Indian National Junior Science Olympiad – 2020

Question Paper INJSO – 2020

Roll Number: ☐☐☐☐ - ☐☐☐☐ - ☐☐☐☐ Date: 1st February 2020

Duration: **Three Hours** Maximum Marks: 180

Please Note:

- Please write your roll number in the space provided above.
- Use of non-programmable scientific calculators is allowed.
- **The answer-sheet must be returned to the invigilator**. You can take this question paper back with you.
- Section I of this question paper has 15 questions.
  - For each question in this section, **only one** of the four options is a correct answer.
  - For each question, a correct answer will earn 3 marks, a wrong answer will earn (-1) mark, and an unattempted question will earn 0 marks.
  - If you mark more than one option, it would be treated as a wrong answer.
- Section II contains 9 questions worth 5 marks each. There is no negative marking.
  - For questions 16 to 21, one or more option(s) may be correct.
    - If you mark all correct options and no wrong option, you get full credit (5 marks).
    - If you mark some correct options and no wrong option, you get 2 marks.
    - If you mark any wrong option, you get zero marks.
  - For questions 22 to 24, only write your final answer in corresponding spaces in the answersheet. No explanation / calculations are necessary.
- Section III contains 11 questions.
  - For all the questions in this section, the process involved in arriving at the solution is more important than the final answer. Valid assumptions / approximations are perfectly acceptable. Please write your method clearly, explicitly stating all the reasoning / assumptions / approximations.
  - 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.

Useful Constants

Gravitational Constant	G	$\approx$	$6.674 \times 10^{-11}\,\mathrm{N\,m^2/kg^2}$
Gravitational acceleration	g	$\approx$	$9.80\ \mathrm{m/s^2}$
Avogadro constant	N_A	$\approx$	$6.022 \times 10^{23}/\mathrm{mol}$
Universal Gas Constant	R	$\approx$	$8.3145\,\mathrm{J/(mol\,K)}$
Atmospheric Pressure	1 atm	$\approx$	$101\,325\,\mathrm{Pa}$

1 **H** Hydrogen 1.008																	2 **He** Helium 4.003
3 **Li** Lithium 6.94	4 **Be** Beryllium 9.012											5 **B** Boron 10.81	6 **C** Carbon 12.011	7 **N** Nitrogen 14.007	8 **O** Oxygen 15.999	9 **F** Fluorine 18.998	10 **Ne** Neon 20.180
11 **Na** Sodium 22.990	12 **Mg** Magnesium 24.305											13 **Al** Aluminum 26.982	14 **Si** Silicon 28.085	15 **P** Phosphorus 30.974	16 **S** Sulfur 32.06	17 **Cl** Chlorine 35.45	18 **Ar** Argon 39.948
19 **K** Potassium 39.098	20 **Ca** Calcium 40.078	21 **Sc** Scandium 44.956	22 **Ti** Titanium 47.867	23 **V** Vanadium 50.942	24 **Cr** Chromium 51.996	25 **Mn** Manganese 54.938	26 **Fe** Iron 55.845	27 **Co** Cobalt 58.933	28 **Ni** Nickel 58.693	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.38	31 **Ga** Gallium 69.723	32 **Ge** Germanium 72.630	33 **As** Arsenic 74.922	34 **Se** Selenium 78.97	35 **Br** Bromine 79.904	36 **Kr** Krypton 83.798
37 **Rb** Rubidium 85.468	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.906	40 **Zr** Zirconium 91.224	41 **Nb** Niobium 92.906	42 **Mo** Molybdenum 95.95	43 **Tc** Technetium [97]	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.906	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.868	48 **Cd** Cadmium 112.414	49 **In** Indium 114.818	50 **Sn** Tin 118.710	51 **Sb** Antimony 121.760	53 **Te** Tellurium 127.60	53 **I** Iodine 126.904	54 **Xe** Xenon 131.293
55 **Cs** Cesium 132.905	56 **Ba** Barium 137.327	* 57 - 70	71 **Lu** Lutetium 174.967	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.948	74 **W** Tungsten 183.84	75 **Re** Rhenium 186.207	76 **Os** Osmium 190.23	78 **Ir** Iridium 192.217	79 **Pt** Platinum 195.084	80 **Au** Gold 196.997	81 **Hg** Mercury 200.592	81 **Tl** Thallium 204.38	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.980	84 **Po** Polonium [209]	85 **At** Astatine [210]	86 **Rn** Radon [222]
87 **Fr** Francium [223]	88 **Ra** Radium [226]	** 89 - 102	103 **Lr** Lawrencium [262]	104 **Rf** Rutherfordium [267]	105 **Db** Dubnium [270]	106 **Sg** Seaborgium [269]	107 **Bh** Bohrium [270]	108 **Hs** Hassium [270]	109 **Mt** Meitnerium [278]	110 **Ds** Darmstadtium [281]	111 **Rg** Roentgenium [281]	112 **Cn** Copernicium [285]	113 **Nh** Nihonium [286]	114 **Fl** Flerovium [289]	115 **Mc** Moscovium [289]	116 **Lv** Livermorium [293]	117 **Ts** Tennessine [293]	118 **Og** Oganesson [294]

*Lanthanide series	57 **La** Lanthanum 138.905	58 **Ce** Cerium 140.116	59 **Pr** Praseodymium 140.908	60 **Nd** Neodymium 144.242	61 **Pm** Promethium [145]	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.964	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.925	66 **Dy** Dysprosium 162.500	67 **Ho** Holmium 164.930	68 **Er** Erbium 167.259	69 **Tm** Thulium 168.934	70 **Yb** Ytterbium 173.045
**Actinide series	89 **Ac** Actinium [227]	90 **Th** Thorium 232.038	91 **Pa** Protactinium 231.036	92 **U** Uranium 238.029	93 **Np** Neptunium [237]	94 **Pu** Plutonium [244]	95 **Am** Americium [243]	96 **Cm** Curium [247]	97 **Bk** Berkelium [247]	98 **Cf** Californium [251]	99 **Es** Einsteinium [252]	100 **Fm** Fermium [257]	101 **Md** Mendelevium [258]	102 **No** Nobelium [259]

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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. $\dfrac{\rho_1 x_1 - \rho_2 x_2}{x_1 - x_2}$ **B.** $\dfrac{\rho_1 x_2 - \rho_2 x_1}{x_2 - x_1}$ C. $\dfrac{\rho_1 x_2 + \rho_2 x_1}{x_1 + x_2}$ D. $\dfrac{\rho_1 x_2 - \rho_2 x_1}{x_1 - x_2}$

Solution:

$$V\rho g - V\rho_1 g = kx_1$$
$$\therefore \rho - \rho_1 = \left(\frac{k}{V.g}\right) x_1$$
$$\text{and } \rho - \rho_2 = \left(\frac{k}{V.g}\right) x_2$$
$$\therefore \rho = \frac{\rho_1 x_2 - \rho_2 x_1}{x_2 - x_1}$$

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 °C, 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.

