# Indian National Junior Science Olympiad (INJSO) – 2024

## Indian Association of Physics Teachers (IAPT)

## QUESTION PAPER / SOLUTION

**Roll Number:** ☐☐☐☐–☐☐☐☐–☐☐☐☐ **Date:** 3rd February 2024

**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.**
   i. For each question in this section, **only one** of the four options is a correct answer.
   ii. For each question, a correct answer will earn 3 marks, a wrong answer will earn (–1) mark, and an un-attempted question will earn 0 marks.
   iii. If you mark more than one option, it would be treated as a wrong answer.
5) **Section II contains 9 questions worth 5 marks each. There is no negative marking.**
   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 11 questions.**
   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 | $g \approx 10$ 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 |
| Permitivity of free space | $\epsilon_0 \approx 8.854 \times 10^{-12}$ C 2N$^{-1}$m$^{-2}$ |
| Radius of the Earth | $R_\oplus \approx 6400$ km |
| Radius of the Moon | $R_{moon} \approx 1700$ km |

| Element | Atomic Number | Atomic Mass | | Element | Atomic Number | Atomic Mass |
|---|---|---|---|---|---|---|
| H | 1 | 1.0 | | Cl | 17 | 35.5 |
| C | 6 | 12.0 | | K | 19 | 39.0 |
| N | 7 | 14.0 | | Ca | 20 | 40.0 |
| O | 8 | 16.0 | | Fe | 26 | 56.0 |
| Na | 11 | 23.0 | | Zn | 30 | 65.4 |
| Al | 13 | 27.0 | | Ag | 47 | 107.9 |
| S | 16 | 32.0 | | Au | 79 | 197.0 |

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## Section – I (consolidated Answer key is provided in the last page)

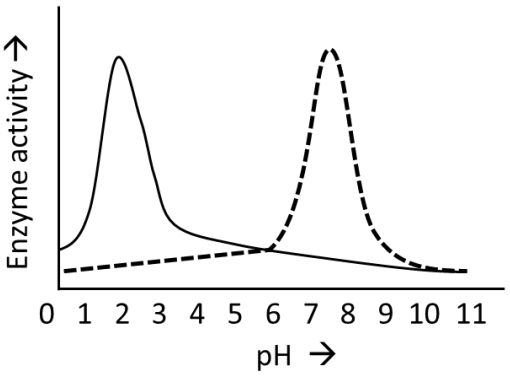
1. From the characteristics of each of the organisms provided in the table below, identify the four organisms, namely P, Q, R and S - from one of the options:

| | 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**
Reason – Snake and Earthworm have bilateral symmetry among which only snake is vertebrate (notochord). Sponge is asymmetric while Jellyfish has radial symmetric with Diploblastic germ layer.

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.



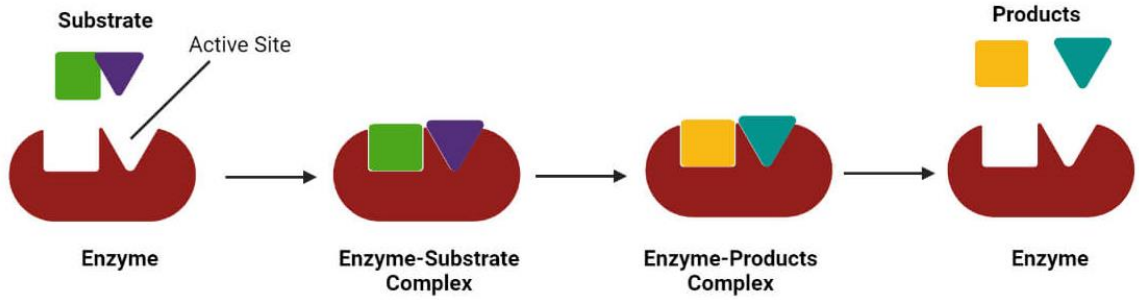

A. P – Mouth and Q – Stomach
B. P – Stomach and Q – Duodenum
C. P – Duodenum and Q – Stomach
D. P – Stomach and Q – Ileum

**Answer: D**

Reason – Proteolytic enzymes are synthesized as inactive enzymes (pro-form) and cleaved in the acidic stomach where their activity is maximum (optimal) at Acidic pH of the stomach ~2.3. Similarly other enzymes released in the intestine (as acid gets neutralized by Bile) get activated in the Ileum/Intestine where the pH becomes slightly alkaline

| |
|---|
| The intraluminal pH is rapidly changed from highly acid in the stomach to about pH 6 in the duodenum. The pH gradually increases in the small intestine from pH 6 to about pH 7.4 in the terminal ileum. The pH drops to 5.7 in the caecum, but again gradually increases, reaching pH 6.7 in the rectum. |

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.



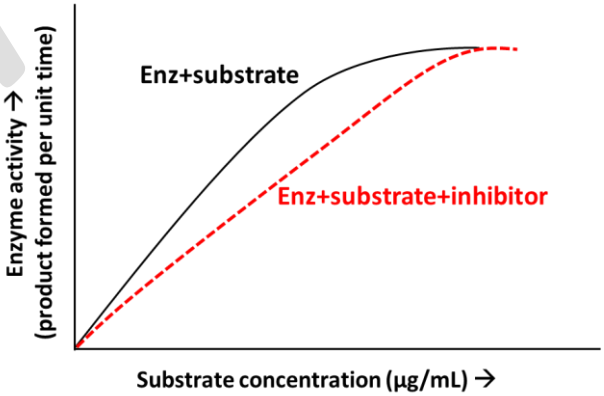

There are some molecules termed as enzyme inhibitors which bind to an enzyme and inhibit its activity or prevent them from working in a normal manner. It is important to note that both the substrate and inhibitor binding to the enzyme, are reversible reactions. The important types of inhibitors classified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

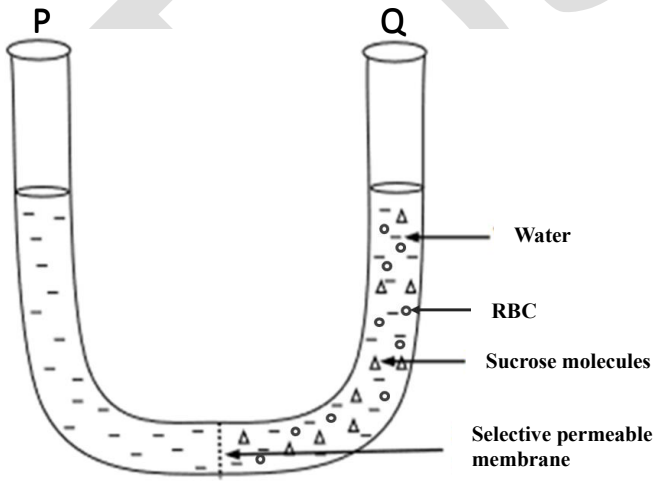



Based on the above pattern of activity of the two reactions, which of the following best concludes the result.

