Indian National Junior Science Olympiad-2020

Date of Examination : 1st February, 2020

SOLUTIONS

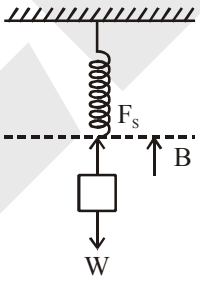
SECTION - I

1. A body with a density ρ is attached to a spring that is known to stretch linearly with the applied force. The spring is held vertically such that the body is fully immersed in a liquid of density $\rho_1 (< \rho)$. In this case, the spring stretches by a length x_1. When the same body is fully immersed in a liquid of density $\rho_2 (< \rho_1)$, the spring stretches by x_2. This implies that the density of the body (ρ) is given by the expression

(A) $\frac{\rho_1 x_1 - \rho_2 x_2}{x_1 - x_2}$ (B) $\frac{\rho_1 x_2 - \rho_2 x_1}{x_2 - x_1}$ (C) $\frac{\rho_1 x_2 + \rho_2 x_1}{x_1 + x_2}$ (D) $\frac{\rho_1 x_2 - \rho_2 x_1}{x_1 - x_2}$

Ans. Option (B) is correct.

Sol. For 1st case



$F_s + B = W$

$\Rightarrow Kx_1 = \rho Vg - \rho_1 Vg$

$\Rightarrow kx_1 = (\rho - \rho_1) Vg$ ...(1)

For 2nd case

$kx_2 = \rho Vg - \rho_1 Vg$

$kx_2 = (\rho - \rho_2) Vg$ ...(2)

Dividing (1) by (2)

$$\frac{x_1}{x_2} = \frac{\rho - \rho_1}{\rho - \rho_2}$$

$$\Rightarrow \rho = \frac{\rho_1 x_2 - \rho_2 x_1}{x_2 - x_1}$$

2. For any conductor, the thermal dependence of resistance is given by $R = R_0[1 + \alpha(\Delta\theta)]$, where $\Delta\theta$ is the temperature difference in ºC, α is a constant having the dimensions of T^{-1} and R_0 is the resistance of the wire at 0°C.

A wire made of a conductor, with $\alpha < 0$, is subjected to a constant voltage V. Then, for the wire, as the time progresses.

(A) The temperature as well as the current will go on decreasing.

(B) The temperature will go on decreasing while the current will go on increasing.

(C) The temperature as well as the current will go on increasing.

(D) The temperature will go on increasing while the current will go on decreasing.

Ans. Option (C) is correct.

Sol. $R = R_0 [1 + \alpha\Delta\theta]$ ...(1)

$\therefore$ α is –ve

As we supply voltage to circuit its temperature increases.

As $T\uparrow$, $R\downarrow$, $i\uparrow$

Hence (c) is correct

3. On a standard chess board with (8 * 8) squares, a chess piece starts to move from the lower left corner, which we shall label as square (1 * 1). This piece is allowed to move only upwards or rightwards. At any point, the piece cannot move downwards, leftwards or diagonally, e.g., from square (2 * 3), the piece may go towards (3 * 3) or (2 * 4) but not any other direction. If this piece continues to move only according to these rules, the number of different paths by which it can reach the square (4 * 4), starting from the square (1 * 1), is

(A) 16 (B) 18 (C) 20 (D) 24

Ans. Option (C) is correct.

Sol. The chess piece will have to move 3 steps right and 3 steps up. The number of such paths is the number of combinations of 6 steps, 3 of which are right and other 3 are up so the position gets reduced to the number of sequence of 3 ups and 3 rights are there , which is equivalent to finding number of ways we can choose 3 places out of an unordered sequence of 6 places. This can be done in ${}^6C_3$ ways

So ${}^6C_3 = \frac{6!}{3! \times 3!} = 20$

4. A train is moving at a speed of v = 108 km/h towards a person standing just next to the rails. The train blows a whistle for 7.0 s. What is the time duration for which the whistle is heard by this person ? Assume that the train does not reach or cross the person until the end of whistle. Speed of sound in air is 350 m/s.

(A) 6.4 s (B) 7.6 s (C) $\frac{245}{38}$ s (D) $\frac{245}{32}$ s

Ans. Option (A) is correct.

Sol. Let t_0 = time for which train whistle = 7 sec

t = time for which person hear whistle

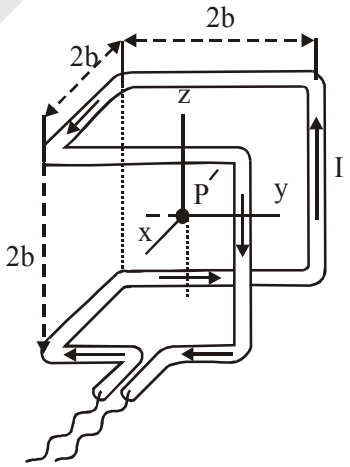
Applying doppler's equation

$$\frac{t}{t_0} = \frac{V_{sound} - V_{source}}{V_{sound}}$$

$$\Rightarrow \frac{t}{7} = \frac{350-30}{350}$$

$\Rightarrow$ t = 6.4 sec.

5. A current carrying wire is bent in the shape shown below. Direction of current is also shown in the figure. The direction of magnetic field at the center P of the cubical shape will be



(A) parallel to the x-axis (B) parallel to the y axis

(C) parallel to the z axis (D) undefined (field will be zero).

Ans. Option (B) is correct.

Sol. By Biot savart's Law and principle of superposition it is clearly seen that magnetic field at centre will be parallel to y-axis.

6. In the balanced chemical equation of the thermal decomposition of lead (II) nitrate to lead(II) oxide, if the coefficient of lead(II) nitrate is 2, then the coefficient of nitrogen dioxide is

(A) 1 (B) 2 (C) 3 (D) 4

Ans. Option (D) is correct.

Sol. $2Pb(NO_3)_2 \rightarrow 2PbO + 4NO_2 + O_2$

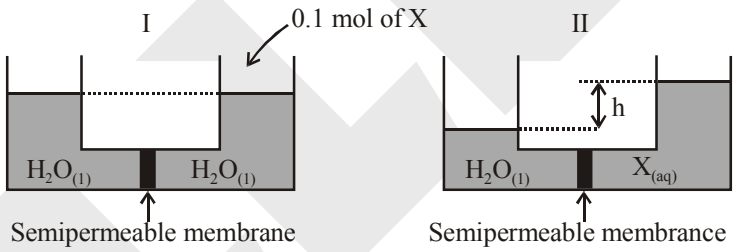
7. Metals react with oxygen to form metal oxides. If the metals considered are K, Cs, Mg and Sr, the correct order of the basic character of their oxides is

(A) $MgO > SrO > K_2O > Cs_2O$ (B) $Cs_2O < K_2O < MgO < SrO$

(C) $MgO < SrO < K_2O < Cs_2O$ (D) $K_2O < MgO < SrO > Cs_2O$

Ans. Option (C) is correct.

8. A U-shaped tube with a semipermeable membrane is filled with 2L of water as shown in figure I. When 0.1 mol of compound X is completely dissolved in the right arm of the tube, the level of $X_{(aq)}$ solution rises as shown in the figure II. Assume that the rise in the solution level is proportional to the number of solute particles in an aqueous solution.



The height h would be the highest when X is

(A) $MgCl_2$ (B) CH_3COOH (C) NH_4NO_3 (D) Cane Sugar

Ans. Option (A) is correct.