Solution:

Joule heating (and hence rise in temperature) is always there. As the resistance decreases with temperature, and the voltage is constant, the current will also go on increasing.

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

Solution:

In all, the piece has to move 3 steps towards right and 3 steps upwards. i.e. total 6 moves. As the 3 rightward moves are identical and 3 upward moves are identical, the problem reduces to fixing 3 moves out of 6 that are rightwards (remaining automatically will be upwards).
The 20 paths can be listed as (r for right and u for up)

rrruuu	rurruu	ruurru	uurrur	ururru
rruuur	rururu	ruuurr	uururr	urruru
rruuru	ruruur	uuurrr	uruurr	urruur
rruruu	ruurur	uurrru	ururur	urrruu

Alternatively, the total number of paths will be

$$^6C_3 = \frac{6!}{3!3!} = \frac{\cancel{2} \times \cancel{3} \times 4 \times 5 \times \cancel{6}}{\cancel{2} \times \cancel{3} \times \cancel{2} \times \cancel{3}} = 20$$

4. A train is moving at a speed of $v = 108\,\text{km/h}$ 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

Solution:

Let T be the instant of time when the train starts blowing the whistle and d be the distance between whistle and the person, at this instant.

Thus, the person starts receiving the sound of whistle at the instant $t_1 = T + \frac{d}{350}$

In next 7 seconds , (i.e., at $t = T + 7$) the train comes 210 m closer to the person, from where the blowing of whistle stops.

This change (stopping of whistle) takes the time $\frac{(d-210)}{350}$ seconds to reach the person.

Thus, it is received by the person at $t_2 = T + 7 + \frac{(d-210)}{350}$

$\therefore$ The time duration for which the person hears the whistle is $t_2 - t_1 = 7 - \frac{210}{350} = 6.4\,\text{s}$

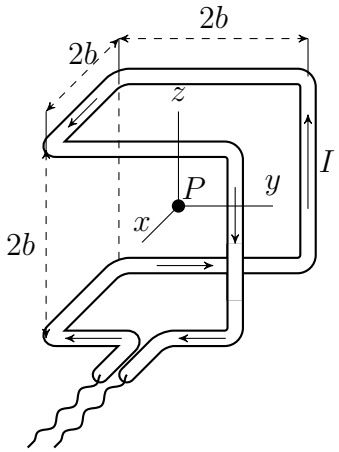
Alternately, according to Doppler effect, with standard conventions (source approaching a stationary listener),

$\frac{t}{t_0} = \frac{T}{T_0} = \frac{n_0}{n} = \frac{(v - v_s)}{v}$

(v = speed of sound, v_s = speed of source)

$\therefore T = T_0\frac{(v - v_s)}{v} = 7\frac{(350 - 30)}{350} = 6.4\,\text{s}$

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).

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**

Solution:

$2\,Pb(NO_3)_2 + \text{Heat} \longrightarrow 2\,PbO + 4\,NO_2 + O_2$

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. $Cs_2O < K_2O < MgO < SrO$

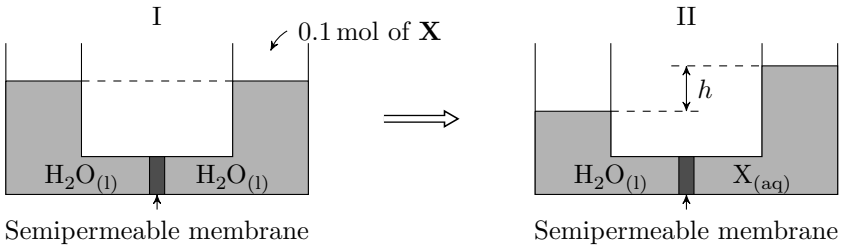
C. $MgO < SrO < K_2O < Cs_2O$

D. $K_2O < MgO < SrO < Cs_2O$

Solution:

Basic character increases down the group and decreases across the period.

8. A U-shaped tube with a semipermeable membrane is filled with 2 L 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 $\boldsymbol{h}$ would be the highest when **X** is

A. $MgCl_2$ B. CH_3COOH C. NH_4NO_3 D. Cane Sugar

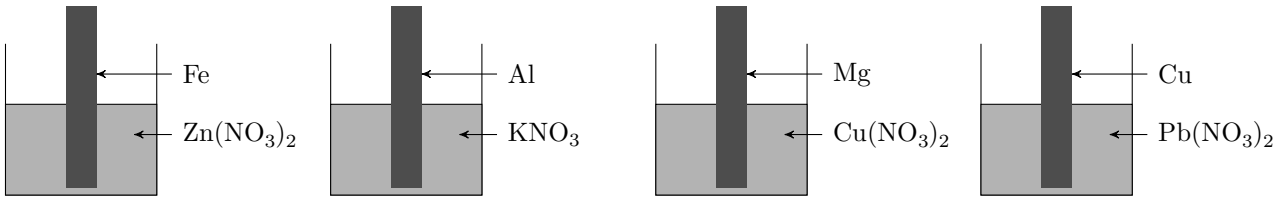
Solution:

In figure II, the difference in water level arises due to the osmotic pressure exerted by the solute particles. Depending on the solute type, different number of solute particles are released into water, and exerts osmotic pressure. When 0.1 mol of each solute is added to water, following amount of solute particles will be released:

- $MgCl_2$: 0.3 mol of particles
- CH_3COOH : $\frac{1+\alpha}{10}$ mol of particles $(0 < \alpha < 1)$
- NH_4NO_3 : 0.2 mol of particles
- Sugar : 0.1 mol of particles

  Therefore, the osmotic pressure will be in the order,
  $MgCl_2$ solution > $CaSO_4$ solution > CH_3COOH solution > Sugar solution

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 1 M salt solution. At room temperature, the displacement reaction will significantly occur in



A. B. C. D.

Solution:

Magnesium is more reactive than copper so it will displace copper from its salt solution, where as all others are less reactive than corresponding salt solutions. Thus, the answer is **(C)**.

