Date: 03/02/2024

Corporate Office : Aakash Tower, 8, Pusa Road, New Delhi-110005 | Ph.: 011-47623456

Answers & Solutions

Time : 3 Hrs. *for* M.M. : 180

Indian National Junior Science Olympiad (INJSO)-2024

IMPORTANT INSTRUCTIONS:

- Section I of this question paper has **15** questions.
  - For each question in this section, **only one** of the four options is a correct answer.
  - For each question, a correct answer will earn **3 marks**, a wrong answer will earn **(–1) mark**, and an unattempted question will earn 0 marks.
  - If you mark more than one option, it would be treated as a wrong answer.
- Section II contains **9** questions worth **5 marks** each. There is no negative marking.
  - For each of these questions one or more option(s) may be correct.
  - You will get full credit for each question only if you mark all correct options and no wrong option. There are no partial marks for these 9 questions.
- Section III contains **11** questions.
  - 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.

SECTION I: Single Correct MCQ

1. From the characteristics of each of the organisms provided in the table below, identify the four organisms, namely P, Q, R and S - from one of the options:

	Symmetry	Germ layers	Coelom	Notochord
P	Bilateral	Triploblastic	Eucoelomate	Present
Q	Bilateral	Triploblastic	Pseudocoelomate	Absent
R	Radial	Diploblastic	Special cavity	Absent
S	Asymmetry	No Germlayers	Special cavity	Absent

(A) P = Fish, Q = Roundworm, R = Starfish, S = Sponge

(B) P = Frog, Q = Filarial worm, R = Jelly fish, S = Hydra

(C) P = Bird, Q = Hook worm, R = Hydra, S = Sponge

(D) P = Snake, Q = Earth worm, R = Jelly fish, S = Flatworm

Answer (C)

Sol.
- Organism **'P'** belongs to phylum Chordata because it possess a notochord.
- Organism **'Q'** belongs to phylum Aschelminthes. Hence, it is pseudocoelomate.
- Organism **'R'** has radial symmetry and diploblastic. It belongs to phylum Coelentrata.
- Organism **'S'** has no germ layers. Hence, it belongs to phylum Porifera.

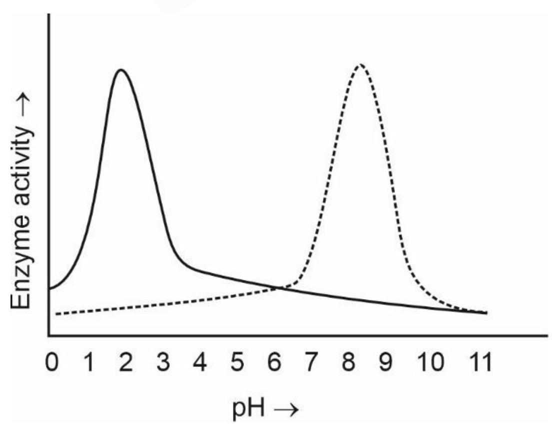
Therefore, P $\rightarrow$ Bird

Q $\rightarrow$ Hookworm

R $\rightarrow$ *Hydra*

S $\rightarrow$ Sponge

2. The graph below shows the activity spectra of two proteolytic enzymes **P** (bold line) and **Q** (dotted line). Identify the combination that identifies the source of the enzymes correctly.



(A) P – Mouth and Q – Stomach

(B) P – Stomach and Q – Duodenum

(C) P – Duodenum and Q – Stomach

(D) P – Stomach and Q – Ileum

Answer (D)

Sol. In the given graph,

'P' $\rightarrow$ Bold line shows acidic pH (1.8 – 2) range

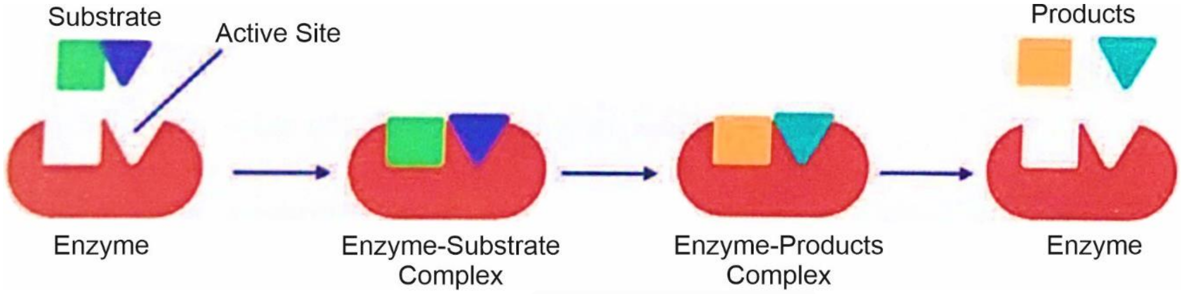
'Q' $\rightarrow$ Dotted line shows alkaline pH (7 – 8) range

Here,

'P' is stomach. It has acidic pH in which HCl is secreted by parietal cells of gastric gland.

'Q' is Ileum. It has alkaline pH which receives secretion of pancreatic juice.

3. Enzymes are biological catalysts that speed up biochemical reactions in living organisms. The active site is the region of an enzyme where substrate molecules bind and undergo a chemical reaction. The following figure demonstrates the process of enzyme-substrate reaction.



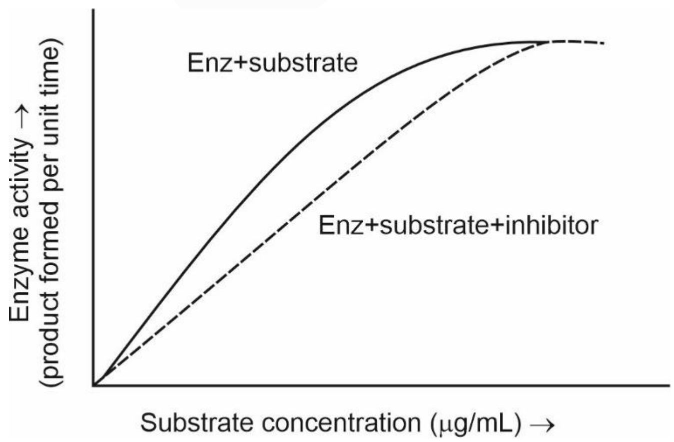
There are some molecules termed as enzyme inhibitors which bind to an enzyme and inhibit its activity or prevent them from working in a normal manner. It is important to note that both the substrate and inhibitor binding to the enzyme, are reversible reactions. The important types of inhibitors classified into the following three types:

(i) Competitive inhibitor directly binds to the enzyme's active site.

(ii) Non-competitive inhibitor binds to a location other than the active site which in turn affects active site and therefore the enzyme activity.

(iii) Uncompetitive Inhibitor binds to the enzyme-substrate complex and slows the rate of reaction to form the enzyme-product complex.

A group of researchers working on various plant extracts evaluated their lipase activity using a fixed concentration of enzyme with/without a fixed concentration of inhibitor, each reaction tested at varying substrate concentrations (all other factors were maintained constant), they found some interesting results. One of the extracts showed the pattern of inhibition as shown in the graph below.



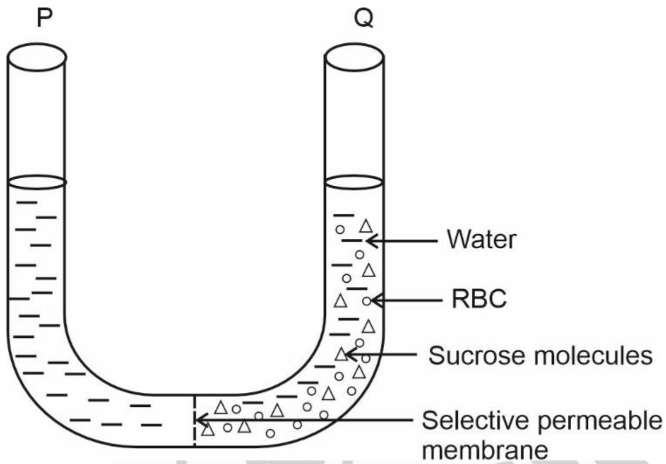
Based on the above pattern of activity of the two reactions, which of the following best concludes the result.

(A) Uncompetitive inhibition
(B) Competitive inhibition
(C) Non-competitive inhibition
(D) Unexplainable by the given data.

Answer (B)

Sol. In competitive inhibition, both substrate and inhibitor compete for the same active site of enzyme, leading to a decrease in the rate of enzymatic reaction. It can be reversed by increasing the substrate concentration in the presence of inhibitor to achieve the same level of enzymatic activity compared to a situation without the inhibitor.

4. A U-shaped glass tube based experiment is depicted below. The two arms are separated by a selectively permeable membrane fixed at the center that allows only water molecules to pass through it. The arm "P" is filled with 10 ml distilled water while arm "Q" is filled with Red Blood Cells (RBC) suspended in 10 ml of an isotonic sucrose solution. Each arm contains 10 mL of solution at 0 min and can accommodate up to a maximum of 12 mL capacity. After 30 minutes, the observation would be:



(A) The water level in "P" would be lower than initial while solution level in "Q" will rise with an increase in RBC size.

(B) The water level in "P" will rise above initial level while in "Q" it will fall with a decrease in RBC size.

(C) The water level in "P" would be lower than initial while water level in "Q" will rise with a decrease in RBC size.

(D) The water level in "P" will remain the same as initial while level in "Q" will rise with an increase in RBC size.

Answer (A)

Sol. The arm 'P' has distilled water which is considered as hypotonic so, there will be the movement of water from arm 'P' to 'Q' through semi-permeable membrane thereby, increasing the level of water in the arm 'Q'.

RBCs present in the arm 'Q' have higher solute concentration hence, water molecules will move into the RBCs and undergo the change in their shape and size.

5. The components of a reflex arc are shown in the flow diagram.

receptor → sensory neuron → synapse → relay neuron → synapse → motor neuron → effector

Which component is responsible for ensuring that the nerve impulses travel in one direction only?

(A) motor neuron (B) receptor

(C) sensory neuron (D) synapse

Answer (D)

Sol. The synapses are structures that allow the one-way transmission of signals.

- The neurotransmitters bind to receptors on the post-synaptic membrane, but there are mechanisms in place to prevent the backward flow of signals.
- This ensures that the nerve impulses move in one direction along the reflex arc.

6. 24 karat gold is 100% pure gold. 18 karat gold is an alloy made by mixing 18 parts of gold with 6 parts of copper by weight. The cost of pure gold is 5560 INR/gram. When it comes to diamonds, 1 carat means a diamond which weighs 200 mg. The cost of diamond is 65,000 INR/carat. If you buy a 15-gram ornament made with 18 karat gold and a 2-carat diamond embedded into it, which of the following statement is NOT true?

(A) You get more atoms of gold than carbon in the ornament.

(B) You pay more per atom of carbon than per atom of gold in the ornament

(C) You get almost same number (within 5%) of atoms of gold and copper in the ornament

(D) The major cost of the ornament is for the gold component in it.

