymerase. **[10 Marks]**

Based on this information, solve the problem sets provided:

Zaira grew a 100 mL culture of *T. aquaticus* in a laboratory up to a density of  $10^8$  cells /mL .

- (i) Using this freshly grown 100 mL bacterial culture, Zaira lysed the cells to extract and purify the *Taq* protein. In the multistep protein purification process, she was able to recover and retain only 5% of the total *Taq* protein at each step. However, the loss of the total non-target protein was about 1000 -fold at each step. Based on this information:

- Q1.** Calculate the total number of non-target proteins in the cell versus the target protein in the table below (column 'a' in the table below).
- Q2.** Based on the loss of protein during the process at each step, determine the minimum number of purification steps Zaira would have to perform, to be able to get at least 95% pure *Taq* (in columns 'b-h' in the table below):

(Show your calculations of the answers to the best accuracy, but should be entered into the table as **single units with two decimal places and corresponding indices** - e.g  $5.04 \times 10^6$  )

Show your calculations in the space below (for each step):

No. of molecules of proteins	In 100 mL	After Step 1	After Step 2	After Step 3	After Step 4	After Step 5	After Step 6	After Step 7
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Non-target protein (P)								
<i>Taq</i> protein (Q)								
Total protein (P + Q)								
Percentage of pure <i>Taq</i> protein								

Minimum number of purification steps required to get at least 95% pure *Taq* is \_\_\_\_\_

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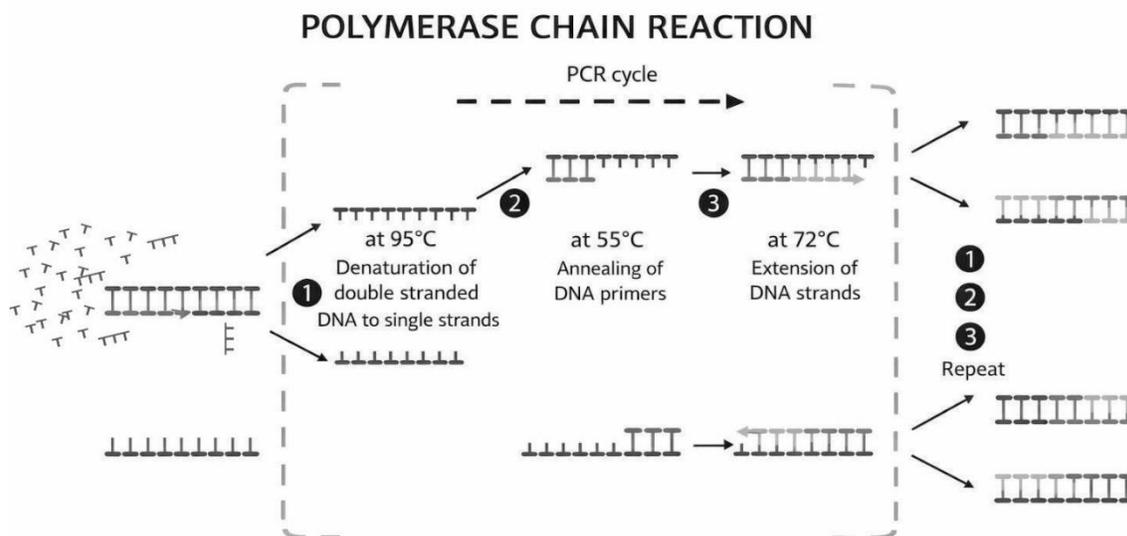
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- (ii) A diagrammatic representation of PCR is given below (templates - red and blue, primer - green, single nucleotides - blue, newly synthesized strands yellow, and the DNA pol enzyme that catalyses the reaction is not depicted).



In order to PCR-amplify the Tubulin gene from human DNA template, Zaira used *Tubulin* specific primers [short pieces of single stranded DNA that can pair in a sequence specific manner (anneal) to the *Tubulin* gene and prime the polymerisation of that gene alone]. She used her own preparation of the ~95% pure *Taq* enzyme as the main source of DNA polymerase when doing the PCR. Let us refer to this PCR reaction as the **Standard Reaction**.

**Q3.** Besides setting up the default Standard Reaction, where she added all the ingredients required for a regular PCR as above (*i.e.* Nucleotides, PCR Primers and Buffer), she kept 2 additional reaction tubes, which had all contents similar, except that: to one reaction tube, she added BSA (**B**ovine **S**erum **A**lbumin - a non-specific protein which is not involved in the PCR reaction) and to the other she added EDTA (a metal chelator). Pick the statement that correctly reasons the outcome of each reaction compared to the Standard Reaction (control), where neither was added:

(A) BSA can bind non-specifically to primers in the reaction thereby inhibiting the PCR → PCR expected to be poorer than the standard.

EDTA will chelate  $Mg^{2+}$  and inhibit the polymerase enzyme → PCR expected to be poorer than the standard.

(B) BSA competes with contaminating proteases, thereby prolonging the half-life of the *Taq* polymerase → PCR expected to be better than the standard.

EDTA chelates  $Mg^{2+}$  that protects the human template DNA from DNases → PCR expected to be better than the standard.

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(C) BSA can bind non-specifically to primers in the reaction thereby inhibiting the PCR → PCR expected to be poorer than the standard.

EDTA chelates  $Mg^{2+}$  that protects the human template DNA from DNases → PCR expected to be better than the standard.

(D) BSA competes with Taq for the action of contaminating proteases, thereby prolonging the half-life of the Taq polymerase → PCR expected to be better than the standard.

EDTA will chelate  $Mg^{2+}$  and inhibit the polymerase enzyme → PCR expected to be poorer than the standard.

**Q4.** To ensure that Zaira wasn't amplifying any contaminating DNA from any of the other reagents in the reaction, she executed a control reaction. In case her standard reaction is positive for PCR, pick which of the following control reactions, if negative (lack of DNA amplification), will provide the information she seeks:

(A) Control tube without Taq polymerase

(B) Control tube with 3-times the amount of Taq polymerase

(C) Control tube without any added nucleotides

(D) Control tube without the human template DNA

**Q5.** Zaira's found out that her Standard Reaction did not work and she suspected the nucleotides might have gotten inactivated over time - either partially or completely, as they were bought 6 months ago. She approached her mentor to help her differentiate these two possibilities. The mentor asked her to do 4 different reactions listed below (from P to S). Based on the description of each reaction (P-S), if the respective outcome is positive (PCR works, DNA gets amplified), match the statements (E or F) that can help Zaira conclude unambiguously about her two hypotheses (if it doesn't match either hypothesis, then label as NONE):

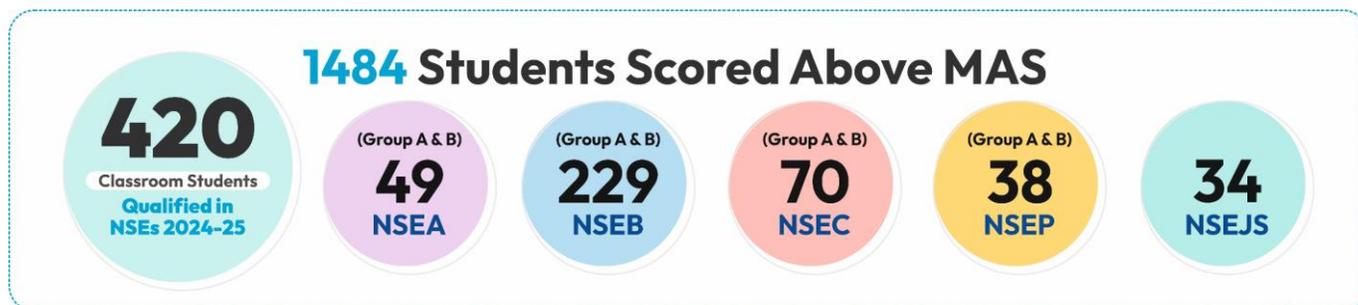
(P) Repeating the standard reaction tube containing the ingredients for PCR along with the human DNA (her template of choice), but with twice the amount of nucleotides she had previously used.