Sol. $MgCl_2(aq) \rightarrow Mg^{2+}(aq) + 2Cl^-(aq)$

3 particle

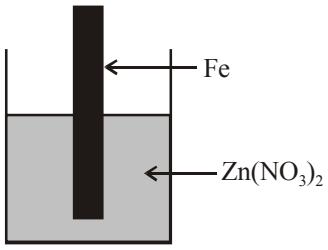
$CH_3COOH(aq) \rightleftharpoons CH_3COO^-(aq) + H^+(aq)$

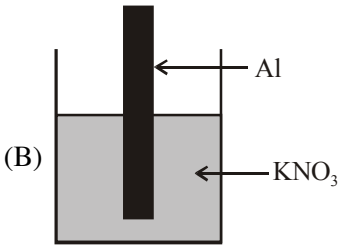
$NH_4NO_3(aq) \longrightarrow NH_4^+(aq) + NO_3^-(aq)$

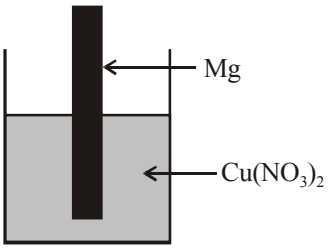
2 particles

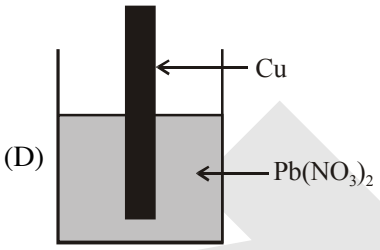
$C_{12}H_{22}O_{11} \longrightarrow$ 1 Particle

9. A more reactive metal displaces a less reactive metal from its salt solution. Observe the following figures in which a metal rod is suspended in 1M salt solution. At room temperature, the displacement reaction will significantly occur in

(A) 

(B) 

(C) 

(D) 

Ans. Option (C) is correct.

Sol. Electrochemical series accordingly.

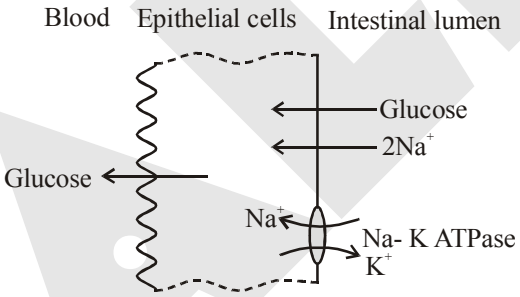
10. Soaps are sodium salts of fatty acids. Which of the following can be added to a pure soap to bring its pH to 7?

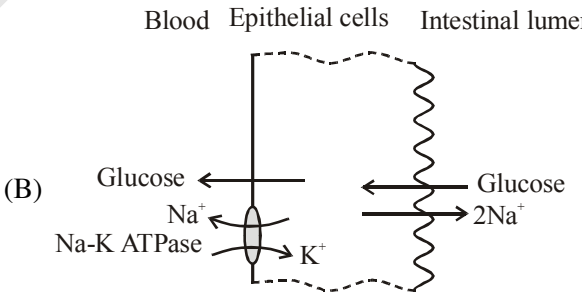
(A) Lemon Juice (B) Common salt (C) Sodium Nitrate (D) Baking Soda

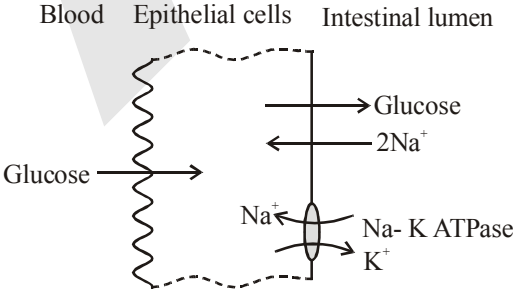
Ans. Option (A) is correct.

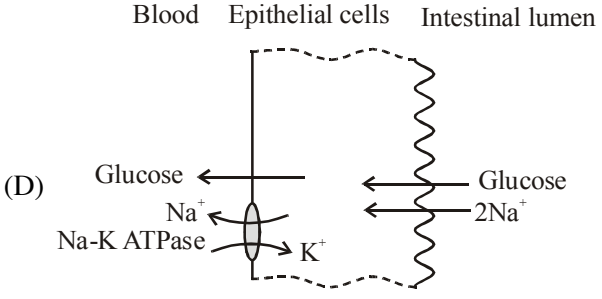
Sol. Acidic lemen juice will decrease pH.

11. In case of diarrhea, oral rehydration salts (ORS) mixed with water is used as a simple therapy to rehydrate the patient. Rehydration occurs only if glucose and NaCl (both present in ORS) are added to water and given to the patient. Which of the diagrams given below correctly represents the initial steps in the working of ORS in the intestine?

(A) 

(B) 

(C) 

(D) 

Ans. Option (D) is correct.

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Sol. The classical pathway of glucose absorption is across the intestinal Brush border membrane (BBM) which is predominantly mediated by $SGLT_1$, A membrane protein that couples two molecules of Na^+ together with one molecule of glucose.

12. Two populations of a land species were effectively isolated from each other for a long period of time. Which of the following would demonstrate that the two population have evolved into separate-species?

(A) The two population differ in at least five morphological traits.

(B) Sterile hybrids are produced when members of the two populations mate.

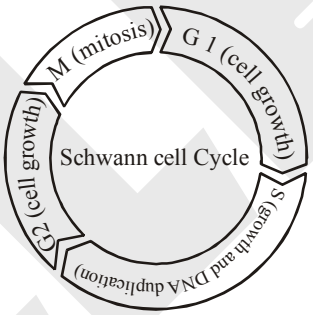
(C) Organism of both the populations do not willingly make with each other.

(D) DNA sequence are different for the two populations

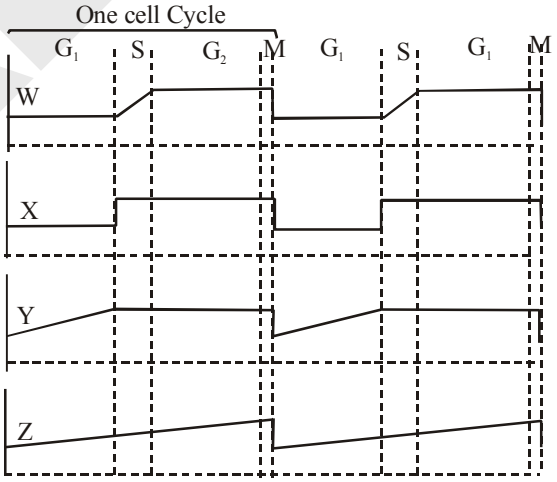
Ans. Option (C) is correct.

Sol. It is example of speciation (pre-zygotic barrier) in which due to different adaption they develop different reproductive organs (mechanical isolation).

13. The figure on the right represents the cell cycle for Schwann cells. As Schwann cells grow, they remain metabolically active for a certain period of time and then either undergo apoptosis (cell death) or divide and form new daughter cells. Actively dividing cells undergo a normal cell cycle as shown in the diagram. A newly formed cell passes through G_1 S, G_2 phases, together called interphase' before entering mitotic division phase (M phase). Mitosis gives rise to two new daugher cells which are genetically identical to the mother cells.



Among the graphs shown below, one represents trend shown by the 'cell volume' during the cell cycle and another represents the trend shown by the amount of genomic DNA'. Identify the two graphs in the same order.



(A) Y and W (B) Y and X (C) Z and X (D) Z and W

Ans. Option (D) is correct.

Sol. Volume of cell at G_1 to G_2 will increase and amount of DNA double at S phase. So option D is correct.

14. Chromophores are commonly used as biological stains to view cell organelles better. When an epithelial cell (e.g. skin cell) is stained with a basic dye like methylene blue and observed under a light microscope (total magnification of 100X), the visible cell organelle(s) will be

(A) Blue nucleus and blue mitochondria. (B) Blue nucleus and blue endosomes.

(C) Blue nucleus and pink mitochondria. (D) Blue nucleus.

Ans. Option (D) is correct.

Sol. Methylene blue satain nucleus and mitochindria both due to lower magnification (100 X) mitochondria not seen.