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

**Answer: B**
Since the substrate and the inhibitor compete for the same exact site on the enzyme (active site), at low conc. of substrate the inhibitor is effective in occupying the active site more often, leading to decrease in enzyme activity. However, as we keep increasing substrate concentration, being a reversible reaction, it outcompetes inhibitor concentration and finally at a very high substrate conc. leads to restoring the level of enzyme activity (as it was without inhibitor). Hence because this inhibitor binds to the active site, this is an example of competitive inhibition.

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 10mL 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**
Water will dialyze from low conc. to high conc. of solute increasing the level in Q, thereby diluting the solute which will be relatively hypotonic for the RBCs and therefore water will move into the RBCs (by osmosis) thereby increasing their 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**
It is known that at the synapse – the signal is transmitted by release of vesicles (packets of chemical information) from the neuron to the motor neuron to the effector cell – and that's what causes unidirectionality of the process. Otherwise electrical signals can flow in both directions from the axon/body to the dendrites.

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.

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**Answer: D**

Cost of 2-carat diamond = 2 x 65000 = 1,10,000 INR

Mass of gold in the ornament = (18/24) (15g – 0.4g) = 10.95 g

Cost of gold = 10.95 x 5560 = 60,882 INR

Major cost of the ornament is for the diamond.

Atomic wt of gold = 197 g/mol

No. of atoms of gold = (10.95/197) x 6.022 x $10^{23}$ = 0.335 x $10^{23}$

Cost of a single atom of gold = 60882/(0.335 x $10^{23}$) = 1,81,737 x $10^{-23}$ INR

Mol wt of carbon = 12 g/mol

No. of atoms of carbon = (0.4/12) x 6.022 x $10^{23}$ = 0.200 x $10^{23}$

Cost of a single atom of carbon = 1,10,0000/ (0.200 x $10^{23}$) = 5,50,000 x $10^{-23}$ INR

Mass of copper in the ornament = (6/24) x 14.6 g = 3.65 g

Mol wt of Cu = 63.5 g/mol

No. of atoms of Cu = 3.65/63.5 x 6.022 x $10^{23}$ = 0.346 x $10^{23}$

7. India has been implementing an Ethanol Blending Program (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**

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

$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$

No of moles of ethanol in 20 g = 20/46 = 0.435

No of moles of petrol in 80 g = 80/114 = 0.712

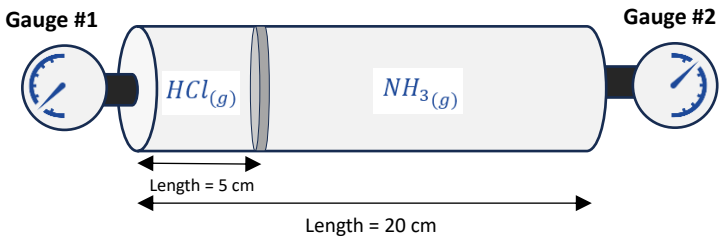
No of moles of $CO_2$ produced by 100g of E20 = (0.435*2) + (0.712*8) = 6.484 moles

No of moles of $CO_2$ produced by 100 g of petrol = 100/114*8 = 7.018 moles

Percentage change in $CO_2$ emission = (7.018 – 6.484)/7.018 *100 = 7.6%

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

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



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 25ºC, 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 25ºC.

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**

No of moles of HCl = 4/36.5 = 0.110

No of moles of $NH_3$ = 4/17 = 0.235

No of moles of ammonia remaining = 0.235-0.110 = 0.125 moles

Pressure in gauge 1 = 0.110 x 8.314 x 298/[(3.14 x 0.05 x 0.05 x 0.050) x 1.013 x $10^5$] = 6.85 atm

Pressure of gauge 2 after the process

= (0.125 x 8.314 x 298)/[(3.14 x 0.05 x 0.05 x 0.2) x 1.013 x $10^5$] = 1.95 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**

**Water flowing over rocky areas contain very little dissolved minerals, because the rate of dissolution is very low (it is low solubility minerals in rocks which keeps them stable over years inspite of annual rains). Carbonic acid in the rain is a weak acid - and the slightly increased solubility of rock minerals is still slow compared to municipal waste.**

**The sand was dumped a decade ago, all the free ions would be expected to be washed away over time. Municipal waste typically contains a variety of substances, including organic matter, dissolved ions from household waste, pieces of metal etc..**

**In this waste, decomposition keeps happening over long time resulting in small soluble organic ions, sulphates, nitrates, chlorides, alkali metal ions, etc. Water can rapidly leach a variety of substances from municipal waste, including organic matter, metallic compounds, and minerals formed. This can result in higher concentrations of ions in the leachate, leading to higher electrical conductivity.**

**The main minerals in concrete are relatively insoluble under typical environmental conditions, which limits the rate at which they can dissolve into water (that is why concrete buildings can stay for years).**

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 $E^o$ (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)

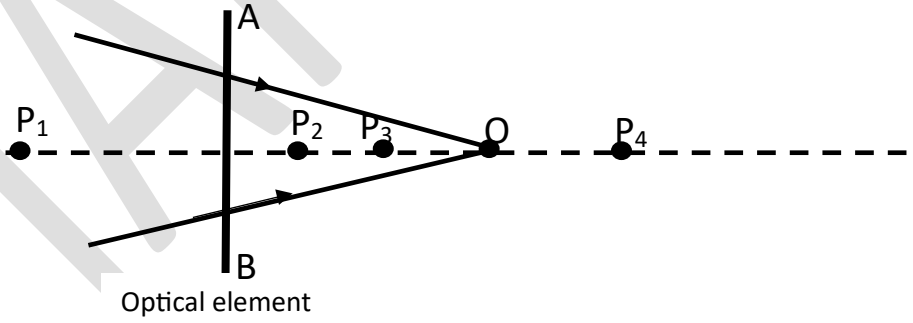
B. $Fe^{2+}$(aq) becomes Fe(s) when paired to Ag(s) and Cu(s); and Fe(s) becomes $Fe^{2+}$ when paired with $Zn^{2+}$(aq)

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**

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.




| 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**
Convex lens will increase the convergence and hence the point shift toward the optical element. Higher the focal length, convergence is lesser. Hence shorter focal length will converge to nearer point ($P_2$) and longer focal length to point ($P_3$). Concave lens being divergent lens will shift the point of convergence further. Plane mirror will form a real image in front of it.

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.