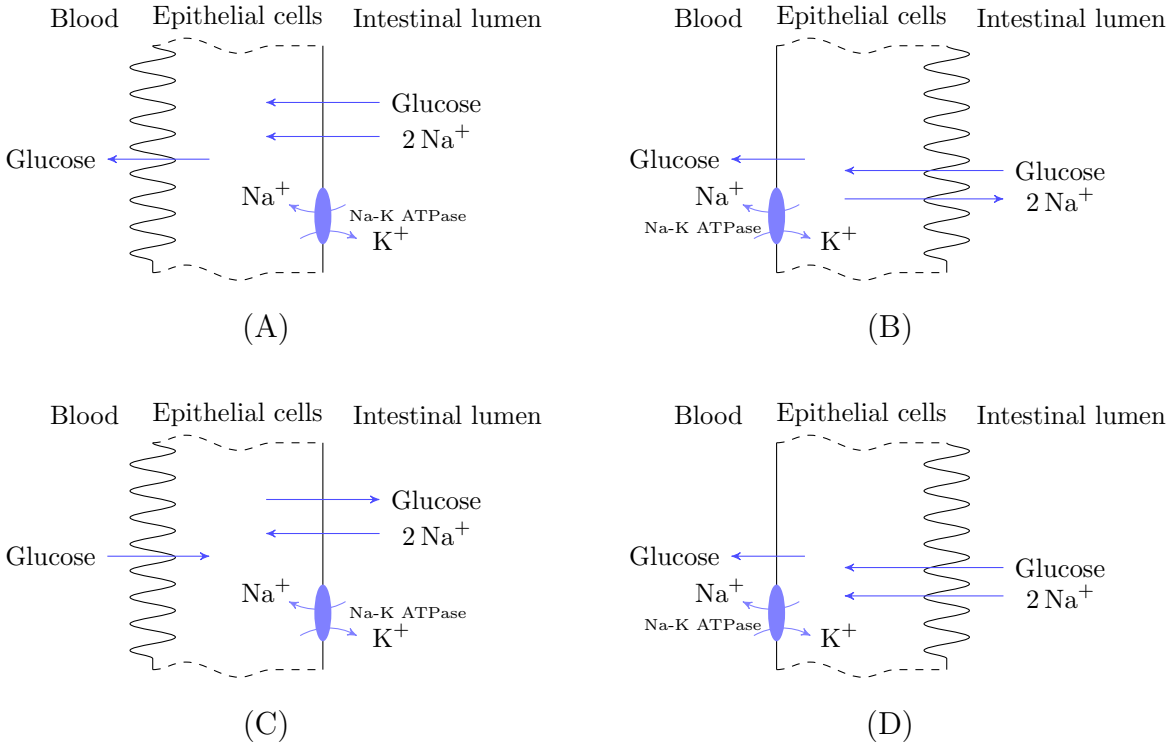
10. Soaps are sodium salts of fatty acids. Which of the following can be added to a pure soap to bring its pH to 7?

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

Solution:

pH of pure soaps is more than 7. To bring the pH to 7, one needs to add some acid to it.

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?



Solution:

An increase in glucose and Na^+ concentration in the blood stream due to ORS creates a transepithelial osmotic gradient and forces water movement into the blood stream. Thus both Na^+ and glucose should enter the lumen. Intestinal lumen has fingerlike projections through which Na^+ and glucose enter. Thus, the answer is D.

Adapted from https://www.ncbi.nlm.nih.gov/books/NBK21739/ Molecular Cell Biology, Lodish, Section 15.8. Osmosis, Water Channels, and the Regulation of Cell Volume

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 populations have evolved into separate species?

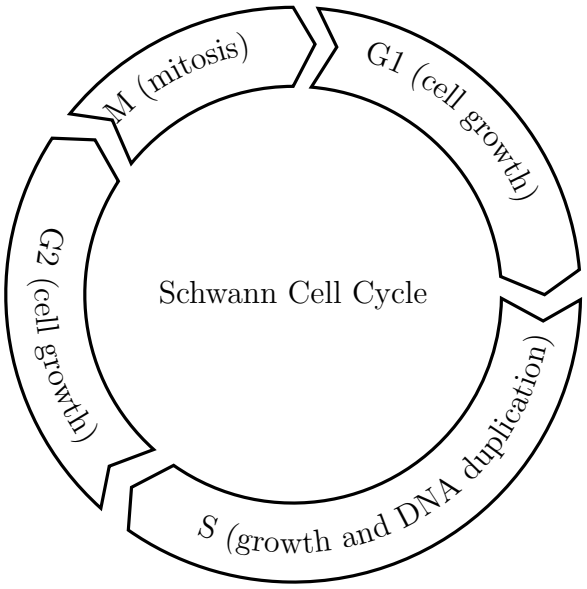
    A. The two populations differ in at least five morphological traits.

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

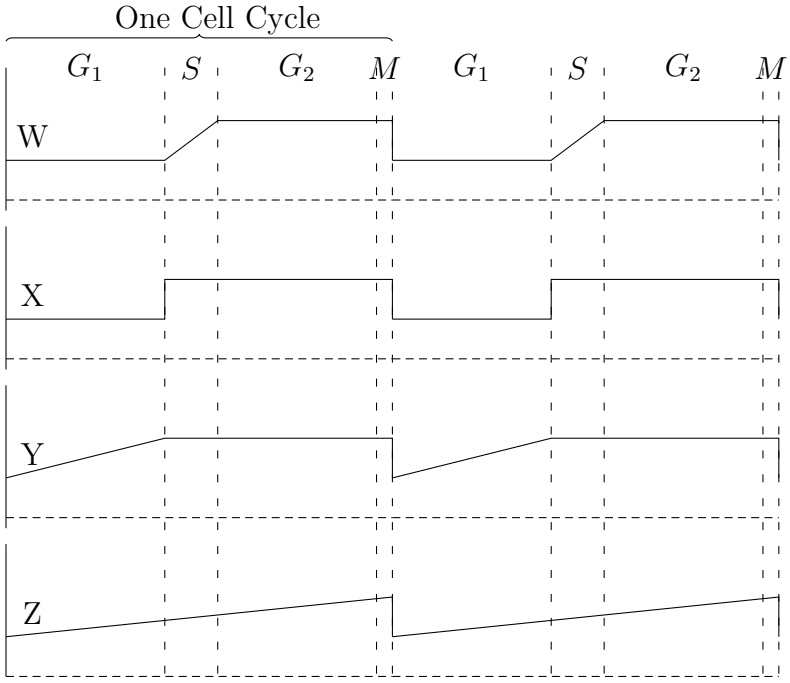
C. Organisms of both the populations do not willingly mate with each other.