(Q) A reaction similar to the standard reaction but using the specific pre-amplified tubulin DNA as template from a previous PCR reaction (that had worked, done by her mentor).

(R) Repeat any PCR reaction (that used a commercially prepared Taq Pol) that she knows had worked previously, but do it this time with the Taq Pol she had purified.

(S) Repeat the standard reaction tube with all the ingredients + human DNA template for PCR, but with a fresh batch of nucleotides.

(E)	The nucleotides she used in the original standard reaction were completely functional.
(F)	The nucleotides she used in the original standard reaction were partially inactivated.



Sol. (1) Total number of cells:

$$\begin{aligned} \text{Total cells} &= 100 \text{ mL} \times 10^8 \text{ cells/mL} \\ &= 10^{16} \text{ cells} \end{aligned}$$

Total Taq polymerase molecules:

$$\text{Taq per cell} = 100$$

$$\text{Total Taq} = 10^{10} \times 100 = 10^{12}$$

Total non-target protein molecules:

$$\text{Non-target proteins per cell} = 10^7 - 100 \approx 10^7$$

$$\text{Total non-target proteins} = 10^{10} \times 10^7 \times 10^{17}$$

$$\text{Target protein (Taq DNA polymerase)} = 10^{12}$$

$$\text{Non-target proteins} = 10^{17}$$

(2)

No. of molecules of proteins	In 100 mL	After Step 1	After Step 2	After Step 3	After Step 4	After Step 5	After Step 6	After Step 7
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Non-target protein (P)	$1 \times 10^{17}$	$1 \times 10^{14}$	$1 \times 10^{11}$	$1 \times 10^8$	$1 \times 10^5$			
Taq protein (Q)	$1 \times 10^{12}$	$5 \times 10^{10}$	$2.50 \times 10^9$	$1.25 \times 10^8$	$6.25 \times 10^6$			
Total protein (P + Q)	$1 \times 10^{17}$	$1 \times 10^{14}$	$1 \times 10^{11}$	$1 \times 10^8$	$1 \times 10^5$			
Percentage of pure Taq protein	0.000001%	0.05%	2.44%	55.56%	98.42%			

Minimum number of purification steps required to get at least 98% pure Taq is 4.

- (3) (D) BSA competes with Taq for the action of contaminating proteases, thereby prolonging the half-life of the Taq polymerase → PCR expected to be better than the standard. EDTA will chelate  $Mg^{2+}$  and inhibit the polymerase enzyme → PCR expected to be poorer than the standard.
- (4) (D) She seeks control tube without the human template DNA.
- (5) P → F, Q → None, R → None, S → E

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27. Tubulin constitutes 6% of the total protein of a cell and exists as a heterodimer composed of  $\alpha$ -tubulin (molar mass  $\approx 50,000\text{Da}$ ) and  $\beta$ -tubulin (molar mass  $\approx 55,000\text{Da}$ ). Biochemical analysis shows that there is 0.5 mg of total protein per million cells. Using this value, estimate the average number of tubulin heterodimeric molecules per cell. Show the complete sequence of calculations required to arrive at each answer. **[4 Marks]**

Tubulin mass per  $10^6$  cells: \_\_\_\_\_

Tubulin mass per cell: \_\_\_\_\_

Moles of tubulin per cell: \_\_\_\_\_

Average number of tubulin molecules per cell: \_\_\_\_\_

**Sol.** Given :

Total protein = 0.5 mg per  $10^6$  cells

Tubulin = 6% of total protein

Tubulin is heterodimer ( $\alpha + \beta$ ),

Hence, Molar mass of  $\alpha$ -tubulin = 50,000Da

Molar mass of  $\beta$ -tubulin = 55,000Da

Molar mass of tubulin heterodimer

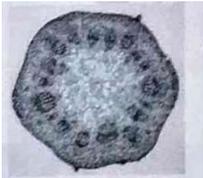
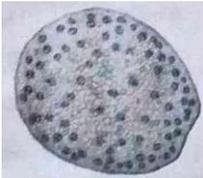
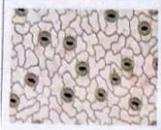
- Tubulin mass per  $10^6$  cells  
 $= 0.5 \text{ mg} \times 0.06$   
 $= 0.03 \text{ mg}$
- Tubulin mass per cell  
 $= \frac{0.03 \text{ mg}}{10^6}$   
 $= 3 \times 10^{-8} \text{ mg/cell}$
- Moles of tubulin per cell  
 $= \frac{3 \times 10^{-11}}{1.05 \times 10^5}$   
 $= 2.86 \times 10^{-16} \text{ mol/cell}$
- Average number of tubulin molecules per cell,  
 Using Avogadro number,  $N = n \times N_A$   
 $= 2.86 \times 10^{-16} \times 6.022 \times 10^{23}$   
 $= 1.72 \times 10^8 \text{ molecules/cell}$

**[4 Marks]**

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28. Plants are classified as monocot and dicot based on certain character. Identify the following plant part as monocot (M) or dicot (D) [6 Marks]

Plant part	Monocot/Dicot	Plant part	Monocot/Dicot
			
			
			
			
 Electron micrograph of a pollen		 Electron micrograph of a pollen	

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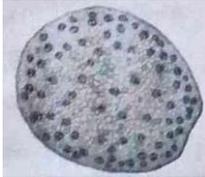
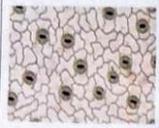
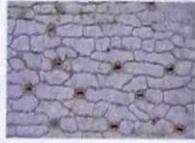
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Sol.

Plant part	Monocot/Dicot	Plant part	Monocot/Dicot
	Dicot (Dicot have five petals)		Monocot (Monocot flowers usually have petals in multiples of three)
	Dicot (The vascular bundles in this cross-section of stem are arranged in a distinct ring)		Monocot (The vascular bundles in this cross-section are scattered randomly throughout the stem tissue)
	Monocot (It is the seed of arca palm ( <i>Areca catechu</i> ) which belongs to the family monocot)		Dicot (Potato is a dicot plant)
	Dicot (The stomata are scattered randomly in epidermis of dicot leaf)		Monocot (The stomata are arranged in parallel rows, typically in the epidermis of a monocot leaf)
 Electron micrograph of a pollen	Monocot (Monocot pollen grains have a single pore or furrow)	 Electron micrograph of a pollen	Dicot (Dicot pollen grains typically have three pores or furrows)

[6 Marks]

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29. The glucometer is a vital tool for persons managing diabetes, as it enables accurate monitoring of blood glucose levels. The operation of a glucometer relies on enzymatic reactions, specifically utilising the enzyme glucose oxidase. When a blood sample comes into contact with the sensor region of a test strip, glucose oxidase catalyses the conversion of glucose in the blood to gluconic acid and hydrogen peroxide. This reaction uses blood water and oxygen and is nearly irreversible.