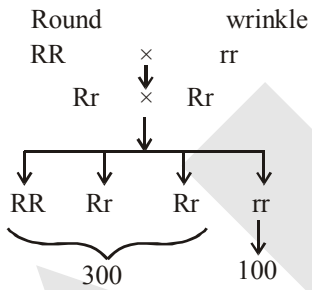
15. Alleles are variant forms of a gene that are located at the same position, or genetic locus, on a chromosome. An allele frequency is calculated by dividing the number of times the allele of interest is observed in a population by the total number of all the alleles at that particular genetic locus in the population.

A cross is made between two pea plants, one bearing round seeds and the other bearing wrinkled seeds. All pea plants in the F_1 progeny had round seeds. When the F_1 progeny were self-pollinated and the F_2 progeny analyzed, it was observed that 300 plants had round seeds while 100 plants had wrinkled seeds. What is the frequency of the dominant allele that is responsible for seed shape in the F_2 progeny?

(A) 25% (B) 50% (C) 75% (D) 100%

Ans. Option (B) is correct.

Sol.



$$q^2 = \frac{100}{400}$$

$$q = \sqrt{\frac{100}{400}} = \frac{1}{2} = .5$$

$$p + q = 1$$

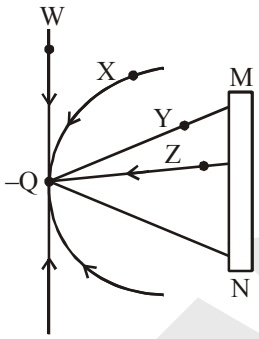
$$p = 1 - q = 1 - .5 = .5$$

%of P = 50%

SECTION - II

16. The figure on the right shows a negative point charge (–Q) and a thick uncharged metal plate. In the two dimensional figure., MN is a cross -section of the plate. As seen in the figure, the charge is located on the normal drawn from the centre of the plate.

A student was given this situation and was asked to draw lines of force through the points W, X, Y and Z. The diagram on the right is the answer given by the student. At which point (s) is drawn lines of force definitely do(es) NOT match the actual lines of force?



(A) W (B) X (C) Y (D) Z

Ans. Option (A) and (C) are correct.

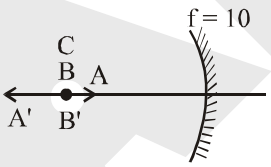
Sol. Line through point W should be radially distorted. Line through point Y should be perpendicular to the plate.

17. A 5 cm long needle is placed along the principal axis of a concave mirror of a focal length 10 cm. It is observed that one end of the image of the needle coincides with one of the ends of the needle. The other end of the image is at a distance x from the pole of the mirror, where x is

(A) 20 cm (B) $\frac{50}{3}$ cm (C) 30 cm (D) 10 cm

Ans. Option (B) and (C) is correct.

Sol. Case-1 :



For point A

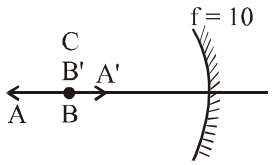
u = –15 cm

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$$

$$\frac{1}{v}=\frac{1}{f}-\frac{1}{u}=-\frac{1}{10}+\frac{1}{15}=-\frac{1}{30}$$

v = –30 cm

Case-2 :



For point A

u = –25 cm

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$$

$$\frac{1}{v}=\frac{1}{f}-\frac{1}{u}=-\frac{1}{10}+\frac{1}{25}$$

$$v=\frac{-250}{15}=\frac{-50}{3}\ \text{cm}$$

18. A body is performing one dimensional motion. After time instant $t = t_1$, the body covers equal distances in two successive time intervals Δt_1 each. Also the speed of the body at time instants $t = t_1$ and at $t = t_1 + 2\Delta t_1$ happens to be the same. Therefore the

(A) acceleration may be zero.

(B) body may be moving with a constant non-zero acceleration.

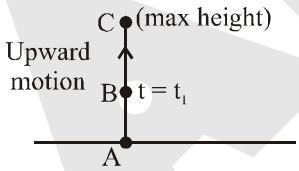
(C) body may be moving with an acceleration proportional to displacement (from a suitably defined origin) and directed opposite to it.

(D) body may be coming to a halt momentarily.

Ans. Option (A),(B),(C) and (D) are correct.

Sol. (A) Body moving with constant velocity covers equal distances in equal interfvals of time. So option (A) is correct.

(B) During free fall



time taken by particle to move from B to C and from C to B are equal. And distances are also equal. So option (B) is correct.

(C) In SHM time taken by particle to move from $\frac{A}{2}$ to A then from A to $\frac{A}{2}$ are equal. So option (C) is also correct.

(D) During free fall at maximum height particle is at rest momentarily, so option (D) is correct.

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19. 3.0 g of ethanoic acid reacts with 1.84 g of absolute ethanol in the presence of an acid catalyst to give an ester. Assuming that the reaction goes to completion, the correct statement(s) is/are

(A) 0.05 mol of Ester is formed (B) 3.5 of ester is produced.

(C) 24×10^{21} molecules of ester are produced. (D) The product contains 9.6×10^{22} carbon atoms.

Ans. Option (B, C, D) is correct.

Sol. $CH_3COOH + C_2H_5OH \longrightarrow CH_3COOC_2H_5 + H_2O$

3g 1.84g

0.05 mole 0.04 mole 0.04 mole

(L.R.)

$\Rightarrow$ 3.52 g

$\Rightarrow 24 \times 10^{21}$ molecules

$\Rightarrow 9.6 \times 10^{22}$ c-atoms

20. One mole of $^{14}_{7}N^{3-}$ ions contains

(A) $10N_A$ electrons (B) $4N_A$ protons (C) $7N_A$ neutrons (D) $7N_A$ protons

Ans. Option (A, C, D) is correct.

Sol. $^{14}_{7}N^{3-}$

10 mole = 10 N_A e^-

7 mole neutrons = 7 N_A neutrons

7 mole proton = 7 N_A protons

21. Q, X, Z, J, E, L and G are some unkown elements. The pair(s) that show similar chemical properties is/ are

(A) $_5Q$, $_{19}X$ (B) $_{12}Z$, $_{38}J$ (C) $_9E$, $_{15}L$ (D) $_{20}G$, $_{12}Z$

Ans. Option (B, D) is correct.

Sol. $_{12}Z$ $_{38}J$ $\Rightarrow$ $_{12}Mg$ $_{38}Sr$ II group

$_{20}G$ $_{12}Z$ $\Rightarrow$ $_{20}Ca$ $_{12}Mg$ II group

22. Karl Landsteiner (1868-1943) discovered the A, B and O blood groups in 1901, which was followed by the identification of AB blood group in 1902 by his student Struli. The ABO blood group system is based on the presence or absence of antigen A and/or B on the RBCs. Antibodies to A and B antigens are present or absent in the plasma, depending on the antigen which is present on the RBC's of an individual. Antibodies are generated in an individual against a foreign antigen, but not against an antigen that is inherently present in the individual. If RBCs carrying an antigen (say A) is mixed with a plasma carrying antibodies against the antigen (say anti-A), the RBCs will agglutinate (clump).

In an experiment, the RBCs and plasma were separated from five different individuals (P to T) and were mixed in different combinations as shown in the table below, which either resulted in agglutination (+) or no agglutination (–).

		Plasma from individuals				
		P	Q	R	S	T
RBC from individuals	P	–	+	+	–	+
	Q	+	–	+	–	–
	R	–	–	–	–	–
	S	+	+	+	–	+
	T	+	–	+	–	–

If it is known that individual Q has antibodies against antigen A, identify the blood groups of all the five individuals.

Sol.

