Indian National Junior Science Olympiad (INJSO) – 2026

Indian Association of Physics Teachers (IAPT)

QUESTION PAPER AND SOLUTION

Roll Number: ☐☐☐☐–☐☐☐☐–☐☐☐☐ **Date:** 1st February 2026

Duration: 3 Hours **Maximum Marks: 180**

***Please Note*:**

1) Please write your roll number in the space provided above.
2) Use of non-programmable scientific calculators is allowed.
3) **The answer-sheet must be returned to the invigilator.** You can carry this question paper with you.
4) **Section I of this question paper has 15 questions (45 marks).**
   i. For each question in this section, **only one** of the four options is the correct answer.
   ii. For each question, a correct answer will earn 3 marks, a wrong answer will fetch a penalty of (–1) mark, and an un-attempted question will have 0 mark.
   iii. If you mark more than one option, it would be treated as a wrong answer, even if one of those is correct.
5) **Section II contains 9 questions worth 5 marks each. There is no negative marking (45 marks).**
   iv. For each of these questions one or more option(s) may be correct.
   v. 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.
6) **Section III contains 8 questions (90 marks).**
   vi. 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.
   vii. In case you fall short of writing space for any question, you can ask for an extra sheet. You can ask for maximum of two extra sheets.

Happy Solving

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USEFUL CONSTANTS

Gravitational constant	$G \approx 6.674 \times 10^{-11}$ N m^2/kg^2
Gravitational acceleration	$g \approx 9.8$ m/s^2
Mass of electron	$m_e \approx 9.109 \times 10^{-31}$ kg
Charge of an electron	$e \approx 1.602 \times 10^{-19}$ C
Avogadro constant	$N_A \approx 6.022 \times 10^{23}$/mol
Specific heat capacity of water	$s = 4.2$ J / (g ^{0}C)
Density of water	$\rho_w = 10^3$ kg/m^3
Universal gas constant	$R \approx 8.314$ J / (mol K) and 0.0821 L.atm/mol.K
Atmospheric pressure	1 atm $\approx$ 101 325 Pa
Molar volume of gas at STP	$V_{STP} \approx 22.4$ L
STP	273 K and 1 atm
Molar volume of gas at 1 atm and 100 ◦C	$V_{100} \approx 30.6$ L
Permittivity of free space	$\epsilon_o \approx 8.854 \times 10^{-12}$ C^2 N^{-1} m^{-2}
Radius of the Earth	$R_\oplus \approx 6400$ km
Radius of the Moon	$R_{moon} \approx 1700$ km

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Periodic Table of the Elements

1 IA 1A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8	9 VIII 8	10	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1 **H** Hydrogen 1.008																	2 **He** Helium 4.003
3 **Li** Lithium 6.941	4 **Be** Beryllium 9.012											5 **B** Boron 10.811	6 **C** Carbon 12.011	7 **N** Nitrogen 14.007	8 **O** Oxygen 15.999	9 **F** Fluorine 18.998	10 **Ne** Neon 20.180
11 **Na** Sodium 22.990	12 **Mg** Magnesium 24.305											13 **Al** Aluminum 26.982	14 **Si** Silicon 28.086	15 **P** Phosphorus 30.974	16 **S** Sulfur 32.066	17 **Cl** Chlorine 35.453	18 **Ar** Argon 39.948
19 **K** Potassium 39.098	20 **Ca** Calcium 40.078	21 **Sc** Scandium 44.956	22 **Ti** Titanium 47.867	23 **V** Vanadium 50.942	24 **Cr** Chromium 51.996	25 **Mn** Manganese 54.938	26 **Fe** Iron 55.845	27 **Co** Cobalt 58.933	28 **Ni** Nickel 58.693	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.38	31 **Ga** Gallium 69.723	32 **Ge** Germanium 72.631	33 **As** Arsenic 74.922	34 **Se** Selenium 78.971	35 **Br** Bromine 79.904	36 **Kr** Krypton 83.798
37 **Rb** Rubidium 85.468	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.906	40 **Zr** Zirconium 91.224	41 **Nb** Niobium 92.906	42 **Mo** Molybdenum 95.95	43 **Tc** Technetium 98.907	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.906	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.868	48 **Cd** Cadmium 112.414	49 **In** Indium 114.818	50 **Sn** Tin 118.711	51 **Sb** Antimony 121.760	52 **Te** Tellurium 127.6	53 **I** Iodine 126.904	54 **Xe** Xenon 131.294
55 **Cs** Cesium 132.905	56 **Ba** Barium 137.328	57-71	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.948	74 **W** Tungsten 183.84	75 **Re** Rhenium 186.207	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.217	78 **Pt** Platinum 195.085	79 **Au** Gold 196.967	80 **Hg** Mercury 200.592	81 **Tl** Thallium 204.383	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.980	84 **Po** Polonium [208.982]	85 **At** Astatine 209.987	86 **Rn** Radon 222.018
87 **Fr** Francium 223.020	88 **Ra** Radium 226.025	89-103	104 **Rf** Rutherfordium [261]	105 **Db** Dubnium [262]	106 **Sg** Seaborgium [266]	107 **Bh** Bohrium [264]	108 **Hs** Hassium [269]	109 **Mt** Meitnerium [278]	110 **Ds** Darmstadtium [281]	111 **Rg** Roentgenium [280]	112 **Cn** Copernicium [285]	113 **Nh** Nihonium [286]	114 **Fl** Flerovium [289]	115 **Mc** Moscovium [289]	116 **Lv** Livermorium [293]	117 **Ts** Tennessine [294]	118 **Og** Oganesson [294]

Lanthanide Series	57 **La** Lanthanum 138.905	58 **Ce** Cerium 140.116	59 **Pr** Praseodymium 140.908	60 **Nd** Neodymium 144.243	61 **Pm** Promethium 144.913	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.964	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.925	66 **Dy** Dysprosium 162.500	67 **Ho** Holmium 164.930	68 **Er** Erbium 167.259	69 **Tm** Thulium 168.934	70 **Yb** Ytterbium 173.055	71 **Lu** Lutetium 174.967
Actinide Series	89 **Ac** Actinium 227.028	90 **Th** Thorium 232.038	91 **Pa** Protactinium 231.036	92 **U** Uranium 238.029	93 **Np** Neptunium 237.048	94 **Pu** Plutonium 244.064	95 **Am** Americium 243.061	96 **Cm** Curium 247.070	97 **Bk** Berkelium 247.070	98 **Cf** Californium 251.080	99 **Es** Einsteinium [254]	100 **Fm** Fermium 257.095	101 **Md** Mendelevium 258.1	102 **No** Nobelium 259.101	103 **Lr** Lawrencium [262]

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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

Solution (D): Myelin sheath on neurons acts as an insulator, thereby preventing the current from dissipating away, so it doesn't slow down conduction.

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.

Solution (C): UV light is not visible to the human eye and hence, the field of observation is dark. Fluorescence observed in the dark, provides a higher signal-to-noise ratio compared to chromogenic dyes which have to be far more contrasting than the ambient background colour in order to be clearly discernible. Option A is untrue because dyes do not bind to DNA "based on molecular weight". Option B and D are factually false.

3) In a practical examination a student collects several different types of fungal species from diverse habitats, labels them as samples P to S, and notes down the following:

Sample	Observation
P	Releases digestive enzymes onto decaying wood
Q	Unicellular
R	Lives symbiotically with algae on tree bark, tolerating extreme environments
S	Causes rust disease in plants and significant crop loss

A classmate observes the same samples, notes down some remarks, and re-labels them as samples I-IV.

Sample	Remarks
I	Has filamentous hyphae to increase the surface area for nutrient absorption.
II	Shows obligate biotrophy (they cannot be cultured in a laboratory on artificial media, but can be maintained on live host)
III	Primarily reproduces asexually by budding
IV	Pioneer species in ecological succession and contributes to soil formation

Which of the following options show the correct combinations depicting the same species?

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A) P–III, Q–IV, R–II, S–I
B) P–I, Q–III, R–IV, S–II
C) P–IV, Q–III, R–II, S–I
D) P–IV, Q–II, R–I, S–III

Solution (B): Among these, pioneer species (IV), is the only one, which can be self-reliant. Lichens (can tolerate extreme dryness, hence, R-IV) – but challenging, as they can also be obligate biotrophs – however to satisfy the other criteria where unicellular yeast clearly reproduce asexually by budding (Q-III). Since, Q-III and R-IV exclude the other options, 'B' is the only correct answer.

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

Solution (C): Both primary oocyte and secondary oocyte are formed after replication and meiosis I, respectively. Before meiosis I, the primary oocyte has 92 chromatids (2n, duplicated). After meiosis II, the secondary oocyte has 46 chromatids. (n, duplicated).

	Cell 1	Cell 2
1.	Oogonium – 46	Primary polar body - 46
2.	Secondary oocyte - 46	Ootid-23
3.	Primary oocyte - 92	Primary polar body - 46
4.	Primary polar body - 46	Secondary polar body- 23
5.	Oogonium – 46	Primary oocyte - 92
6.	Secondary oocyte - 46	Oogonium - 46
7.	Primary oocyte - 92	Secondary oocyte - 46
8.	Secondary polar body - 23	Ootid -23

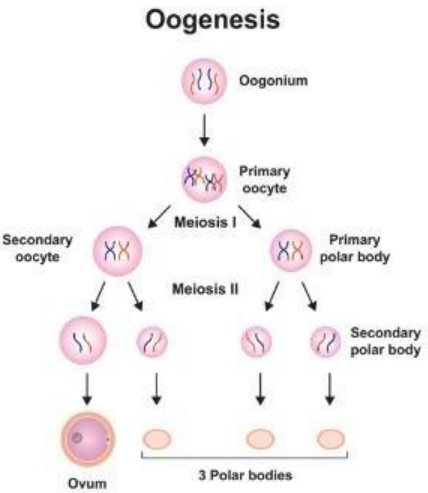
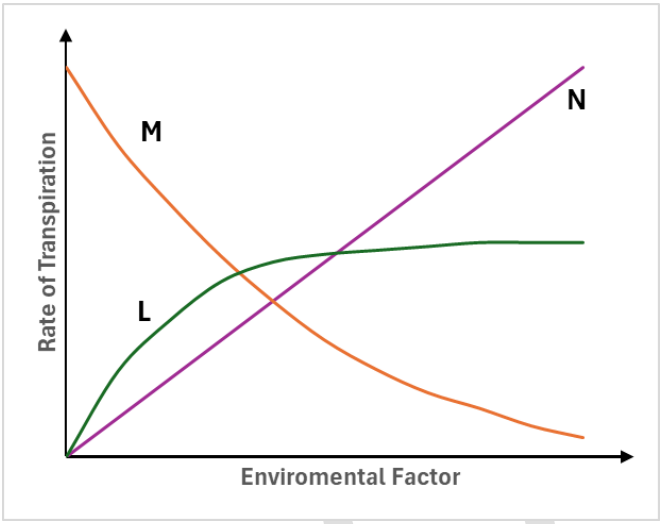


Image Credit ALI DAMOUH / SCIENCE PHOTO LIBRARY (https://www.sciencephoto.com/media/1292644/view/oogenesis-illustration)

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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

Solution (D): Light intensity: Photosynthesis, specifically the light reactions, require light to occur. The light's photons excite the electrons in the pigments of the photosystems which activates the light reactions portion of photosynthesis. The more light there is, the more photosystems in the thylakoid membrane can be activated. However, light intensity can only increase up to a certain point before the rate of photosynthesis no longer increases (graph L).
High humidity decreases the rate of transpiration because humid air is already saturated with water vapor, reducing the concentration gradient needed for water to diffuse out of the plant's leaves. Conversely, low humidity (dry air) increases transpiration by creating a steep gradient, allowing water to evaporate more quickly from the stomata (graph M).
Temperature — Higher temperatures increase the rate of transpiration due to faster evaporation of water (graph N).