The quantity of hydrogen peroxide formed during this process is directly proportional to the concentration of glucose present in the blood sample. The generation of hydrogen peroxide leads to the production of an electric current. The device then calculates the corresponding blood glucose level based on the magnitude of this electrical current.

**[15 Marks]**

Every component within the glucometer is designed to contribute towards the precision and reliability of the measurement. To maintain consistent and reliable results, regular calibration and maintenance of the glucometer are essential.

The following steps outline the typical procedure for using a glucometer:



1. Insert Test Strip: Insert a test strip into the glucometer as per the instructions provided with the device.
2. Clean the Finger: Use the supplied wet swab to clean the surface of the finger you intend to prick.
3. Lancing: Use the lancet to gently prick your finger, typically near the tip, to produce a small drop of blood.
4. Blood Sample: Carefully touch the blood drop to the designated area on the test strip.
5. Measurement: The test strip draws the blood sample into contact with the embedded enzyme.
6. Reading Display: Within seconds, the glucometer displays your blood sugar level on its screen.

By following these straightforward steps, users can efficiently monitor their blood glucose levels at home, helping in diabetes management.

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Based on the description given above answer the following questions:

**Q1.** Describe the chemical reaction in a word equation **[0.5 Mark]**

**Q2.** What type of reaction is taking place **[0.5 Mark]**

**Q3.** What is the physical process that allows for blood components to come into contact with the sensor? **[1 Mark]**

**Q4.** What is the chemical reason for this method to be accurate despite blood containing other sugars or carbohydrates? **[1 Mark]**

Ranga wanted to test the accuracy of his glucometer. He bought glucose from a store and made a series of standard glucose solutions. Then he used the glucometer available in his house and measured the glucose values. The concentration of the solutions he made, and the corresponding values are given in the table below.

	<b>Standard Concentration of Glucose solution (mg/dL)</b>	<b>Values obtained on glucometer (mg/dL)</b>
<b>Trial 1</b>	50	50
<b>Trial 2</b>	100	100
<b>Trial 3</b>	150	155
<b>Trial 4</b>	200	212
<b>Trial 5</b>	250	265
<b>Trial 6</b>	300	319
<b>Trial 7</b>	350	373

To make his solutions Ranga made a stock of 250 ml of 500mg/dL solution which he diluted subsequently to obtain the required solutions.

**Q5.** What was the amount of glucose (in mg) used to make the stock solution? **[1 Mark]**

**Q6.** What is the amount of water and glucose stock solution that he had to mix to obtain 15 mL of 150 mg/dL solution? **[1 Mark]**

**Q7.** Plot a single graph that Ranga can use to clearly show the deviation between the standard values and the values measured with the glucometer. **[8 Marks]**

**Q8.** Ranga calculated the average percentage deviation of the measurements. What is the value? **[2 Marks]**

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- Sol.** (1) Glucose + Oxygen + Water → Gluconic acid + Hydrogen peroxide [0.5 Mark]  
 (2) Enzyme - catalysed oxidation reaction/Oxidation reaction [0.5 Mark]  
 (3) Capillary action [1 Mark]  
 (4) Glucose oxidase (enzyme) is highly specific for glucose and does not react with other sugars. [1 Mark]  
 (5)  $V = 250 \text{ mL}$

$$= 250 \text{ mL} \times \frac{1 \text{ dL}}{100 \text{ mL}}$$

$$= 2.5 \text{ dL}$$

$$\text{Glucose required} = \text{Concentration} \times \text{Volume}$$

$$= 5000 \times 0.25$$

$$= 1250 \text{ mg}$$

[1 Mark]

- (6) Using dilution formula,

$$C_1V_1 = C_2V_2$$

$$500 \times V_1 = 150 \times 15$$

$$V_1 = 4.5 \text{ mL}$$

$$\text{Volume of water} = 15 - 4.5$$

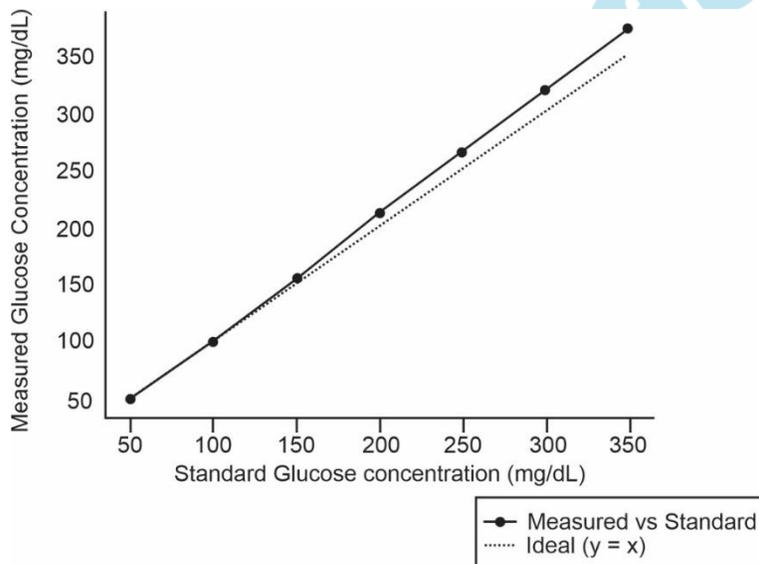
$$= 10.5 \text{ mL}$$

$$\text{Amount of glucose stock solution} = 4.5 \text{ mL}$$

$$\text{Amount of water} = 10.5 \text{ mL}$$

[1 Mark]

- (7) Deviation of Glucometer Readings



[8 Marks]

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(8) % deviation =  $\frac{\text{Measured} - \text{Standard}}{\text{Standard}} \times 100$

Trial	% Deviation
1	0
2	0
3	$\frac{5}{150} \times 100 = 3.33$
4	$\frac{12}{200} \times 100 = 6.00$
5	$\frac{15}{250} \times 100 = 6.00$
6	$\frac{19}{300} \times 100 = 6.33$
7	$\frac{23}{350} \times 100 = 6.57$

Average % deviation =  $\frac{0 + 0 + 3.33 + 6.00 + 6.00 + 6.38 + 6.57}{7}$

Average % deviation  $\approx 4.03\%$

[2 Marks]

30. **Lead Accumulator: Structure and Function**

[10 Marks]

A lead accumulator, commonly referred to as a car battery, is a rechargeable electrochemical cell that transforms chemical energy into electrical energy. The cell's electrode system comprises negative electrodes made from pure spongy lead (Pb), while the positive electrodes consist of lead dioxide (PbO<sub>2</sub>). Both types of electrodes are immersed in diluted sulphuric acid (H<sub>2</sub>SO<sub>4</sub>), which has a concentration of 38% by mass and a specific gravity of 1.33 g/cm<sup>3</sup>.

Thin plastic layers serve as separators between the electrodes, effectively preventing them from making direct contact with each other. All internal components are securely housed in a protective plastic casing, as depicted in Figure-1. The typical dimensions of a lead accumulator are 300 mm in length, 150 mm in breadth, and 200 mm in height. Approximately 80% of the cell's volume is occupied by the sulphuric acid electrolyte.