		Plasma from individuals				
	Blood groups	P (Anti B)	Q (Anti A)	R (Anti A) (Anti B)	S	T (Anti A)
	Antigen on RBC surface					
RBC from individuals	P(A)	–	+	+	–	+
	Q(B)	+	–	+	–	–
	R(O)	–	–	–	–	–
	S(AB)	+	+	+	–	+
	T(B)	+	–	+	–	–

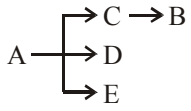
23. Molecular phylogeny is used to trace the changes in DNA or protein backwards in time to find out when each change led to divergence. The following are the amino acid sequences of a protein derived from the DNA sequences of 5 different organisms. (sequences A to E).

K N S Y S G G R C S I I R - Sequence A
K N S Y N G S R C S I I R - Sequence B
K N S Y N G G R C S I I R - Sequence C
K N S Y S G G R R S I I R - Sequence D
K N S Y S G G R C S T I R - Sequence E

How would you label the tree diagram below, which explains the evolution of this protein?

Note : The most ancestral form of the sequence should be at the origin (leftmost box). Assume that each step involves one change.

Sol.



24. An ecological pyramid is a diagrammatic representation of the relationship between various organisms in an ecosystem. These Pyramids can be drawn to represent the organic material (biomass), or number, or energy at each trophic level.

We list here four different ecosystems (i to iv) and five different ecological pyramids (P to T). Match the ecosystems with the correct pyramids.

Ecosystems :

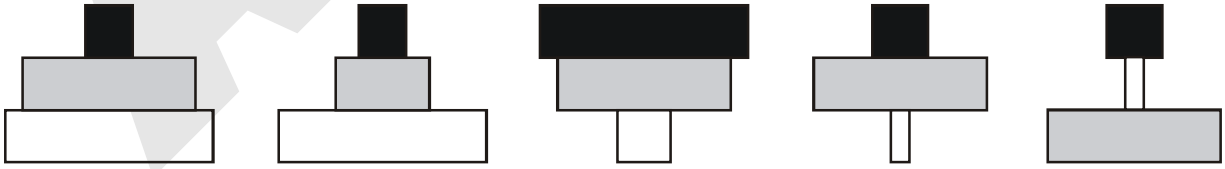
i. Number pyramid of an ecosystem consisting of grasses, snails and mice.

ii. Number pyramid of an ecosystem cosisting of a tree, caterpillars and mynas.

iii. Biomass pyramid of an ecosystem consisting of a tree, caterpillars and mynas.

iv. Number pyramid of an ecosystem consisting of a rose bush, aphids and parasites.

Pyramids :



(P) (Q) (R) (S) (T)

Sol. i → Q

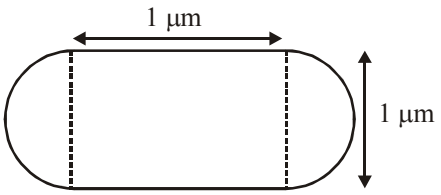
ii → S

iii → P

iv → S

SECTION - III

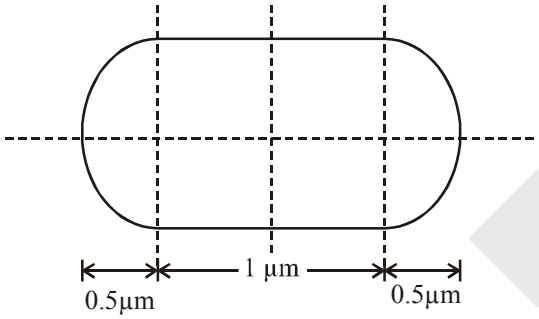
25. (6 Marks) Consider a toy model of E. coli cell (bacterial cell) as a cylindrical body with hemispherical caps at both ends of the cylinder. The diameter of this cylinder is taken as 1μm and the length of its cylindrical part is also 1μm (See the figure on the right).



(a) Estimate the average distance between two E.coli cells (centre to centre distance) in a saturated growth medium having saturation density of E.coli cells of about 10^9 cells/mL.

(b) Many biochemical studies specify the concentration of proteins in a cell in units of nanomolar (nM) concentration. If such a protein species inside an E.coli cell has a concentration of at least 20 nM, how many minimum molecules of that protein species are present in each cell?

Sol. (a)



Let n cells are arranged on each axis having average seperation distance d.

Total volume = n^3d^3

Given $n^3 = 10^9$ cells in each cm^3

So $n^3d^3 = 1\ cm^3$

$d = 10^{-3}cm$

(b) $V = \frac{4}{3}\pi r^3 + \pi r^2 \ell$

$$= \left\{\frac{4}{3}\pi(0.5\times10^{-6})^3 + \pi\times(0.5\times10^{-6})^2\times1\times10^{-6}\right\}$$

$V = (4.188 + 7.85) \times 10^{-19} = 13.08 \times 10^{-19}\ m^3$

V in liters $= 13.08 \times 10^{-19} \times 10^3$

$= 13.08 \times 10^{-16}$ Liters

$\because$ Protein molarity/bacterial cell $= 20 \times 10^{-9}$ mol/liter

$\therefore$ Protein molecules/liter $= 20 \times 10^{-9} \times 6.023 \times 10^{23}$

$\therefore$ Protein molecules/bacterial volume

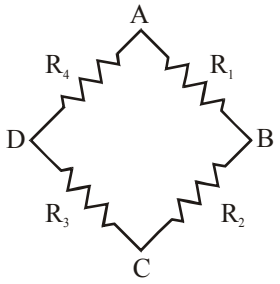
$= 20 \times 10^{-9} \times 6.023 \times 10^{23} \times V_{(liters)}$

$= 20 \times 10^{-9} \times 6.023 \times 10^{23} \times 13.08 \times 10^{-16}$

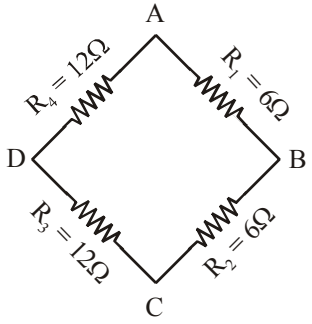
$= 15.75$

26. (5 Marks) Resistances R_1, R_2, R_3 and R_4 are electrically connected between points A, B, C and D, as shown in the given figure. Their individual values can either be 6Ω or an integral multiple of 6Ω (All need not be different)

A multimeter connected between points A and C reads 8Ω (say $R_{AC} = 8\Omega$). Calculate R_{AB}, R_{BC}, R_{CD}, R_{DA} and R_{BD}.



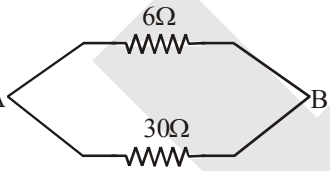
Sol. Let $R_1 = 6\Omega$, $R_2 = 6\Omega$, $R_3 = 12\Omega$, , $R_4 = 12\Omega$

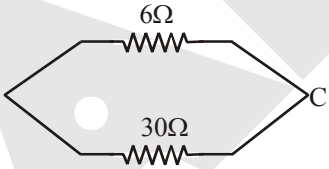


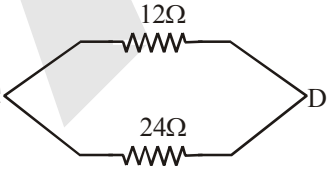
Given $R_{AC} = 8\Omega$

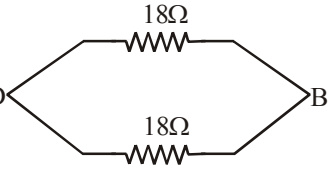
$$\frac{(R_1+R_2)(R_3+R_4)}{(R_1+R_2+R_3+R_4)} = 8\Omega$$

$$\frac{12\times 24}{12+24} = \frac{288}{36} == 8\Omega$$

R_{AB} :  $\Rightarrow R_{AB} = \frac{30\times 6}{36} = 5\Omega$

R_{BC} :  $\Rightarrow R_{BC} = \frac{30\times 6}{36} = 5\Omega$

R_{CD} :  $\Rightarrow R_{CD} = \frac{12\times 24}{36} = 8\Omega$

R_{DB} :  $\Rightarrow R_{DB} = 9\Omega$

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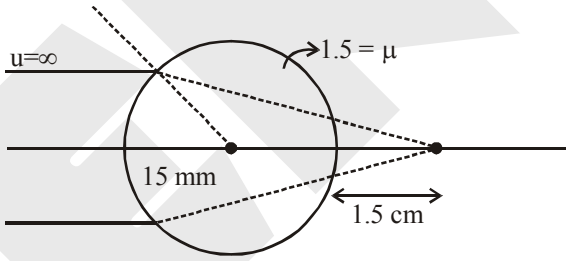
27. (4 marks) Read each of the following passages and point out, with a short justification (2-3 lines), the scientific mistakes, if any.