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:

$$Ca_3(PO_4)_{2(s)} \rightleftharpoons 3Ca^{2+}_{(aq)} + 2PO_4^{3-}{}_{(aq)}$$

The equilibrium constant for the dissolution of a sparingly soluble salt like calcium phosphate, is the **solubility product (K_{sp})** of the salt. The activity of pure $Ca_3(PO_4)_2$ is a constant at given salt concentration. The solubility product expression for calcium phosphate is:

$$K_{sp} = [Ca^{2+}]^3[PO_4^{3-}]^2$$

At 25°C and pH 7.00, K_{sp} for calcium phosphate is 2.07×10^{-33}, indicating that the concentrations of Ca^{2+} and 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 $Ca_3(PO_4)_2$ in moles/litre			
	Aqueous solution	0.01 M calcium chloride solution	0.025 M calcium nitrate solution	0.05 M sodium phosphate solution
A)	1.14×10^{-7}	1.97×10^{-11}	4.38×10^{-15}	1.11×10^{-15}
B)	1.14×10^{-7}	1.11×10^{-15}	4.38×10^{-15}	1.97×10^{-11}
C)	1.14×10^{-7}	4.38×10^{-15}	1.11×10^{-15}	1.97×10^{-11}
D)	1.14×10^{-7}	4.38×10^{-15}	1.11×10^{-15}	1.97×10^{-15}

Solution (C): K_{sp} for calcium phosphate is 2.07×10^{-33} at 25°C and pH 7.00

Solubility of $Ca_3(PO_4)_2$ in water:

$$Ca_3(PO_4)_{2(s)} \rightleftharpoons 3Ca^{2+}_{(aq)} + 2PO_4^{3-}_{(aq)}$$

$$K_{sp} = [Ca^{2+}]^3[PO_4^{3-}]^2 = (3S_1)^3(2S_1)^2 = 108S_1^5$$

$$2.07 \times 10^{-33} = 108S_1^5$$

$$S_1 = 1.14 \times 10^{-7} \text{ mole/litre}$$

Solubility of $Ca_3(PO_4)_2$ in 0.01 M $CaCl_2$:

$$[Ca^{2+}] = 3(0.01 + S_2); [PO_4^{3-}] = 2S_2$$

$$K_{sp} = [Ca^{2+}]^3[PO_4^{3-}]^2 = [3(0.01 + S_2)]^3(2S_2)^2 \approx 108 \times 10^{-6} \times S_2^2$$

$$2.07 \times 10^{-33} = 108 \times 10^{-6} \times S_2^2$$

$$S_2 = 4.38 \times 10^{-15} \text{ mole/litre}$$

Solubility of $Ca_3(PO_4)_2$ in 0.025 M $Ca(NO_3)_2$:

$$[Ca^{2+}] = 3(0.025 + S_3); [PO_4^{3-}] = 2S_3$$

$$K_{sp} = [Ca^{2+}]^3[PO_4^{3-}]^2 = [3(0.025 + S_3)]^3(2S_3)^2 \approx 108 \times 1.56 \times 10^{-5} \times S_3^2$$

$$2.07 \times 10^{-33} = 108 \times 1.56 \times 10^{-5} \times S_3^2$$

$$S_3 = 1.11 \times 10^{-15} \text{ mole/litre}$$

Solubility of $Ca_3(PO_4)_2$ in 0.05 M Na_3PO_4:

$$[Ca^{2+}] = 3S_4; [PO_4^{3-}] = 2(0.05 + S_4)$$

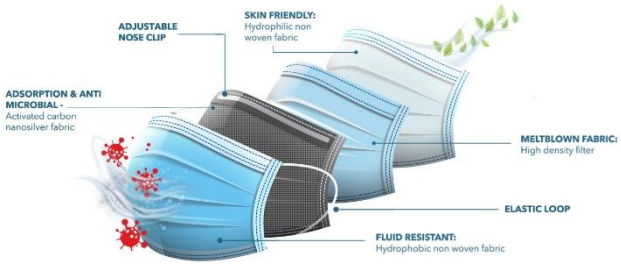
$$K_{sp} = [Ca^{2+}]^3[PO_4^{3-}]^2 = (3S_4)^3[2(0.05 + S_4)]^2 \approx 108 \times 2.5 \times 10^{-3} \times S_4^3$$

$$2.07 \times 10^{-33} = 108 \times 2.5 \times 10^{-3} \times S_4^3$$

$$S_4 = 1.97 \times 10^{-11} \text{ mole/litre}$$

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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 absorbate) is dissolved by or permeates a liquid or solid (the absorbent).

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

(i) Gibbs free energy change (ΔG) which is the criterion for determining whether a chemical reaction or physical transformation will occur on its own under constant temperature and pressure conditions.

(ii) Enthalpy change (ΔH) which is a measure of the heat gained or lost by a system during a process under constant pressure.

(iii) Entropy change (ΔS) - a positive change in entropy indicates a system is becoming more disordered, while a negative change indicates a move toward greater order.

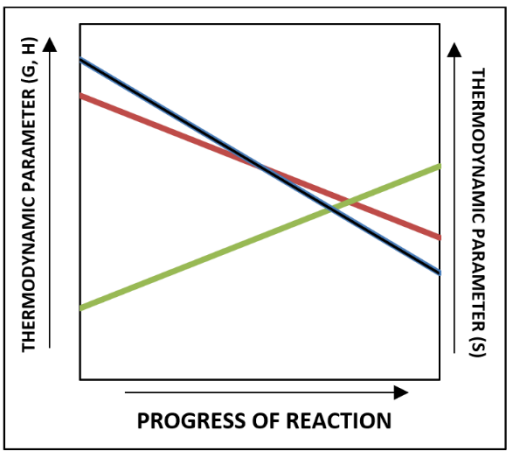
And, they are also related by the equation: $\boldsymbol{\Delta G = \Delta H - T\Delta S}$

[where, T = absolute temperature];

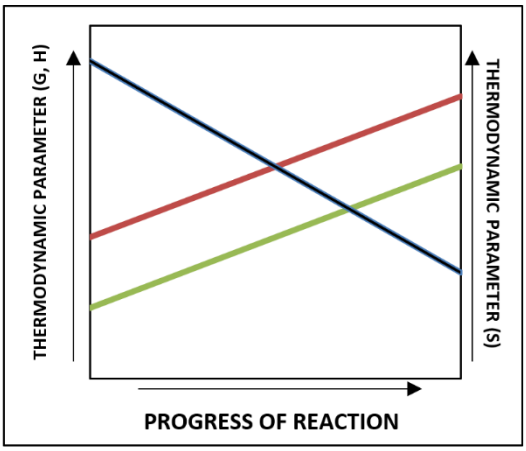
Which of the following graphs represent the adsorption process on the system, where the following lines represent each thermodynamic property

G
H
S

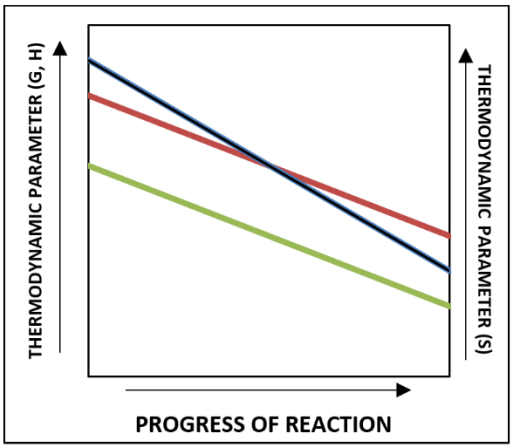
A.



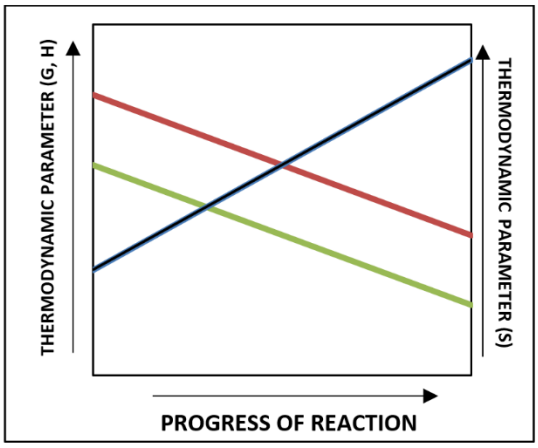
B.



C.

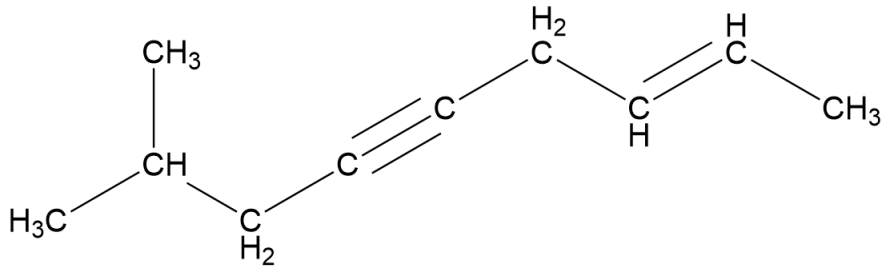


D.