D. DNA sequences are different for the two populations.

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 daughter cells which are genetically identical to the mother cell.



Among the graphs shown below, one represents the 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**

Solution:

Cell volume should keep increasing throughout till M phase and as S phase is characterised as the phase for genetic material duplication, the increase in genetic material will happen over the entire time of S phase.

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.

Solution:

An understanding of the relative size of organelles is necessary to appreciate that a common light microscope will only be able to detect the nucleus and the idea that nucleus contains DNA and hence is highly acidic and will therefore efficiently bind a basic dye like methylene blue.

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?

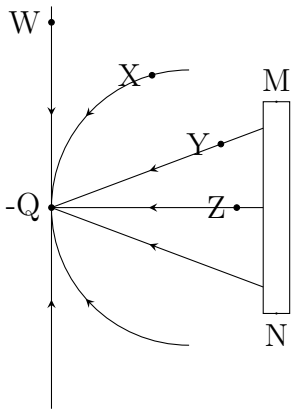
    A. 25% **B. 50%** C. 75% D. 100%

Solution:

If R is the allele for round seeds and r is the allele for wrinkled seeds, then a cross between two plants, one bearing round seeds and other bearing wrinkled seeds, with entire F_1 progeny of round seeds, must be represented as $RR \times rr$. Now, for F_2 progeny, you will get the progeny in the ratio of $RR : Rr : rr = 1 : 2 : 1$. Thus, out of 800 alleles, 400 are R.

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) the drawn lines of force definitely do(es) NOT match the actual lines of force?



A. W B. X **C. Y** D. Z

Solution:

At point W, the field line should incline towards the plate.
At point X, the field should appear to be terminating on the plate along a *normal*.
At point Y, it can be correct and at point Z, it is correct.
Thus, (A) and (C) are the correct options.

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

Solution:

We note that any point object, placed on the principal axis, will have its image at the same point, if it is either at distance $2f$ or if it is at the pole.
Possibility 1: One end at $2f$, the other end beyond $2f$. This gives $v = \frac{-50}{3}$cm.
Possibility 2: One end at $2f$, the other end between f and $2f$.
This gives $v = -30$ cm
Possibility 3: One end at pole, the other 5 cm from the pole. This gives $v = 10$ 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.

Solution:

Option (A) is possible for uniform motion.

Option (B) is possible if the uniform nonzero acceleration is opposite to the initial velocity. The two intervals of $\Delta\ t$ will then be just before and just after the velocity momentarily becomes zero (Object thrown vertically upwards, etc.)

Option (C) corresponds to simple harmonic motion. In this case, the intervals are just before and just after crossing the mean position, or extreme position.

Option (D) is part of option (B).

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 g **of ester is produced.**

C. 24×10^{21} **molecules of ester are produced.**

D. The product contains 9.6×10^{22} **carbon atoms.**

Solution:

Chemical reaction:
$CH_3COOH + CH_3CH_2OH_{(Acid)} \longrightarrow CH_3COOCH_2CH_3$

One mole of ethanoic acid combines with one mole of ethanol to give one mole ester

3 g of ethanoic acid $= \frac{3}{60} \approx 0.05$ mol

1.84 g of absolute ethanol$= \frac{184}{46} \approx 0.04$ mol

0.04 mol of absolute ethanol will combine with 0.04 mol of ethanoic acid to give 0.04 mol ester.

1 mol of an ester contains 6.022×10^{23} molecules. Hence, 0.04 mol of the ester contains $6.022 \times 10^{23} \times 4 = 24 \times 10^{21}$ molecules.

One molecule of the ester contains 4 atoms of carbon. Number of carbon atoms in the product is $4 \times 24 \times 10^{21} = 9.6 \times 10^{22}$

Molecular mass of the ester formed ($CH_3COOC_2H_5$) is 88.

Hence weight of ester $= 0.04 \times 88 = 3.52$ g

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.**

Solution:

$^{14}_{7}N$ contains 7P + 7E + 7N

but $^{14}_{7}N^{3-}$ contains 7P + 10E + 7N

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

A. $_{5}Q$, $_{19}X$ **B. $_{12}Z$, $_{38}J$** C. $_{9}E$, $_{15}L$ **D. $_{20}G$, $_{12}Z$**

Solution:

Electronic configuration(EC) of valance orbit is similar, Chemical properties depend on EC

- EC of Q 2,3
- EC of X 2,8,8,1
- EC of Z 2,8,2
- EC of J 2,8,18,8,2
- EC of E 2,7
- EC of L 2,8,5
- EC of G 2,8,8,2

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 RBCs 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.

Solution:

- The diagonal of the table should be ignored as RBCs of any individual won't show any agglutination with plasma from the same individual.
- As RBCs from individual S show agglutination in all cases, the blood group for S is **AB**.
- As RBCs from individual R show agglutination in all cases, the blood group for R is **O**.
- Individuals Q and T have the same blood group.
- As plasma from Q has antibodies against antigen A, the blood group for Q and T is **B**.
- As individual P shows reverse response to that of Q, the blood group for P is **A**.

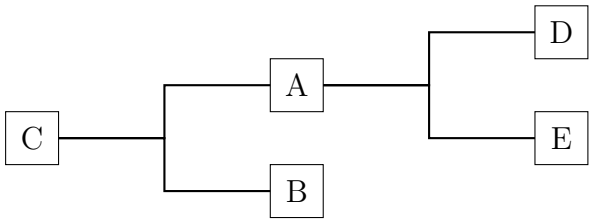
23. Molecular phylogeny is used to trace the changes in DNA or protein backwards in time to find out when each change led to divergence. The following are the amino acid sequences of a protein derived from the DNA sequences of 5 different organisms (sequences A to E).

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.

Solution:



Obviously, positions of D and E can be interchanged.