(a) A spherical lens is a transparent medium bound by spherical surfaces. A glass marble can therefore be considered as a lens. Consider a glass marble (refractive index 1.50) of radius 15.00 mm. Using the geometrical optics formulae taught in high school, Prajakta calculated the focal length of this marble to be 15.00 mm. Consider a group of parallel rays incident on the marble. These rays will pass through the marble and get converged at 15.00 mm on the other side.

(b) A ray of white light is incident on a rectangular slab at an angle i. When the ray enters the glass slab from one surface, dispersion takes place. In other words, since the refractive index of glass is different for different constituent colours of white light, the angles of refraction are different, say r_{violet}, r_{indigo}, r_{blue}, etc. After travelling along different directions inside the glass slab, the rays of different colours will be incident on the glass-air interface at the opposite parallel surface, at different angles of incidence. The rays of different colours will then leave this surface with different angles of refraction. Therefore, when white light passes through a glass slab, the constituent colours will spread out in different directions while leaving the slab.

Sol. (a) For I-st curved surface

$$\frac{\mu_2}{v}-\frac{\mu_1}{u}=\frac{\mu_2-\mu_1}{R}$$



$$\frac{1.5}{v}=\frac{0.5}{15}$$

v = 4.5 mm

It means For second curved surface object is at a distance of 15 mm

For second surface $\frac{\mu_2}{v}-\frac{\mu_1}{u}=\frac{\mu_2-\mu_1}{R}$

$$\frac{1}{v}-\frac{1.5}{15}=\frac{(1-1.5)}{-15}$$

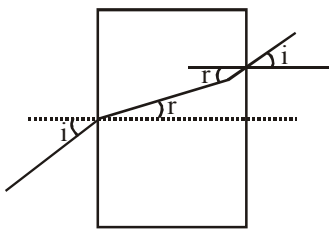
$$\frac{1}{v}-\frac{1}{10}=\frac{0.5}{1.5}$$

$$v=\frac{30}{13}$$

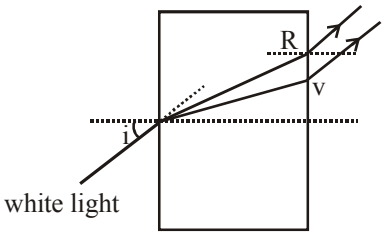
v = 2.3 mm

It is clear that the final image formed at 2.3 mm from second surface. Hence it is clear that she has missed refraction from the second surface. And in geometrical optics formulae are applicable for only paraxial rays.

(b)



From shell's law, it is clear that any light entering the slab will come out parallel to incident ray.



Hence the light of different colour will come out parallel to incident ray and all colour will spread out in same direction.

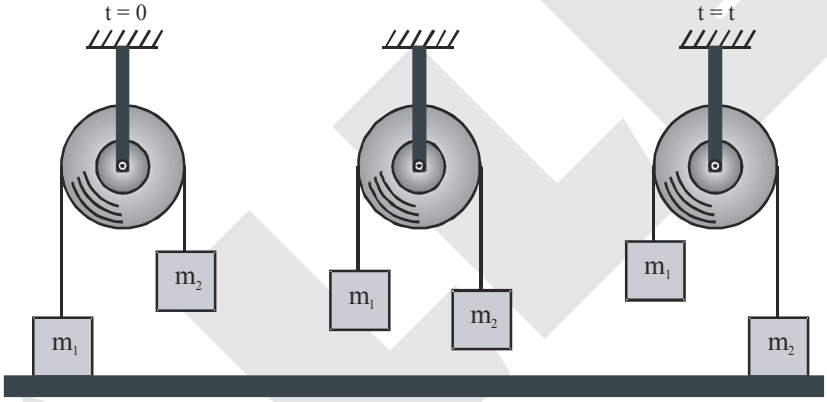
28. (15 marks) The free body diagram (a diagram that shows forces on individual objects) for an Atwood's machine (a system with a rope passing over a fixed pulley, with two masses attached at either end of the rope - see the figure) yields the following equation :

$$(m_2 - m_1)g = (m_2 + m_1)a$$

where a is the acceleration of the system of masses m_1 and m_2.

The following data were recorded for an Atwood's machine, with the total mass $(m_1 + m_2)$ being kept constant. Each reading corresponds to a different value of the mass difference $(m_2 - m_1)$ as shown in the table. In each case, at t = 0, the mass m_1 was resting on the ground below and the mass m_2 was at a height of x = 1.00 m. The time recorded in the data table is the time taken for the mass m_2 to hit the ground.

Using the given data and equation of motion, plot a suitable graph and determine total mass strictly using the slope of the graph.



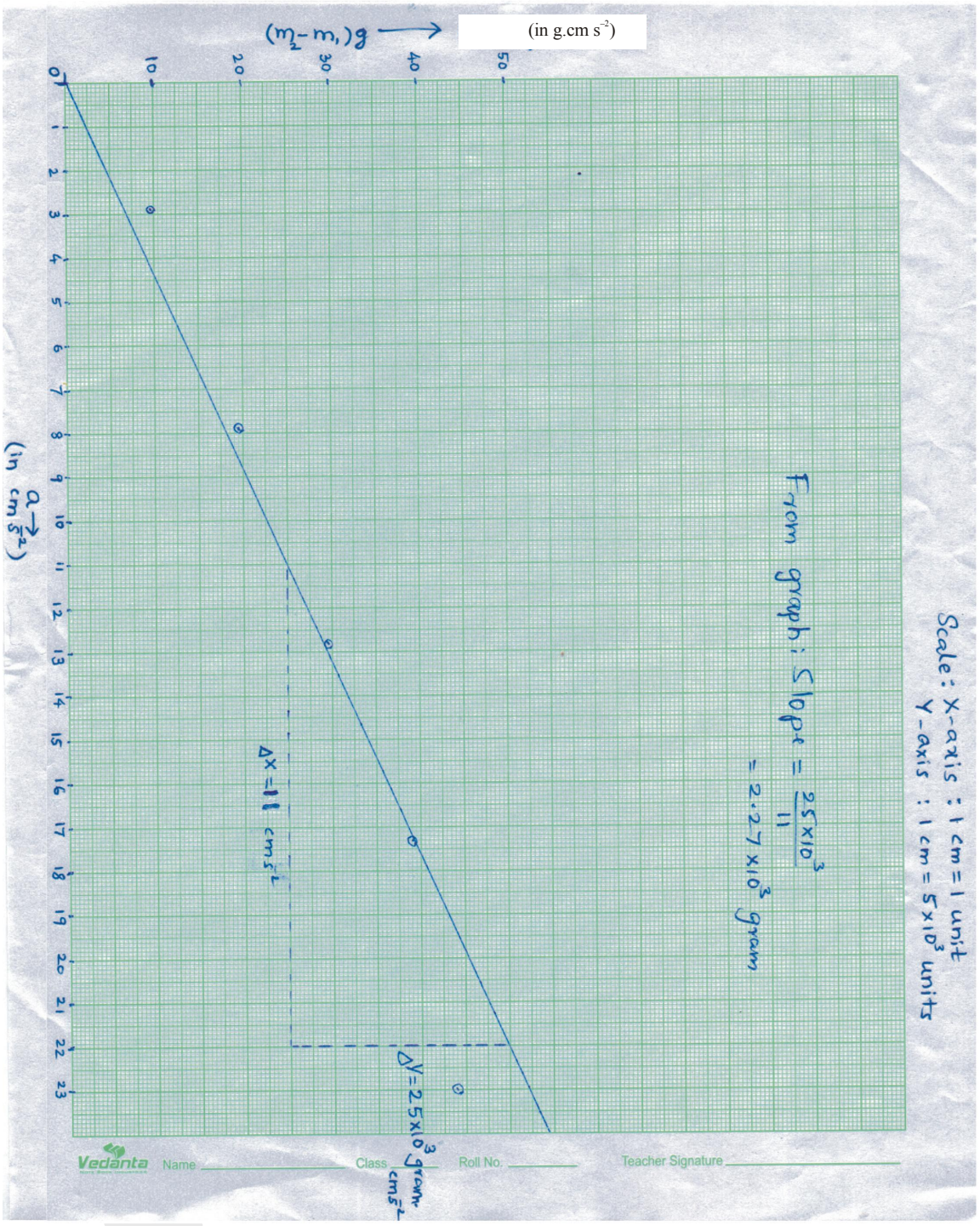
$(m_2 - m_1)$ (in g)	time (t) (in s)
10.0	8.35
20.0	5.03
30.0	3.95
40.0	3.40
50.0	2.95