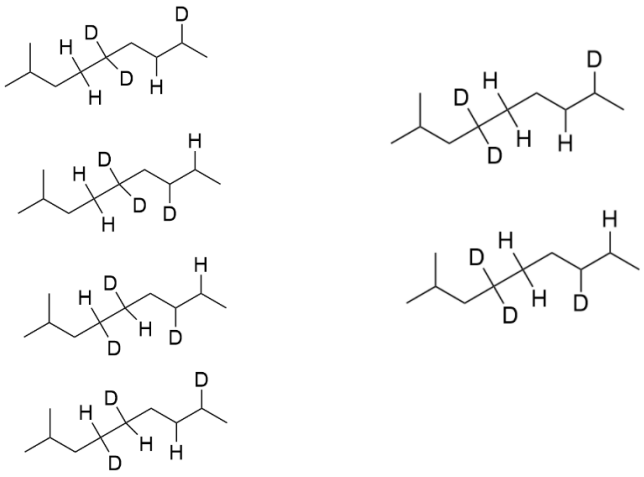
Solution (C): G decreases with progress, S decreases with progress, H also decreases with progress.

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 B) 4 C) 6 D) 8

Solution (C): The products are



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 g dm^{-3}. What is the molarity of her freshly prepared urea solution?

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

Solution (B): PROBABLE SOLUTIONS:
Let, x be the moles of urea present in solution.
Moles of water present in 900 g = 900/18 = 50
Thus, 0.05 = x / (x + 50)
Then x = 50/19
Now, mass of 1000 mL solution is 1200 g.
Again, 50/19 x 60 = 157.9 g urea dissolved in 900 g of water.
1057.9 g solution contains 157.9 g of urea.
Thus, 1030 g solution contains 153.7 g = 2.56 mole of urea.
Molarity of urea solution =2.56

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 0.1M HCl. After completion of the reaction, the remaining acid required 35.0 mL of 0.05M 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}

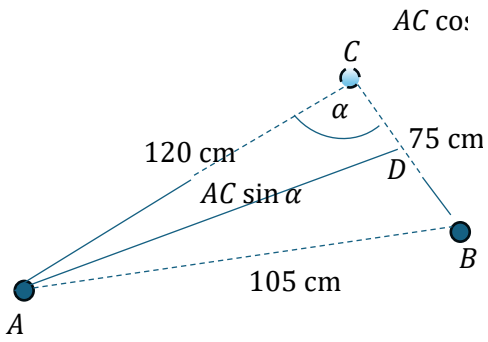
Solution (D):
100 * 0.1 = 10 mmol of HCl ---- 1
35*0.05 = 1.75 mmol of HCl left.
10-1.75 mmol of HCl consumed == 8.25 mmol == 8.25 mmol of ammonia == 8.25 mmol of Nitrogen == 115.5 mg of nitrogen.
6.25 * 0.115 = 0.72 g of protein the sample.
% protein = (0.72/3)*100 = 24%

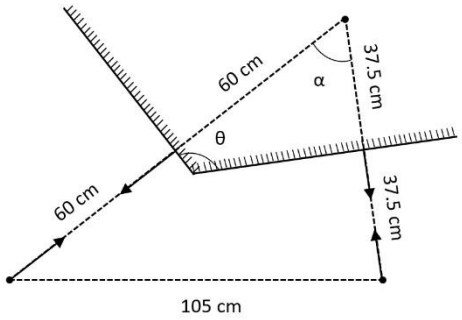
11) Two point-sources of light lying on a plane of the paper are separated by 105 cm. Two plane mirrors are placed at a perpendicular distance of 60 cm and 37.5 cm respectively from the two sources. The mirrors are oriented in such a way that the images of the two light sources of light formed by them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

A) 90^0 B) 120^0 C) 60^0 D) 0^0

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Solution (B): The image formation is shown in the figure. The angle between the mirrors θ is to be determined by first finding angle α. AD is perpendicular to CB.





$$AB^2 = (AC\sin\alpha)^2 + (75 - AC\cos\alpha)^2 AB^2 = (AC\sin\alpha)^2 + (AC\cos\alpha)^2 + 75^2 - (2 \times 75 \times AC\cos\alpha)$$

$$AB^2 = AC^2 + 75^2 - (2 \times 75 \times AC\cos\alpha)$$

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

$$\cos\alpha = \frac{120^2 + 75^2 - 105^2}{2 \times 75 \times 120} = 0.5$$

Thus, the angle $\alpha = 60^0$. The angle $\theta = 180 - \alpha = 180 - 60 = 120^0$.

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) $\frac{4}{3}$

Solution (B): For the case (i), let u be initial speed. The final speed is zero. Applying conservation of energy,

$$\frac{1}{2}mv^2 - \frac{1}{2}mu^2 = -RS_0$$

$\therefore\ 0 - u^2 = 2\left(-\frac{R}{m}\right)S_0$ ..... (1)

For the case (ii), let u be initial speed and final common speed be v.

The momentum conservation suggests, $mu = (m + 9m)v \Rightarrow v = {}^{u}/_{10}$

Heat energy relation is

$\frac{1}{2}mu^2 = \frac{1}{2}10m\left(\frac{u}{10}\right)^2 + RS$

$-\frac{9}{10}u^2 = 2\left(-\frac{R}{m}\right)S$ (2)

Dividing (1) by (2), we get

$\frac{S_0}{S} = \frac{10}{9}$

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13) This question is on combustion, temperature change and phase change.

Combustion: Combustion is a chemical reaction in which a substance reacts with oxygen to produce heat and light, like when wood burns in a fire. If 1 gram of gasoline burns, i.e., undergoes combustion, it releases 45000 J of heat.

Temperature Change: A temperature change happens when heat energy is gained or lost, such as water warming up when heated on a gas stove. To increase the temperature of 1 kg of water through 1 °C, the heat to be supplied is 4200 J.

Phase Change: A phase change occurs when a substance changes its state, like ice melting into water or water boiling into steam. To convert 1 kg of water at 100 °C into 1 kg steam at 100 °C the heat to be supplied is 2250 kJ. During the phase change, there is no change in the temperature of water.

In an experiment, 1 kg of water is taken in a pot on a gas stove which produces heat energy by combustion of gasoline. On lighting the stove, only 40 % of heat is transferred to water. Initial temperature of water is 25 °C. The amount of gasoline required to heat the water up to 100 °C and boil of 250 g of it is

A) 33.00 g B) 48.75 g. C) 40.25 g D) 75.30 g

Solution (B):

- To increase the temperature heat required:

$$Q_1 = \text{mass} \times \frac{\text{Energy}}{\text{mass} \times \text{temperature rise}} \times \text{temperature rise}$$

$$Q_1 = 1 \times 4200 \times 75 = 315000\ \text{J}$$

- To boil 250 g of water

$$Q_1 = \text{mass} \times \frac{\text{Energy}}{\text{mass}}$$

$$Q_1 = 0.250 \times 2250 \times 10^3 = 562500\ \text{J}$$

- Total heat required is $Q = 877500$ J.

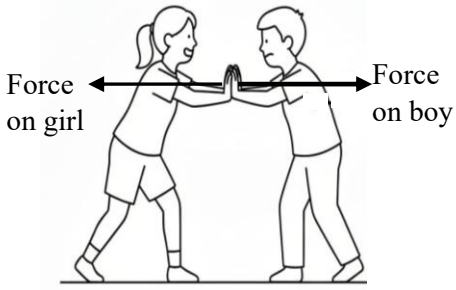
This is 40% of energy released by gasoline. Therefore, energy released is

$$Q_0 = \frac{100}{40} Q$$

$$Q_0 = \frac{100}{40} \times 877500 = 21{,}93{,}750\ \text{J}$$

- Mass of gasoline required is, $m = \frac{2193750}{45000} = 48.75$ g

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 m s^{-1}.
Statement 2: The speed of girl is 2.0 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.

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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.

Solution (C):

The conservation of linear momentum gives

$$m_1 v_1 + m_2 v_2 = 0$$

$$60 \times 1.5 + 45 v_2 = 0$$

$$\therefore v_2 = -2 \text{ m/s}$$

Work done by the boy is increase in energy of the girl,

$$W_{B\to G} = \Delta K = \frac{1}{2} m_2 v_2^2 = \frac{1}{2} \times 45 \times 2^2 = 90 \text{ J}$$

Work done by the girl is increase in energy of the boy,

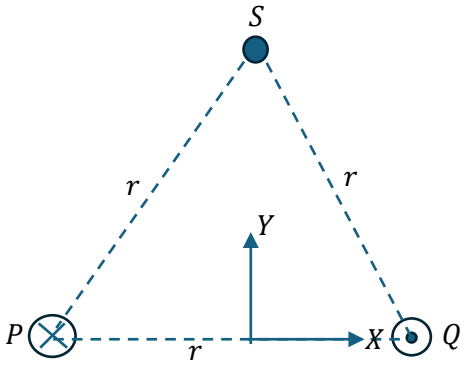
$$W_{G\to B} = \Delta K = \frac{1}{2} m_1 v_1^2 = \frac{1}{2} \times 60 \times (1.5)^2 = 67.5 \text{ J}$$

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 120^0 with each other.

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

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



Current I getting into the plane of the paper

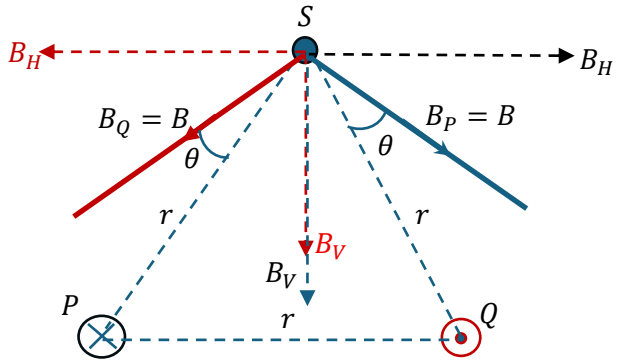
Current I coming out of the plane of the paper

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.

Solution (C): The magnetic field at S due to each wire can be determined using Amperes right hand thumb rule as shown in the figure. The magnetic field must be at right angle to line joining the wire with S. The angle $\theta = 90^0 - 60^0 = 30^0$. Thus, the angle between the two magnetic fields is at 120^0. Satatement 1 is correct.

Resolving the magnetic field along the X and Y axis, indicates that the magnetic field is cancelled along X direction while adding up along the Y direction. Statement 2 is correct.