Answer (D)

Sol. Weight of diamond (carbon) = 2 carat

= 2 × 200 mg

= 400 mg

= 0.4 g

Hence weight of 18 carat gold used = 15 – 0.4

= 14.6 g

Weight of pure gold $= 14.6 \times \frac{18}{24}$

= 10.95 g

Cost of pure gold = 10.95 × 5560 g

= 60,882 INR

Cost of diamond = 2 × 65,000

= 1,30,000 INR

Now, moles of Au $= \frac{10.95}{197}$

No. of Au atom $= \frac{10.95}{197} \times 6.022 \times 10^{23}$

$= 0.335 \times 10^{23}$

$= 3.35 \times 10^{22}$ Au atom

Similarly no. of C-atom $= \frac{0.4}{12} \times 6.022 \times 10^{23}$

$= 2.007 \times 10^{22}$ C-atom

Cost per atom of Au $= \frac{60,882}{3.35 \times 10^{22}}$

$= 1.82 \times 10^{-18}$ INR per atom

Cost per atom of C $= \frac{1,30,000}{2.007 \times 10^{22}}$

$= 6.48 \times 10^{-18}$ INR per atom

Weight of copper = 14.6 – 10.95

= 3.65 g

No. of atoms of Cu $= \frac{3.65}{63.5} \times 6.022 \times 10^{23}$

$= 3.46 \times 10^{22}$

Hence option (D) is incorrect (NOT true)

7. India has been implementing an Ethanol Blending Programme (EBP) to increase the ethanol content in petrol. The use of ethanol can reduce greenhouse gas emissions. Ethanol, like petrol, burns in the internal combustion engine to produce water and carbon dioxide. What is the decrease in carbon dioxide emission resulting from using E20 fuel (consider 20% ethanol by mass in petrol) in place of just petrol? Ethanol is C_2H_5OH and Petrol is C_8H_{18}.

(A) 20%
(B) 15%
(C) 10%
(D) 7.5%

Answer (D)

Sol. Let weight of petrol = 100 g

Moles of C_8H_{18} (petrol) $= \frac{100}{114} = 0.8771$

= 0.88 mol

$$C_8H_{18} + \frac{25}{2}O_2 \longrightarrow 8CO_2 + 9H_2O$$

Moles of CO_2 produced = 8 × 0.88

= 7.04 mol

Now, when mixture is used

$$C_8H_{18} + \frac{25}{2}O_2 \longrightarrow 8CO_2 + 9H_2O$$

Now, 80 g petrol and 20 g C_2H_5OH is used

So moles of $C_8H_{18} = \frac{80}{114} = 0.702$

Moles of CO_2 produced = 0.702 × 8

= 5.616 mol

$$C_2H_5OH + 3O_2 \longrightarrow 2CO_2 + 3H_2O$$

Moles of CO_2 produced $= \frac{20}{46} \times 2$

= 0.87 mol

Total moles of CO_2 produced = 5.616 + 0.87

= 6.486 mol

Decrease in number of moles of CO_2 = 7.04 – 6.486

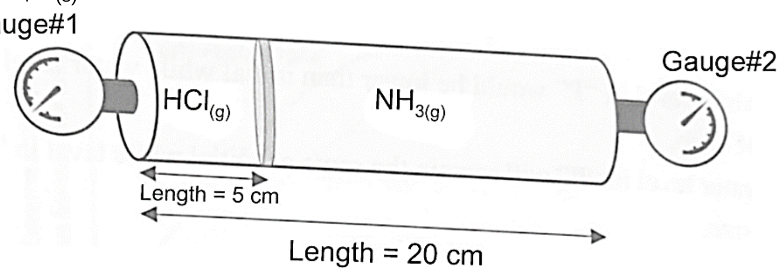
= 0.554 mol CO_2

% decrease in CO_2 emission $= \frac{0.554}{7.04} \times 100$

$= 7.86 \simeq 7.5$ %

8. Ammonia (NH_3) and hydrogen chloride (HCl) react to form solid ammonium chloride.

$NH_{3(g)} + HCl_{(g)} \longrightarrow NH_4Cl_{(s)}$



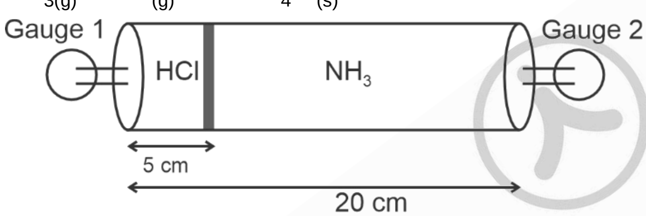
In a cylinder of radius 5 cm with two chambers as shown above, 4 gram of ammonia and 4 gram of hydrogen chloride were placed in the respective compartments. After keeping at 25°C, the plate separating the two chambers was removed that enables the cylinder to have a single compartment. The cylinder was allowed to come back to 25°C.

The pressure reading in gauge #1 in the initial setup and for gauge #2 after the process were:

(A) 4.12 atm and 1.03 atm
(B) 6.85 atm and 1.95 atm
(C) 6.85 atm and 4.68 atm
(D) 4.12 atm and 1.22 atm

Answer (B)

Sol. $NH_{3(g)} + HCl_{(g)} \longrightarrow NH_4Cl_{(s)}$



Cylinder's radius = 5 cm

Mass of NH_3 = 4 g Moles of NH_3 = 0.2352 mol

Mass of HCl = 4 g Moles of HCl = 0.1095 mol

Volume of cylinder = $\pi r^2 h$

$$= 3.14 \times \frac{25 \times 5}{1000} \text{ L}$$

Now, using ideal gas equation

PV = nRT

Pressure in gauge 1 will be because of HCl

$$P_{HCl} = \frac{nRT}{V} = \frac{4}{36.5} \times \frac{0.0821 \times 298}{\left(\frac{3.14 \times 25 \times 5}{1000}\right)}$$

P_{HCl} = 6.82 atm.

After removing plate, reaction takes place. Since HCl is limiting reagent. So, pressure in gauge 2 will be due to remaining NH_3

Number of moles of NH_3 left = 0.2352-0.1095 = 0.1256

$$P_{NH_3} = \frac{nRT}{V}$$

$$P_{NH_3} = 0.1256 \times \frac{0.0821 \times 298}{\left(\frac{3.14 \times 25 \times 20}{1000}\right)}$$

$$P_{NH_3} = 1.95 \text{ atm.}$$

9. Rainwater runoff in which of the following cases is likely to have the highest electrical conductivity?

(A) Water flowing over rocky area

(B) Water flowing through mounds of sand dumped a decade ago

(C) Water flowing down a municipal waste dumped a year ago

(D) Water flowing down broken concrete dumped a year ago

Answer (C)

10. Standard reduction potential, often denoted as E°, is a measure used in electrochemistry to indicate the tendency of a species (a reduction reaction) to gain electrons and be reduced. E° quantifies the relative ease or difficulty with which a species can be reduced or oxidized under standard conditions. The more positive the standard reduction potential of a species, the greater its tendency to act as an oxidizing agent in a chemical reaction. Conversely, species with more negative standard reduction potentials are more likely to act as electron donors. Given the following standard reduction potentials for the redox species:

Chemical species	**Standard Reduction Potential E° (V)**
Fe^{2+}(aq) becoming Fe(s)	–0.44
Cu^{2+}(aq) becoming Cu(s)	+0.34
Zn^{2+}(aq) becoming Zn(s)	–0.76
Ag^{+}(aq) becoming Ag(s)	+0.80

When arranging these species in pairs in an electrochemical cell, which one of the following statements is correct, under standard conditions:

(A) Fe^{2+}(aq) becomes Fe(s) when paired with all Cu(s), Zn(s) and Ag(s)

(B) Fe^{2+}(aq) becomes Fe(s) when paired to Ag(s) and Cu(s); and Fe(s) becomes Fe^{2+} when paired with Zn^{2+}(aq)

(C) Fe becomes Fe^{2+} when paired with Ag^{1+}(aq), Cu^{2+}(aq); and Fe^{2+}(aq) becomes Fe(s) when paired with Zn(s)

(D) Fe(s) becomes Fe^{2+}(aq) only when paired with Zn^{2+}(aq)

Answer (C)

Sol.

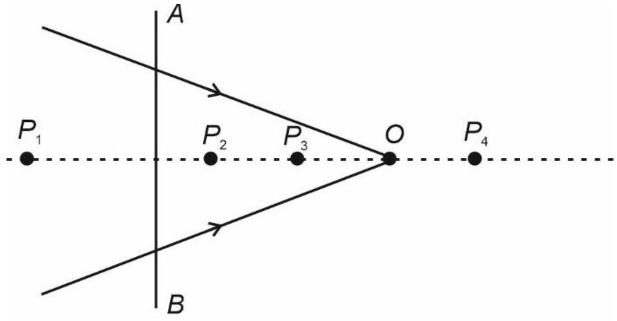
Chemical species	**E° (V)**
Fe^{2+}(aq) becoming Fe(s)	–0.44
Cu^{2+}(aq) becoming Cu(s)	+0.34
Zn^{2+}(aq) becoming Zn(s)	–0.76
Ag^{+}(aq) becoming Ag(s)	+0.80

More positive the standard reduction potential, greater is the tendency to act as oxidising agent and conversely.

Hence, decreasing order of oxidizing power will be:

$Ag^{+} > Cu^{+2} > Fe^{+2} > Zn^{+2}$

11. A converging beam is about to converge at O. However, on introducing an optical element AB (a mirror or a lens) the point of convergence shifts from O to a new location. Column 1 is list of optical elements and column 2 is a list of possible image locations. Match the optical element with the location where the light is made to converge due to their intervention



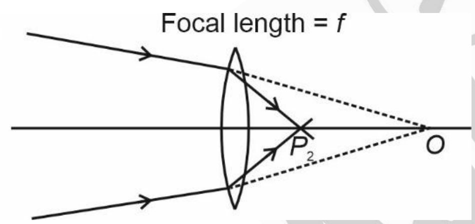
Optical element

	Column 1		Column 2
(a)	Convex lens of a certain focal length f	(p)	P_1
(b)	Convex lens of focal length greater than f	(q)	P_2
(c)	Plane mirror	(r)	P_3
(d)	Concave lens	(s)	P_4

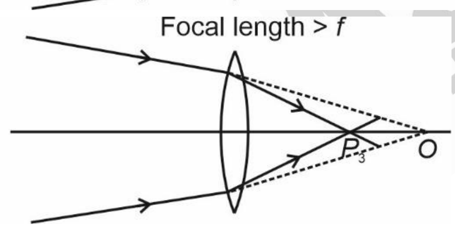
(A) a - r; b - q; c - s; d - p
(B) a - q; b - r; c - p; d - s
(C) a - r; b - q; c - p; d - s
(D) a - q; b - r; c - s; d - p

Answer (B)

Sol. (a) $\rightarrow$ (q)

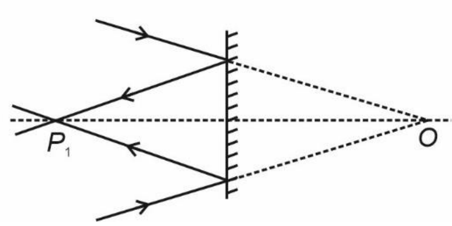


(b) $\rightarrow$ (r)

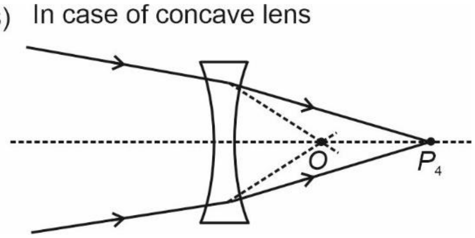


If focal length increases converging power decreases

(c) $\rightarrow$ (p) For plane mirror



(d) $\rightarrow$ (s) In case of concave lens



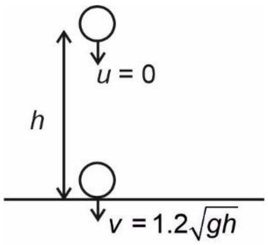
12. A body of mass m dropped from a height h reaches the ground with a speed of $1.2\sqrt{gh}$. The work done by air-resistance is

(A) 0.12 mgh (B) –0.12 mgh

(C) –0.28 mgh (D) 0.28 mgh

Answer (C)

Sol.