Sol. For m_2

$x = \frac{1}{2}at^2$ $\qquad\qquad$ $\therefore a = \frac{2x}{t^2}$

$(m_2 - m_1)$ (in g)	$(m_2 - m_1)g$ (in g.cm/s^2)	time(t) (in s)	$a = \frac{2x}{t^2}$ (cm/s^2)
10	$9800 = 9.8 \times 10^3$	8.35	2.86
20	$19600 = 19.6 \times 10^3$	5.03	7.90
30	$29400 = 29.4 \times 10^3$	3.95	12.81
40	$39200 = 39.2 \times 10^3$	3.40	17.30
50	$49000 = 49.0 \times 10^3$	2.95	22.98

Drawing graph between $(m_2 - m_1)$ g and a



From graph : Total mass

$$m_1 + m_2 = \text{slope} = \frac{\Delta y}{\Delta x} = \frac{(m_2 - m_1)g}{a}$$

$$= \frac{25}{11} \times 10^3$$

$$= 2.27 \times 10^3 \text{ g} = 2.27 \text{ kg}$$

29. (7 marks) Fossil fuels are used in car engines. These fuels, when burnt, emit different gases, which are responsible for air pollution.

A catalytic converter is an amazingly simple device that is highly effective at reducing harmful emissions produced by a car engine.

Modern catalytic converters are constructed from a mixture of metals. One metal serves as a catalyst for oxidation and other serves as catalyst for reduction reaction. A certain heat resistant ceramic material is thus coated with catalyst Pt-Pd/Rh.

In this catalytic converter, upto 90% of carbon monoxide from the exhaust of a car engine is oxidized to carbon dioxide, while NO and NO_2 are reduced to N_2.

Note : The exhaust of a car engine also includes small quantities of unused organic hydrocarbons, which are also oxidized to carbon dioxide in the catalytic converter. However, for this problem, we will ignore the oxidation of hydrocarbons.

For a certain amount of fuel, the amount of carbon dioxide emitted from a car engine, without a catalytic converter, was found to be 110 g. The same car engine, when fitted with a catalytic converter, emitted 132 g of carbon dioxide, for the same amount of fuel.

(a) Calculate the mass of carbon monoxide emitted by the engine, without the catalytic converter, for that amount of fuel.

(b) Arnav travelled from Jodhpur to Bikaner by car, a distance of 256 km. Fuel efficiency of the car is 16km/L. Burning one litre of the fuel produces 2.3 kg of carbon dioxide in the engine of the car. The same catalytic converter (as described above) is fitted to the car engine. Find the mass of carbon dioxide emitted by the Arnav's car during the travel.

(c) How many moles of carbon dioxide does this mass correspond to?

(d) How much mass of CO produced in this journey remains unconverted?

Sol. (a) With convertor = 132 g CO_2

Without convertor 110 g CO_2

22 g CO_2 formed by CO

$$CO + \frac{1}{2}O_2 \rightarrow CO_2$$

$$\frac{90}{100}\times\frac{x}{28}=\frac{22}{44} \Rightarrow x = 15.55 \text{ g}$$

(b) Fuel burnt = $\frac{256}{16}$ = 16 litre

CO_2 emitted = 2.3 × 16 = 36.8 kg

(c) moles CO_2 = $\frac{36.8\times10^3 \text{ g}}{44}$ = 836.36

(d) mole fraction of CO_2 produced by CO = $\frac{(22/44)}{\left(\frac{22}{44}\right)+\left(\frac{110}{44}\right)}$ = 0.1666 = 16.67%

CO_2 produced by 90% CO during travel = $\frac{16.67}{100}\times836.36$ = 139.39 mole

Total CO formed = $\frac{100}{90}\times139.39$ = 154.88 mole

CO unoxidised = 154.88 – 139.39 = 15.49 mole

= 433.76 g

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30. (16 marks) The year 2019 was proclaimed by UNESCO as the International Year of the Periodic Table (IYPT 2019), marking the 150th anniversary of the Mendeleev periodic table, which is an iconic representation and a vital tool to all who learn and work in science. In this question, some elements have had their symbols replaced by greek letters α, β, γ, etc., but not in order. All such elements in this question have atomic number of 20 or less. In addition, two more elements in the periodic table have been assigned codes X and Q.

Use the information about their properties, as given below, to assign each element to its correct greek / roman alphabet code.

(a) Element α, β and γ are unreactive monatomic gases. β has the smallest atomic radius of the three and α has a higher boiling point than γ.

Identify elements α, β and γ.

The elements δ, $\in$, Ω, ψ θ, X and Q exist as diatomic molecules (i.e. δ_2, $\in_2$, Ω_2, Ψ_2, θ_2, X_2 and Q_2). We also know that, at room temperature, X_2 is a liquid and Q_2 is a solid; the other five are gases.

(b) Identify element X and Q.

Ψ_2 forms compounds with each of the other six diatomic elements. Compounds of Ψ with δ, $\in$, and X result in diatomic gases that react with the liquid $\Psi_2\theta$ to form acidic solutions.

(c) Identify elements Ψ and θ. Also write a balanced chemical reaction to show how they combine with each other.

(d) δ has the highest electronegativity of these elements. The reaction between Ω_2 and Ψ_2 is of immense industrial importance, the product being a gas that reacts with liquid $\Psi_2\theta$ to form a basic solution. Identify elements δ, $\in$ and Ω and write balanced chemical reactions of the processes described here.

The Ideal gas law is an equation to explain the behaviour of many gases under different conditions. The ideal gas equation can be written as PV = nRT where P is the pressure of the ideal gas, V is the volume of the ideal gas, n is the amount of ideal gas measured in terms of moles, R is the universal gas constant, T is the temperature of the ideal gas in Kelvin. We now consider elements κ, λ, μ and ν, which are metals that react vigorously with liquid $\Psi_2\theta$ to produce Ψ_2 and a basic solution.

(e) 1 g of element λ reacts with excess $\psi_2\theta$ to produce 0.3080 L of ψ_2 at 20°C and pressure of 1 atm. (Assume that ψ_2 behaves as an ideal gas under the given conditions.)

Write possible balanced chemical reaction(s), calculate possible atomic mass(es) of element λ and deduce the name of this element.

(f) κ is more reactive than ν. The stable ions formed form λ and μ in this reaction have the same electron configuration. Identify elements κ, μ, ν.