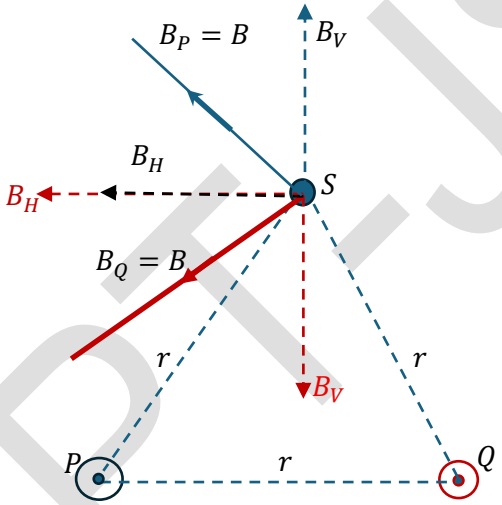
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Current I getting into the plane of the paper

Current I coming out of the plane of the paper

When the current in the wire P reverses the magnetic field is shown in the figure below. Statement 3 is incorrect.



Current I coming out of the plane of the paper

Current I coming out of the plane of the paper

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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.

Solution (A and B): Insulin sensitivity will improve upon fasting, not reduce. Fermentative metabolism primarily occurs in muscles and does not result from prolonged fasting.

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.

Solution (A, C and D): A reduction in predatory birds will lead to an increase in small animals like lizards and frogs, which in turn often feed on crawling insects (like centipedes, beetles etc). This will result in fewer beetles (making option A and C correct), which are also known to participate in pollination. Windmill activity is a strong deterrent to multiple flying insect species and hence in the long-term it will reduce the number of pollinators, lowering the number of flowering plants.

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 (NOx) 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_2 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.

Solution (A, C and D):

A) ✔ Nitrification is a two-step aerobic process: When nitrogen-rich fertilizers are applied excessively, nitrification produces large amounts of nitrate, which is highly soluble and easily leaches into groundwater. This runoff leads to eutrophication — nutrient enrichment of water bodies, causing algal blooms and oxygen depletion.
B) ✘ Denitrification does not convert nitrate into ammonium; it reduces nitrate (NO_3^-) to gaseous forms of nitrogen such as nitric oxide (NO), nitrous oxide (N_2O), and nitrogen gas (N_2) under anaerobic conditions. These gases escape to the atmosphere, reducing soil nitrogen rather than conserving it. Hence, the statement incorrectly describes both the product (ammonium instead of nitrogen gas) and

the effect (loss prevention instead of nitrogen depletion).

C) ✔ Ammonification is the natural biological process where microbes break down organic matter to release ammonia, keeping nitrogen within the soil for plant uptake. Combustion bypasses this microbial decay, instead causing nitrogen to react with oxygen at high temperatures to release nitrogen oxides directly into the atmosphere. This shift disrupts the cycle by moving nitrogen into the air rather than the soil, leading to the formation of acid rain and ground-level ozone through secondary chemical reactions.

D) ✔ Biological nitrogen fixation converts atmospheric N_2 into ammonia (NH_3) through symbiotic bacteria (*Rhizobium*) or free-living bacteria (*Azotobacter, Clostridium*). Overuse of synthetic fertilizers increases available nitrogen in soil, so plants depend less on microbial symbionts. This leads to suppression of nodulation, reduced symbiotic nitrogen fixation, and altered soil microbial diversity — all well-documented ecological effects.

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 $AgNO_3$ 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

Solution (A &C):

$Cu + 2AgNO_3 \rightarrow Cu(NO_3)_2 + 2Ag$

(63.5) (2 x 108)

Assuming, S = the quantity of deposited silver, C = the quantity of dissolved copper

Then,

$(63.5 / C) = (2 \times 108) / S$ …….(1)

$S - C = 51.5 - 50$ ……..(2)

From (1) and (2), we find that

S = the quantity of deposited silver = **2.1246 g**

C = the quantity of dissolved copper = 0.6246 g

Molar mass of $AgNO_3$ = 108 + 14 + 48 = 170

1000 mL 0.495 M $AgNO_3$ solution contains = 170 x 0.495 g = 84.15 g of $AgNO_3$
Now, 170 mL of 0.495 M $AgNO_3$ solution contains = 84.15 x (170/1000) g
= 14.31 g of $AgNO_3$
Therefore, Ag^+ present in 14.311 g of $AgNO_3$ = (108/170) x 14.31 g
= 9.091 g
Again, the quantity of deposited Ag = 2.1246 g
Initial reaction taken place,

$$NaCl + AgNO_3 \rightarrow NaNO_3 + AgCl$$

And, $KCl + AgNO_3 \rightarrow KNO_3 + AgCl$

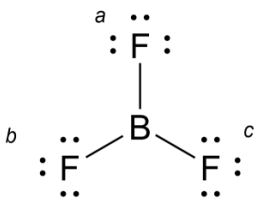
Thus, Ag^+ involved in AgCl precipitation = (9.091 – 2.1246) g
= 6.9664 g
Therefore, total mass of Cl^- = 6.9664 x (35.5/108) = 2.29 g
Let us assume that,
N = the quantity of NaCl present in ORS sachet
K = the quantity of KCl present in ORS sachet
Then,

$$N + K = 4.1 \quad \text{……..(3)}$$

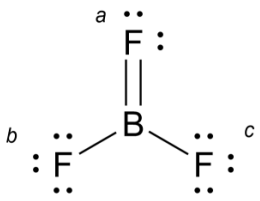
$$(35.5/58.5) \times N + (35.5 / 74.6) \times K = 2.29 \quad \text{…….(4)}$$

From (1) and (2), we find that
N = the quantity of NaCl present in ORS sachet = 2.6 g
K = the quantity of KCl present in ORS sachet = 1.5 g
Therefore,
The percentage composition of sodium chloride present
= (2.6/21.8) x 100 %
= **11.93 %**
The percentage composition of potassium chloride present
= (1.5/21.8) x 100 %
= **6.88 %**

20) Two structures have been assigned to BF_3



Structure - I



Structure - II

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.

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

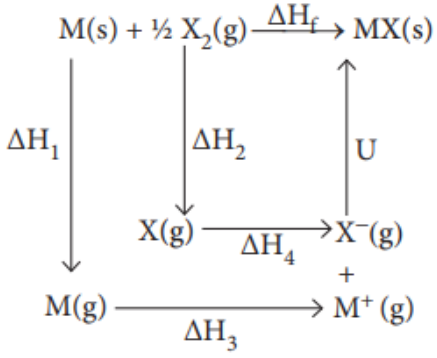
electrons, oxidation number helps in understanding electron transfer and chemical reactivity in compounds.

Choose the correct statements.

A) Formal charge and the oxidation number of boron in the BF_3 in **Structure I** is 0 and +3 respectively, while formal charge and the oxidation number of boron in the 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 BF_3

Solution (A, B, D)

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 ΔH_1 is the enthalpy change for sublimation of the metal, ΔH_2 is enthalpy change for dissociation $\frac{1}{2}X_2 \rightarrow X$, ΔH_3 is the ionisation energy for $M \rightarrow M^+$, ΔH_4 is the electron affinity for $X \rightarrow X^-$, U is the lattice energy for the formation of solid MX and ΔH_f is enthalpy change for formation of MX directly from the elements.



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

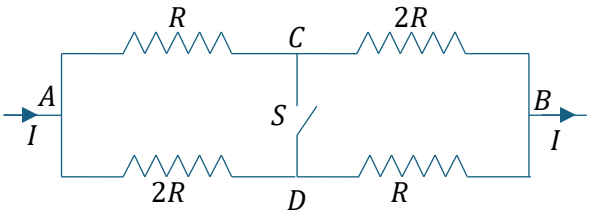
Given the data below, what are the reasons for the high heat of formation of LiF over NaCl?

Reaction	Energy change ($kJmol^{-1}$)	Reaction	Energy change ($kJmol^{-1}$)
$Li_{(s)} \rightarrow Li_{(g)}$	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

Solution (C and D)

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 $\frac{I^2R}{2}$.

B) Power consumed by R before closing the switch is $\frac{I^2R}{4}$.

C) Power consumed by R after closing the switch is $\frac{4I^2R}{9}$.

D) The current that flows through the key after closing the switch is $\frac{I}{3}$.

Solution: B, C and D

Before closing the key, it is parallel combination of two series combinations. Series equivalent of both branches being the same i.e., 3R. So, current through each branch is $I/2$.

Power consumed by R is $P_1 = \left(I/2\right)^2 R = \frac{I^2R}{4}$.

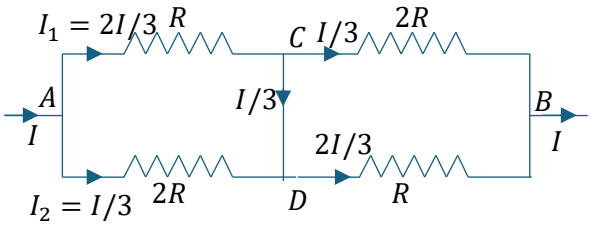
After closing the key, it is series combination of two parallel combinations. For parallel combination, if I_1 is current through R and I_2 is current through 2R, then

$I_1 R = I_2 2R$ also $I_1 + I_2 = I$. Solving the two equations, we get $I_1 = 2I/3$ *and* $I_2 = I/3$.

Power consumed by R is $P'_1 = \left(2I/3\right)^2 R = \frac{4I^2R}{9}$.

Now, in this situation the currents in various branches are as shown. This distribution of current is amply supported by the symmetry involved.

The current $2I/3$ in R splits into two parts as $2R$ cannot accommodate whole of $2I/3$. Therefore, excess current $I/3$ flows down the key.



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 $0.03\ \mathrm{m\ s^{-2}}$. 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 $3\ \mathrm{m\ s^{-1}}$, right from the beginning then she will have at least $50\ \mathrm{s}$ to finish the tea and run to reach the compartment door.

C) The length of the platform should be at least $150\ \mathrm{m}$ from the tea shop for the passenger to safely reach the door of the compartment and catch the train.

D) If she takes $60s$ to finish her tea, the minimum speed required to catch the train by reaching the compartment door is $3.6\ \mathrm{m\ s^{-1}}$.

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Solution (B, C and D): Let the distance travelled by train when the passenger catches the coach is $d = \frac{1}{2}at^2$. Here a is acceleration of train and t is the time from when train starts.