By work energy theorem

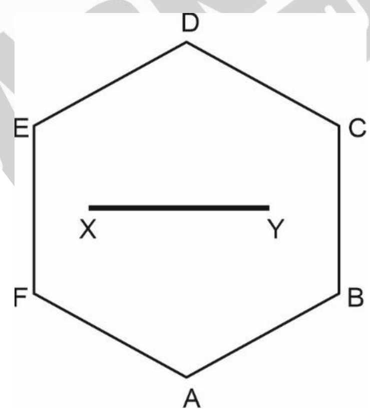
$$W_{gravity} + W_{air\ resistance} = KE_f - KE_i + mgh + W_{air} = \frac{1}{2}m\left(v_f^2 - v_i^2\right)$$

$$W_{air} = \frac{1}{2}m(1.44)gh - mgh$$

$$W_{air} = mgh(0.72 - 1)$$

$$W_{air} = -0.28\ mgh$$

13. Six-point charges are placed at A, B, C, D, E and F on a regular hexagon. If a test charge (+1 nC) is placed at any point on XY and it is found to go in the upward direction (in figure). Line XY is on bisector of sides EF and BC. Then the charge distribution can be respectively

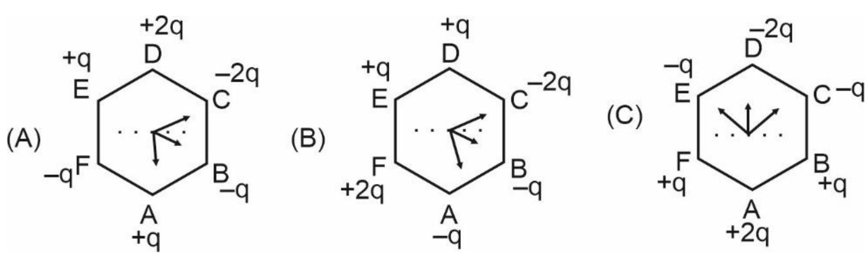


(A) +q, –q, –2q, +2q, +q, –q (B) –q, –q, –2q, +q, +q, +2q

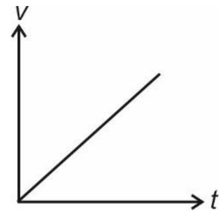
(C) +2q, +q, –q, –2q, –q, +q (D) +q, –2q, –q, +q, +2q, +q

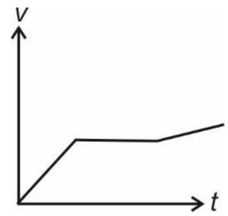
Answer (C)

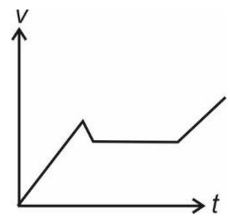
Sol.

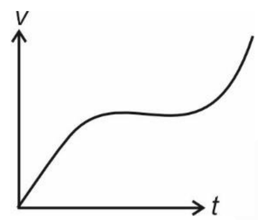


14. A bar magnet is let free to fall from some height staring from rest through a hollow conducting cylinder. Then identify speed-time graph (v - t graph) that best explains its motion.

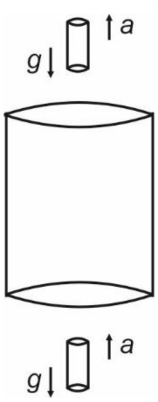
(A) 

(B) 

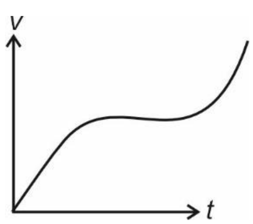
(C) 

(D) 

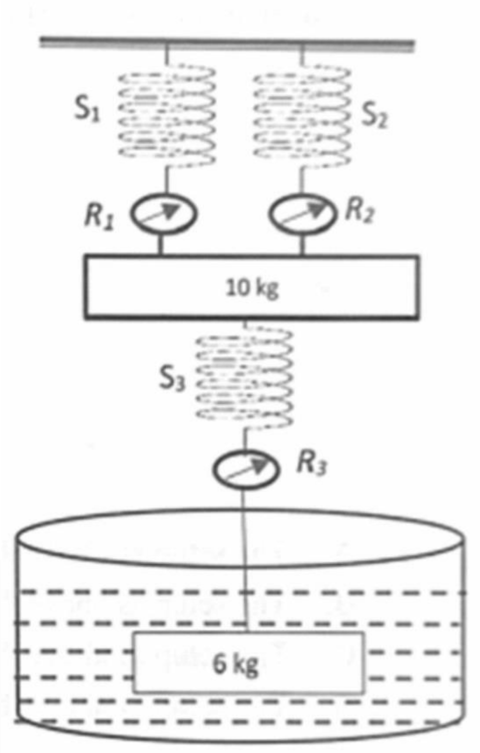
Answer (D)

Sol. 

As magnet falls down speed increases due to gravity and it will experience some opposing force due to change in magnetic flux. Net acceleration decreases due to increasing rate of change of flux. When opposite force is equal to weight speed becomes constant, when magnet is coming out from cylinder then the opposing force decreases because rate of change of flux decreases.



15. A block of mass 10 kg is suspended from a rigid support via two identical spring balances S_1 and S_2. Another block of mass 6 kg is suspended from bottom of 10 kg block via a third spring balance S_3. All the spring balances are assumed to be massless. The block of mass 6 kg (Relative Density = 10) is fully immersed in water contained in a big container. The arrangement is shown in the adjacent figure. If the readings (in kg - wt) on spring balances S_1, S_2 and S_3 are R_1, R_2, R_3 respectively, choose the correct option (assume all the springs stretch within the elastic limits).



	R_1	R_2	R_3
(A)	5.0	5.0	5.4
(B)	8.2	8.2	6.4
(C)	10.0	10.0	5.4
(D)	7.7	7.7	5.4

Answer (D)

Sol.

For 6 kg block

$R_3 + U = mg$

$R_3 + U = 6$ …(i)

Again,

$U = Vf_l g$

$= \frac{6}{10} \times 1 \times g$

= 0.6 kg wt

Now from equation (i) we get

$R_3 = 6 - 0.6 = 5.4$ kg wt

For 10 kg block

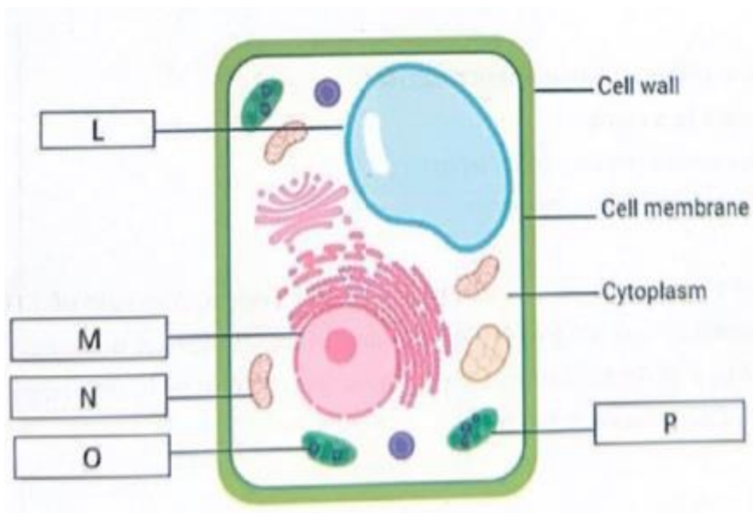
$R_1 + R_2 = 10 + R_3$

$\Rightarrow \quad 2R = 10 + 5.4 \; [\because R_1 = R_2 = R]$

$\therefore \quad R = 7.7$ kg wt

SECTION II: Multiple Correct MCQ

16. The figure below shows the ultrastructural details of a plant cell. Some parts are labelled as L, M, N, O and P. Identify the correct statement(s) w.r.t. these labels.



(A) O is granule of reserve food Glycogen.

(B) L is concerned with spindle fibre formation.

(C) M and P are energy transducers.

(D) N helps in aerobic respiration.

Answer (D)

Sol. The given figure is of plant cell.

The labelled parts:

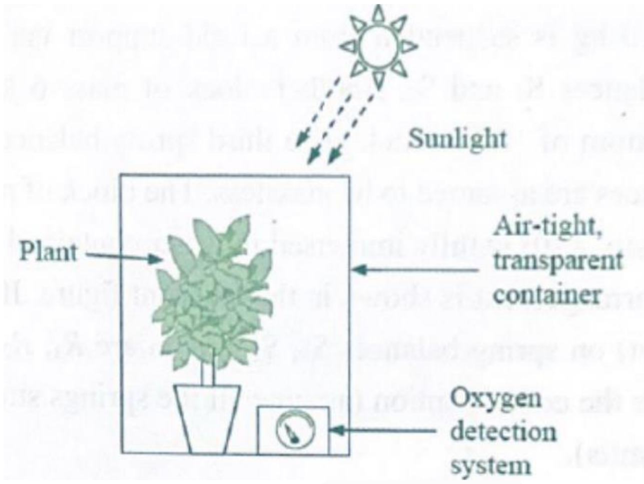
'O' and 'P' → Chloroplasts (Are energy transducers and granule of reserve food *i.e.* starch)

'L' → Vacuole (Not concerned with spindle fibre formation.)

'M' → Nucleus (No role in energy production)

'N' → Mitochondrion (Helps in aerobic respiration)

17. You are trying to demonstrate to your friends that plants require the presence of light to produce oxygen. To do this you assemble the experimental system shown below and make your observations at the beginning and the end of the experiment after 6 hrs. Which setup(s) from the ones below would be useful as a control for your experiment?



(A) The setup as above, but placed in a dark room.

(B) The setup as above, but placed in a dark room with holes in the top of the container

(C) The setup as above, but with the plant removed from the pot.

(D) The setup as above, but with a constant supply of CO_2

Answer (A and C)

Sol. To prove that plants require presence of light to produce oxygen, the above depicted setup should be placed in a dark room and with the plant removed from the pot.

18. Hemophilia is commonly called bleeder's disease. It is a X-linked recessive disorder. Males are more frequently affected by this. If 'H'- is the normal gene, 'h'-is its recessive allele, trace the genotype and phenotype of Mr. Ramesh's family. Mr. Ramesh is normal and non-hemophilic. His father is also non- hemophilic. Ramesh marries Radha, who is also normal, and her father is also non-hemophilic. This couple has 3 children, one boy and two girls, who are all normal. One of the daughters marries a man who is also normal. She has a son (Ramesh's grandson) who is hemophilic. Which of the following outcome(s) will result from the genetic trace between the F_1, F_2 and F_3 generations?