(g) Elements ξ, σ and ϕ are also metals. They do not react with cold $\psi_2\theta$ but do react with θ_2 to form $\xi\theta$, $\sigma_2\theta_3$ and $\phi\theta$ respectively. Out of these, $\phi\theta$ contains the largest percentage of θ by mass. Identify the elements ξ, σ, ϕ and write these balanced chemical reactions.

Sol. (a) α = Argon (Ar)

β = Helium (He)

ν = Neon (Ne)

(b) $X_2 = Br_2$

$Q_2 = I_2$

(c) Ψ = hydrogen, θ = oxygen

$2H_2 + O_2 \longrightarrow 2H_2O$

(d) s = F

ε = Cl

$\Omega = N_2$

$N_2 + 3H_2 \rightarrow 2NH_3$

$NH_3 + H_2O \rightarrow NH_4OH$

(e) $\frac{1\times 22.4}{273.15} = \frac{1\times V_2}{293.15}$

v_2 = 24.04 litre

no. of eq. of metals = no. of eq. of H_2 gas

$$\frac{1}{\text{eq. of M}} = \frac{0.3080}{\left(\frac{24.04}{2}\right)} \text{ at } 20^\circ C$$

Eq. of M = 39.025

λ =K

$2K + 2H_2O \rightarrow 2KOH + H_2$

(f) Given that λ & μ are isoelectronic

so that μ should be Ca.

λ = K

μ = Ca

and as per given information κ & ν are vigourously react with H_2O

Therefore, If we consider that both belongs to

Group 1A, then 'κ' should be Na and ν should be Li.

(Melting point of Li is more that of Na)

(g) $\xi \rightarrow$ Mg

$2Mg + O_2 \rightarrow 2MgO$

σ = Al

$4Al + 3O_2 \rightarrow 2Al_2O_3$

$\phi \rightarrow$ Be

$2Be + O_2 \rightarrow 2BeO$.

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31. (7 Marks) The term pseudo-science refers to the ideas which claim to be scientific, but don't stand the scrutiny of modern science. Although many such claims have been clearly shown to be un-scientific through detailed studies, they continue to fool non-experts by using scientific sounding arguments. The pseudo-science of homeopathy began over two hundred years ago, long before modern medicine. The main claim in homeopathy is that the medicines become increasingly potent the more they are diluted. Let us do a series of calculations to estimate the amount of supposed medicinal molecules in a typical homeopathic solution.

Homeopaths recommend a diluted solution of arsenic oxide (As_2O_3) as a treatment for digestive disorders and anxiety. In their vocabulary, it is called by its Latin name Arsenicum album (white arsenic). The oxide is prepared industrially by roasting arsenic containing ores, such as arsenopyrite (FeAsS), in air. The other products formed are Iron(III) oxide and sulphur dioxide.

(a) Write the balanced chemical reaction for the preparation of As_2O_3 from FeAsS.

(b) As_2O_3 is moderately soluble in water. When dissolved in water, the oxide reacts to form Arsenous acid (H_3AsO_3). Write a balanced chemical equation for the formation of Arsenous acid from As_2O_3.

(c) One litre of a saturated solution of As_2O_3 at 25 °C contains 20.6 g of As_2O_3. Calculate the concentration of the Arsenous acid in mol/L in the saturated solution.

In homeopathy, a 'decimal-scale' is often used to specify the dilution of a given sample: Dl (sometimes labelled IX) means the sample has been diluted 1 part in 10. D2 (or 2X) means the sample has first been diluted 1 in 10, then 1 part of that solution has been further diluted 1 in 10 again to give a 1 part in 100 dilution. A D6 (or 6X) solution has repeated this process six times to give a final dilution of 1 in 10^6. Arsenicum album is often sold as a D30 preparation. Let us assume that the initial stock solution, before dilution, was the saturated solution containing 20.6 g/L of AS_2O_3.

(d) Calculate the mass (in g) of As_2O_3 present in 100 mL glass bottle of the D30 Arsenicum album.

(e) How many such bottles (in millions, 1 million = 10^6) of the supposed medicine should one drink to be sure that at least one atom of arsenic has entered one's body?

(f) Total volume of water on the Earth is estimated to be about 1.4×10^9 km^3. If our stock solution at the start is 1L of saturated solution of As_2O_3, what is the maximum dilution of the entire stock solution one can achieve by utilizing all this water?

Note: In reality, more than 97% of water on the earth is salt water. However, for this calculation, you may assume that even this water can be desalinated and be made available for dilution.

Sol. (a) $2FeAsS + 5SO_2 \rightarrow Fe_2O_3 + 2SO_2 + AS_2O_3$

(b) $As_2O_3 + 3H_2O \rightarrow 2H_3\ AsO_3$

(c) $As_2O_3 + 3H_2O \rightarrow 2H_3AsSO_3$

$$\frac{20.6}{198} \qquad 2 \times \frac{20.6}{198} \qquad = 0.208\ M$$

(d) In 1 litre solution wt. of solute = 20.6 g

So, in 1 ml it will be = 20.6×10^{-3} g

Now according to question this amount diluted to 10^{30} times.

10^{30} ml contain 20.6×10^{-3} g solute

In, 100 ml contain = $20.6 \times 10^{-3} \times \frac{100}{10^{30}} = 20.6 \times 10^{-31}$ g

(e) 20.6×10^{-31} g present in one bottle (V = 100 ml, D 30)

so, 1 gm contain in $\frac{1}{20.6\times10^{-31}}$ bottle

since

[wt. of one Arsenic 75 amu ($75 \times 1.6 \times 10^{-24}$g)]

so, $75 \times 1.6 \times 10^{-24}$ gm contain

$= \frac{75\times1.6\times10^{-24}}{20.6\times10^{-31}}$ bottles

$= 5.83 \times 10^{7}$ bottles. = 58.3 millions bottles

(f) Volume of earth water = 1.4×10^{9} km^3

$= 1.4 \times 10^{18}$ ml

1 ml contain = 20.6×10^{-3}g solute.

Now this amount diluted to the maximum dillution that is entire earth water used.

so, 1.4×10^{18} ml contain $= 20.6 \times 10^{-3}$ g solute

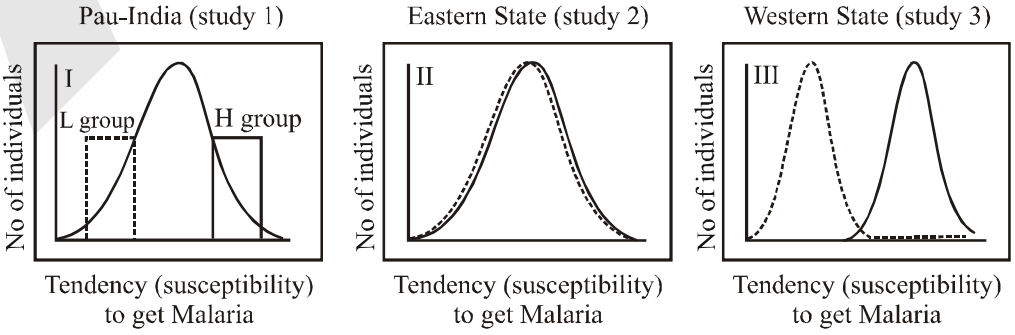
1 ml contain $= \frac{20.6\times10^{-3}}{1.4\times10^{18}} = 14.71 \times 10^{-21}$

Now, ratio = $\frac{20.6\times10^{-3}}{14.71\times10^{-21}} = 1.40 \times 10^{18}$

32. The malarial parasite (Plasmodium) matures into an infective form inside the mosquito gut and is then transmitted to humans by mosquito bites. A survey monitored the number of malarial infections per individual in different regions of India, over a 5 year period. In this survey, certain pockets of India were deemed to be endemic, i.e. these regions showed higher incidence of the disease than average. One reason for such endemic pockets could be higher numbers of mosquito larvae in the waterlogged bodies often found in these areas.