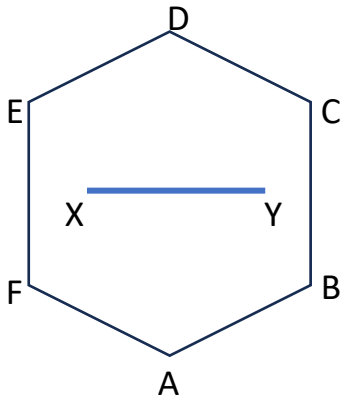
**Answer: C**
Work done by gravity $= mgh$.
Work done by air resistance be $W$.
Change in kinetic energy is

$$\frac{1}{2}mv^2 - 0 = \frac{1}{2}m\left(1.2\sqrt{gh}\right)^2 = \frac{1}{2}m1.44\text{gh} = 0.72\text{gh}.$$

Total work done = Change in kinetic energy

$$mgh + W = 0.72gh.$$
$$W = 0.72gh - mgh = -0.28mgh$$

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

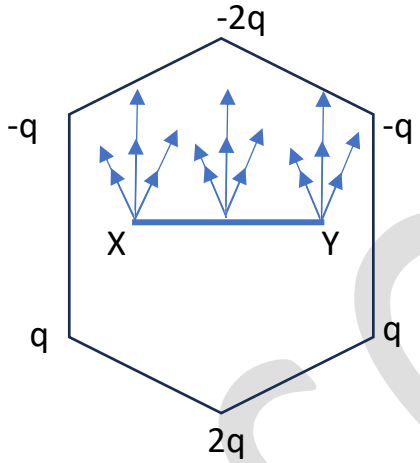



A. $+q, -q, -2q, +2q$, +q, –q
B. –q, –q, –2q, +q, +q, +2q
C. +2q, +q, –q, –2q, –q, +q
D. +q, –2q, –q, +q, +2q, +q

**Answer: C**

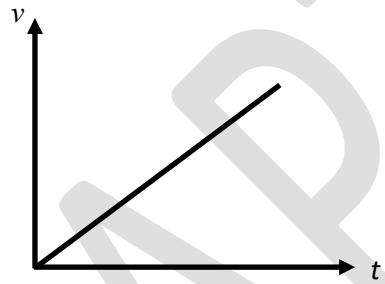
The charge configuration as in option c is shown in figure below.

The direction of forces on 1 nC at any position is upward.

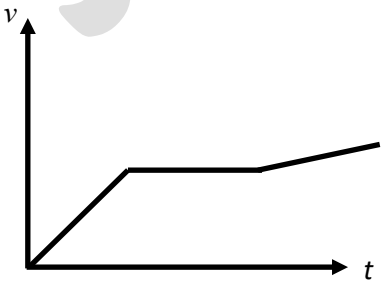



14. A bar magnet is let free to fall from some height staring from rest through a hollow conducting cylinder. Then identify speed-time graph ($v$ - $t$ graph) that best explains its motion.

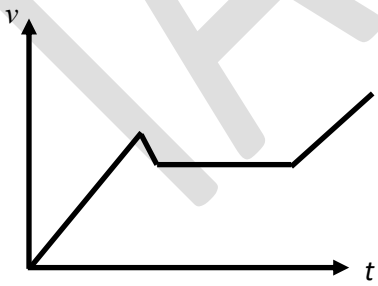
A.



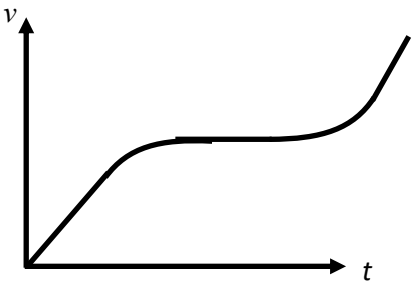

B.




C.



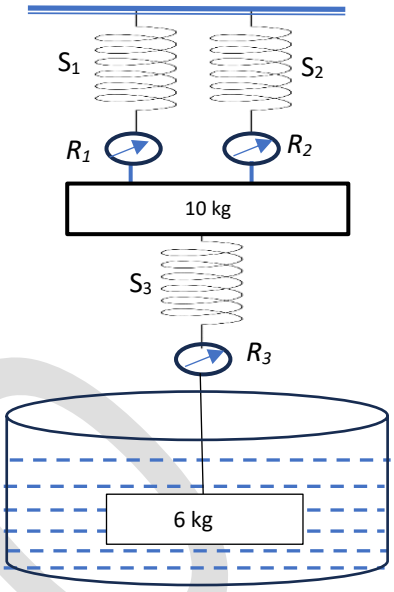

D.




**Answer: D**

Before entering the cylinder, it is like a free-falling body, so v-t would be straight line. Then acceleration decreases due to eddy current, and velocity attains terminal velocity. After coming out of the tube it again behaves like a free-falling body.

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**

$F_1 = F_2 = F$ (say)

For vertical equilibrium of blocks

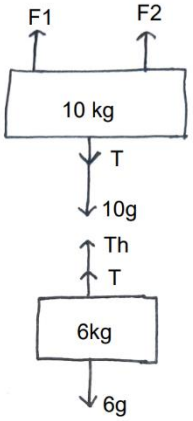
$$T + 10g - 2F = 0 \quad \ldots (1)$$

$$6g - T - Th = 0 \quad \ldots (2)$$

The upthrust is $Th$ = Volume of 6 kg block × density of water × $g$

= (6/density of block) × density of water × $g$

$= 6\,(1/10)g = 0.6g$




Hence, from eq. (2)

$$6g - T - 0.6g = 0$$

i.e. $$5.4g - T = 0 \quad \ldots (3)$$

Solving eqns. (1) and (3)

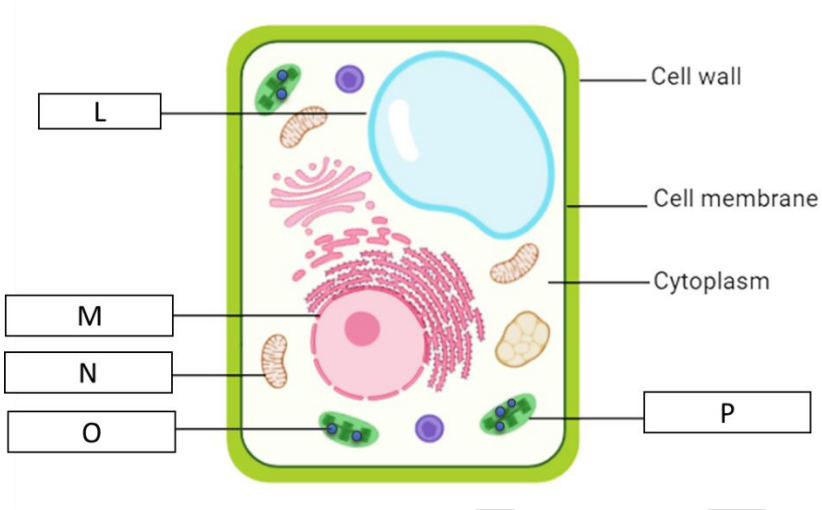
$$F = 7.7g \quad \text{and} \quad T = 5.4g$$

Hence $R_1 = R_2 = 7.7$ kg-wt, $R_3 = 5.4$ kg-wt

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## Section - II

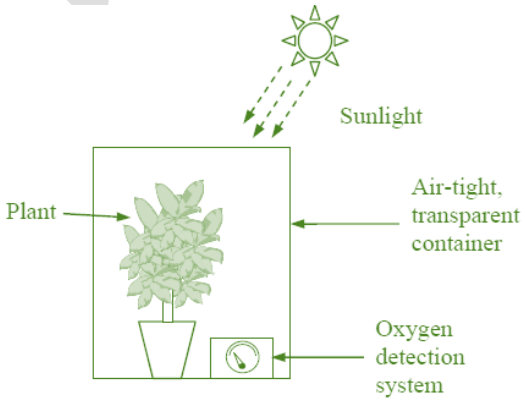
16. The figure below shows the ultrastructural details of a plant cell. Some parts are labelled as L, M, N, O and P. Identify the correct statement(s) w.r.t to these labels.