The passenger completes tea in time t_0 and catches the coach should travel the same distance, $d = v(t - t_0)$. Here v is the speed of the passenger. That is

$$\frac{1}{2}at^2 = v(t - t_0)$$

Re-writing the equation, $t^2 - \frac{2vt}{a} + \frac{2vt_0}{a} = 0$.

Solving the quadratic equation, $t = \frac{\frac{2v}{a} \pm \sqrt{\frac{4v^2}{a^2} - \frac{8vt_0}{a}}}{2}$. For catching the coach, the time should be real, that is $\frac{4v^2}{a^2} \geq \frac{8vt_0}{a}$. To calculate the maximum time passenger has to drink tea is

$$t_0 = \frac{v}{2a} = \frac{3}{2 \times 0.03} = 50 \text{ s}$$

Option A is wrong, and option B is correct.

Substituting the value of t_0, the value of time taken is $t = \frac{\frac{2\times3}{0.03}}{2} = 100$ s . The distance travelled by the coach from the tea stall is

$$d = \frac{1}{2}at^2 = \frac{1}{2} \times 0.03 \times 100^2 = 150 \text{ m}$$

Option C is correct

If the time taken to drink tea is 60 s, then minimum speed required is given by

$$v \geq 2at_0$$

The minimum speed is

$$v = 2 \times 0.03 \times 60 = 3.6 \text{ m s}^{-1}$$

Option D is correct

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 8ρ
The density of wood is ρ.
The density of liquid is 2ρ.
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.

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D) The water level in the vessel remains the same on flipping the cuboid.

Solution (B) and (D)

Equation of equilibrium in the first case,

$$2\rho(100a^2h_1)g = \rho(100a^2 10a)g + 8\rho(100a^2 a)g$$

$$2h_1 = 10a + a \Rightarrow h_1 = 9a$$

Equation of equilibrium in the second case,

$$2\rho(100a^2(h_2 + a))g = \rho(100a^2 10a)g + 8\rho(100a^2 a)g$$

$$2(h_2 + a) = 10a + 8a \Rightarrow h_2 = 8a$$

$$h_1 - h_2 = 9a - 8a = a$$

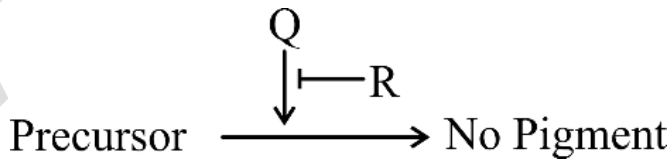
Section III

(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*'. **(Total 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 **F1** generation. When the white chickens of **F1** were interbred (selfing), the **F2** 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)**

IART-ISO

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 _____

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 $\mathbf{F_2}$. Which genotype of the coloured birds will produce more white chickens than the coloured ones, when mated with white birds of $\mathbf{F_1}$ 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)**

Solution:

Q1) The correct matching pair from column A and B is __a : y and/or 118:511__

Explanation: In the figure below substitute *C* by *Q* and *I* by *R* to arrive at the answer of Q1.

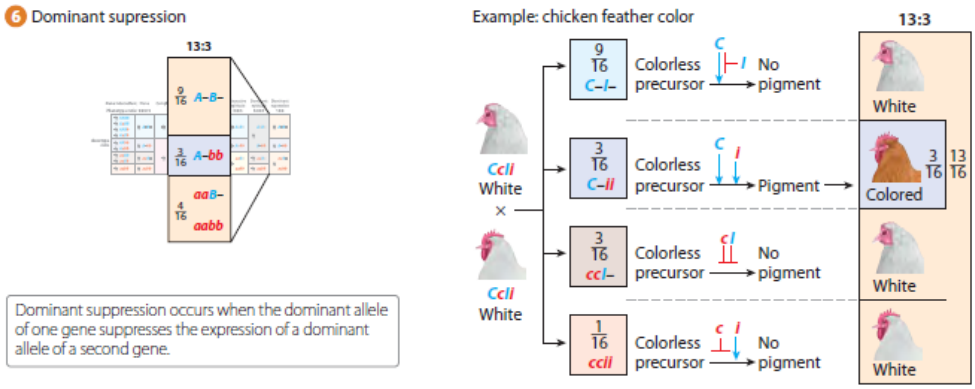


Figure credit: from Sanders, S. K., & Bowman, B. *Genetic Analysis: An Integrated Approach*. 3rd edition. Pearson Education. Chapter 4: Gene Interaction.

Q2) Answer: Qqrr

Explanation: The students can arrive at the answer directly by writing the correct cross or can try all combinations possible. The possible crosses are written below. The cross written on the right-hand side is the correct cross.

First possibility for Coloured

QqRr x QQrr
White Coloured

	Qr
QR	QQRr - white
Qr	QQrr - coloured
qR	QqRr - white
qr	Qqrr – coloured

White : coloured
1 : 1

Second possibility for Coloured

QqRr x Qqrr
White Coloured

	Qr	qr
QR	QQRr – white	QqRr-white
Qr	QQrr – coloured	Qqrr-coloured
qR	QqRr – white	qqRr-white
qr	Qqrr – coloured	qqrr-white

White : coloured
5 : 3

Q3) Answer is (Qqrr X Qqrr)
Explanation: The students can arrive at the answer directly by writing the correct cross or can try all combinations possible. The possible crosses are written below. The first cross from the crosses shown below is the correct one.

1 Qqrr x Qqrr

	Qr	qr
Qr	QQrr – coloured	Qqrr-coloured
qr	Qqrr – coloured	qqrr-white

Coloured : white
3 : 1

2 QQrr x Qqrr

	Qr	qr
Qr	QQrr – coloured	Qqrr-coloured

All are coloured

3 QQrr x QQrr

	Qr
Qr	QQrr – coloured

All are coloured

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. **(Total 11 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):

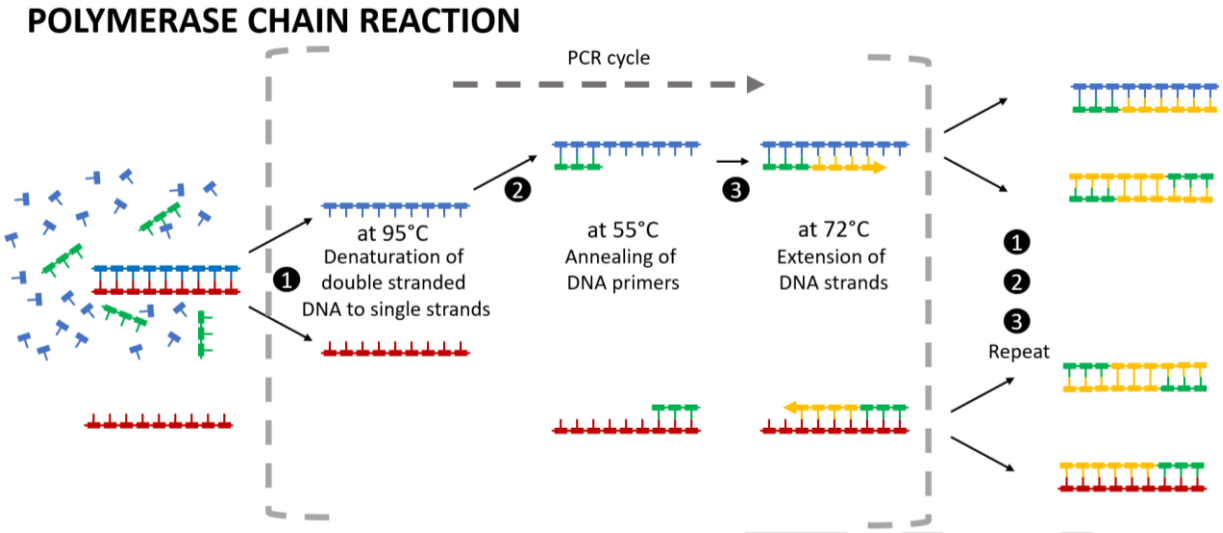
(Show your calculations of the answers to the best accuracy, but should be entered into the table as **single units with two decimal places and corresponding indices** – e.g. 5.04×10^4)
Show your calculations in the space below (for each step):

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)								
Taq protein (Q)								
Total protein (P+Q)								
Percentage of pure Taq protein								

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

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).

IAPT-ISO



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.

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.

Solution

Q1) For total non-target protein: Total number of proteins = 100ml x 10^8 cells/mL x 10^7 protein molecules per cell.
Taq protein – 100mL x 10^8 cells/mL x 10^2 protein molecules per cell.
At each step there is a 95% loss – so carry forward only 5% of the calculated number for *Taq* protein. Since there is 1000 fold loss of total protein – divide the total protein by 1000 for each step. Answers are given for 1 unit and 2 decimal places below (as requested in the question).

Q2) Solution for both Q1 and Q2 in the table below:

	In 100 mL (a)	*After Step 1(b)*	*After Step 2 (c)*	*After Step 3 (d)*	*After Step 4 (e)*
Non-target protein (P)	1.00E+17	1.00E+14	1.00E+11	1.00E+08	1.00E+05
Target Protein (*Taq*) (Q)	1.00E+12	5.00E+10	2.50E+09	1.25E+08	6.25E+06
Total protein (P+Q)	1.00E+17	1.00E+14	1.03E+11	2.25E+08	6.35E+06
% of pure Taq	0.001	0.05	2.44	55.56	98.43

Answer: Minimum number of purification steps required to get at least 95% pure *Taq is* **4** **(total 4 marks)**

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Q3) Solution: D **(2 marks)**

Explanation: Since the Taq preparation Zaira used is 95% pure, it means that other protein impurities in it constitutes about 5%. It is also mentioned that nucleases and proteases are part of these other proteins in the cell. All the options indicate one common principle that EDTA chelating Mg will either inhibit the Polymerase or the DNase enzyme. Since neither EDTA nor BSA were added to the standard reaction, EDTA will inhibit the PCR while BSA will act as a competitor for Taq polymerase protein as a substrate for the contaminating proteases. Hence option D is true.

Q4) Answer: D **(1 mark)**

Explanation: Removing Taq will not allow the PCR to work, and does not test for contamination (A untrue). Adding 3 times excess Taq will only make the overall reaction more robust, but it does not DISTINGUISH between target-DNA versus contaminating DNA that is getting amplified (B untrue). Not adding any nucleotides will also not allow the DNA amplification to work (C untrue). If human DNA template is not added, then all ingredients required for PCR are there in the tube - now if we see amplification in the absence of the target, that would indicate contaminating DNA. Hence D is the correct control - if it shows no amplification, no contaminating DNA.