However, we also know that people who suffer from sickle cell anemia (a genetic disorder) seem to possess some inherent resistance to the malarial infection. This is particularly evident in endemic African populations, where sickle cell anemia is also common. It is probable that sickle cell anemia was naturally selected over generations in these populations.

The results of the study, with randomly selected 100,000 individuals from all over the country, are shown in graph I. The L group (dashed box) were people with lower susceptibility to malaria, while the H group (solid box) had high susceptibility to malaria. Geographical areas (localities / towns / districts) where most of the population fell in either L group or H group were carefully identified.



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After 10 years the study was repeated, for 5 more years, in two states [Eastern and Western]. In each state, the population was resampled in a randomised way from the areas identified previously as belonging to L and H groups. Each sample again consisted of 100,000 individuals. Graph II corresponds to the Eastern state and Graph III corresponds to the Western state. Here the dashed line shows the L group sample and the solid line shows the H group sample. Scale/axis is same for all three graphs.

The researchers of this study want to discuss the biological basis of these differences. The following statements were considered by them for inclusion in their final report. Which of these statements may be true, based on the evidence you have?

For each statement write True / False. Each answer must be accompanied with a short (1-2 fines) justification for your claim.

(i) Graph I clearly indicates that there is no genetic basis for malarial resistance in India.

(ii) From graph I, it can be said that the chance of mosquito bites for an individual in the Indian population is totally random.

(iii) Susceptibility of individuals to malaria in the eastern state is pre-dominantly random.

(iv) In the western state, susceptibility among the H group individuals may have a genetic basis.

(v) If there is a global malarial epidemic, the H individuals in the western state have a higher chance of infection than the H individuals in the eastern state.

(vi) If there is a global malarial epidemic, the graph of malarial susceptibility of the L individuals in the western state is likely to remain unchanged.

(vii) If there is a random breakout of flu, both the L and H groups in the western state will be equally susceptible to flu.

(viii) Among the individuals who have recovered from malaria, the individuals of the H group in the western state are more likely to have scurvy than the H group individuals in the eastern state.

(ix) Some areas in the western state probably have a high incidence of waterlogging.

(x) Chances of finding people having sickle cell anemia will be higher in the western state than in the eastern state.

Sol. (i) False : In Graph-I L group is a sickle cell infected people.

(ii) True : It is a random case of mosquito bite.

(iii) True : As per graph susceptibility of individual to malaria in the eastern state is pre-dominantly random.

(iv) True : In western state H group has normal RBC.

(v) False : During global malarial epidemic, the H individual in western state does not have higher chance of infection.

(vi) True : Due to sickle cell anemia the malarial susceptibility of the L individual in western state is likely to remain unchanged.

(vii) False : During random breakout of flu L and H groups in the western state will not equally susceptible to flu.

(viii) False : There is no relation between malaria and scurvy.

(ix) False : Western state have normal environment.

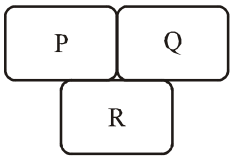
(x) True : Due to different tendency to get malaria chances of finding people having sickle cell anemia will be higher in western state as compare to eastern state.

33. In any plant body, movement of the water highly depends on water potential of cells, denoted by Ψ_ω. The Ψ_ω of pure water is zero by definition. Typically, when solutes dissolve in water, Ψ_ω becomes negative.

In a cellular environment, pressure exerted by the cell wall on the inner aqueous system also contributes to Ψ_ω along with the dissolved solutes. Thus Ψ_ω is comprised of Ψ_s and Ψ_p (solute potential and pressure potential and pressure potential). Due to the difference in solute potentials of adjacent cells, water moves from high Ψ_ω to low Ψ_ω until equilibrium is attained. This movement is also restricted by the pressure potential created by the water entering from one cell to another.

Therefore, solute potential and pressure potential both play a role in equilibrating Ψ_ω in adjacent cells.

In a hypothetical situation, plant cells P, Q and R were placed in the arrangement as shown on the right.



(a) Based on the values given for the cells P and R at time zero, fill the missing value in the table below.

Cell	Ψ_S(MPa)	Ψ_P(MPa)	Ψ_W(MPa)
P	–8	2	
R		2	–3

(b) At a stage when the system is at equilibrium and there is no external solute being added or pressure acting on above three cells, the water potential of the system is close to –7. What would be the Ψ_ω of Q at time zero?

(c) Show the water movement immediately after time zero, using an arrow diagram. Draw all possible interaction in a single diagram.

(d) At time zero, which one of these three cells is most likely to represent guard cell when the stomata needs to be opened?

Sol. (a) ψ_w of cell P = $\psi_s + \psi_p$

$= -8 + 2$

$\psi_w = -6$

(b) $\psi_w = -12$ $\quad P_{-b}\ Q_x$ at equilibirium = – 7

(c) 

(d) Q

34. Lions can feed on different wild animals such as zebra, wildebeest, pigs and gazelles. The efficiency of catching any particular prey will depend on a number of factors such as the net energy (E) gained by eating the prey, number of hours (s) required to search for the prey and handling time (h), i.e. the time taken to capture, kill and eat the prey. In order to maximize its overall rate of energy gain, a predator must consider the profitability (P) of the prey. It is defined as the ratio of energy gained to the time spent. Answer the following questions with a short justification (1-2 lines). Support your arguments with the data available to you.

Species	kg	h	s
Wildebeest	85	12.5	2.6
Zebra	80	11.3	4.1
Pig	37	6.8	17.8
Gran's Gazelle	27	8.0	10

(a) During the rainy season, both wildebeest and zebra are abundant. Which of them would be the preferred prey of the lion?

(b) On a regular hunt, while searching for its most preferred prey, the lion encounters a gazelle. Will it be more profitable for the lion to hunt the gazelle or leave it and continue the search?

(c) During a particular summer, all zebras and wildebeest from a jungle have migrated to another jungle. Thus, a lion is reduced to hunting either pigs or gazelles. In this situation, which would be the more profitable prey?

Sol. a $\rightarrow$ Wildebeest because of searching time is less than zebra.

b $\rightarrow$ Yes. It will hunt the gazelle.

c $\rightarrow$ Gazelle

35. Any change in an environmental parameter can have a large effect on an ecosystem. Consider a pond ecosystem. Some researchers designed an experiement to study the effect of certain treatments on food webs in pond ecosystems. Four artificial identical ponds (P, Q, R and S) were created and each was independently subjected to three treatments (W, N and F)

- W : warming of the water body
- N : addition of nutrients to the water
- F : introduction of predator fish.

Following the above treatments, each pond was studied for one of the following components,

i. Number of floating plants.

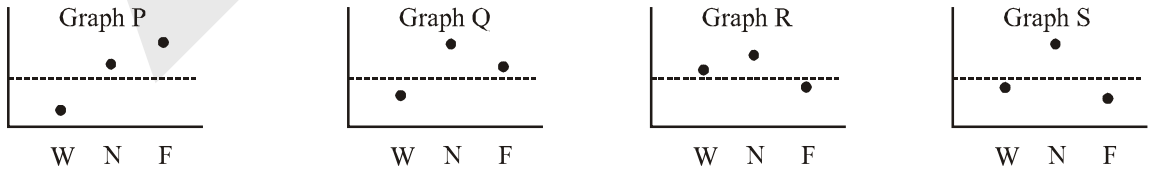
ii. Number of invertebrates.

iii. Number of plants at the bottom of the pond.

iv. Number of bacterial species.

The data obtained is represented in four graphs, where the horizontal dashed line in each figure indicates the baseline data.

Match the components (i, ii, iii, iv) with the graphs (P, Q, R and S). You MUST give a brief justification (2-3 lines) for each match.



Sol.

Graph–P	Graph–Q	Graph–R	Graph–S
(ii)	(i)	(iv)	(iii)