A. O is a 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 only**
N is mitochondria which is the powerhouse of the cell as it makes ATP via aerobic respiration. A is untrue because storage in plants is Starch and NOT glycogen.

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 & C**

A controls for the role of light in oxygen evolution by the plant while C controls for the plant itself being responsible for oxygen evolution. In B. by making an open system, oxygen from the environment will also be measured thereby making the control irrelevant. Also in D although $CO_2$ will lead to more $O_2$ release, it is NOT a control for requirement of light for photosynthesis (as the original aim of the expt) – rather an added experiment that proves that plants require CO2 for carbon fixation and a result of that is $O_2$ evolution.

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 and D**

Radha can be a carrier since the mutation is on her X and so although Ramesh is normal (with one non-faulty X), their girl-Child can become a carrier which can then pass on the disease to the grandchildren. Also Ramesh's daughter HAS to be a carrier as that is the only way one of the grandchildren can get the disease. Ramesh's mother can be a carrier too but ends up passing the normal X to Ramesh- hence he doesn't have the disease.

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]

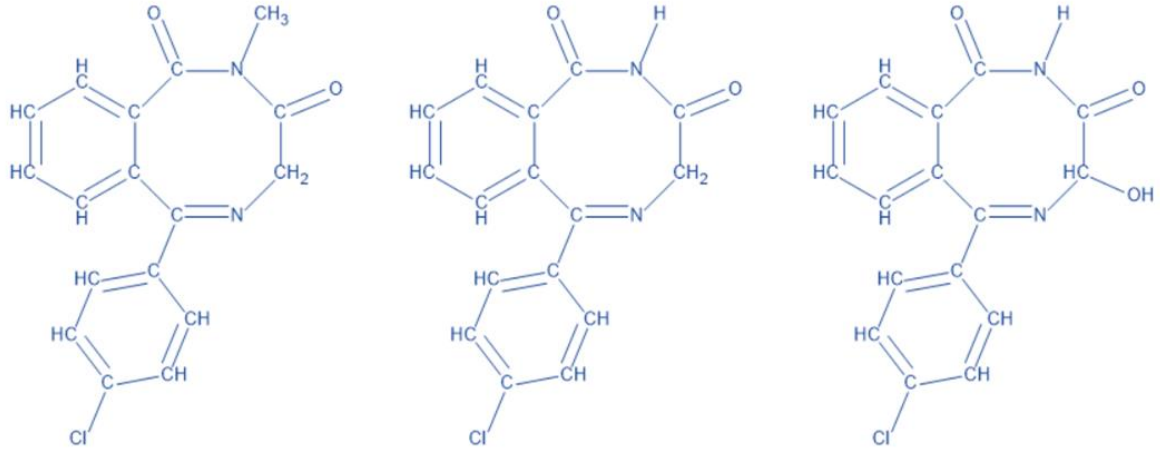
A. ~ 0.25 mole %
B. ~ 8400 ppm
C. ~ 0.14 Molar
D. ~ 4 % weight

**Answer: A, B and C**

Molarity of acetic acid solution = (0.5 M * 14 mL)/50 mL = 0.14 M
Mass of acetic acid = 0.14 M * 0.05 L * 60 g/mol = 0.42 g
Mass of solution assuming the density of solution to be 1 g/mL = 50 g
Ppm = (0.42/50) * 1000000 = 8400 ppm

Mole% = (0.14/55.5)*100 = 0.25%

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 and C**

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 ºC has a pH of 7. On a hot summer day when the temperature was 40 ºC, 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 for 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 and D**

pH = 7

$[H^+] = 10^{-7}$

pH = 6.77

$[H^+] = 10^{-6.77}$

Percentage Change in hydrogen ion concentration = $[10^{-6.77} - 10^{-7}] * 100 / 10^{-7} = 70\%$

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 $P_2$

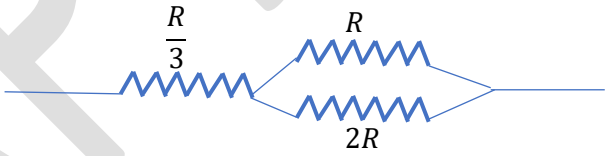
B. $P_3$ is lesser than $P_2$

C. $P_2$ is greater than $P_1$

D. $P_1$ is greater than $P_3$

**Answer: B, C & D**

For equivalent resistance the connection must be as shown in the figure below.




If the current in $\frac{R}{3}$ is $I$, then current in $R$ is $\frac{2I}{3}$ and in $2R$ it is $\frac{I}{3}$. Power consumption in each of the resistance is

$$P_1 = \frac{R}{3}I^2$$

$$P_2 = R\frac{4I^2}{9}$$

$$P_3 = 2R\frac{I^2}{9}$$

Thus $P_2 > P_1 > P_3$

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**

The mass of hollow ($m_1$) is less than solid sphere ($m_2$). Since heat supplied is same, the temperature attained is different.

$$m_1 S t_1 = m_2 S t_2$$

And hence $t_1 > t_2$. That is temperature of hollow sphere is more than that of solid sphere.

The volume expansion is higher if the temperature is more. Hence Hollow sphere will expand more.

D is correct since expansion will depend on temperature of the bodies.

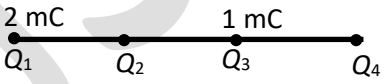
24. Like charges repel, and unlike charges attract. Magnitude of force ($F$) between two stationary point charges $Q_1$ and $Q_2$ separated by a distance r is expressed as $F = \frac{KQ_1Q_2}{r^2}$ (Coulomb's Law) where $K$ is a positive constant. Consider four-point charges $Q_1$, $Q_2$, $Q_3$ and $Q_4$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

A. $Q_2 = +\frac{44}{9}\ mc$ and $Q_4 = +4\ mc$

B. $Q_2 = -\frac{44}{9}\ mc$ and $Q_4 = +4\ mc$

C. $Q_2 = +\frac{44}{9}\ mc$ and $Q_4 = -4\ mc$

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




**Answer: B & D or Only B**

Let the distance between two consecutive charges = X

For equilibrium of $Q_2$

$\frac{K}{X^2}\left(\frac{2Q_2}{1} - \frac{1Q_2}{1} - \frac{Q_2Q_4}{4}\right) = 0$ and $\frac{KQ_2}{X^2}\left(1 - \frac{Q_4}{4}\right) = 0$ and $Q_4 = 4mC$

For equilibrium of $Q_4$

$\frac{K}{X^2}\left(\frac{2Q_4}{9} + \frac{Q_2Q_4}{4} + \frac{1Q_4}{1}\right) = 0$ and $\frac{KQ_4}{X^2}\left(\frac{2}{9} + \frac{Q_2}{4} + 1\right) = 0$

i.e. $\frac{2}{9} + \frac{Q_2}{4} + 1 = 0$ and $\frac{Q_2}{4} = -\frac{11}{9}$ or $Q_2 = -\frac{44}{9}mC$

Further, if $Q_2 = 0$ forces on $Q_4$ due to $Q_1$ and $Q_3$ both will be attractive and in same direction. Hence the resultant force on $Q_4$ will never be zero. Hence option (D) is true.