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:

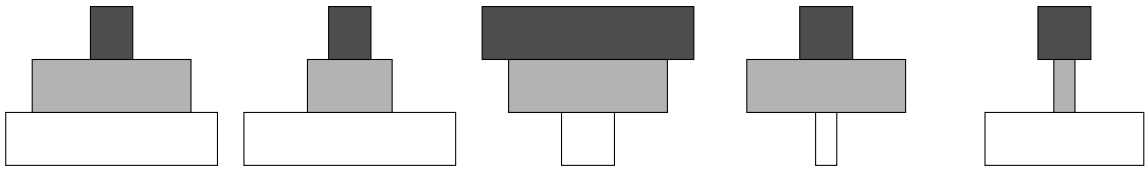
    i. Number pyramid of an ecosystem consisting of grasses, snails and mice.

    ii. Number pyramid of an ecosystem consisting 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)

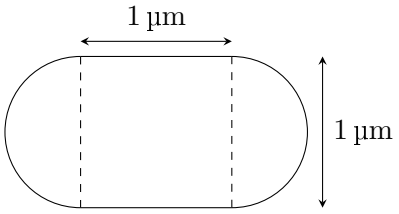
Solution:

i - P, ii - S, iii - Q and iv - R

P & Q may be interchanged.

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 1 µm and the length of its cylindrical part is also 1 µm (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?

Solution:

(a) To calculate average distance, the simplest approach will be to assume that the cells are identical and uniformly distributed in the medium.

10^9 cells/mL means a volume of 10^{-9} mL $= 10^3\,\mu m^3$ is available for each cell.
Thus, the mean intercell distance (centre to centre) $= \sqrt[3]{10^3} = 10\,\mu m$.

(b)

$$V_{E.coli} = \frac{4}{3}\pi(0.5)^3 + [\pi(0.5)^2 \times 1] = 1.31\,\mu m^3$$

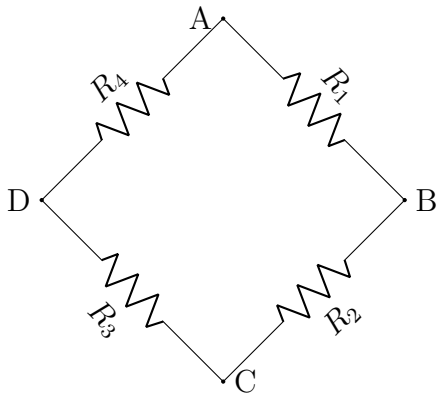
$$\therefore \frac{1}{V_{E.coli}} = \frac{1}{1.31\,\mu m^3} = \frac{1}{1.31 \times 10^{-15}\,L}$$

$$= \left(\frac{1}{1.31 \times 10^{-15} \times 6.023 \times 10^{23}}\right) M$$

$$= 1.27 \times 10^{-9}\,M = 1.27\,nM$$

$\therefore$ 1.27 nM concentration corresponds to 1 protein molecule in the volume of 1 cell of *E.coli*.
$\therefore$ 20 nM concentration will correspond to $\frac{20}{1.27} = 15.7$ protein molecules per cell.
As number of protein molecules will always be integer, we need at least 16 molecules per cell.

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 $6\,\Omega$ or an integral multiple of $6\,\Omega$ (All need not be different).
A multimeter connected between points A and C reads $8\,\Omega$ (say, $R_{AC} = 8\,\Omega$). Calculate R_{AB}, R_{BC}, R_{CD}, R_{DA} and R_{BD}.



Solution:

Given: $\dfrac{(R_1 + R_2)(R_3 + R_4)}{(R_1 + R_2) + (R_3 + R_4)} = 8\,\Omega$
Thus, $(R_1 + R_2)$ and $(R_3 + R_4)$ are those multiples of 6, for which the ratio of product and sum is 8.
Only such options are 12 and 24.
Alternately, let $R_1 + R_2 = 6m$ and $R_3 + R_4 = 6n$.....$(m, n \geq 2)$
$\therefore R_{AC} = 8 = \left(\frac{mn}{m+n}\right) \times 6$.
One possible integral option for m and n are 2 and 4.
$\therefore R_1 = R_2 = 6\,\Omega$ and $R_3 = R_4 = 12\,\Omega$
$\therefore R_{AB} = R_{BC} = 5\,\Omega$; $R_{CD} = R_{DA} = 8\,\Omega$ and $R_{BD} = 9\,\Omega$

Alternatively, one can take three of the resistances to be $6\,\Omega$ and last one (say R_4) as $18\,\Omega$. In that case, the values will be,

$R_{AB} = R_{BC} = R_{CD} = 5\,\Omega$; $R_{DA} = 9\,\Omega$; $R_{BD} = 8\,\Omega$

Due to symmetry of the circuit, we can write more solutions with same numerical values at different locations of resistors.
Thus, there is one more case similar to first solution and three more cases similar to second solution.

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

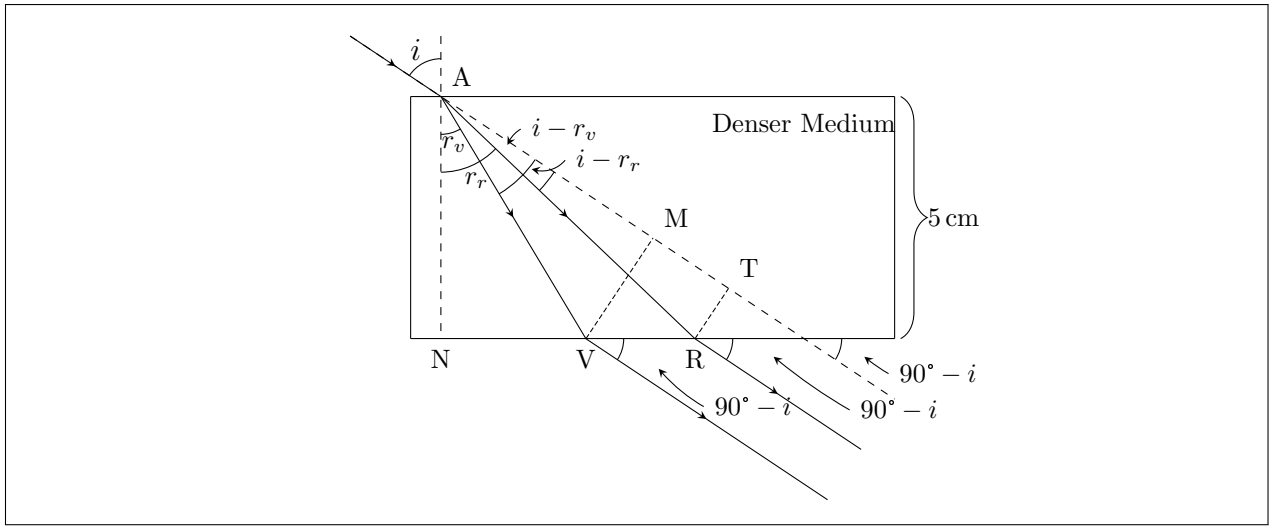
    (a) A spherical lens is a transparent medium bound by spherical surfaces. A glass marble can therefore be considered as a lens. Consider a glass marble (refractive index 1.50) of radius 15.00 mm. Using the geometrical optics formulae taught in high school, Prajakta calculated the focal length of this 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.