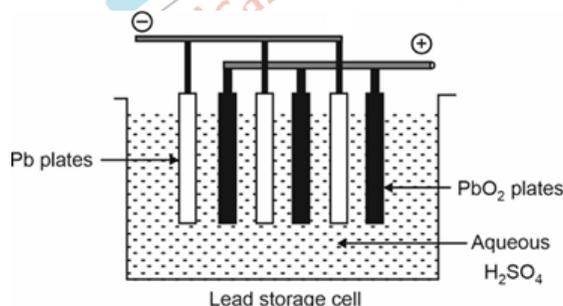


Figure-1: Schematic diagram of Lead Accumulator

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### Electrochemical Reactions During Discharge and Charge

During the discharge process, the lead electrode reacts with sulphuric acid, resulting in the formation of lead (II) sulphate. Similarly, the lead dioxide electrode reacts with sulphuric acid to produce lead (II) sulphate and water as the final products. These reversible chemical reactions facilitate the release of stored electrical energy. When the accumulator is recharged, a direct current is applied, reversing the reactions at the respective electrodes. This process restores the electrodes to their original chemical states and also returns the sulphuric acid to its initial concentration, enabling repeated cycles of charging and discharging.

### Determination of EMF

$$E = E^{\circ} - \frac{RT}{nF} \ln Q$$

Here,  $E^{\circ}$  represents the standard EMF of the cell, defined as the difference in reduction potentials between the two half-cells under standard conditions. Standard conditions are specified as solutions with a concentration of 1 molar (M), gases at 1 atmosphere pressure, and a temperature of 25° C (298 K). Assume that sulfuric acid at all concentrations is dissociated completely and activity of water is 1.0 under all conditions.

$$E = E^{\circ} - \frac{0.0591}{n} \log Q$$

- Q1.** Write reactions at anode, cathode and overall reaction taking place in Lead Accumulator at the time of discharging leading to the products as mentioned in the description. **[2 Marks]**
- Q2.** What is the molar concentration of sulfuric acid ( $\text{H}_2\text{SO}_4$ ) used as an electrolyte in the Lead accumulator? **[2 Marks]**
- Q3.** Calculate EMF of the Lead accumulator battery whose electrode system is shown in the Figure 1. [Given: Standard reduction potential of  $\text{Pb}^{2+}/\text{PbO}_2 = -0.126 \text{ V}$  **[3 Marks]**  
Standard reduction potential of  $\text{PbO}_2/\text{Pb}^{2+}$  in the presence of standard  $\text{H}_2\text{SO}_4 = 1.455 \text{ V}$ ]
- Q4.** The specific gravity of the electrolyte (sulfuric acid) is a direct indicator for the state of a lead-acid battery. The EMF of the battery drops when the specific gravity of  $\text{H}_2\text{SO}_4$  is at 1.17 g/cc or less. This indicates that the battery needs charging. Calculate the charge in units (Ampere-hour) A.h delivered by the car battery when its specific gravity falls from 1.33 g/cm<sup>3</sup> (38% by mass) to 1.17 g/cm<sup>3</sup> (23.43% by mass) [Given: 3600 C = 1 Ampere. hour; Faraday constant = 96500 C] Assume no change in the volume of the solution. **[3 Marks]**

**[3 Marks]**

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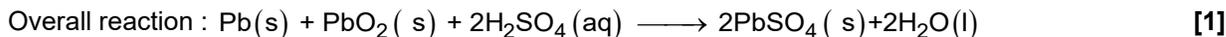
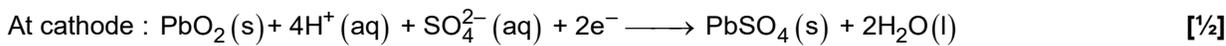
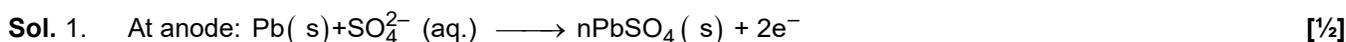
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2. Density of solution = 1.33 g/cm<sup>3</sup>

Concentration = 38% (w/w)

$$\text{Molarity} = \frac{\% (w/w) \times d \times 10}{\text{Molar mass of solute}}$$

$$= \frac{38 \times 1.33 \times 10}{98}$$

$$= 5.16 \text{ M} \quad [1]$$

3.  $E_{\text{cell}}^0 = E_{\text{cathode}}^0 - E_{\text{anode}}^0$  [½]

$$E_{\text{cell}}^0 = 1.455 - (-0.0126)$$

$$= 1.581 \text{ V} \quad [½]$$

$$E = E_{\text{cell}}^0 - \frac{0.0591}{2} \log \frac{1}{[\text{H}_2\text{SO}_4]^2} \quad [½]$$

$$E = 1.581 - \frac{0.0591}{2} \log \left( \frac{1}{5.16} \right)^2 \quad [½]$$

$$E = 1.623 \text{ V} \quad [½]$$

4. Volume of battery = 300 mm × 150 mm × 200 mm = 9,000,000 mm<sup>3</sup>

Or

$$9000 \text{ cm}^3 \quad [0.25]$$

Volume of electrolyte = 80% of volume of battery (given)

$$= 0.8 \times 900 \text{ cm}^3$$

$$= 7200 \text{ cm}^3 \text{ or } 7.2 \text{ L} \quad [½]$$

$$\text{Initial moles of H}_2\text{SO}_4 = 1.33 \text{ g/cm}^3 \times 7200 \text{ cm}^3 \times \frac{0.38}{98} \quad [0.25]$$

$$\approx 37.13 \quad [½]$$

$$\text{Final moles of H}_2\text{SO}_4 = 1.17 \text{ g/cm}^3 \times 7200 \text{ cm}^3 \times \frac{0.2343}{98} \quad [½]$$

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$$\text{Final moles of H}_2\text{SO}_4 = 1.17 \text{ g/cm}^3 \times 7200 \text{ cm}^3 \times \frac{0.2343}{98} \quad [1/2]$$

$$\approx 20.14$$

$$\text{Change in moles of H}_2\text{SO}_4 = 37.13 - 20.14 = 16.99 \text{ moles} \quad [0.25]$$

$$\begin{aligned} \text{Total charge} &= 6.99 \text{ mole} \times 96500 \text{ C/mole} \\ &= 1639535 \text{ C} \quad [1/2] \end{aligned}$$

$$1 \text{ A.h} = 3600 \text{ C}$$

$$\text{Charge in A.h} = \frac{1639535}{3600} \quad [1]$$

$$= 455.4 \quad [1]$$

### 31. Inorganic Reactions [5 Marks]

A chemistry student named Mira was performing a set of experiments in her school laboratory. She started with a **white powder (A)**. When she added dilute hydrochloric acid to it, the mixture began to fizz, releasing a **colourless gas (Y)** and forming a **solution of another compound (B)**.

Curious about the gas, Mira passed **Y** through **limewater**. The limewater immediately turned **milky**, forming a **white precipitate (D)**. When she continued passing more of gas **Y**, the milky mixture surprisingly cleared up and turned into a colourless solution of **E**.

Later that day, she mixed the **same original powder (A)** with **ammonium chloride** and heated the mixture strongly. This produced **compound B again**, along with two gases: **one was Y**, the same gas from earlier, and the other was a **pungent-smelling gas (F)**.

To confirm its identity, Mira brought a glass rod dipped in concentrated hydrochloric acid near the gas **F**. Instantly, dense **white fumes (G)** appeared.