(A) Ramesh's mother is definitely not a carrier.

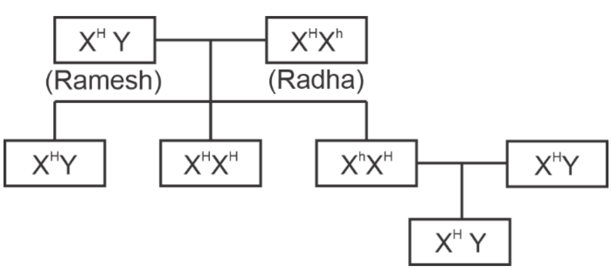
(B) Radha must be a carrier.

(C) Ramesh's son-in law may be a carrier.

(D) Ramesh's daughter must be carrier.

Answer (B, D)

Sol.



19. Acetic acid (CH_3COOH) is an important ingredient of vinegar. A sample of 50.0 mL of a commercial vinegar is titrated against a 0.5 M NaOH solution. 14 mL of the base was needed for the titration to be completed. Which of the following describes the acetic acid content in the vinegar?

[The density of the solution is 1 g/mL]

(A) ~ 0.25 mole %

(B) ~ 8400 ppm

(C) ~ 0.14 Molar

(D) ~ 4% weight

Answer (A, B, C)

Sol. $Eq._{Acid} = Eq._{Base}$

$$(M\times V)_{CH_3COOH} = (M\times V)_{NaOH}$$

$$M_{CH_3COOH}\times 50 = 0.5\times 14$$

$$M_{CH_3COOH} = \frac{0.5\times 14}{50}$$

$$= 0.14\text{ M}$$

$$\Rightarrow\ M = \frac{w}{GMW}\times\frac{1000}{V}$$

$$0.14 = \frac{w_{CH_3COOH}}{60}\times\frac{1000}{50}$$

$$w_{CH_3COOH} = \frac{0.14\times 60\times 50}{1000}$$

$$= 0.42\text{ g}$$

$$\Rightarrow\ d = \frac{w_T}{V_T} = 1\text{ gram/mL}$$

$$w_T = 1\times V_T = 1\times 50\text{ g}$$

$$\%\,(w/w) = \frac{w_{CH_3COOH}}{w_T}\times 100$$

$$= \frac{0.42}{50}\times 100$$

$$= 0.84\ \%\text{ by weight}$$

$$ppm = \frac{w_{CH_3COOH}}{w_T}\times 10^6$$

$$= \frac{0.42}{50}\times 10^6$$

$$= \frac{420}{50}\times 10^3$$

$$= 8.4\times 10^3$$

$$= 8400\text{ ppm}$$

$$\%\text{ mole} = \frac{n_{CH_3COOH}}{n_T}\times 100$$

$$= \frac{n_{CH_3COOH}}{n_{CH_3COOH}+n_{water}}$$

$w_T = w_{water} + w_{Acid}$

$50 = w_{water} + 0.42$

$w_{water} = 50 - 0.42 = 49.58$

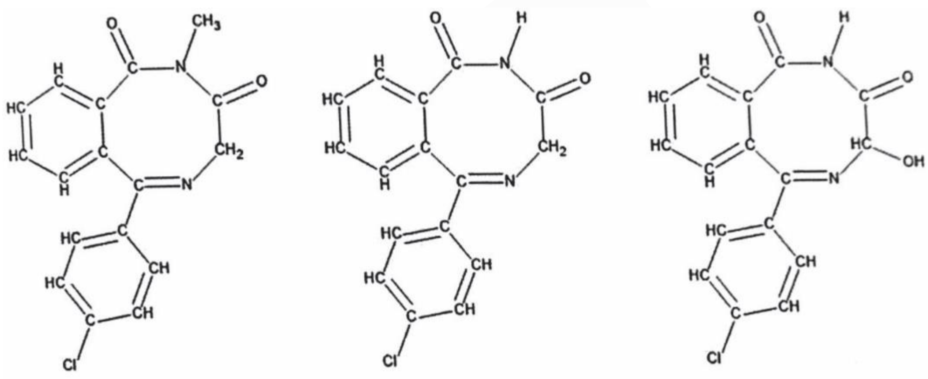
$$\%(n/n) = \frac{\frac{0.42}{60}}{\frac{0.42}{60} + \frac{49.58}{18}} \times 100$$

$$= \frac{0.007}{0.007 + 2.7544} \times 100$$

$$= \frac{0.7}{2.761}$$

$= 0.253$ mole %

20. As xenobiotic substances, such as drug molecules, enter the bloodstream, the body needs an effective mechanism to eliminate these substances. The liver plays a crucial role in this clearance process. Diazepam, a drug, being a lipophilic (fat-loving) molecule with relatively low water solubility, undergoes metabolic transformation within the liver into desmethyldiazepam, oxazepam, and various other metabolites as it circulates through this organ.



Diazepam   Desmethyl diazepam   Oxazepam

Which statement(s) are true for this process?

(A) The liver metabolizes diazepam into compounds that exhibit a greater affinity for lipids than diazepam itself, thereby prolonging the drug's presence in the body.

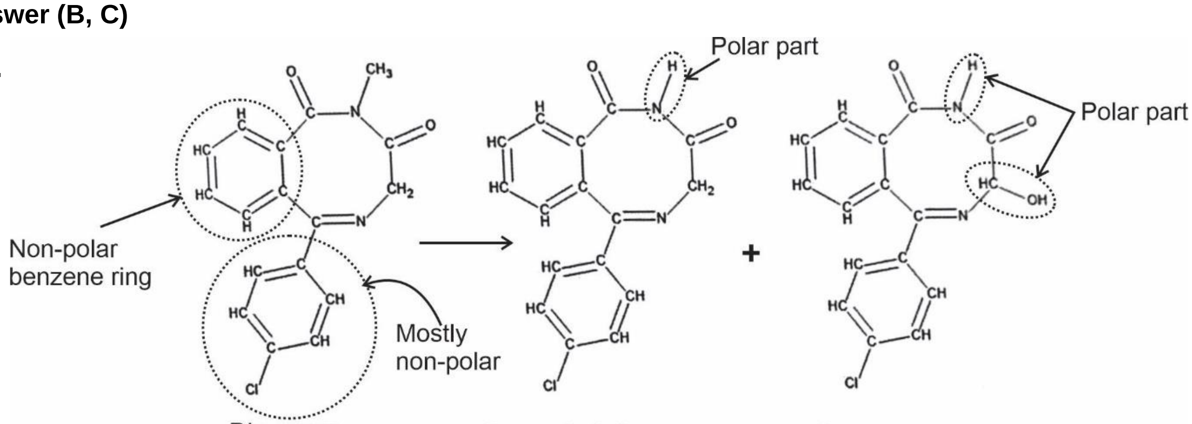
(B) The liver transforms diazepam into metabolites that are more polar than diazepam, facilitating their elimination through urine.

(C) Desmethyl diazepam possesses increased polarity compared to diazepam due to the presence of a polar N-H bond.

(D) Oxazepam is less polar than diazepam because it contains one less methyl (CH_3) group.

Answer (B, C)

Sol.



Diazepam   Desmethyl diazepam   Oxazepam

21. Ms. Ruhina teaches her students the concept of pH. She defines pH as negative logarithm to the base ten of hydrogen ion concentration, and says pure water at 25°C has a pH of 7. On a hot summer day when the temperature was 40°C, she wants to demonstrate that the pH of distilled water is 7 to her class. On measuring the pH of packaged distilled water with a simple pH meter, the value obtained was 6.77.

Which of the following statement(s) is/are offer(s) the best explanation for this discrepancy?

(A) At a higher temperature, the extent of ionization of water has increased and, hence, the water has become acidic.

(B) At a higher temperature, the extent of ionization of water has increased by ~3% and as a result, the "neutral" value of pH is indeed 6.77

(C) At a higher temperature, the extent of ionization has increased and a solution with pH = 7 at this temperature is slightly alkaline.

(D) At a higher temperature, the extent of ionization of water has increased by ~70% and as a result, the "neutral" value for pH is indeed 6.77

Answer (C, D)

Sol. At 25°C

pH = 7, $[H^+] = [OH^-] = 1 \times 10^{-7} M$

At high temperature (40°C)

pH = 6.77

Now $[H^+] = 10^{-6.77} = 1.7 \times 10^{-7}$ M

Now at 40°C

$[H^+] = [OH^-] = 1.7 \times 10^{-7} M$ *i.e.* H_2O is neutral

Hence, extent of ionisation increases

$$\% \text{ increase} = \left(\frac{1.7 \times 10^{-7} - 1 \times 10^{-7}}{1.0 \times 10^{-7}}\right) \times 100$$

$$= \frac{0.7 \times 10^{-7}}{1 \times 10^{-7}} \times 100$$

$$= 70\%$$

Now if at 40°C, pH is 7, then the solution is slightly alkaline.

22. Three resistors $\frac{R}{3}$, R and $2R$ are connected in such a way that their equivalent resistance is R. The respective electrical power consumed by the resistor are P_1, P_2 and P_3. Then choose the correct option/s.

(A) P_1 is greater than P_2

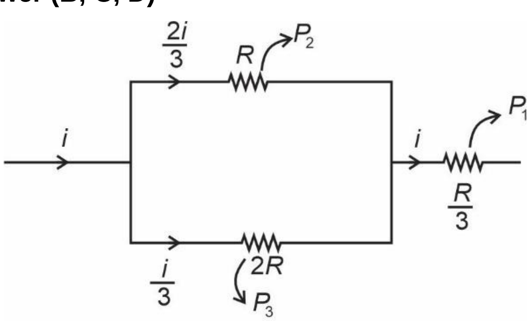
(B) P_3 is lesser than P_2

(C) P_2 is greater than P_1

(D) P_1 is greater than P_3

Answer (B, C, D)

Sol.



$$P_2 = \left(\frac{2i}{3}\right)^2 R = \frac{4i^2R}{9} = \frac{4}{9}(i^2R)$$

$$P_1 = i^2\frac{R}{3} = \frac{1}{3}(i^2R) = \frac{3}{9}(i^2R)$$

$$P_3 = \frac{i^2}{9}(2R) = \frac{2}{9}(i^2R)$$

$$\boxed{P_3 < P_1 < P_2}$$

23. Amount of heat H_1 and H_2 are supplied respectively to a hollow and a solid metallic sphere of same material and same radius.

(A) The volume expansion will be same for both if, $H_1 = H_2$

(B) Hollow sphere will expand more than solid sphere, if $H_1 = H_2$

(C) The solid sphere will expand more than hollow sphere if $H_1 = H_2$

(D) If they are heated up to the same temperature, amount of expansion will be same for both

Answer (B, D)

Sol. Mass of solid sphere (m_2) > Mass of hollow sphere (m_1), because both have same radius.

As the material is same, therefore specific heat will be same for both spheres.

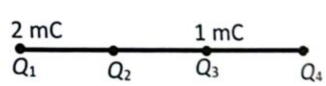
$H = ms\Delta T$

$\Rightarrow \quad \Delta T = \dfrac{H}{ms}$

$\therefore \quad \Delta T_1 > \Delta T_2 \ (\because m_2 > m_1)$

$\Rightarrow$ Volume expansion in hollow sphere will be more than that of solid sphere.