Solution:

(a) Geometrical optics formulae are applicable only for a thin lens. The marble can no more be considered as a thin lens for the measurements given.

(b) Refer the following figure: There is lateral dispersion but not angular, as long as the two refracting surfaces are parallel to each other. The emergent rays are parallel to each other with no angular dispersion (or no direction wise separation).
Thus, the wording "spread out in different directions" is not correct as the refracting surfaces are given to be parallel.



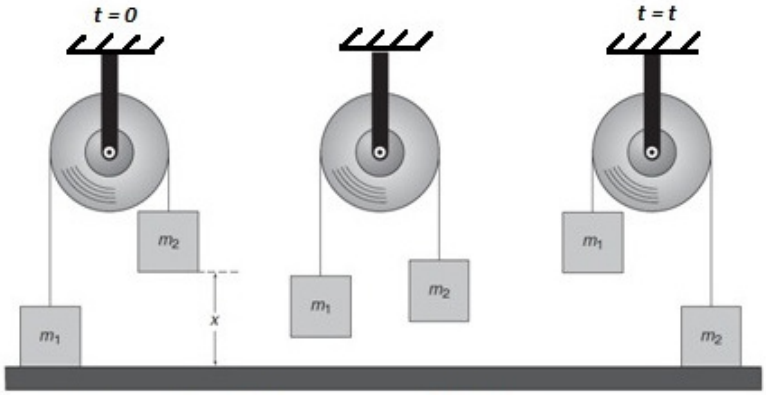
28. (15 marks) The free body diagram (a diagram that shows forces on individual objects) for an Atwood's machine (a system with a rope passing over a fixed pulley, with two masses attached at either end of the rope – see the figure) yields the following equation:

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

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 $x = 1.00\,\text{m}$. 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

Solution:

Free body diagram gives equation $(m_2 - m_1)g = (m_2 + m_1)a$

From equation of motion for mass m_2, as initial velocity $u = 0$ m/s,

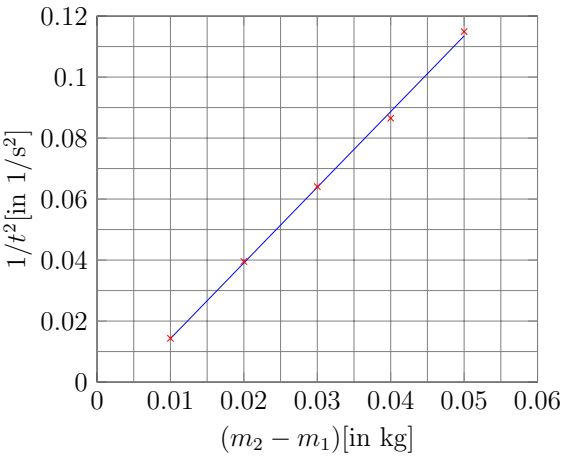
$x = \dfrac{at^2}{2} \Rightarrow a = \dfrac{2x}{t^2}$

Linearization of the equation gives

$(m_2 - m_1) = (m_2 + m_1)\dfrac{2x}{g}\left(\dfrac{1}{t^2}\right)$

Graph of $(m_2 - m_1)$ against $\dfrac{1}{t^2}$ is to be plotted.

$(m_2 - m_1)$ (in g)	$(m_2 - m_1)$ (in kg)	t (in s)	t^{-2} (in $1/s^2$)
10.0	0.0100	8.35	0.01434
20.0	0.0200	5.03	0.03952
30.0	0.0300	3.95	0.06409
40.0	0.0400	3.40	0.08651
50.0	0.0500	2.95	0.11491



$$\text{Slope of the graph} = 2.48\,\text{s}^2/\text{kg}$$

$$\therefore \frac{2x(m_2 + m_1)}{g} = \frac{1}{\text{slope}} = 0.4030\,\text{kg/s}^2$$

$$\therefore (m_2 + m_1) = \frac{0.4030 \times 9.80}{2 \times 1.00}$$

$$(m_2 + m_1) = 1.97\,\text{kg}$$

One can also plot $\dfrac{1}{(m_2 - m_1)}$ vs t^2 or $\dfrac{1}{\sqrt{(m_2 - m_1)}}$ vs t or $\dfrac{1}{t}$ vs $\sqrt{(m_2 - m_1)}$. All these will also lead to linear plots. However, they will lead to slightly different values of slope and hence different values of $m_1 + m_2$. All such solutions are evaluated based on their own calculations, although they differ from model answer.

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.

Solution:
Molar mass of CO_2 is $12 + 32 = 44$ g/mol
Extra CO_2 emitted by the engine after fitting of catalytic coverter is $132 - 110 = 22$ g
This 22 g = 0.5 M CO_2 is a result of catalytic coversion.

$$2\,CO + O_2 \longrightarrow 2\,CO_2$$

From the reaction, it is clear that number of moles of CO_2 produced by catalytic conversion are same as the number of moles of CO converted.
The diagram indicates that only 90% of CO is converted by the catalyic converter.
Molar mass of CO is $12 + 16 = 28$ gram/mol
Thus, mass of CO produced by engine will be,

$$0.5 \times \frac{10}{9} \times 28 = 15.55\,\text{g}$$

(b) Arnav travelled from Jodhpur to Bikaner by car, a distance of 256 km. Fuel efficiency of the car is 16 km/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.

Solution:
Fuel required for the travel = $\frac{256}{16} = 16$ L.
As seen in previous part, due to catalytic converter, $\frac{22}{110} = 20\%$ extra CO_2 is produced.
Thus, weight of CO_2 released $= 16 \times 2.3 \times 1.2 = 44.16$ kg

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

Solution:
Molar mass of CO_2 is 44 g
Thus, 44.16 kg of CO_2 contain

$$\frac{44.16}{0.044} \approx 1004\,\text{mol}$$

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

Solution:
From the first part when we get 132 g of CO_2, it includes CO_2 produced by conversion 15.55 g of CO by the engine.