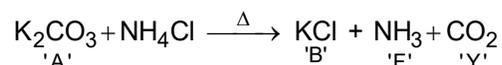
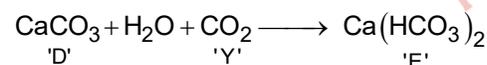
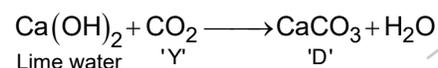
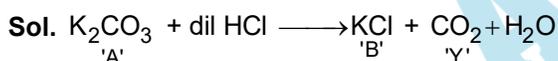
**Q1.** Draw the Lewis structure of gas 'Y'.

**Q2.** Draw the Lewis structure of gas 'F'.

**Q3.** What is the molecular formula of 'E'.

**Q4.** What type of reaction leads to formation of G?

**Q5.** The difference in molecular weight of A and B is 63.5, identify A and B?



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(1) Gas 'Y' = CO<sub>2</sub>

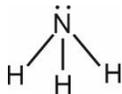
Lewis structure of CO<sub>2</sub> :



[1]

(2) Gas 'F' = NH<sub>3</sub>

Lewis structure of NH<sub>3</sub> :



[1]

(3) Molecular formula of 'E' = Ca(HCO<sub>3</sub>)<sub>2</sub>

[1]

(4) Neutralisation / Combination reaction

[1]

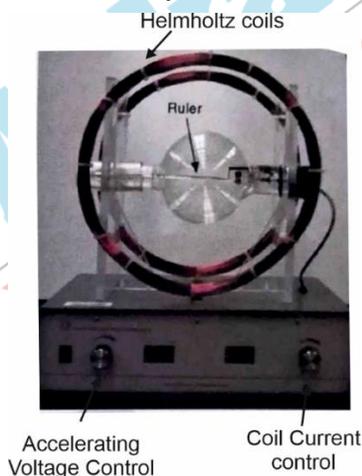
(5) A = K<sub>2</sub>CO<sub>3</sub> and B = KCl

[½ + ½]

32. This question is based on an experiment to determine the ratio of the charge to mass of an electron. The ratio has a great physical significance in the field of charged particle dynamics. A brief description of the experiment and theoretical background is provided for your information and understanding. The data that has been collected using the apparatus is also provided. Using the information and data find the charge to mass ratio of electron by plotting a graph. Graph plotting is an important skill to analyse the data. A good graph should utilise at least 75% of the given area and have its axes properly labelled.

**Theoretical Background:** The charge-to-mass ratio  $\left(\frac{e}{m}\right)$  of an electron is one of the fundamental constants in physics. It was first measured by J.J. Thomson in 1897 using the deflection of cathode rays in electric and magnetic fields. In this experiment, we determine  $\frac{e}{m}$  by observing the motion of electrons in a uniform magnetic field produced by a pair of coils.

**Principle:** When a charged particle such as an electron of charge  $e$  is accelerated through a potential difference ( $V$ ), it gains kinetic energy equal to the work done by the electric field. The relationship is given by:



$$eV = \frac{1}{2}mv^2 \quad \dots(1)$$

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where  $e$  is the charge of the electron,  $m$  is its mass, and  $v$  is its velocity after acceleration.

When this electron beam enters a region of uniform magnetic field ( $B$ ) perpendicular to its velocity, it experiences a magnetic Lorentz force that causes it to move in a circular path. The required centripetal force for circular motion is provided by the magnetic force:

$$evB = \frac{mv^2}{r}$$

$$\therefore eB = \frac{mv}{r} = \frac{p}{r} \quad \dots(2)$$

Here  $p$  is the momentum of the electron.

The magnetic Field at the centre of a pair of identical circular coils (each having  $N$  turns and radius  $R$ ), carrying current  $I$ , and separated by a distance equal to  $R$  is

$$B = \mu_0 \left(\frac{4}{5}\right)^2 \left(\frac{NI}{R}\right) \quad \dots(3)$$

These coils are called Helmholtz coils. This arrangement ensures that the magnetic field near the centre is nearly uniform, allowing the electrons to follow a circular trajectory.

**Experimental Method:** In the laboratory setup, electrons emitted from a heated cathode are accelerated through a known potential difference  $V$  and enter the magnetic field region between the Helmholtz coils. The electron beam forms a circular path whose radius  $r$  can be measured using a fluorescent screen. By keeping the coil current  $I$  (and hence  $B$ ) constant and varying  $V$ , a series of ( $V$ ,  $r$ ) data pairs are obtained as provided in the table.

From these,  $\frac{e}{m}$  can be calculated. **[10 Marks]**

**Q1.** Show that the ratio  $\frac{e}{m} = \frac{2V}{B^2 r^2}$ . **[2 Marks]**

**Q2.** For the given values of current, calculate value of magnetic field using equation (3). **[1 Mark]**

**Q3.** Identify two parameters that can be used to plot a straight-line graph to obtain  $\frac{e}{m}$ . Enter their values in the empty columns in the table. **[3 Marks]**

**Q4.** Plot a linear graph and obtain the ratio  $\frac{e}{m}$  from its slope. **[4 Marks]**

**Data:** Apparatus Parameters:

- (a) Number of turns per coil,  $N = 130$
- (b) Coil radius,  $R = 0.150$  m
- (c) Current flowing through the coils,  $I = 1.40$  A (constant)

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(d) Permeability of free space,  $\mu_0 = 4\pi \times 10^{-7} \text{ T m A}^{-1}$

Trial No.	Accelerating Voltage, $V$ (V)	Measured diameter, $d$ (cm)			
1	100	6.2			
2	120	6.8			
3	140	7.4			
4	160	8			
5	180	8.3			
6	200	8.8			
7	220	9.6			
8	240	10			
9	260	10.4			
10	280	10.7			

Sol. 1.  $eV = \frac{1}{2}mv^2$  ... (i)

$evB = \frac{mv^2}{r}$  ... (ii)

From equation (i) and (ii)

$\frac{e}{m} = \frac{2V}{B^2 r^2}$

2.  $B = \mu_0 \left(\frac{4}{5}\right)^2 \left(\frac{NI}{R}\right)^3$

$= 4\pi \times 10^{-7} \times \left(\frac{4}{5}\right)^2 \left(\frac{130 \times 1.4}{0.15}\right)^3$   
 $= 1.09 \times 10^{-3} \text{ T}$