24. Like charges repel, and unlike charges attract. Magnitude of force (F) between two stationary point charges Q_1 and Q_2 separated by a distance r is expressed as $F = \dfrac{KQ_1Q_2}{r^2}$ (Coulomb's Law) where K is a positive constant. Consider four-point charges Q_1, Q_2, Q_3 and Q_4 lying in a straight line as shown in the figure besides. The distance between any two consecutive charges is the same. Here Q_1 = +2 mC and Q_3 = +1 mC. If Q_2 and Q_4 are in equilibrium, correct option is/are



(A) $Q_2 = +\dfrac{44}{9}mc$ and $Q_4 = +4mc$

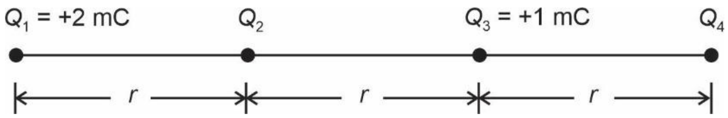
(B) $Q_2 = -\dfrac{44}{9}mc$ and $Q_4 = +4mc$

(C) $Q_2 = +\dfrac{44}{9}mc$ and $Q_4 = -4mc$

(D) If $Q_2 = 0$, Q_4 cannot be in equilibrium

Answer (B, D)

Sol.



For charge Q_4 to be in equilibrium

$$\frac{KQ_1Q_4}{(3r)^2}+\frac{KQ_3Q_4}{r^2}=\frac{KQ_2Q_4}{(2r)^2} \quad \ldots(i)$$

$$\Rightarrow \quad \frac{2}{9}+1=\frac{Q_2}{4}$$

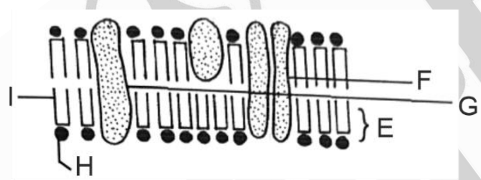
$\Rightarrow \quad Q_2=-\frac{44}{9}\text{mC}$ [Q_2 should be opposite in nature than Q_1 and Q_3]

If $Q_2 = 0$, net force on Q_4 cannot be zero, hence it cannot be in equilibrium.

SECTION III: Descriptive Questions

25. (a) The structure of an animal cell plasma membrane is shown below. The bi-layered plasma membrane is made up of both proteins & polar lipids along with carbohydrates found attached to either proteins and/or lipids. Some proteins are embedded in the membrane while others exist more towards the internal surface of the membrane (internal proteins) & or on the external part (surface/external proteins). **[1.5 Marks]**

Facing outside of the cell



Facing the cytoplasm (inside)

Based on above information, identify the labels (of each letter) and choose the correct options:

(i) E is lipid molecule

(ii) F is bi-layered lipid

(iii) G is a transmembrane protein

(iv) H is the polar part of the molecule

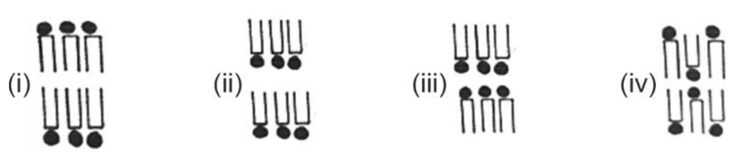
(v) E is entirely polar

(vi) H & I are both non-polar

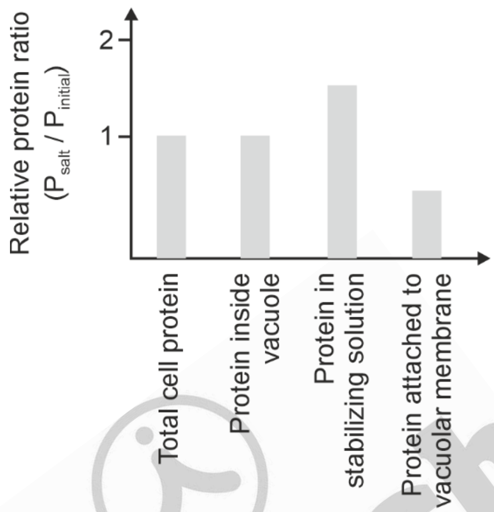
(vii) I is polar

With respect to nature of plasma membrane, which of the following statement(s) is/are correct?

(b) Whenever a solid food molecule approaches a cell, then plasma membrane surrounds it & engulfs the food particle (phagocytosis), and the food vacuole pinches off into the cytoplasm. As a result the orientation of the membrane proteins get altered, as the membrane of the vacuole now faces inside-out. Identify the arrangement of these molecules in the altered plasma membrane of the vacuole and pick the correct one from the options below. **[1 Mark]**



(c) In another experiment, a scientist isolated the food vacuoles from the cells & put them in a solution that increased the stability of the vacuolar membrane. In the second part of the experiment, when she added a small amount of salt to the stabilizing solution, the membrane still seemed to remain intact. The decipher what had happened, she performed a protein estimation assay on the samples before ($P_{initial}$) and after addition of the salt (P_{salt}). She divided the values of her salt-treated readings by the corresponding protein readings of the same fraction-type (X axis) from the original solution (before adding the salt). Her data is depicted in the graph →



Based on her data, which of the following interpretation(s) is/are true?

(i) The decrease is due to external proteins that dissociate into the stabilizing solution.

(ii) The increase is due to external proteins that dissociate into the stabilizing solution.

(iii) The decrease is due to dissociation of transmembrane proteins into the vacuole.

(iv) The increase is due to dissociation of internal proteins into the stabilizing solution.

[1.5 Marks]

Sol. (a) Answer (i), (iii) and (iv)

Here, 'E', represents a phospholipid molecule.

'F' is a protein (transmembrane protein) not a bi-layered lipid.

'G' is a transmembrane protein.

'H' is a polar part of membrane.

'E' is amphipathic not entirely polar.

'H' is a polar whereas 'I' is non-polar.

'I' is non-polar. **[1.5 Marks]**

(b) Answer (i)

The arrangement of polar and non-polar parts will remain same in plasma membrane. **[1 Mark]**

(c) Answer (iv)

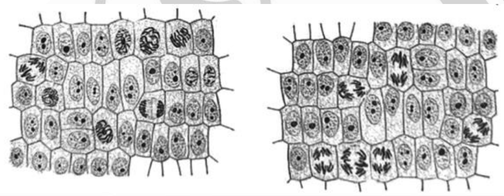
The increase is due to dissociation of internal proteins into the stabilizing solution. **[1.5 Marks]**

26. (a) The growth and development of vertebrate embryo begin immediately after fertilization. The table below shows some of the events (S to Y) between fertilization and birth. **[3 Marks]**

Table

S	Development of the heart
T	Placenta forms
U	Hormones are released by the mother to start contractions
V	Implantation of the embryo in the lining of the uterus
W	Embryo forms into a ball of eight cells
X	Development of nervous system
Y	Fertilized ovum divides into two cells by mitosis

(b) Cells of a tissue having an average doubling time of 12h were analysed by dye-staining for DNA-chromosomes. In a hypothetical experiment described below, the different phases of the cell cycle were observed among the dividing tissue. One could distinctly observe 1-2 dark stained nucleoli, within each interphase nucleus. Sample P was untreated while Sample Q (similar tissue) was treated with a newly discovered drug for 24h, before staining and analysis. Based on your interpretation of the data provided, choose the correct statement(s). **[1 Mark]**



P Q

(i) The drug acts like an enhancer of cell division.

(ii) The drug acts to stall the cells in anaphase.

(iii) The drug acts to accelerate metaphase in the cells.

(iv) The drug acts like an enhancer of chromosome disruption.

(c) In each of the following stages of the cell cycle of a diploid organism (not provided in sequence), indicate whether the chromosome number is haploid (H), diploid (D) or could be either (E). Also depending on if the chromosomes have replicated (R, sister chromatids joined at the kinetochore) or not replicated (N/R), state the corresponding chromosome status in each phase of the cell cycle.

***interkinesis** – phase between Meiosis I and Meiosis II **[5 Marks]**

Chromosome number	Chromosome status	Cell cycle phase
		G2
		Meiotic metaphase I
		Mitotic metaphase
		Meiotic interkinesis
		G1

(d) Which of these phenomenon can be equated to or most closely represent the corresponding activity associated with a phase of the cell cycle? Choose your options from the following: prophase, metaphase, anaphase, interphase, S phase. Each option can be used only once. **[5 Marks]**

Analogous of the status of DNA in the cell	**Phase of cell cycle**
Teams when "in-a-tie" at a tug of war	
Transition from a bowl of cooked noodles to a dehydrated pack	
Serving equal portions of a cake to their two children	
Noodles in its most relaxed form –cooked noodles in a bowl	
Polymerase Chain Reaction (PCR)	

(Note: A "*TUG OF WAR*" is a game where two groups pull/tug a tight-rope between the two, with the aim of one team tugging the opposing team beyond a midpoint, OR to eventually dragging down the opposing team completely towards one side).

Sol. (a) The correct sequence of events in the growth and development of vertebrate embryo after fertilisation is

$Y \rightarrow W \rightarrow V \rightarrow T \rightarrow S \rightarrow X \rightarrow U$ **[3 Marks]**

(b) Answer (ii)

The number of anaphasic cells in the sample Q are high because the drug acts to stall the cells in anaphase.

[1 Mark]

(c)

Chromosome number	**Chromosome status**	**Cell cycle phase**
D (2n)	R	G2
D (2n)	R	Meiotic metaphase I
D (2n)	R	Mitotic metaphase
H (n)	R	Meiotic interkinesis
D (2n)	N/R	G1

[5 Marks]

(d)

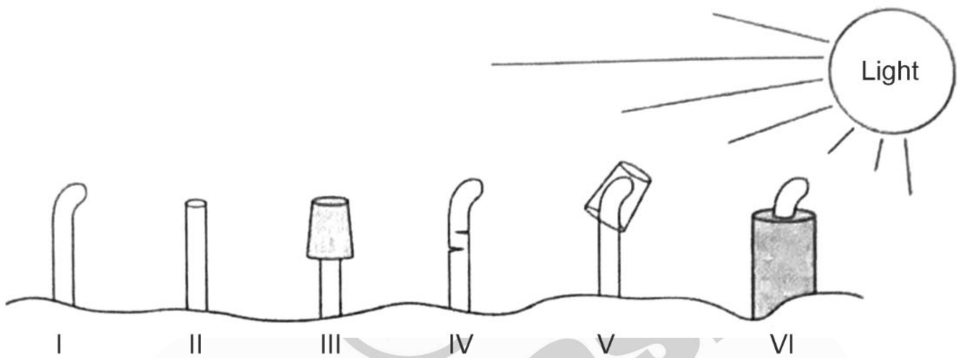
Analogous of the status of DNA in the cell	**Phase of cell cycle**
Teams when "in-a-tie" at a tug of war	Metaphase
Transition from a bowl of cooked noodles to a dehydrated pack	Prophase
Serving equal portions of a cake to their two children	Anaphase
Noodles in its most relaxed form –cooked noodles in a bowl	Interphase
Polymerase Chain Reaction (PCR)	S-phase

[5 Marks]

27. An experimenter tried to recapitulate the experiments done by Charles Darwin. He performed a series of experiments on phototropism (growth towards light) of the coleoptile (the cap that covers the first leaves of new seedlings of grass). The treatments they used are described in the first column of the table below:

Treatment		Results: Growth towards light
I.	Coleoptile untreated.	Allowed
II.	Tip of coleoptile cut off.	Prevented
III.	Opaque cap placed over coleoptile tip.	Prevented
IV.	Coleoptile cut halfway through.	Allowed
V.	Transparent cap placed over coleoptile tip.	Allowed
VI.	Opaque sleeve placed over base of coleoptile.	Allowed

After the treatment, the plants were allowed to grow (as shown below) for a week and the observations are as in the figure below (corresponding results are tabulated above).