Thus, 1.55 g of CO remains unconverted.
Thus, if total CO_2 is 44.16 kg, the unconverted CO is

$$\frac{1.555 \times 44.16}{132} \approx 520\,\text{g}$$

30. (16 marks) The year 2019 was proclaimed by UNESCO as the International Year of the Periodic Table (IYPT 2019), marking the 150$^{\text{th}}$ 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 $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$, $\boldsymbol{\gamma}$, 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) Elements $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$ are unreactive monatomic gases. $\boldsymbol{\beta}$ has the smallest atomic radius of the three, and $\boldsymbol{\alpha}$ has a higher boiling point than $\boldsymbol{\gamma}$.
Identify elements $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$.

Solution:
$\boldsymbol{\alpha}$ = Ar, $\boldsymbol{\beta}$ = He and $\boldsymbol{\gamma}$ = Ne

The elements $\boldsymbol{\delta}$, $\boldsymbol{\epsilon}$, $\boldsymbol{\Omega}$, $\boldsymbol{\psi}$, $\boldsymbol{\theta}$, **X** and **Q** exist as diatomic molecules (i.e. $\boldsymbol{\delta}_2$, $\boldsymbol{\epsilon}_2$, $\boldsymbol{\Omega}_2$, $\boldsymbol{\psi}_2$, $\boldsymbol{\theta}_2$, $\mathbf{X_2}$ and $\mathbf{Q_2}$). We also know that, at room temperature, $\mathbf{X_2}$ is a liquid and $\mathbf{Q_2}$ is a solid; the other five are gases.

(b) Identify element **X** and **Q**.

Solution:
X = Br and **Q** = I

$\boldsymbol{\psi}_2$ forms compounds with each of the other six diatomic elements. Compounds of $\boldsymbol{\psi}$ with $\boldsymbol{\delta}$, $\boldsymbol{\epsilon}$, and **X** result in diatomic gases that react with the liquid $\boldsymbol{\psi}_2\boldsymbol{\theta}$ to form acidic solutions.

(c) Identify elements $\boldsymbol{\psi}$ and $\boldsymbol{\theta}$. Also write a balanced chemical reaction to show how they combine with each other.

Solution:
$\boldsymbol{\psi}$ = H and $\boldsymbol{\theta}$ = O
$2\,H_2 + O_2 \longrightarrow 2\,H_2O$

(d) $\boldsymbol{\delta}$ has the highest electronegativity of these elements. The reaction between $\boldsymbol{\Omega}_2$ and $\boldsymbol{\psi}_2$ is of immense industrial importance, the product being a gas that reacts with liquid $\boldsymbol{\psi}_2\boldsymbol{\theta}$ to form a basic solution. Identify elements $\boldsymbol{\delta}$, $\boldsymbol{\epsilon}$ and $\boldsymbol{\Omega}$ and write balanced chemical reactions of the processes described here.

Solution:
$\boldsymbol{\delta}$ = F, $\boldsymbol{\epsilon}$ = Cl and $\boldsymbol{\Omega}$ = N
$N_{2(g)} + 3\,H_{2(g)} \longrightarrow 2\,NH_{3(g)}$
$NH_{3(g)} + H_2O_{(l)} \longrightarrow NH_4OH_{(aq)}$

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 $\mathbf{PV = nRT}$ 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 $\boldsymbol{\kappa}$, $\boldsymbol{\lambda}$, $\boldsymbol{\mu}$ and $\boldsymbol{\nu}$, which are metals that react vigorously with liquid $\boldsymbol{\psi_2\theta}$ to produce $\boldsymbol{\psi_2}$ and a basic solution.

(e) 1 g of element $\boldsymbol{\lambda}$ reacts with excess $\boldsymbol{\psi_2\theta}$ to produce 0.3080 L of $\boldsymbol{\psi_2}$ at 20 °C and pressure of 1 atm. (Assume that $\boldsymbol{\psi_2}$ behaves as an ideal gas under the given conditions.)
Write possible balanced chemical reaction(s), calculate possible atomic mass(es) of element $\boldsymbol{\lambda}$ and deduce the name of this element.

Solution:
From the description, it is clear that $\boldsymbol{\lambda}$ is either a group 1 or group 2 element.
Number of moles of H_2 are given by

$$n = \frac{PV}{RT} = \frac{101\,325 \times 0.3080 \times 10^{-3}}{8.3145 \times 293.15} = 0.0128\,\text{mol}$$

Case 1: If it is a group 2 element, the balanced chemical reaction would be,

$$\boldsymbol{\lambda} + 2H_2O \rightarrow \boldsymbol{\lambda}(OH)_{2(aq)} + H_2 \uparrow$$

In this case, every mole of $\boldsymbol{\lambda}$ produces 1 mole of H_2, The number of moles in 1 g of $\boldsymbol{\lambda}$ are 0.0128 mol. Thus, the atomic mass of $\boldsymbol{\lambda}$ is $\frac{1}{0.0128} = 78.02\,\text{g/mol}$
By periodic table, closest element is Selenium (atomic number 38). But question says the atomic number should be 20 or less. So this answer is not correct.

Case 2: If it is a group 1 element, the balanced chemical reaction would be,

$$2\boldsymbol{\lambda} + 2H_2O \rightarrow 2\boldsymbol{\lambda}(OH)_{(aq)} + H_2 \uparrow$$

As every 2 moles of $\boldsymbol{\lambda}$ produces 1 mole of H_2, The number of moles in 1 g of $\boldsymbol{\lambda}$ are 0.0256 mol. Thus, the atomic mass of $\boldsymbol{\lambda}$ is $\frac{1}{0.0256} = 39.01\,\text{g/mol}$
Thus, the element $\boldsymbol{\lambda}$ is Potassium (K).

(f) $\boldsymbol{\kappa}$ is more reactive than $\boldsymbol{\nu}$. The stable ions formed from $\boldsymbol{\lambda}$ and $\boldsymbol{\mu}$ in this reaction have the same electron configuration. Identify elements $\boldsymbol{\kappa}$, $\boldsymbol{\mu}$, $\boldsymbol{\nu}$.