3.  $V = \frac{e}{2m} B^2 r^2$

For a straight line graph the graph can be plotted between  $V$  and  $r^2$

slope =  $\frac{e}{2m} B^2$

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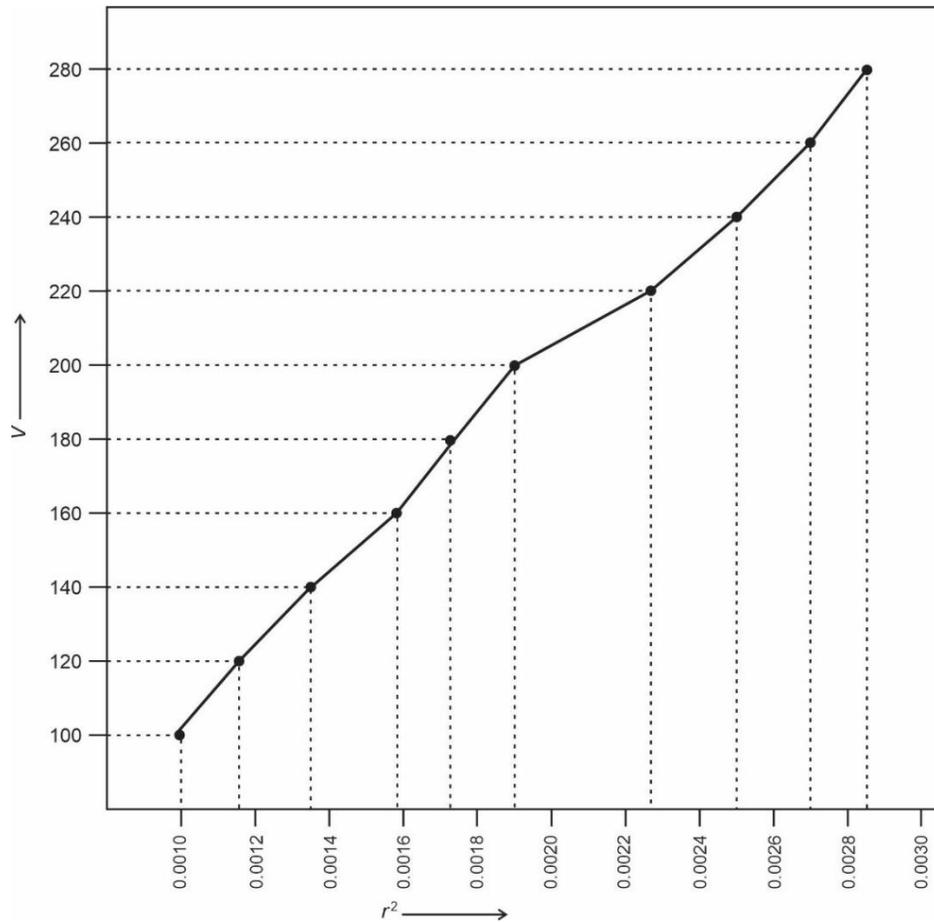
4. Observation table

Trail	V(V)	D (cm)	r(m)	r <sup>2</sup> (m <sup>2</sup> )	e/m (C/kg)
1	100	6.2	0.0310	0.000961	1.76 × 10 <sup>11</sup>
2	120	6.8	0.0340	0.001156	1.75 × 10 <sup>11</sup>
3	140	7.4	0.0370	0.001369	1.72 × 10 <sup>11</sup>
4	160	8.0	0.0400	0.001600	1.68 × 10 <sup>11</sup>
5	180	8.3	0.0415	0.001722	1.75 × 10 <sup>11</sup>
6	200	8.8	0.0440	0.001936	1.73 × 10 <sup>11</sup>
7	220	9.6	0.0480	0.002304	1.61 × 10 <sup>11</sup>
8	240	10.0	0.0500	0.002500	1.62 × 10 <sup>11</sup>
9	260	10.4	0.0520	0.002704	1.62 × 10 <sup>11</sup>
10	280	10.7	0.0535	0.002862	1.65 × 10 <sup>11</sup>

From the given table

$$\frac{e}{m} \approx (1.70 \pm 0.1) \times 10^{11} \text{ C / kg}$$

Which matches closely with the standard value  $1.76 \times 10^{11} \text{ C/kg}$



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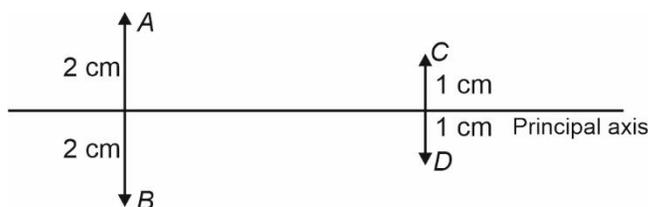
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33. Object and Image: The figure given below is a part of several ray diagrams. Out of the two arrow lines AB and CD, anyone can be object, and the other is its image (i.e., if AB is an object, CD is its image, and vice versa).

You are given a concave mirror, a convex mirror, a biconcave lens and a biconvex lens as optical devices. Radius of curvature of both the mirrors and of all the surfaces of both the lenses is 30 cm. Both the lenses are thin and are made up of glass of refractive index,  $n = 1.5$ . Each one of these optical devices can have AB and CD as either object or image.

In case of a lens, according to the Cartesian coordinate system, its focal length is related to refractive index  $n$  and radii of curvature of the two surfaces  $R_1$  and  $R_2$  as **[8 Marks]**

$$\frac{1}{f} = (n - 1) \left( \frac{1}{R_1} - \frac{1}{R_2} \right)$$



**Q1.** Considering CD as object, find the positions of the converging optical devices that can give the AB as image. Fill the table with the required values. The axial distance is the distance between AB and CD.

Converging Optical device	Object	Image	Arrangement (Sequence of AB, CD and optical device from Left to Right)	$u$ cm	$v$ cm	Expression for Axial distance $ v - u $ ,	Axial Distance (value, cm)
	CD	AB					
	CD	AB					
	CD	AB					
	CD	AB					

**[4 marks]**

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Q2. Considering AB as object, find the positions of the optical devices that can give the CD as image. Fill the table with the required values.

Converging Optical device	Object	Image	Arrangement (Sequence of AB, CD and optical device from Left to Right)	$u$ cm	$v$ cm	Expression for Axial distance	Axial Distance (value, cm)
Concave mirror	AB	CD					
Convex mirror	AB	CD					
Concave lens	AB	CD					
Convex lens	AB	CD					

[4 marks]

Sol. (1)

Converging Optical device	Object	Image	Arrangement (Sequence of AB, CD and optical device from Left to Right)	$u$ cm	$v$ cm	Expression for Axial distance $ v - u $ ,	Axial Distance (value, cm)
Concave mirror	CD	AB	AB, CD, mirror	-22.5	-45	$ -45 + 22.5 $	22.5
Concave mirror	CD	AB	AB, mirror, CD	7.5	-15	$ -15 - 7.5 $	22.5
Convex lens	CD	AB	AB, lens, CD	45	-90	$ -90 - 45 $	135
Convex lens	CD	AB	AB, CD, lens	-15	-30	$ -30 + 15 $	15

[4 marks]

Sol. (2)

Converging Optical device	Object	Image	Arrangement (Sequence of AB, CD and optical device from Left to Right)	$u$ cm	$v$ cm	Expression for Axial distance	Axial Distance (value, cm)
Concave mirror	AB	CD	AB, CD, mirror	-45	-22.5	$ -22.5 + 45 $	22.5
Convex mirror	AB	CD	AB, mirror, CD	-15	+7.5	$ 7.5 + 15 $	22.5
Concave lens	AB	CD	AB, CD, lens	-30	-15	$ -15 + 30 $	15
Convex lens	AB	CD	AB, Lens, CD	-90	+45	$ 45 + 90 $	135

[4 marks]

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34. In cold climates, our bodies expend extra energy to warm the cold air we inhale to our body temperature (around  $37^\circ$ ). This thermoregulatory process burns an additional 100 to 200 calories per day, even without doing any physical activity. The colder the air, the greater the energy demand, as the body maintains core temperature through shivering and increased metabolism - essentially making us burn calories just by breathing and staying warm.

Metabolism is a continuous process in the body and remains active even when we are sleeping. The energy released through metabolism is used to support the functioning of internal organs as well as activities such as walking, running, and other physical tasks. Energy expenditure during activities is often expressed in units called METs, which stands for Metabolic Equivalent of Task.