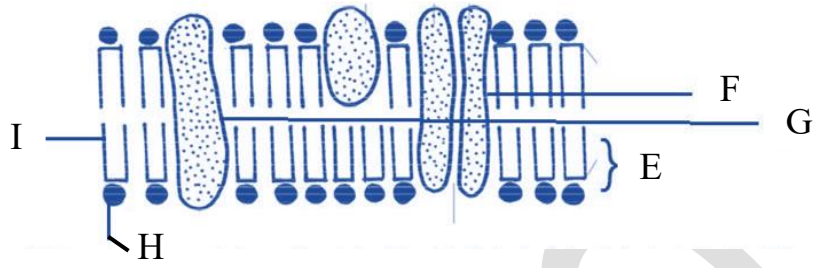
## Section - III

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 a 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?

**ANSWER: I, III & IV are true.**

**Reason** – simple nature of the proteins mentioned as a function of their hydrophobic and functional properties. **(0.5 mark each – total 1.5 marks)**

**(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)**

A. 

B. 

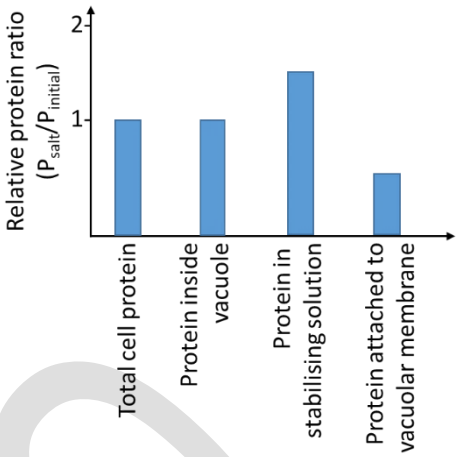
C. 

D. 

**Answer: A**

Reason: because the membrane ultrastructure does not change, just the inside and outside facing topologies change. **(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. To 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

A. The decrease is due to external proteins that dissociate into the stabilizing solution.
B. The increase is due to external proteins that dissociate into the stabilizing solution.
C. The decrease is due to dissociation of transmembrane proteins into the vacuole.
D. The increase is due to dissociation of internal proteins into the stabilizing solution.

**(1.5 marks)**

**Answer: D**

Reason – as the inside of the membrane now becomes the outside of the vesicle and the weakly associated proteins from that side (previously intracellular proteins) will now dissociate and leach out into the stabilizing solution. **(1.5 marks)**

26. **(a)** The growth and development of a 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 |

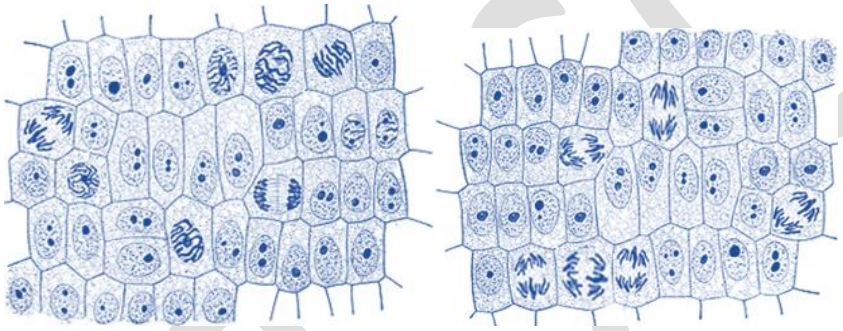
Put the events into the correct sequence from Y onwards (in the table provided in the answer sheet).

**Answer:**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Y** | ***W*** | ***V*** | ***T*** | ***S*** | ***X*** | ***U*** |

This is the simple progression of events that lead to fertilization and development.
(0.5 marks for each consecutive right answer, total 3 marks, if chain breaks, then only marks upto where the chain is intact)

(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**

A. The drug acts like an enhancer of cell division
B. The drug acts to stall the cells in anaphase
C. The drug acts to accelerate metaphase in the cells
D. The drug acts like an enhancer of chromosome disruption

**Answer: B**
Reason: No of mitotic cells remain the same – so its not enhancing cell division, more number of Anaphase cells are visible; and because Anaphase comes after metaphase – cells are getting slowed down or blocked/stalled in Anaphase, which are not proceeding to telophase; and hence the number of those cells are over-represented. If the drug was to accelerate metaphase, then lesser number of metaphase cells would be visible at any given point of time, as the cell cycle will be shorter, and overall proportions of Anaphase and Telophase cells will be larger among the mitotically active cells (which is clearly NOT the case). The multiple chromosomes of anaphase do not happen due to chromosome disruption – the morphology of V shaped chromosomes zipping apart is HIGHLY typical of anaphase.

**(1 marks)**

**(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 |

**Answer:**

| Chromosome number | Chromosome status | Cell cycle phase |
|---|---|---|
| D | R | G2 |
| D | R | Meiotic metaphase I |
| D | R | Mitotic metaphase |
| H | R | Meiotic interkinesis |
| D | N/R | G1 |

**(0.5 marks each – total 5 marks)**

**(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 to 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).

**Answer:**

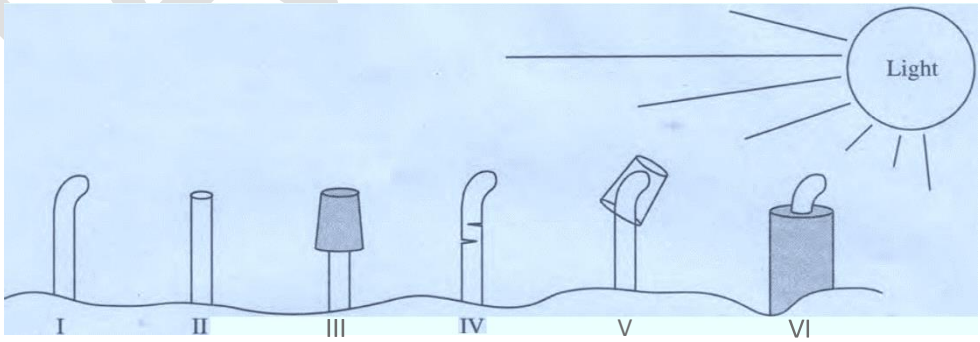
| Status of DNA | Phase of cell cycle |
|---|---|
| Teams when "in-a-tie" at a tug of war | Metaphase |
| Transition from a bowl of cooked noodles to a dehydrated pack | Prophase |
| Serving equal portions of a cake to their two children | Anaphase |
| Noodles in its most relaxed form –cooked noodles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

These can be molecularly equated to the status of DNA chromosome compaction in each of these phases of mitosis. In PCR primers anneal to allow DNA pol (Taq Pol) to copy the template DNA and that's what happens in S phase. **(1 marks each, total 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)**

A. Growth is promoted by cutting off the tip
B. The tip is the site of auxin synthesis.
C. The tip is necessary for the response to light.
D. There is a range of responses to a single treatment.