Q5) Answer: P - ___F__ ; Q: __E__ ; R: _None_ ; S: _None_. **(1.0 ma ea., total 4 ma)**

Explanation:
For P: If she adds excess nucleotides and now the PCR works, it indicates that her nucleotides might be partially inactivated. The excess now fulfils that void, and allows the PCR to come out positive (hypothesis F).
For Q: Zaira's standard reaction did not work. Now if she repeats the PCR with a DNA template that was obtained from a reaction that had worked previously, and now her PCR works, this indicates that changing the DNA variable alone was the key to getting the reaction working. This would indicate that the problem in PCR was not her reaction constituents, but rather the DNA she was using. (supports hypothesis E).
For R: By changing the Taq Pol as the variable, she cannot be testing if her nucleotides were fine or not. (supports neither, NONE).
For S: using a fresh batch of nucleotides only indicates that the nucleotide mixture she used before was insufficient for amplification – it does not differentiate between partial inactivation *versus* complete inactivation of the nucleotides (supports neither, NONE).

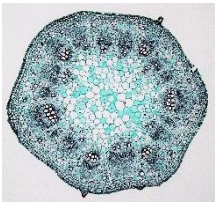
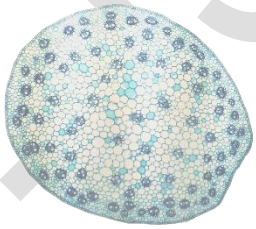
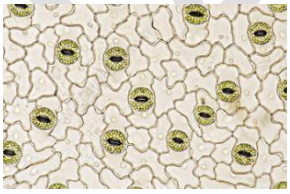
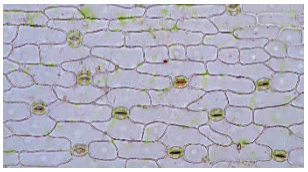
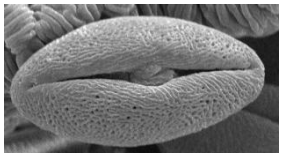
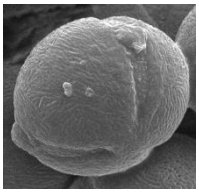
27) Tubulin constitutes 6% of the total protein of a cell and exists as a heterodimer composed of α-tubulin **(**molar mass ≈ 50,000 Da**)** and β-tubulin (molar mass ≈ 55,000 Da). Biochemical analysis shows that there is 0.5 mg of total protein per million cells. Using this value, estimate the average 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:_____

Solution:
Molar mass of each tubulin heterodimer: 50000+55000 = 105000 Da $gmol^{-1}$ = $1.05x10^5$ **(1 mark)**
Tubulin mass per 10^6 cells: 6% of 0.5 mg = 0.03 mg = $3x10^{-5}$ g
Tubulin mass per cell: $3x10^{-11}$ g **(1 mark)**

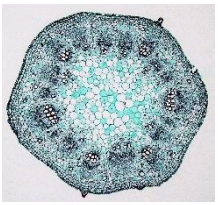
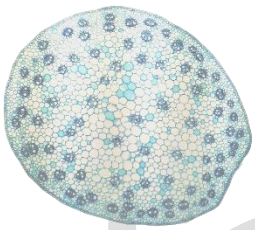
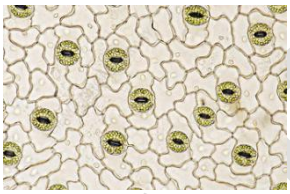
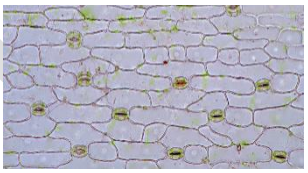
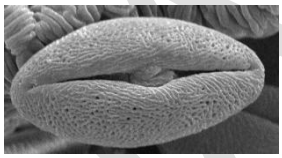
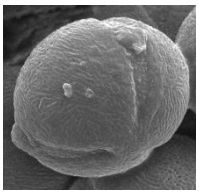
Moles of tubulin per cell: Mass of tubulin in grams/molar mass of tubulin
$= 3x10^{-11}$ g/$1.05x10^{5} = 2.875x10^{-16}$ moles **(1 mark)**
Each mole tubulin contains Avogadro number ($6.022x10^{23}$) of tubulin molecules.
Average number of tubulin molecules per cell= $2.875x10^{-16}x6.022x10^{23} = 1.73\times10^{8}$ tubulin molecules per cell **(1 mark)**

28) Plants are classified as monocot and dicot based on certain character. Identify the following plant part as monocot (M) or dicot (D) **(Total 5 marks)**

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

KAPISO

Solution:

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

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)**

IPTISO

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.

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.

IAPT-JSC

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

To make his solutions Ranga made a stock of 250 ml of 500 mg/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 15mL 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 mark]

Solution:

Q1) $\text{Glucose} + O_2 + H_2O \xrightarrow{\text{Glucose Oxidase}} \text{Gluconic acid} + H_2O_2$ Or In Words

Q2) Redox reaction (OR enzymatic redox reaction)

Q3) Capillary action

Q4) Other sugars do not get oxidized (OR glucose oxidase is specific to glucose)

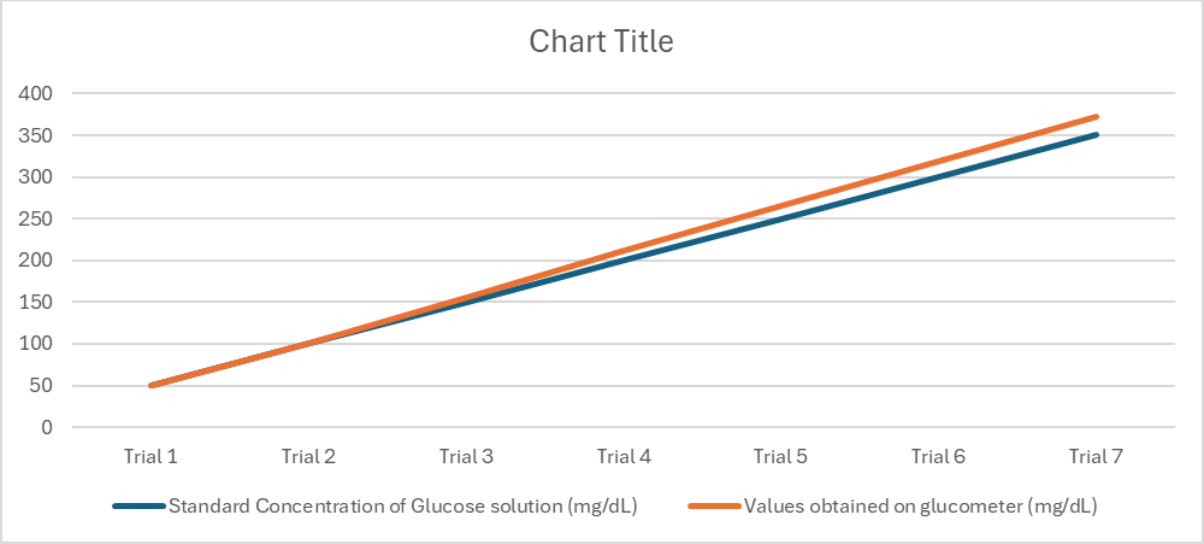
Q5) 1250 mg

Q6) $150 * 15 = 500 * X$

$X = (150*15)/500$

X = 4.5 mL of stock solution; Water = 10.5 mL

IAT-JSO



Q8) X = (150*15)/500

X = 4.5 mL of stock solution; Water = 10.5 mL

and Average % deviation = 3.8%

	Standard Concentration of Glucose solution (mg/dL)	Values obtained on glucometer (mg/dL)	Percentage Deviation
Trial 1	50	50	0
Trial 2	100	100	0
Trial 3	150	155	3.2
Trial 4	200	212	5.6
Trial 5	250	265	5.6
Trial 6	300	319	5.9
Trial 7	350	373	6.1

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_2). Both types of electrodes are immersed in diluted sulphuric acid (H_2SO_4), which has a concentration of 38% by mass and a specific gravity of 1.33 g/cm^3.

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.

IAPT-ISC

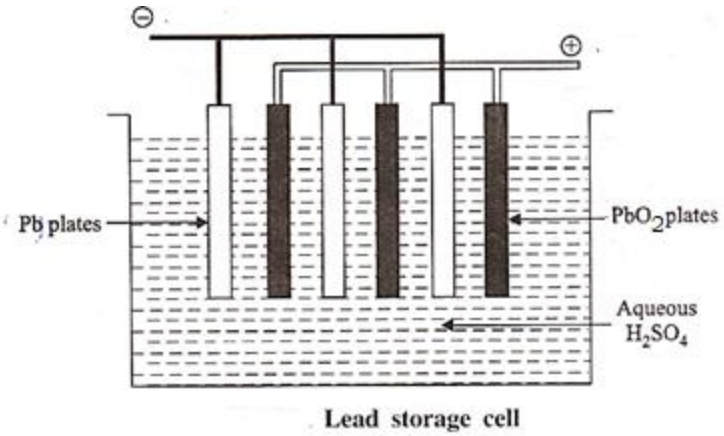


Figure-1: Schematic diagram of Lead Accumulator

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

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

Here, E^0 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.

$$E = E^0 - \frac{0.0591}{n} \log Q$$

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 (H_2SO_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 Pb^{2+}/PbO_2 = -0.126V
Standard reduction potential of PbO_2/ Pb^{2+} in the presence of standard H_2SO_4 = 1.455V] **[3 marks]**

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 H_2SO_4 is at 1.17g/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 1.33g/cm^3 (38% by mass) to 1.17 g/cm^3(23.43% by

mass)[Given: 3600C = 1Amepere.hour; Faraday constant = 96500 C] Assume no change in the volume of the solution. **[3 marks]**

Solution:

Q1)

$Pb \rightarrow Pb^{2+} + 2e^-$

$Pb^{2+} + SO_4^{2-} \rightarrow PbSO_4$

$Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$

overall anodic reaction 0.5M

$PbO_2 + 4H^+ + 2e^- \rightarrow Pb^{2+} + 2H_2O$

$Pb^{2+} + SO_4^{2-} \rightarrow PbSO_4$

$PbO_2 + 4H^+ + 2e^- + SO_4^{2-} \rightarrow PbSO_4 + 2H_2O$

overall cathodic reaction 1M

$Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$

$PbO_2 + 4H^+ + 2e^- + SO_4^{2-} \rightarrow PbSO_4 + 2H_2O$

$Pb + PbO_2 + 4H^+ + 2SO_4^{2-} \rightarrow 2PbSO_4 + 2H_2O$

Net cell reaction 0.5M

Q2)