(a) Comparison of treatments I and II shows which of the following option(s)? **[1.5 Marks]**

(i) Growth is promoted by cutting off the tip.

(ii) The tip is the site of auxin synthesis.

(iii) The tip is necessary for the response to light.

(iv) There is a range of responses to a single treatment.

(b) The fact that the effect of cutting off the tip (treatment II) is not simply due to wounding of the plant is demonstrated by comparison of which of the treatments? Pick the correct option(s) from below: **[1.5 Marks]**

(i) I, II and III

(ii) I, II and IV

(iii) II, III and IV

(iv) IV, V and VI

(c) Comparison of treatment III, V and VI shows that... [pick the correct option(s) from below]: **[1.5 Marks]**

(i) the tip plays a role in sensing the light

(ii) the base plays a role in sensing the light

(iii) confinement of the tip inhibits the response to light

(iv) confinement of the base facilitates the response to light

(d) To test the hypothesis that the response to light involves differential cell elongation, an experimenter could... [pick the correct option(s) from below]: **[1.5 Marks]**

(i) measure the distance between marks made on the seedling after it has bent.

(ii) count the number of cells visible in a cross section of the coleoptile.

(iii) compare the length of cells on the sides of the stem towards, and away from the light.

(iv) repeat the experiment using light of a different wavelength.

Sol. (a) Answer (iii)

The tip is necessary for the response to light. **[1.5 Marks]**

(b) Answer (ii) **[1.5 Marks]**

(c) Answer (i)

The tip plays a role in sensing light. **[1.5 Marks]**

(d) Answer (iii)

To test the hypothesis that the response of light on different plant parts, the experimenter can compare the length of cells on the sides of the stem towards, and away from the light. **[1.5 Marks]**

28. Can a healthy person spend overnight for 8 hours in an airtight room with all the windows and doors closed without ventilation? Let's find out! Consider a closed room of 10 × 10 × 10 ft.

I. Find out the volume of the room. Assume about 27 litres is equal to one cubic ft at normal temperature and pressure.

II. Find out the initial total volume of air in the room.

III. Then at the rate of 21% of oxygen in air, calculate the total amount of oxygen present in the closed room.

A normal healthy person at rest or sleeping consumes 250 ml of oxygen per minute. If he is locked in the room for 8 hours.

IV. Calculate the total amount of oxygen utilised by him in 8 hours.

V. Find out the difference in amount of oxygen between the initial and after 8 hours of oxygen content in the room.

VI. State whether the person is dead or alive!!

Write down every step of your calculations clearly for each corresponding step (I-VI), with precise description of what is being calculated with the corresponding formula in words. **[6 Marks]**

Sol. I. Volume of the room = length × width × height

= 10 ft × 10 ft × 10 ft

= 1000 ft^3 **[1 Mark]**

II. Initial total volume of air in the room = 1000 ft^3 × 27 L

= 27000 L **[1 Mark]**

III. Given that oxygen constitutes 21% oxygen in air.

Amount of oxygen in the closed room = 27000 L × 0.21

= 5670 L **[1 Mark]**

IV. Total volume of O_2 utilised by person per minute = 250 ml

Total volume of O_2 utilised by person in 8 hours = 250 × 60 × 8

= 1,20,000 ml

= 120 L **[1 Mark]**

V. Difference in oxygen level = Initial volume of O_2 in the room – Oxygen utilised by the person

$$= (5670 - 120)\ \text{L}$$

$$= 5550\ \text{L}$$

[1 Mark]

VI. Difference in the level of oxygen is lower than the initial amount indicating a reduction in the oxygen levels. However, survival of the person also depends on factors like CO_2 build up in the room but since oxygen is still available, thus the person will be alive. **[1 Mark]**

29. Airplanes are equipped with emergency slides that are used when an aircraft lands on water. The emergency slide is rolled up and stored underneath the emergency door and is deployed when the emergency exit on an aircraft is opened. This enables people to exit the aircraft and slide out. The aircraft emergency slide must be very quickly inflated and expanded out. Sometimes, this inflation process is carried out by a chemical reaction. The chemical that is commonly used is the thermal decomposition of sodium azide (NaN_3). When the emergency lever is pulled in the aircraft for opening the emergency slide, an igniter compound ignites and the resulting heat degrades sodium azide to form nitrogen gas. This is the same phenomenon that is used in many car air bags.

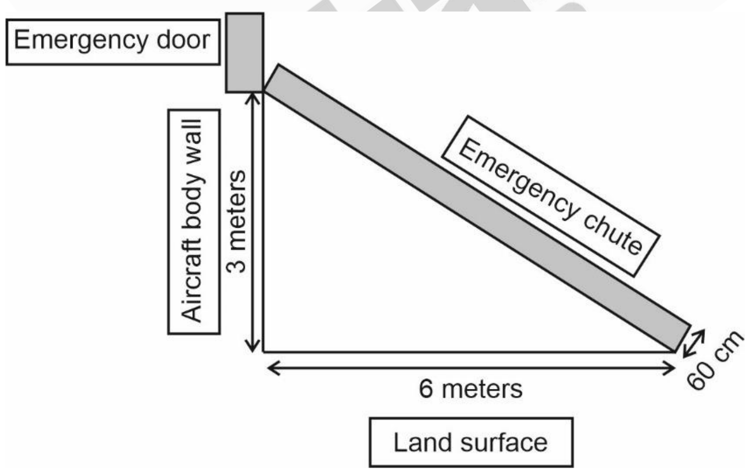
[13 marks]

(a) Dry Sodium azide in an inert atmosphere upon heating undergoes a decomposition reaction. One of the products is nitrogen gas. The other is a reactive metal. Write a balanced equation for the decomposition of sodium azide.

(b) What is the mass of nitrogen gas released when 100 grams of sodium azide is decomposed?

(c) The emergency chute connects the emergency exit with the land surface, as shown below. The width of the chute is 120 cm and the depth is 60 cm. What is the volume of gas that needs to be filled in the chute?

(d) To achieve the volume requirement, how much sodium azide should be carried on an aircraft with 6 emergency slides? The pressure inside the chute is 1.3 atm and assume the temperature to be 273 K.



High-energy nitrogen compounds are known for their energetic properties, often used as powerful explosives, propellants, or components in pyrotechnics. These compounds contain a significant amount of energy stored within their molecular structure due to the presence of multiple nitrogen atoms, often in a highly strained or unstable configuration. Some high energy nitrogen compounds like TNT (trinitrotoluene) are used as explosives. TNT ($C_7H_5N_3O_6$) breaks down to give only nitrogen gas, hydrogen gas, carbon monoxide gas and elemental solid carbon.

(e) Write a balanced equation for the decomposition of TNT.

(f) How many moles of total gas is released in the decomposition of 1 mole of TNT?

(g) If 140 grams of nitrogen gas was obtained from the complete decomposition of TNT, how much TNT was used?

Sol. (a) Balanced chemical equation for the thermal decomposition of sodium azide

$2NaN_3 \longrightarrow 3N_2 + 2Na$ **[1 Mark]**

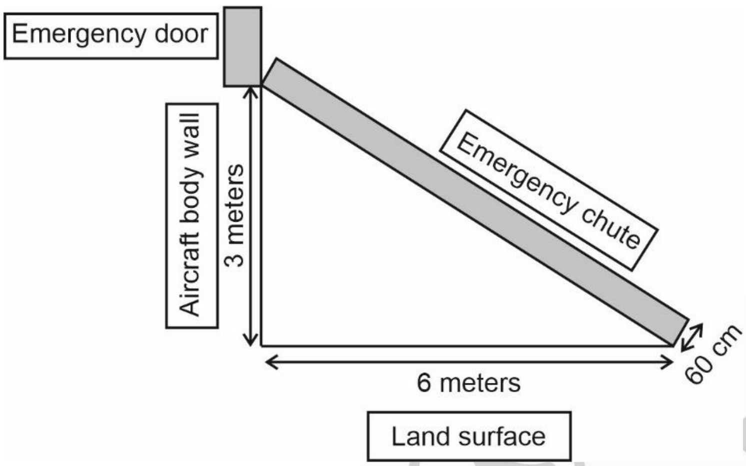
(b) $2NaN_3 \longrightarrow 3N_2 + 2Na$

65 g of sodium azide gives 42 g of nitrogen gas **[1 Mark]**

100 g of sodium azide will give = $\left(\frac{42}{65} \times 100\right)$ g of nitrogen gas

$\Rightarrow$ 64.62 g of nitrogen gas **[1 Mark]**

(c)



Width of the chute = 120 cm

Depth of the chute = 60 cm

For length of the chute using Pythagoras theorem,

Length = $\sqrt{6^2 + 3^2}$ m

= $\sqrt{36 + 9}$ m

$\Rightarrow \sqrt{45}$ m $\Rightarrow$ 6.71 m or 671 cm **[1 Mark]**

Volume of gas that needs to be filled in the chute will be

= 120 cm × 60 cm × 671 cm

= 4,831,200 cm^3

or

= 4831.2 L **[1 Mark]**

(d) PV = nRT

1.3 × 4831.2 = n × 0.0821 × 273

$n = \frac{6280.56}{22.4133}$

n = 280.22 moles/slide **[1 Mark]**

For 6 slides, number of moles of nitrogen gas required = 280.22 × 6 moles

$\Rightarrow$ 1681.32 moles **[1 Mark]**

So, number of moles of sodium azide required = 1120.86 moles **[1 Mark]**

Mass of sodium azide required = 1120.86 × 65 = 72856.33 g or 73kg **[1 Mark]**

(e) $2C_7H_5N_3O_{6(s)} \longrightarrow 12CO_{(g)} + 5H_{2(g)} + 3N_{2(g)} + 2C_{(s)}$ **[1 Mark]**

(f) 2 moles $C_7H_5N_3O_6$ (TNT) give 12 moles of CO gas + 5 moles of H_2 gas + 3 moles of N_2 gas **[0.5 Mark]**

2 moles of TNT give 20 moles of gases **[0.5 Mark]**

So, 1 mole of TNT will give 10 moles of gases

(g) 42 g nitrogen gas is obtained from 227 g of TNT **[1 Mark]**

140 g nitrogen gas will be obtained from = $\frac{227}{42} \times 140$ g of TNT

$\Rightarrow$ 756.67 g of TNT **[1 Mark]**

30. Manufacturing of H_2SO_4: The manufacturing of sulfuric acid (H_2SO_4) is an important process. Contact process is an industrial process that involves burning of elemental sulphur in presence of oxygen to sulfur dioxide (SO_2). The sulfur dioxide gas is then purified and cooled to remove impurities and moisture, resulting in a relatively pure SO_2 gas. The purified SO_2 gas is mixed with excess air and passed over a solid catalyst at 450°C and 1-2 atmospheric pressure to convert the SO_2 into sulfur trioxide (SO_3). Vanadium(V) oxide (V_2O_5) on a solid support is commonly used as the catalyst. The sulfur trioxide is then mixed with a carefully controlled amount of water to form sulfuric acid. This is a highly exothermic reaction and must be carefully controlled to prevent overheating and ensure the safety of the process. Sulfuric acid can be further concentrated by dissolving SO_3 in dilute H_2SO_4, thus steadily increasing the concentration of H_2SO_4. Ultimately, further dissolution of SO_3 into H_2SO_4 results in the formation of oleum ($H_2S_2O_7$) also known as fuming sulfuric acid.