**Answer: Only C (1.5 marks). If additional options are marked then zero marks**

**(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)**

A. I, II and III
B. I, II and IV
C. II, III and IV
D. IV, V and VI

**Answer: Only B (1.5 marks) If additional options are marked then zero marks**

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

A. the tip plays a role in sensing the light
B. the base plays a role in sensing the light
C. confinement of the tip inhibits the response to light
D. confinement of the base facilitates the response to light

**Answer: A (1.5 marks) If additional options are marked then zero marks**

**(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)**

A. measure the distance between marks made on the seedling after it has bent.
B. count the number of cells visible in a cross section of the coleoptile.
C. compare the length of cells on the sides of the stem towards, and away from the light.
D. repeat the experiment using light of a different wavelength

**Answer: C (1.5 marks) If additional options are marked then zero 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)**

**Answer:**

(I) The volume of the room = 10 X 10 x 10 ft = 1000 cubic ft. **(0.5 marks)**

(II) If in 1 cubic ft. 27 litre of air is present at normal temperature and pressure,
Total volume of air in the room= 27 X 1000 = 27,000 litres of air. **(0.5 marks)**

(III) Total volume of oxygen present in 27,000 litres of air at the rate of 21% will be
27000 X 21/ 100 = 5670 **or expressed in moles; 253.12 moles or in mass; 8100g (8.1 Kg) (1 mark)**

(IV) If a man at rest/ sleeping consumes 250 ml/cc of oxygen, calculate the total amount of oxygen consumed by man sleeping in the room for 8 hours will be:
250 X 60 (minutes/hour) X 8 (hours) = 120,000mililitres or (120 litres) **or expressed in moles; 5.36 moles or in mass; 171.42g (0.171 Kg) (1 mark)**

(V) Initial amount of oxygen in air in the room = 5670 litres
Amount of oxygen after the consumption by man in 8 hours = 120 litres **(1 mark)**
So, still 5670-120 = 5550 litres of oxygen is present. **or expressed in moles; 247.76 moles or in mass; 7928.8g (7.92 Kg) (1 mark)**

(VI) Man will be very much alive. **(1 mark)**

Marks should be allotted to the steps as well, even if the previous answer is wrong and the current answer as per the values and correct formulae taken are accurate. A previous error cannot be carried forward in the deduction of marks.

If formula is correct and answer wrong – 0.5 marks.

If formula is wrong and answer is correct – 0 marks.

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.

**Answer:** $2NaN_3$ (s) → 2Na (s) + $3N_2$ (g) or $2NaN_3$ → 2Na + $3N_2$

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

**Answer:**

Molecular weight of sodium azide = 23 + 3(14) = 65 g/mol

Number of moles of sodium azide = 100 g/65 g/mol = 1.538 mol

Number of moles of nitrogen gas released = 3/2*1.538 mol = 2.307 mol

Molecular weight of nitrogen gas = 28 g/mol

Mass of nitrogen gas released = 2.307 * 28 = 64.596 g

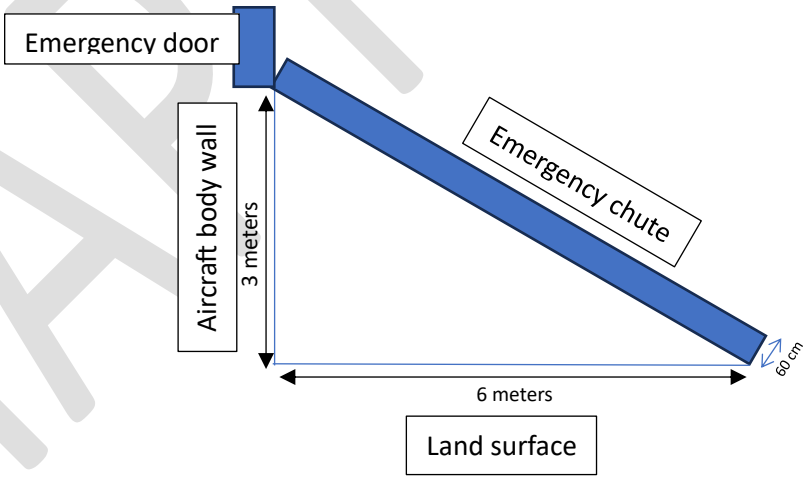
c) The emergency chute connects the emergency exit with the land surface, as shown below. The width of the chute is 120 cm and the depth is 60 cm. What is the volume of gas that needs to be filled in the chute?

**Answer:**

Length of the chute = $\sqrt{(6^2 + 3^2)}$ = 6.708 m = 670.8 cm

Volume of the chute = 120 * 60 * 670.8 = 4829760 $cm^3$ = 4.83 $m^3$

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 273K.




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.

**Answer:**
1 atm = $1.013 * 10^5$ $Nm^{-2}$
PV = nRT
$(1.3 \text{ atm} * 1.013*10^5) * (6 * 4.83) = n * 8.314 * 273$
n = 1681.43 moles of nitrogen gas
Number of moles of sodium azide = 2/3*1681.43 = 1120.95 moles
Mass of sodium azide required = 1120.95 mol * 65 g/mol= 72861.92 g = 72.862 kg

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

**Answer:** $2C_7H_5N_3O_6$ (s) → 2C (s) + 12CO (g) + $3N_2$(g) + $5H_2$ (g)

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

**Answer:** 10 moles of gas

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

**Answer:**
Mass of one mole of nitrogen gas = 28 g
Number of moles of nitrogen gas = 140 g / 28 g/mol = 5 mol
Number of moles of TNT = 2/3*5 = 3.333 moles
Mass of TNT used = 3.333 * 227 g/mol = 756.591 g

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 450ºC 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.

**Answer:**

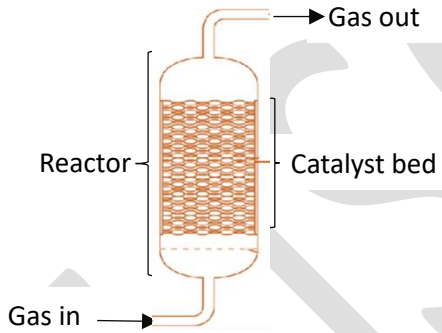
$S(s) + O_2(g) \rightarrow SO_2(g)$

$2SO_2(g) + O_2(g) \xrightarrow{V_2O_5,\ 450\ ^\circ C,\ 1\text{-}2\ atm} 2SO_3(g)$

$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$

$H_2SO_4(aq) + SO_3(g) \rightarrow H_2S_2O_7(aq)$

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 $SO_2$

**Answer:**

He should increase the size of catalyst bed
He should increase the contact time/residence time of $SO_2$ with the catalyst bed
He should increase the pressure of the gases in the reactor.
He should increase the concentration of oxygen in the air that he is using.
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 $H_2SO_4$.