Answer

Volume of the box = 30 x 15x 20 = 9000 cm^3 = 9000ml = 9L

Box is 80% occupied by sulphuric acid

Volume of sulphuric acid = 9 x 0.8 = 7.2 L

Volume of 100g of sulphuric acid = $\frac{100}{1.33}$ = 75.188 ml = 0.0752L ---------- 1M

Since 100 g of H_2SO_4 solution contains = 38 g of H_2SO_4 + 62 g of H_2O 0.0752L

= $\frac{38}{98}$ = 0.387 mol of sulphuric acid

7.2 L = 37.05 mol

Hence 37.05 mol are present in 7.2 L of acid, hence molarity = 5.146 M -------1M

Q3)

Answer

$E^0_{cell} = E^0_{RHS} - E^0_{LHS}$

$E^0_{cell} = E^0_{PbO2} - E^0_{Pb}$

$E^0_{cell} = 1.455 - (-0.126) = 1.581V$ ---------- 1.0 M

$E_{cell} = E^0_{cell} - \frac{0.0591}{2} \log \frac{1}{[H+]^4[SO4-]^2}$

$E_{cell} = 1.581 - 0.0295 \log \frac{1}{[H+]^4[SO4-]^2}$ ---------- 0.5M

Since Molarity is 5.146 for H_2SO_4

$[H^+] = 10.286$ M

$[SO_4^{2-}]$= 5.146 M ----------0.5M

E_{cell} = 1.581 - 0.0295 log $\frac{1}{[10.286]^4[5.146]^2}$ = 1.742 V ---------- 1.0 M

Q4)

Initial Mass of H_2SO_4

Volume of solution = 7.2 L=7200 mL7.2 L equals 7200 mL and Initial density = 1.33 g/mL Initial
mass of solution = 7200 mL×1.33 g/mL=9576 g Initial
mass of H_2SO_4 = 9576 g×0.38=3638.88 g ---------- 0.5M

Final Mass of H_2SO_4

Volume of solution = 7.2 L=7200 mL(no change in volume of solution --- Given) Final
density = 1.17 g/mL Final
mass of solution = 7200 mL×1.17 g/mL= 8424 g Final
mass of H_2SO_4 = 8424 g×0.2343 = 1973.74 g ---------- 0.5M

Amount of H_2SO_4 consumed = 3638.88 -1973.74 = 1664.26 g

Number of moles consumed = $\frac{1664.26}{98}$ = 16.98 mol ---------- 0.5 M

From the reaction in 1.1 we know that

$PbO2+Pb+2H2SO4 \rightarrow 2PbSO4+2H2O$ 2

moles of $2SO4$ = 2 moles of electrons transferred. ---------- 0.5M

This means 1 mole of $H2SO4$ is consumed = 1 mole of electrons.

Hence, Moles of electrons = Moles of H_2SO_4 consumed = 16.98 mol

Hence the charge delivered by the cell

Charge (Q) = moles of electrons × Faraday's constant (F)

Q= 16.98 mol×96500 C/mol = 1638570 C = 455.15 Ah ---------- 1.0 M

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'.

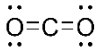
Q2) Draw the Lewis structure of gas 'F'.

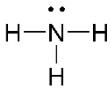
Q3) What is the molecular formula of 'E'.

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?

Solution:

Q1) 

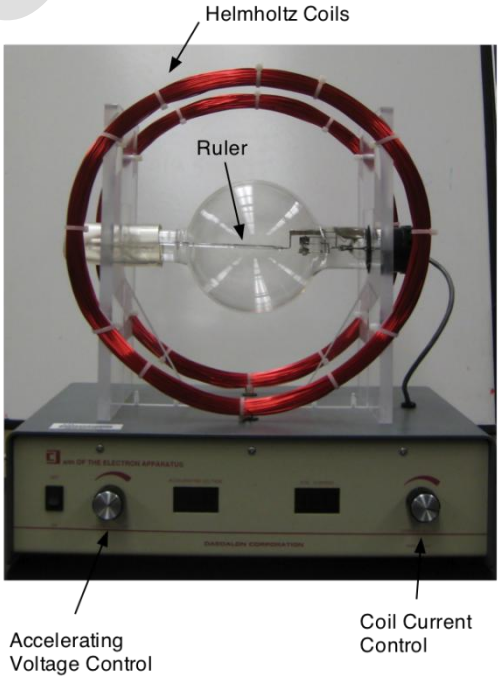
Q2) 

Q3) $Ca(HCO_3)_2$

Q4) Acid-Base reaction/ Neutralization

Q5) $KCl - K_2CO_3 = 74.5 - 138 = 63.5$

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:

$$eV = \frac{1}{2} m v^2 \quad \ldots\ldots (1)$$

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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:

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

$$\therefore\ eB = \frac{m\,v}{r} = \frac{p}{r} \ldots\ldots\ldots (2)$$

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

$$B = \mu_0 \left(\frac{4}{5}\right)^{\frac{3}{2}} \left(\frac{N\,I}{R}\right) \ldots\ldots\ldots (3)$$

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.

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)
d) Permeability of free space, $\mu_0 = 4\pi \times 10^{-7}$ 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			

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6	200	8.8			
7	220	9.6			
8	240	10			
9	260	10.4			
10	280	10.7			

Solution:

Q1) The equation (2) can be written as $eB = \frac{\sqrt{2Km}}{r}$. Where $K$is the kinetic energy is given by $K = \frac{1}{2}mv^2 = eV$.

Thus $eB = \frac{\sqrt{2eVm}}{r}$

$$B = \frac{\sqrt{2eVm}}{er} = \frac{1}{r}\sqrt{\frac{2Vm}{e}}$$

$$B^2r^2 = \frac{2Vm}{e}$$

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

Q2) The Magnetic field is $B = \mu_0\left(\frac{4}{5}\right)^{\frac{3}{2}}\left(\frac{N\,I}{R}\right) = 4\pi \times 10^{-7} \times \left(\frac{4}{5}\right)^{\frac{3}{2}}\left(\frac{130\times1.4}{0.15}\right)$

$$B = 10.91 \times 10^{-4}\ \text{T} = 1.091\ \text{mT}$$

Q3) The equation for $\frac{e}{m}$ can be written as

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

The Parameters for plotting the graph are

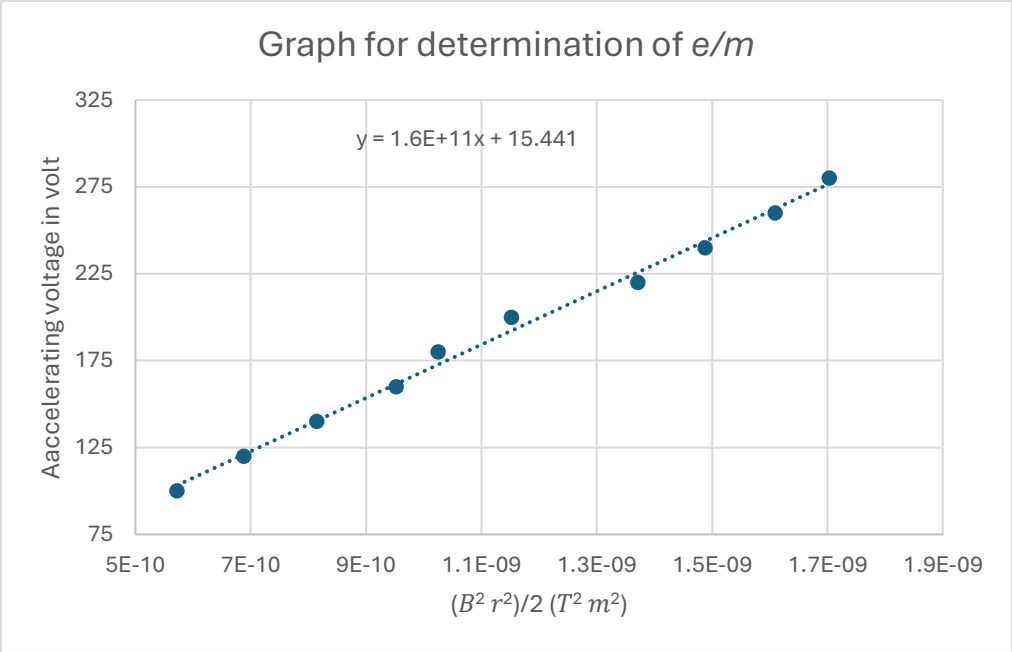
X-axis: $\frac{B^2r^2}{2}$

Y-axis: V

Trial No.	Accelerating Voltage V (V)	Measured diameter d (cm)	Radius (r cm)	$\frac{B^2r^2}{2}$ (T^2m^2)
1	100	6.2	3.1	0.000572
2	120	6.8	3.4	0.000688
3	140	7.4	3.7	0.000815
4	160	8.0	4.0	0.000952
5	180	8.3	4.15	0.001025
6	200	8.8	4.4	0.001152
7	220	9.6	4.8	0.001371
8	240	10.0	5.0	0.001488
9	260	10.4	5.2	0.001609
10	280	10.7	5.35	0.001703

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Q4) The slope of the graph is equal to $\frac{e}{m}$. That is $\frac{e}{m} = 1.6 \times 10^{11} Ckg^{-1}$.

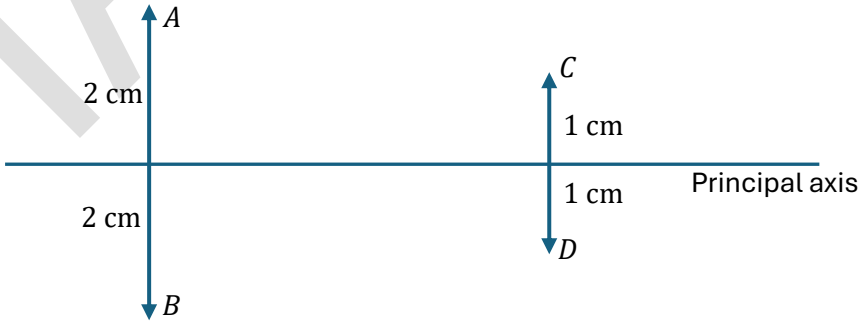


33) Object and Image: The figure given below is a part of several ray diagrams. Out of the two arrow lines AB and CD, anyone can be object, and the other is its image (i.e., if AB is an object, CD is its image, and vice versa).