1 MET = the energy you expend while resting, sitting quietly or sleeping.

It is approximately 4.2 kJ per kg of body weight per hour.

A tourist in Ooty is fasting on the day when the least temperature is  $6^\circ\text{C}$ . He wants to manage the day with 2 bananas, 1 apple and few glasses of plain water. He spends a good 14 hours inside the room where the temperature is maintained at  $20^\circ\text{C}$ . During this time, he hardly does any physical activities and inhales 6 litres of air per minute. He spends time with other tourists about 6 hours in the lounge, sit out, roof top where the temperature is  $9^\circ\text{C}$ , and inhales 6 litres of air per minute. When temperature hits  $12^\circ\text{C}$  he joins others for a hike. He manages to complete the task in four hours, including two hours of slow walk, one hour of rigorous walk and a total of one hour rest. On an average he inhales 25 litres of air per minute during these 4 hours.

**[7 Marks]**

Use the following data to answer the following questions.

- Mass of the tourist 70 kg.
- Useful energy released by digesting a banana is 440 kJ.
- Useful energy released by digesting an apple is 400 kJ.
- No energy is released by water.
- Normal body temperature is  $37^\circ\text{C}$ .
- Density of air  $1.2\text{ kg/m}^3$ .
- Energy required to increase the temperature of 1 kg air through  $1^\circ\text{C}$  is 1 kJ .
- Energy expended during slow walk is 3 MET.
- Energy expended during rigorous walk is 6 MET.
- To burn one gram of fat one needs to spend 40 kJ of energy.

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**Questions:**

- Q1.** How much total useful energy does the tourist obtain from eating 2 bananas and 1 apple during the day? **[1 Mark]**
- Q2.** While inside the room at 20°C (for 14 hours), how much energy does his body spend in heating the inhaled air to 37°C, given that he inhales 6 litres of air per minute? **[1 Mark]**
- Q3.** During the 6 hours spent in roof top at 9°C, how much energy is required to warm all the air he inhales from 9°C to 37°C? **[1 Mark]**
- Q4.** During the 4-hour hike, he inhales 25 litres of air per minute. If the temperature is 12°C, how much energy does his body use to warm the inhaled air to 37°C during the entire hike? (1 mark) **[1 Mark]**
- Q5** How much energy he expends during this day for physical activities and for functioning of internal organs? **[1 Mark]**
- Q6.** Using all the above energy expenditures, determine whether the energy obtained from food is sufficient. If not, how many grams of fat must his body burn to meet the shortage, given that burning 1 gram of fat provides 40 kJ? **[2 Marks]**

**Sol.** (1) Total useful energy obtained from food.

The tourist consumes 2 bananas and 1 apple.

$$\text{Total Energy} = (2 \times \text{Energy}_{\text{banana}}) + (1 \times \text{Energy}_{\text{apple}})$$

$$\text{Total Energy} = (2 \times 440 \text{ kJ}) + 400 \text{ kJ}$$

$$\text{Total Energy} = 880 + 400 = 1280 \text{ kJ}$$

(2) Energy spent heating air (Inside room)

- Conditions:  $T_{\text{room}} = 20^\circ\text{C}$ , Duration  $t = 14$  hours, Rate = 6 L/min.
- Temperature difference ( $\Delta T$ ):  $37^\circ\text{C} - 20^\circ\text{C} = 17^\circ\text{C}$
- Total volume of Air Inhaled:  
 $6 \text{ L/min.} \times 60 \text{ min/hr} \times 14 \text{ hrs} = 5040 \text{ L}$
- Mass of Air:  
 $5040 \text{ L} \times 0.0012 \text{ kg/L} = 6.048 \text{ kg}$
- Energy Required :  
 $E = \text{Mass} \times \text{Specific Heat} \times \Delta T$   
 $E = 6.048 \text{ kg} \times 1 \text{ kJ/kg. C} \times 17^\circ\text{C}$   
 $E = 102.816 \text{ kJ}$

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(3) Energy spent heating air (roof top)

- Conditions:  $T_{\text{roof}} = 9^{\circ}\text{C}$ , Duration  $t = 6$  hours, Rate = 6 L/min. (from text description)
- Temperature difference ( $\Delta T$ ) :  $37^{\circ}\text{C} - 9^{\circ}\text{C} = 28^{\circ}\text{C}$
- Total volume of Air Inhaled:  
 $6 \text{ L/min} \times 60 \text{ min/hr} \times 6 \text{ hrs} = 2160 \text{ L}$
- Mass of Air:  
 $2160 \text{ L} \times 0.0012 \text{ kg/L} = 2.592 \text{ kg}$
- Energy Required :  
 $E = 2.592 \text{ kg} \times 1 \text{ kJ/kg} \cdot ^{\circ}\text{C} \times 28^{\circ}\text{C}$   
 $E = 72.576 \text{ kJ}$

(4) Energy spent heating air (Hike)

- Conditions:  $T_{\text{hike}} = 12^{\circ}\text{C}$ , Duration  $t = 4$  hours, Rate = 25 L/min. (average)
- Temperature difference ( $\Delta T$ ) :  $37^{\circ}\text{C} - 12^{\circ}\text{C} = 25^{\circ}\text{C}$
- Total volume of Air Inhaled:  
 $25 \text{ L/min} \times 60 \text{ min/hr} \times 4 \text{ hrs} = 6000 \text{ L}$
- Mass of Air:  
 $6000 \text{ L} \times 0.0012 \text{ kg/L} = 7.2 \text{ kg}$
- Energy Required :  
 $E = 7.2 \text{ kg} \times 1 \text{ kJ/kg} \cdot ^{\circ}\text{C} \times 25^{\circ}\text{C}$   
 $E = 180 \text{ kJ}$

(5) Energy expended for metabolic functions and physical activities.

We calculate the energy for each activity period using the MET values provided

(1 MET = 294 kJ/hr for this tourist)

- Room (14 hours): Resting  $\rightarrow$  1 MET  
 $14 \text{ hrs} \times 1 \text{ MET} = 14 \text{ MET - hours}$
- Lounge/Roof (6 hours): Sitting  $\rightarrow$  1 MET  
 $6 \text{ hrs} \times 1 \text{ MET} = 6 \text{ MET - hours}$

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- (iii) Hike (4 hours total)
  - Slow walk (2 hours): 3 MET  $\rightarrow 2 \times 3 = 6$  MET - hours
  - Rigorous walk : 6 MET  $\rightarrow 1 \times 6 = 6$  MET - hours
  - Rest (1hour): 1 MET  $\rightarrow 1 \times 1 = 1$  MET - hours
  - Total MET - hours for the day:  
 $14 + 6 + 6 + 6 + 1 = 33$  MET - hours
  - Total Energy:  
 $33 \times 294$  kJ = 9702 kJ

(6) Energy sufficiency and fat burning

First, we calculate the total energy Expenditure by summing the metabolic energy (Q5) and the air heating energy (Q2, Q3, Q4)

Total expenditure = Metabolic + Heating (Room) + Heating (Roof) + Heating (H)

Total expenditure = 97.2 + 102.816+ 72.576 + 180

Total Expenditure = 10057.392 kJ

Comparison: The energy from food is 1280 kJ. Since 1280 kJ < 10057.392 kJ, the food is no sufficient.