**Answer:**

Molecular weight of sulfur = 32 g/mol
Number of moles of sulfur = 1000 * 1000 g / 32 g/mol = 31250 mol
Expected Number of moles of sulfur dioxide = 31250 mol
Step 1 yield = 95%
Actual number of moles of sulfur dioxide obtained = 95/100*31250 = 29687.5 mol
Expected number of moles of sulfur trioxide = 29687.5 mol
Actual number of moles of sulfur trioxide = 88/100 * 29687.5 = 26125 mol
Expected number of moles of sulfuric acid = 26125 mol
Actual number of moles of sulfuric acid obtained = 99/100*26125 = 25863.75 mol
Mass of sulfuric acid obtained = 25863.75 * 96 g/mol = 2482920 g
Overall percentage yield = 25863.75/31250*100 = 82.764%

$C_6H_{12}O_6$ (s) + $H_2SO_4$ (aq) → 6C (s) + $6H_2O$ (l) + $H_2SO_4$ (aq)

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

**Answer:**

$$H_2SO_4 + H_2O \rightarrow HSO_4^- + H_3O^+$$
$$HSO_4^- + H_2O \rightarrow SO_4^{2-} + H_3O^+$$

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)**

**Answer:**

When John left the sulfuric acid open to atmosphere for 15 minutes, some of the sulfur trioxide gas would have escaped, thereby changing the density of the acid solution. Instead, he should have carried out the dilution immediately.

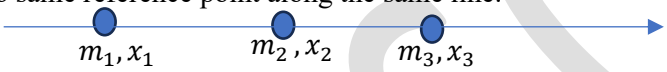
A standard flask of volume 1 L has to be used to make the dilution instead of adding 1L of water to 5 mL of the acid in a beaker. He prepared a solution of volume 1.005 L instead of 1.000 L leading to a decrease in the final concentration than the expected value.

1L of 0.05 M sulfuric acid contains 4.9 g of sulfuric acid. By adding 5 mL of 98% sulfuric acid of density 1.8 g/mL, he has added 8.82 g (=0.98*5*1.8) of sulfuric acid which is more than what is

required to prepare 0.05 M of sulfuric acid. Instead he should have used 2.8 mL (=4.9/(.98*1.8)) of the concentrated acid.

Dissolution of concentrated acid in water is a highly exothermic reaction. One has to add concentrated acid dropwise to excess of water with constant swirling/stirring to prevent build up of large amount of heat that can make the acid spurt out and/or the container to crack. Here, John adds water to the acid which is a safety hazard. Instead, he could have taken some water in the standard flask. Added the acid dropwise with constant swirling and then made up the solution to 1 L with water.

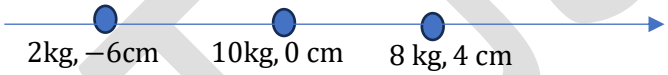
32. The concept of centre of masses plays an important role in analysing the dynamics of collection of particles and extended objects. The position of centre of mass (CM) represents the point where entire mass can be assumed to be concentrated. In a simple case as shown the position of centre of mass ($X_{cm}$) 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.




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

Based on the above information answer the following questions **(5 marks)**

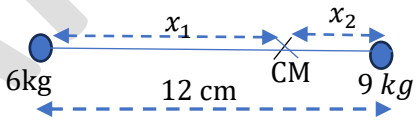
a) The centre of mass of the system of three particle given in the figure is given by.




**Answer:**

$X_{CM} = \frac{2X(-6)+8X4}{2+10+8} = \frac{20}{20} = 1$ cm

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 $x_2$.




**Answer:**

$\frac{9x_2-6x_1}{6+9} = 0$ or $9x_2 - 6x_1 = 0$ or $3x_2 = 2x_1$

And $x_2 + x_1 = 12$

Solving the two equations, we get is $x_1 = 7.2$ cm and $x_2 = 4.8$ cm

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.

**Answer:** $6\Delta x_1 = 9\Delta x_2$ or $6 \times 3 = 9\Delta x_2$ or $\Delta x_2 = 2$cm towards left.

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 $g$,

**Answer:**

The equation of motion is $y = h + ut - \frac{1}{2}gt^2$. From the given data we have

$114 = h + u - \frac{1}{2}g$ or $228 = 2h + 2u - g$

$106 = h + 3u - \frac{9}{2}g$ or $212 = 2h + 6u - 9g$

$50 = h + 5u - \frac{25}{2}g$ or $100 = 2h + 10u - 25g$

Solving the three equations simultaneously, the value of

$h = 100$ m, $u = 20$ m s$^{-1}$ and $g = 12$ m s$^{-2}$

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 |

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**Answer:**

Universal law of gravitation, $F = \frac{GMm}{R^2}$ and Equation of circular motion $F = \frac{mv^2}{R}$.

Equating, $\frac{mv^2}{R} = \frac{GMm}{R^2} \Rightarrow v = \sqrt{\frac{GM}{R}}$.

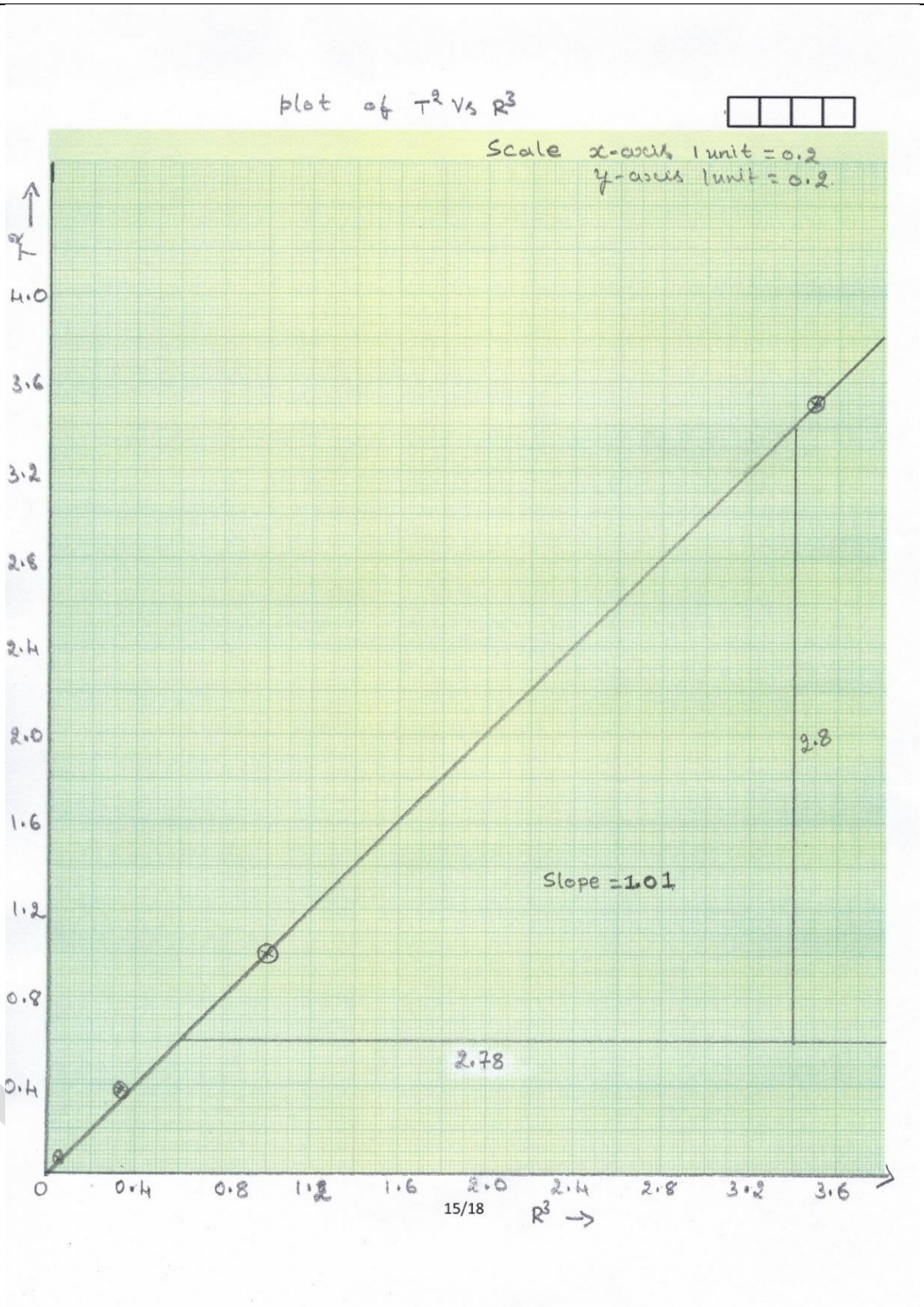
Time period is given by, $T = \frac{2\pi R}{v} = 2\pi R\sqrt{\frac{R}{GM}}$.