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_1 as

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



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**)

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**)

Solution: Q1) The optical devices which can converge the rays are concave mirror and convex lens. If CD is considered as object, there are two possible images formed by concave mirror. One is real and other is virtual. Convex lens also can form two images satisfying the condition.

Case 1) Concave mirror

a) Real image formation. The magnification is -2. The object distance can be obtained using the relation $m = \frac{f}{f-u}$. Here the focal length is given by $f = \frac{30}{2} = -15$ cm
That is $-2 = \frac{-15}{-15-u}$.
$-30 - 2u = 15$ or $2u = -45$
Thus, the object distance is -22.5 cm and the image distance is $-$ 45 cm

b) Virtual image formation: The magnification is $+2$. The object distance can be obtained using the relation $m = \frac{f}{f-u}$.
That is $2 = \frac{-15}{-15-u}$.
$-30 - 2u = -15$ or $2u = -15$
Thus, the object distance is -7.5 cm, image distance is +15 cm

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Case 2) Convex lens

a) Real image formation. The magnification is -2. The object distance can be obtained using the relation $m = \frac{f}{f+u}$. Here the focal length is given by

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R} - \left(-\frac{1}{R}\right)\right) = \left(\frac{3}{2} - 1\right)\left(\frac{2}{R}\right) = \frac{1}{R}$$

That is $f = R = 30cm$

$-2 = \frac{30}{30+u}$.

$-60 - 2u = 30$ or $2u = -90$

Thus, the object distance is -45 cm, image distance is 90 cm

b) Virtual image formation. The magnification is +2. The object distance can be obtained using the relation $m = \frac{f}{f+u}$.

$2 = \frac{30}{30+u}$.

$60 + 2u = 30$ or $2u = -30$

Thus, the object distance is -15 cm, image distance is -30 cm

Converging Optical device	Object	Image	Arrangement	u cm	v cm	Expression for Axial distance	Axial Distance (value, cm)
Concave mirror (real image)	CD	AB	AB, CD, Concave mirror	-22.5	-45	$\|v-u\|$	22.5
Concave mirror (virtual image)	CD	AB	AB, Concave mirror CD	-7.5	15	$\|v+u\|$	22.5
Convex lens (real image)	CD	AB	AB, Convex lens, CD	-45	+90	$\|v+u\|$	135
Convex lens (Virtual image)	CD	AB	AB, CD, Convex lens	-15	-30	$\|v-u\|$	15

Solution: Q2) All the optical devices can produce an image AB for the object CD.

For spherical mirrors, $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$ and $m = \frac{f}{f-u}$ $R = 2f$ (Numerically)

For thin symmetric lenses, $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ and $m = \frac{f}{f+u}$

$|R_1| = |R_2|$ and $n = 1.5, \therefore R = f$ (Numerically)

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Optical device	Object	Image	Arrangement	$\lvert u \rvert =$	u cm	v cm	Axial distance	Axial Distance (value, cm)
Concave mirror	AB	CD	AB, CD, mirror	$\frac{3}{2}f = \frac{3}{2}R$	-45	-22.5	$\lvert u - v \rvert$	22.5
Convex mirror	AB	CD	AB, mirror, CD	$f = \frac{1}{2}R$	-15	$+7.5$	$\lvert u + v \rvert$	22.5
Concave lens	AB	CD	AB, CD, lens	$f = R$	-30	-15	$\lvert u - v \rvert$	15
Convex lens	AB	CD	AB, lens, CD	$3f = 3R$	-90	$+45$	$\lvert u + v \rvert$	135

34) In cold climates, our bodies expend extra energy to warm the cold air we inhale to our body temperature (around 37°C). 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 °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 °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 °C, and inhales 6 litres of air per minute. When temperature hits 12 °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.

Use the following data to answer the following questions.

a. Mass of the tourist 70 kg.
b. Useful energy released by digesting a banana is 440 kJ.
c. Useful energy released by digesting an apple is 400 kJ.
d. No energy is released by water.
e. Normal body temperature is 37 °C .
f. Density of air 1.2 kg/m^3.
g. Energy required to increase the temperature of 1 kg air through 1 °C is 1 kJ.
h. Energy expended during slow walk is 3 MET.
i. Energy expended during rigorous walk is 6 MET.
j. To burn one gram of fat one needs to spend 40 kJ of energy.

Questions:

Q1) How much total useful energy does the tourist obtain from eating 2 bananas and 1 apple during the day? **(1 mark)**

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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? **(1mark)**

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)**

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)**

Solution:

Q1) Total energy = (2 × 440 kJ) + (1 × 400 kJ) = 880 + 400 = 1280 kJ.

Q2) Energy due to inhalation ≈ 102.8 kJ (to heat inhaled air while inside room for 14 h).

Temperature rise needed: $\Delta T = 37 - 20 = 17°C$

Inhalation rate = 6 L/min = 0.006 m³/min

Volume per hour = 0.006 × 60 = 0.36 m³/hr

Volume for 14 hr = 0.36 × 14 = 5.04 m³

Mass of that air = 5.04 × 1.2 = 6.048 kg

Energy = mass × ΔT × (1 kJ/kg·°C) = 6.048 × 17 = 102.816 kJ

Q3) Energy spent on the roof top ≈ 72.6 kJ

$\Delta T = 37 - 9 = 28°C$

Inhalation rate and per-hour volume same as above: 0.36 m³/hr

Volume for 6 hr = 0.36 × 6 = 2.16 m³

Mass = 2.16 × 1.2 = 2.592 kg

Energy = 2.592 × 28 = 72.576 kJ

Q4) Energy spent during hike ≈ 180 kJ

$\Delta T = 37 - 12 = 25°C$

Inhalation rate = 25 L/min = 0.025 m³/min

Volume per hour = 0.025 × 60 = 1.5 m³/hr

Volume for 4 hr = 1.5 × 4 = 6.0 m³

Mass = 6.0 × 1.2 = 7.2 kg

Energy = 7.2 × 25 = 180 kJ

Q5) Energy spent during day of physical work out ≈ 9702 kJ

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Slow walk: 2 hours at 3 MET
$E_1 = 70 \times 3 \times 2 \times 4.2 = 1764$ kJ

Rigorous walk: 1 hour at 6 MET
$E_2 = 70 \times 6 \times 1 \times 4.2 = 1764$ kJ

For rest of the day Rest: 21 hours at 1 MET
$E_3 = 70 \times 1 \times 21 \times 4.2 = 6174$ kJ

Total activity energy = 1764 + 1764 + 6174 = 9702 kJ

Q6) Food energy is not sufficient. Fat burned is 219 g.

Energy spent heating inhaled air = 102.816 + 72.576 + 180 = 355.392 kJ (≈ 355.4 kJ)

Energy spent on activity = 9702 kJ

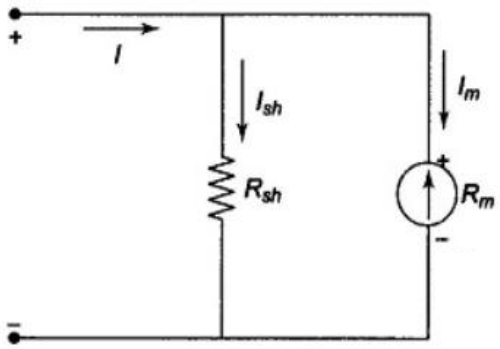
Total energy = 355.4 + 9702 =10057.4 kJ

Food energy available = 1280 kJ

Net energy spent = 10057-1280 = 8777 kJ

Fat burned is $m = \frac{8777}{40} = 219$ g.

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 ($\boldsymbol{R_{sh}}$) 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,

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

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

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 S 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

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

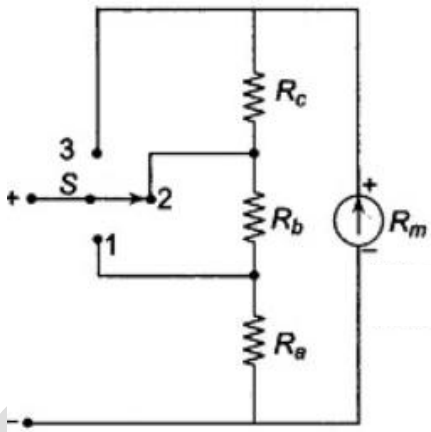
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If the current required for full-scale deflection is $I_{\mathrm{M}} = 1$ mA

Q1) Calculate value of $R_{\mathrm{a}}, R_{\mathrm{b}}$ 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)**



Solution:

(a) When switch S is in position 3, Range of ammeter is 0-2mA.

For full scale deflection

$$I_{sh}(R_a + R_b + R_c) = I_m R_m$$

$$(2-1)(R_a + R_b + R_c) = 1 \times (50)$$

i.e. $R_a + R_b + R_c = 50\Omega$ .....(1)

When switch S is in position 2, Range of ammeter is $0 - 10mA$.

For full scale deflection

$$I_{sh}(R_a + R_b) = I_m(R_m + R_c)$$

$$(10-1)(R_a + R_b) = (1)(50 + R_c)$$

i.e. $9R_a + 9R_b - R_c = 50\Omega$ .....(2)

When switch S is in position 1, Range of ammeter is $0 - 50mA$.

For full scale deflection

$$I_{sh}(R_a) = I_m(R_m + R_b + R_c)$$

$$(50-1)(R_a) = 1 \times (50\Omega + R_b + R_c)$$

i.e. $49R_a - R_b - R_c = 50\Omega$ .....(3)

Solving equations (1),(2) and (3)

$$\boldsymbol{R_a = 2\Omega \quad R_b = 8\Omega \quad and\ R_c = 40\Omega}$$

(b) (i) Resistance of 0-2 mA range ammeter

$\boldsymbol{R}$ = $(2 + 8 + 40)\Omega$ in parallel with 50Ω

$$\boldsymbol{R} = \frac{50\times50}{50+50} = \mathbf{25\ \Omega}$$

(ii) Resistance of 0-10 mA range ammeter

$\boldsymbol{R}$ = $(2 + 8)\Omega$ in parallel with $(40 + 50)\ \Omega$

$$\boldsymbol{R} = \frac{10\times90}{10+90} = \mathbf{9\ \Omega}$$

(iii) Resistance of 0-50 mA range ammeter

$\boldsymbol{R}$ = $2\ \Omega\ in\ parallel\ with\ (8 + 40 + 50)\ \Omega$

$$\boldsymbol{R} = \frac{2\times98}{2+98} = \mathbf{1.96\ \Omega}$$

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