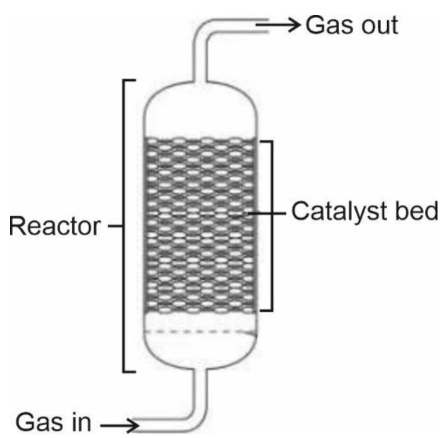
Concentrated H_2SO_4 is quite often used as a dehydrating agent. It reacts with glucose to give a brittle spongy black mass of carbon. The other organic matter that reacts strongly with concentrated H_2SO_4 include skin, cellulose, plant and animal matter.

Sulfide minerals are one of the major ores that are used for extraction of the different metals, Oxidation of these minerals like iron pyrite (FeS) leads to formation of H_2SO_4 and during rainy season it forms aqueous solution. The acidic nature of this solution is responsible for dissolution of metal ores and generates highly toxic stream.

[13 marks]

(a) Write balanced equations for the 4 major reactions in the Contact process leading to formation of oleum as described above.

(b) There are four steps in the process for manufacturing H_2SO_4. In a well optimized industrial process, yields for each step in the process can exceed 98%. Sahil starts a new industry using the contact process to manufacture H_2SO_4 in India. In the trial runs, he has optimization issues in the conversion of SO_2 to SO_3. He finds the purity of SO_3 gas is low and the chief contaminant is SO_2.



Choose all the correct steps that Sahil should take to optimize this process?

I. He should increase particle size of catalyst

II. He should increase the size of catalyst bed

III. He should increase the flow rate of SO_2

IV. He should increase the contact time/residence time of SO_2 with the catalyst bed

V. He should increase the concentration of oxygen in the air that he is using.

VI. He should increase the pressure of the gases in the reactor.

VII. He should increase the ratio of oxygen to SO_2

(c) After optimizing the process, Sahil finds that his overall yield did increase. His final yield for each reaction is given below. What is the amount of H_2SO_4 Sahil gets when he uses 1000 kg of pure sulfur in the process? And what is the overall percentage yield?

Step 1 yield = 95%

Step 2 yield = 88%

Step 3 yield = 99%

Write a balanced equation for what happens to glucose on contact with H_2SO_4.

(d) H_2SO_4 is a strong dibasic acid. Write a step wise equation to show its dissociation in water.

Sol. (a) (i) Production of SO_2

$S + O_2 \rightarrow SO_2$ **[1 Mark]**

(ii) Catalytic oxidation

$2SO_2 + O_2 \xrightarrow[450°C,\,1\text{–}2\text{ atm}]{V_2O_5} 2SO_3$ **[1 Mark]**

(iii) Mixing with water

$H_2O + SO_3 \longrightarrow H_2SO_4 + \text{Heat}$ **[1 Mark]**

(iv) Absorption of SO_3 in H_2SO_4

$SO_3 + H_2SO_4 \longrightarrow \underset{\text{(pyrosulphuric acid or oleum)}}{H_2S_2O_7}$ **[1 Mark]**

Note : Generally (iii) step is not used as SO_3 does not dissolve in water satisfactorily & give a lot of heat.

(b) $2SO_2 + O_2 \rightleftharpoons 2SO_3$ ΔH = –ve, i.e., exothermic

According to Le–Chatelier principle, the favourable condition for greater yield of SO_3 are

(i) Best result are obtained when SO_2 and O_2 are present in molecular proportion of 2 : 3

(ii) Low temperature

(iii) High pressure.

So, option II, IV, V, VI, VII should be correct. **[4 Marks]**

(c) Overall yield = $\left(\frac{95}{100} \times \frac{88}{100} \times \frac{99}{100}\right) \times 100$

= 82.76% **[1 Mark]**

Moles of $H_2SO_4 = \frac{1000}{32} \times 1000 \times \frac{95}{100} \times \frac{88}{100} \times \frac{99}{100} = 25863.75$ g **[1 Mark]**

Mass of H_2SO_4 = 25863.75 × 98

= 2534,647.5 g

= 2534.6475 kg **[1 Mark]**

(d) $H_2SO_4 + H_2O \rightleftharpoons HSO_4^- + H_3O^+$ **[1 Mark]**

$HSO_4^- + H_2O \rightleftharpoons SO_4^{-2} + H_3O^+$ **[1 Mark]**

31. Titrations are a common laboratory technique used in analytical chemistry to determine the concentration of a substance in a solution. They involve the controlled addition of a reagent (known as the titrant) to a sample (known as the analyte) until a chemical reaction is complete. In a titration it is critical to know the exact concentration of the titrant to determine the concentration of an analyte. In Sahil's industry, the Quality Control department decides to make 1.0 Litre of 0.05 M of H_2SO_4 solution for some titration activity and the work is assigned to John. To make this solution, John opens an old bottle of sulfuric acid marked as 98% [by mass] (Density 1.8 g/mL) and takes out 5 mL of the liquid into a beaker. After about 15 minutes he comes back and adds 1.0 Litre of water to the concentrated sulfuric acid to dilute it. Then he labels the beaker as 1 Litre 0.05 M H_2SO_4.

There are several mistakes that John has made in his preparation. Can you list out at least 3 mistakes that John made, why is it a mistake and what is the remedy for the mistake? **[4 Marks]**

Sol. Mistake:

1. Upon adding 1 L water to the 5 mL of H_2SO_4, the total volume of the solution will exceed the required amount i.e., Sahil needed only 1 L 0.05 M H_2SO_4. The amount (volume) of H_2O and H_2SO_4 should be calculated properly. **[1 Mark]**
2. Always acid should be added to the water to prevent the acid from getting splashed out and cause burns because this process is highly exothermic when we add water to an acid. **[1 Mark]**
3. The amount of H_2SO_4 is very small, so for precision it should be taken in a measuring cylinder and should not be kept exposed to the atmosphere for 15 min as it may react with the other chemicals and gases present in the atmosphere. **[1 Mark]**

- Solution of H_2SO_4 which Sahil want to prepare = 1 L of 0.05 M of H_2SO_4
- Given conditions, sulphuric acid bottle labelled as 98% (by mass) (density = 1.8 g/mL)

Mass of H_2SO_4 = 98 g

Molar mass of H_2SO_4 = 98 g

(m) mass of solution = 100 g

(ρ) density of solution = 1.8 g/mL

(V) volume of solution = $\frac{m}{\rho} = \frac{100}{1.8} = \frac{1000}{18}$

To find concentration of H_2SO_4, calculate molarity

$$M_2 = \frac{\text{given mass}}{\text{Molar mass}} \times \frac{1000}{V_{(\text{solution})}}$$

$$M_2 = \frac{98}{98} \times \frac{1000}{1000} \times 18 = 18\ M = 18\ mol/L$$

Now, using the formula

(want to prepare) $M_1V_1 = M_2V_2$ (Bottle)

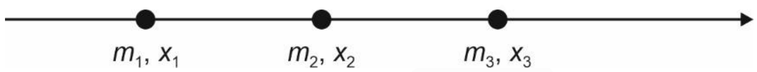
$1000 \times 0.05 = (18) \times V_2$

$$\frac{1000 \times 0.05}{18} = V_2$$

$\boxed{2.77 \text{ mL} = V_2}$ → This much volume of H_2SO_4 should be taken from bottle **[1 Mark]**

Water needed = 1000 – 2.78 = 997.22 mL

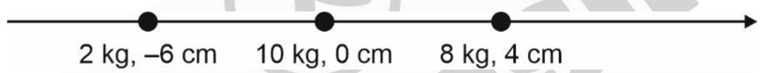
32. The concept of centre of masses plays an important role in analysing the dynamics of collection of particles and extended objects. The position of centre of mass (CM) represents the point where entire mass can be assumed to be concentrated. In a simple case as shown the position of centre of mass (X_{cm}) can be expressed as (*ms* and *xs* are the masses and positions of the respective particles). All positions are measured with respect to same reference point along the same line.



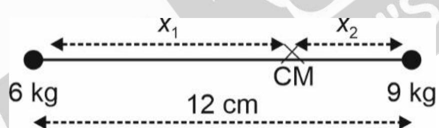
$$X_{CM} = \frac{m_1x_1 + m_2x_2 + m_3x_3 + ...}{m_1 + m_2 + m_3 + ...}$$

Based on the above information answer the following questions **[5 Marks]**

(a) The centre of mass of the system of three particles given in the figure is given by.

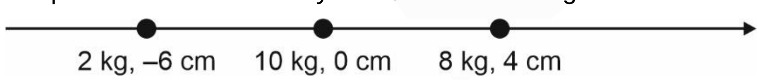


(b) Two particles of mass 6 kg and 9 kg are separated by 12 cm. If the centre of mass is at the origin then find x_1 and x_2.



(c) The 6 kg mass is displaced by 3 cm towards right. By what distance the 9 kg mass be moved in order that the position of CM of the system does not change.

Sol. (a) **[5 Marks]**

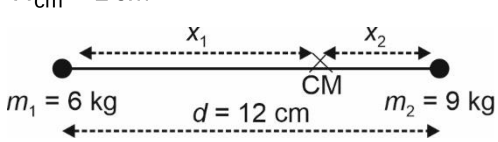


$$X_{cm} = \frac{m_1x_1 + m_2x_2 + m_3x_3}{m_1 + m_2 + m_3}$$

$$X_{cm} = \frac{2 \times (-6) + 10 \times 0 + 8 \times 4}{2 + 10 + 8}$$

$$X_{cm} = 1 \text{ cm}$$

(b)



$$x_1 = \frac{m_2}{m_1 + m_2}d = \frac{9}{9+6} \times 12 = 7.2 \text{ cm}$$

$$x_2 = \frac{m_1}{m_1 + m_2}d = \frac{6}{9+6} \times 12 = 4.8 \text{ cm}$$

(c) $x_{cm} = \dfrac{m_1x_1 + m_2x_2}{m_1 + m_2}$

$$\Delta x_{cm} = \frac{m_1\Delta x_1 + m_2\Delta x_2}{m_1 + m_2}$$

If $\Delta x_{cm} = 0$

$$m_1\Delta x_1 + m_2\Delta x_2 = 0$$

$$6 \times (+3) + 9\Delta x_2 = 0$$

$$\Delta x_2 = -2 \text{ cm}$$

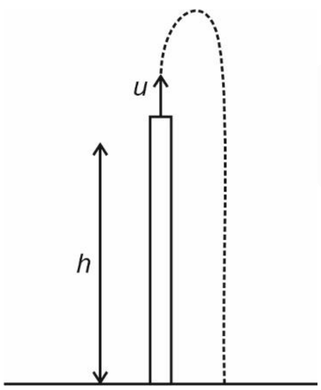
Hence 9 kg should be moved in left direction by 2 cm.