Squaring, $T^2 = \frac{4\pi^2 R^3}{GM} \Rightarrow M = \frac{4\pi^2 R^3}{GT^2}$. i.e., $M = \frac{4\pi^2}{G\ (slope)}$

We can now treat the data to get the slope.

| | **Planet** | ***R* in AU** | $\boldsymbol{R^3}$ **(AU)³** | ***T* in Earth Years** | $\boldsymbol{T^2}$ **(Yr)²** |
|---|---|---|---|---|---|
| 1 | Mercury | 0.39 | 0.059 | 0.24 | 0.0484 |
| 2 | Venus | 0.72 | 0.373 | 0.62 | 0.3844 |
| 3 | Earth | 1.00 | 1 | 1.00 | 1 |
| 4 | Mars | 1.52 | 3.511 | 1.88 | 3.5344 |
| 5 | Jupiter | 5.20 | 140.60 | 11.90 | 141.61 |
| 6 | Saturn | 9.58 | 879.217 | 29.5 | 870.25 |
| 7 | Uranus | 19.22 | 7100.02 | 84.00 | 7056 |
| 8 | Neptune | 30.05 | 27135.22 | 164.80 | 27159.04 |

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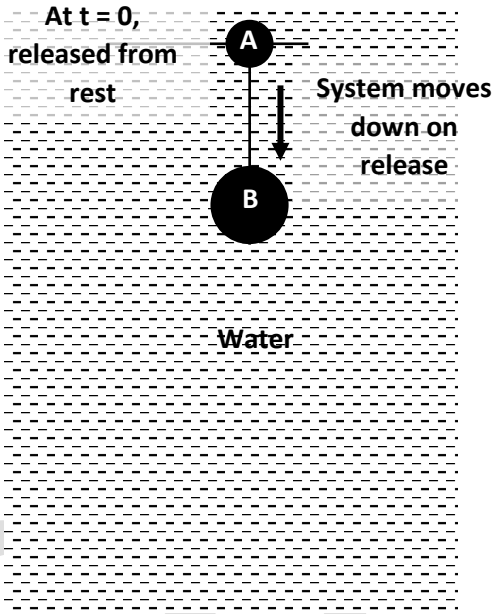



From the graph, $slope = \frac{2.55\times(365\times24\times60\times60)^2}{2.5\times(1.49\times10^{11})^3} = 1.01 \times 301 \times 10^{-21}$

$$Slope = 307.02 \times 10^{-21}\ s^2m^{-3}$$

The mass of sun is $M = \frac{4X3.14^2}{6.67\times10^{-11}\times307\times10^{-21}} = 1.93 \times 10^{30}\ kg$

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 $F_r = (6\pi \times 10^{-3})rv$ in SI units. Where $v$ is the speed of the ball. Two small solid balls A and B of radius $r$ and $2r$ 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) is 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)**

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**Answer:**

Putting all values in SI

(a) Mass of ball A: $m = \frac{4}{3}\pi r^3 d = \frac{4}{3}\left(\frac{22}{7}\right)(0.001)^3(2.5 \times 10^3)$

$m = 1.0476 \times 10^{-5}$ kg

Mass of ball B: $m_B = \frac{4}{3}\pi(2r)^3 d = 8m$

$= 8.380 \times 10^{-5}$kg

(b) At t = 0 s system is at rest hence $F_r$=0.If downward acceleration of the system is a, then the eq. of vertical motion are :

$T_1 + mg - Th_1 = ma$ … (1)

$8mg - T_1 - Th_2 = 8ma$ … (2)

$Th_2 = 8Th_1$ … (3)

Putting this in eqn. (2) and solving eqns. (1) and (2) we get

$T_1 = 0$

(c) At $t$ = 0, substituting $T_1 = 0$ in eqn. (1)

$ma = mg - Th_1 = mg\left[1 - \left(\frac{\text{denisty of water}}{\text{density of ball}}\right)\right] = mg\left(1 - \frac{1}{2.5}\right) = \frac{6\text{mg}}{10}$

$$a = \frac{6\text{g}}{10} = 5.88 \text{ m s}^{-2}$$

(d) At t >> $t_1$ s, Let the system will be falling with a uniform velocity $v$ ($a$ = 0).

If $F_r$=$F$ on ball A then $F_r$= 2$F$ on ball B. Then the eq. of vertical motion are:

$T_2 + mg - Th_1 - F = 0$ … (4)

$8mg - T_2 - 8Th_1 - 2F = 0$ … (5) (since $Th_2$ =8 $Th_1$)

Solving eq. (4) and (5) for eliminating F, we get

$T_2 = 2(mg - Th_1) = 2\left(\frac{6mg}{10}\right) = 1.2 \times 1.0476 \times 10^{-5} \times 9.8 = 1.23 \times 10^{-4}$ N

At $t$ >> $t_1$ : Solving eqns. (4) and (5) for eliminating mg and $Th_1$,

we get $F = \frac{3}{2}T_2 = 1.5 \times 1.23 \times 10^{-4}$ N $= 1.845 \times 10^{-4}$ N

$(6\pi \times 10^{-3})rv = 1.845 \times 10^{-4}$ N

$v = \frac{1.845 \times 10^{-4}}{6 \times 3.14 \times 10^{-3} \times 10^{-3}} = 9.79 \text{ m s}^{-1}$

**Section 1 and 2 Answer keys**

| Q No | Answer KEY |
|---|---|
| 1 | C |
| 2 | D |
| 3 | B |
| 4 | A |
| 5 | D |
| 6 | D |
| 7 | D |
| 8 | B |
| 9 | C |
| 10 | C |
| 11 | B |
| 12 | C |
| 13 | C |
| 14 | D |
| 15 | D |
| 16 | D |
| 17 | A and C |
| 18 | B and D |
| 19 | A, B and C |
| 20 | B and C |
| 21 | C and D |
| 22 | B, C and D |
| 23 | B and D |
| 24 | B and D or also only B |

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