Fat to be burnt:

- Energy shortage: 10057.392 – 1280 kJ = 8777.392 kJ
- Fat Conversion: 1 gram fat = 40 kJ
- Mass of fat needed:

$$\frac{8777.392}{40} = 219.4348 \text{ grams}$$

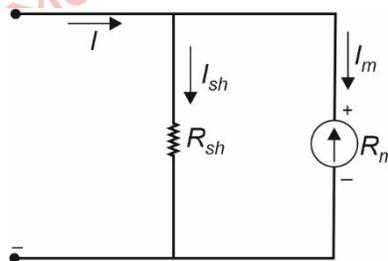
Answer: The tourist must burn approximately 219.43 grams of fat.

35. A basic dc (direct current) ammeter circuit consists of a galvanometer in which pointer deflection is directly proportional to the amount of current passing through the meter. The current producing full-scale deflection in galvanometer is very small. When large currents are to be measured, a major part of the current is bypassed through a small resistance ( $R_{sh}$ ) called **shunt**, connected in parallel with meter, as shown in the figure.

If  $R_m$  is the resistance of meter and  $I_m$  is the meter current and  $I_{sh}$  is the Current through shunt. At any instant,

$$I = I_{sh} + I_m$$

$$I_m R_m = I_{sh} R_{sh}$$



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**Problem:** Now, consider a typical multirange dc ammeter circuit shown in figure 2. It consists of a single meter having resistance  $R_m = 50 \Omega$ , in parallel with series of resistors  $R_a$ ,  $R_b$  and  $R_c$  which can be selected in different combinations by rotary switch that can be represented by an arrow. The arrow may be turned about its midpoint and accordingly the arrowhead can touch the points 1, 2 or 3. The position of switch S determines the total resistance in series and parallel with the meter. The two terminals of the ammeter in the figure have been with a positive sign (+) and a negative (-)

The position of the arrowhead switch S and the corresponding operating range of the ammeter are related as shown in the following table. **[5 Marks]**

Arrowhead in S	Operating range of ammeter
Position 3	0 – 2 mA
Position 2	0 – 10 mA
Position 1	0 – 50 mA

If the current required for full-scale deflection is  $I_M = 1 \text{ mA}$

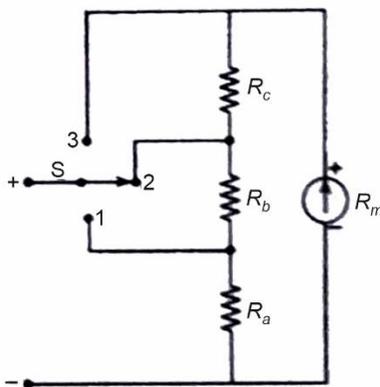
**Q1.** Calculate value of  $R_a$ ,  $R_b$  and  $R_c$

**[3 marks]**

**Q2.** Calculate the effective ammeter resistance when operating in the following ranges

- (i) 0 – 2 mA
- (ii) 0 – 10 mA
- (iii) 0 – 50 mA

**[2 marks]**



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Sol. Given:

- Meter resistance:  $R_m = 50 \Omega$
- Full scale deflection current of meter:  $I_m = 1 \text{ mA}$
- Hence full scale meter voltage:  $V_m = I_m R_m = 0.001 \times 50 = 0.05 \text{ V}$

This 0.05 V must appear across the entire parallel combination at full scale in every range.

Correct interpretation of switch positions (key point)

From your clarification and the figure:

**Position 1 (0-50 mA range)**

- $R_b$  and  $R_c$  are in series with the meter.
- This series branch is in parallel with  $R_a$

Equivalent branches

- Branch 1 :  $R_a$
- Branch 2:  $R_m + R_b + R_c$

**Position 2 (0-10 mA range)**

- $R_c$  is in series with the meter.
- Parallel with  $R_a + R_b$

Equivalent branches

- Branch 1 :  $R_a + R_b$
- Branch 2:  $R_m + R_c$

**Position 3 (0 - 2 mA range)**

- Meter alone in one branch
- Parallel with  $R_a + R_b + R_c$

Equivalent branches

- Branch 1 :  $R_a + R_b + R_c$
- Branch 2:  $R_m$



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**Q.1 Find  $R_a, R_b, R_c$**

**Position 3 (0 – 2 mA)**

Total current at FSD:

$$I = 2 \text{ mA}$$

Meter current:

$$I_m = 1 \text{ mA} \rightarrow I_{sh} = 1 \text{ mA}$$

Voltage across both branches:

$$V = 0.05 \text{ V}$$

So, shunt resistance:

$$R_a + R_b + R_c = \frac{0.05}{0.0001} = 50 \Omega$$

$$R_a + R_b + R_c = 50 \Omega \quad \dots(1)$$

**Position 2 (0 - 10 mA)**

Total current

$$I = 10 \text{ mA} \Rightarrow I_{sh} = 9 \text{ mA}$$

Series resistance with meter:

$$R_m + R_c = 50 + R_c$$

Voltage across meter branch:

$$V = I_m (R_m + R_c) = 0.0001(50 + R_c)$$

This equals voltage cross shunt branch:

$$0.001(50 + R_c) = 0.009(R_a + R_b)$$

$$50 + R_c = 9(R_a + R_b) \quad \dots(2)$$

**Position 1 (0 - 50 mA)**

Total current

$$I = 50 \text{ mA} \Rightarrow I_{sh} = 49 \text{ mA}$$

Series resistance with meter:

$$R_m + R_b + R_c = 50 + R_b + R_c$$

Voltage equality:

$$0.001(50 + R_b + R_c) = 0.049R_a$$

$$50 + R_b + R_c = 49R_a \quad \dots(3)$$

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Solve equations (1), (2), (3)

From (1):

$$R_c = 50 - R_a - R_b$$

Substitute into (2)

$$50 + (50 - R_a + R_b) = 9(R_a + R_b)$$

$$100 = 10R_a + 10R_b \Rightarrow R_a + R_b = 10 \Omega$$

So,  $R_c = 50 - 10 = 40 \Omega$

Now use (3) :

$$50 + R_b + 40 = 49R_a \Rightarrow 90 + R_b = 49R_a$$

But  $R_b = 10 - R_a$  :

$$90 + 10 - R_a = 49R_a$$

$$100 = 50R_a \Rightarrow R_a = 2 \Omega$$

Then:

$$R_b = 8 \Omega, R_c = 40 \Omega$$

**Final answer for Q. 1**

$$R_b = 8 \Omega, R_c = 40 \Omega, R_a = 2 \Omega$$

$$50 + R_b + R_c = 49R_a \dots(3)$$

**Q2.** Effective ammeter resistance in each range

Effective resistance = parallel combination of the two branches.

(i) 0.2 mA

Branches:

$$R_m = 50 \Omega$$

$$R_a + R_b + R_c = 50 \Omega$$

$$R_{\text{eff}} = \frac{50 \times 50}{50 + 50} = 25 \Omega$$

(ii) 0 – 10 mA

Branches:

$$R_m + R_c = 90 \Omega$$

$$R_a + R_b = 10 \Omega$$

$$R_{\text{eff}} = \frac{90 \times 10}{100} = 9 \Omega$$



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(iii) 0 – 50 mA

Branches:

$$R_m + R_b + R_c = 98 \Omega$$

$$R_a = 2 \Omega$$

$$R_{\text{eff}} = \frac{98 \times 2}{100} = 1.96 \Omega$$