33. A ball is thrown up with a velocity u from a tall building of height h. The position of the ball from the ground level is measured with respect to time. The data is provided in the table below. **[5 Marks]**

Time (s)	Position (m)
1	114
3	106
5	50

From the given data find the initial value of u, height of building h and acceleration due to gravity g.

Sol. **[5 Marks]**



$$(114 - h) = u - \frac{g}{2} \quad \ldots(1)$$

$$(106 - h) = 3u - \frac{9}{2}g \quad \ldots(2)$$

$$-(h - 50) = 5u - \frac{25}{2}g \quad \ldots(3)$$

From equations (1) & (2)

$8 = 24 + 4g$ ...(4)

From equations (2) & (3)

$56 = -24 + 8g$ ...(5)

From equations (4) & (5)

$48 = 4g$

$$\boxed{g = 12 \text{ m/s}^2}$$

$u = 2g - 4$

$\boxed{u = 20\text{ m/s}}$

$h = 114 - 20 + 6$

$\boxed{h = 100\text{ m}}$

34. The knowledge of universal law of gravitation and the circular motion helps you to obtain the relation between the period and the radius of the circular orbit. Orbits of solar planets are nearly circular. The following table provides the mean radii of solar planets and the corresponding period. Plot an appropriate graph and hence calculate mass of the Sun. Showcase your skills of approximation techniques and short listing the data.

[10 Marks]

Given: Universal gravitational constant $G = 6.67 \times 10^{-11}$ Nm^2 kg^{-2}

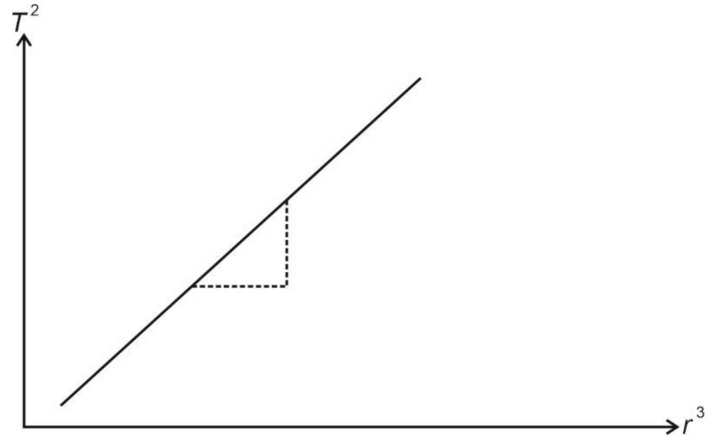
	Planet	Mean Radius in AU	Time Period in Earth Years
1	Mercury	0.39	0.24
2	Venus	0.72	0.62
3	Earth	1.00	1.00
4	Mars	1.52	1.88
5	Jupiter	5.20	11.90
6	Saturn	9.58	29.5
7	Uranus	19.22	84.00
8	Neptune	30.05	164.80

Sol. We know that for circular motion orbital motion time period of satellite is **[10 Marks]**

$$T = \frac{2\pi}{\sqrt{GM_S}} r^{3/2}$$ [M_s = mass of Sun]

$$\Rightarrow \quad T^2 = \frac{4\pi^2}{GM_S} r^3 \quad \ldots(i)$$

	r	***r*³**	***T***	***T*²**
1	0.39	0.06	0.24	0.08
2	0.72	0.37	0.62	0.38
3	1.00	1.00	1.00	1.00
4	1.52	3.51	1.88	3.53
5	5.20	140.61	11.90	141.61
6	9.58	879.28	29.50	870.25
7	19.22	7100.03	84.00	7056
8	30.55	28512.39	164.80	27159.04



Graph of T^2 versus r^3 must be straight line, hence from equation (i) slope = $\dfrac{4\pi^2}{GM_S}$

Slope can be calculated by taking difference of any two value of variable on *y*-axis divided by difference of corresponding values of *x*-axis variable.

$$\therefore \quad m_1 = \frac{1-0.08}{1-0.06} = 1,\ m_2 = \frac{141.61-1}{140.61-1} = 1.00,\ m_3 = \frac{3.53-0.38}{3.51-0.37} = 1.003$$

$$\text{Average slope} = \frac{m_1+m_2+m_3}{3} = 1.007\frac{(\text{Year})^2}{(AU)^3} = \frac{1.007\times(365\times24\times3600)^2}{\left(1.5\times10^{11}\right)^3}\frac{\text{s}^2}{\text{m}^3}$$

From equation (i) we can say that slope = $\dfrac{4\pi^2}{GM_S}$

$$M_S = \frac{4\pi^2}{G}\times\frac{1\times\left(1.5\times10^{11}\right)^3}{1.007\times(365\times24\times3600)^2}$$

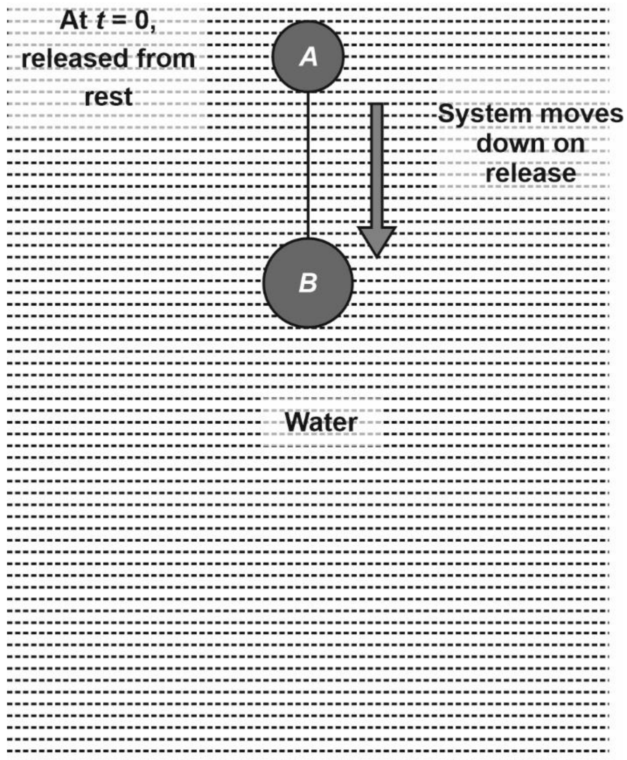
$$M_S = \frac{4\times(3.14)^2\times\left(1.5\times10^{11}\right)^3}{6.67\times10^{-11}\times1.007\times(365\times24\times3600)^2}$$

$$M_S = \frac{133.104\times10^{33}}{6.68\times10^{15}\times10^{-11}}$$

$$M_S = 19.92\times10^{29}$$

$$M_S \approx 1.99\times10^{30}\ \text{kg}$$

35. It is known that when a small spherical ball of radius *r* moves inside water, water exerts a resistive force F_r on the ball opposite to direction of motion, expressed as $F_r = (6\pi\times10^{-3})r\nu$ in SI units. Where ν is the speed of the ball. Two small solid balls *A* and *B* of radius *r* and 2*r* respectively, made up of same material, are tied at two ends of a massless thread and the system (Ball *B* hanging from ball *A* via thread) in just immersed in a pond filled with water as shown in the adjacent figure. At instant *t* = 0, the system is released from rest and allowed to fall vertically inside water. At $t = t_1$ s, the system attains a constant velocity. Compute



(a) Mass of ball A and ball B

(b) Tension in the thread at t = 0 s

(c) Acceleration of the system at t = 0 s

(d) Tension in the thread at $t >> t_1$ s

(e) Velocity of the system at $t >> t_1$ s

(Given: Density of material of balls = 2.5 g cc^{-1}, Density of water = 1 g cc^{-1}, Radius of ball A = 1 mm, g = 9.8 m s^{-2}) **[10 Marks]**

Sol. (a) $m_A = \rho_b\left(\frac{4}{3}\pi r^3\right)$ **[10 Marks]**

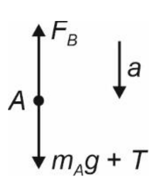
$$= \left(2.5\times10^3\right)\left(\frac{4}{3}\right)\left(\frac{22}{7}\right)\left(10^{-3}\right)^3$$

$$\boxed{m_A = 10.5\times10^{-6}\ \text{kg}}$$

$$m_B = \left(2.5\times10^3\right)\left(\frac{4}{3}\right)\left(\frac{22}{7}\right)8\times10^{-9}$$

$$\boxed{m_B = 83.8\times10^{-6}\ \text{kg}}$$

(b) At t = 0



$$m_A a = m_A g + T - F_B$$

$$T = m_A(a - g) + F_B$$

$$= m_A a - m_A g + \frac{\rho_w}{\rho_b} m_A g$$

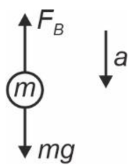
$$= m_A\left[a - g + \frac{\rho_w}{\rho_b} g\right]$$

$$= m_A\left[5.88 - \frac{1.5}{2.5} \times 9.8\right]$$

$$T = m_A[0]$$

$$\boxed{T = 0}$$

(c) At $t = 0$



$$ma = mg - F_B$$

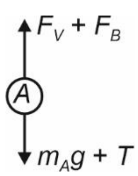
$$a = g\left[1 - \frac{\rho_w}{\rho_b}\right]$$

$$a = g\left[1 - \frac{1}{2.5}\right]$$

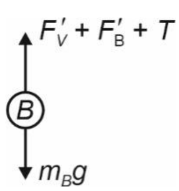
$$a = (9.8)\left(\frac{1.5}{2.5}\right)$$

$$\boxed{a = 5.88 \text{ m/s}^2}$$

(d) $t >> t_1$



$$\boxed{F_V + F_B = m_A g + T}$$



$$F_V' + F_V$$

$$F_B' + 8F_B$$

$$F_V' + F_B' + T = m_B g$$

$$2F_V + 8F_B + T = m_B g$$

$$2(m_A g + T - F_B) + 8F_B + T = m_B g$$

$$3T = m_B g - 2m_A g - 6F_B$$

$$T = \frac{(m_B - 2m_A)g}{3} - 2F_B$$

$$T = \frac{6m_A g}{3} - 2F_B \qquad [\because\ m_B = 8m_A]$$

$$T = 2\left[m_A g - \frac{\rho_w g m_A}{\rho_b}\right]$$

$$T = 2m_A g\left[1 - \frac{\rho_w}{\rho_b}\right]$$

$$T = (2)\left(10.5\times10^{-6}\right)(9.8)\left(\frac{1.5}{2.5}\right)$$

$$\boxed{T = 123.48\times10^{-6}\ \text{N}}$$

(e) $F_V = m_A g + T - F_B$

$$6\pi\times10^{-3} rv = 10.5\times10^{-6}\times9.8 + 123.48\times10^{-6} - \frac{\rho_L m_A g}{\rho_b}$$

$$v = \frac{226.38\times10^{-6} - 41.16\times10^{-6}}{18.85\times10^{-6}}$$

$$= \frac{185.22}{18.85}$$

$$\boxed{v = 9.8\ \text{m/s}}$$

❑ ❑ ❑