Solution:
$\boldsymbol{\kappa}$= Na; $\boldsymbol{\mu}$ = Ca and $\boldsymbol{\nu}$ = Li

(g) Elements $\boldsymbol{\xi}$, $\boldsymbol{\sigma}$ and $\boldsymbol{\phi}$ are also metals. They do not react with cold $\boldsymbol{\psi_2\theta}$ but do react with $\boldsymbol{\theta_2}$ to form $\boldsymbol{\xi\theta}$, $\boldsymbol{\sigma_2\theta_3}$ and $\boldsymbol{\phi\theta}$ respectively. Out of these, $\boldsymbol{\phi\theta}$ contains the largest percentage of $\boldsymbol{\theta}$ by mass. Identify the elements $\boldsymbol{\xi}$, $\boldsymbol{\sigma}$, $\boldsymbol{\phi}$ and write these balanced chemical reactions.

Solution:
$\boldsymbol{\xi}$ = Mg; $\boldsymbol{\sigma}$ = Al and $\boldsymbol{\phi}$ = Be
$2\,Mg + O_2 \longrightarrow 2\,MgO$
$4\,Al + 3\,O_2 \longrightarrow 2\,Al_2O_3$
$2\,Be + O_2 \longrightarrow 2\,BeO$

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 unscientific 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.

Solution:
$2\,FeAsS + 5\,O_2 \longrightarrow Fe_2O_3 + As_2O_3 + 2\,SO_2$

(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.

Solution:
$As_2O_3 + 3\,H_2O \longrightarrow 2\,H_3AsO_3$

(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.

Solution:

Molecular mass of $As_2O_3 = (2 \times 74.92) + (3 \times 16) = 197.84\,g$
$\therefore$ Number of moles of As_2O_3 in 1 L= $\frac{20.6}{197.84} = 0.104\,mol$
From equation, 1 mol of oxide forms 2 mol acid.
$\therefore$ Concentration of acid =0.208 mol/L

In homeopathy, a 'decimal-scale' is often used to specify the dilution of a given sample: D1 (sometimes labelled 1X) 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*.

Solution:
Mass of As_2O_3 in 1 L D30 solution = $\frac{20.6}{10^{30}} = 2.06 \times 10^{-29}\,g$
$\therefore$ Mass in $100\,cm^3 = 2.06 \times 10^{-30}\,g$

(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?

Solution:
Molar mass of As_2O_3 is 197.84 g/mol.
Each bottle of D30 solution contains 2.06×10^{-30} g of As_2O_3.
$\therefore$ Number of atoms of As in each bottle = $N_A \times \dfrac{2.06 \times 10^{-30} \times 2}{197.84} = 1.254 \times 10^{-8}$ atoms
$\therefore$ Number of bottles needed for 1 atom = $\dfrac{1}{1.254 \times 10^{-8}} = 7.97 \times 10^7 \approx 80$ million

(f) Total volume of water on the Earth is estimated to be about $1.4 \times 10^9\,km^3$. If our stock solution at the start is 1 L 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.

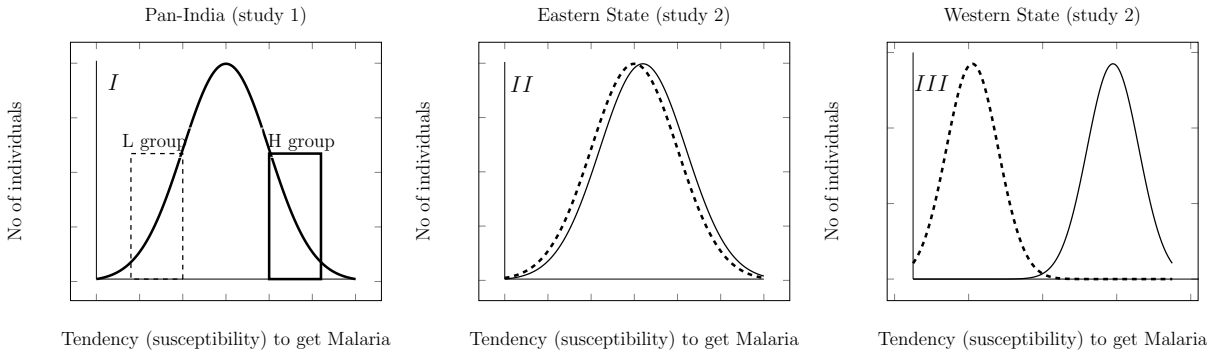
Solution:
The volume of water = $1.4 \times 10^9\,km^3 = 1.4 \times 10^{21}$ L
Thus, you can at max achieve a D21 level dilution by using all the water on the planet.

32. (10 marks) 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.



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 lines) 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.

Solution:

(i) **False**. The **information** from graph 1 is **not enough** to suport such definitive conclusion.

(ii) **False**. The data is for susceptibility for Malaria. There is **not enough information** to extrapolate the same to chance of mosquito bite.

(iii) **True**. As seen graph 2, both L and H group populations **approximately have same distribution as in graph 1**.

(iv) **False**. As per the information available to us, the researchers have not uncovered any genetic basis for high susceptibility. Thus, presently there is **no basis to consider a possibility of genetic basis of high susceptibility**.

(v) **True**. The H group in the east merely fell in H group due to random chance, whereas H group in the West has some **non-random basis for their high susceptibility**.

(vi) **True**. L group in West is dominated by people whose **malarial susceptibility is determined by non-random factors**, including possible genetic factors.

(vii) **True**. As malaria and flu have unrelated causative agents and are different diseases, hence **immunity against one will not dictate immunity against the other**. The information available to us gives no indication about difference in susceptibility to flu for different individuals.

(viii) **False**. Scurvy is caused by **vitamin-C deficiency** and has no relation to malaria.

(ix) **True**. This is a **likely cause of non-random incidence of high susceptibility** as seen in the graph.

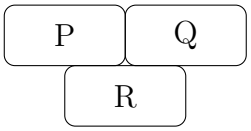
(x) **True**. There is fair chance that L group in the West **includes individuals who have developed genetic immunity** for malaria, possibly through sickle cell anemia.

33. (7 marks) In any plant body, movement of the water highly depends on water potential of

cells, denoted by Ψ_w. The Ψ_w of pure water is zero by definition. Typically, when solutes dissolve in water, Ψ_w becomes negative.

In a cellular environment, pressure exerted by the cell wall on the inner aqueous system also contributes to Ψ_w along with the dissolved solutes. Thus Ψ_w is comprised of Ψ_s and Ψ_p (solute potential and pressure potential). Due to the difference in solute potentials of adjacent cells, water moves from high Ψ_w to low Ψ_w 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_w 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 values in the table below.

Cell	Ψ_s (MPa)	$\Psi_p(MPa)$	$\Psi_w(MPa)$
P	-8	2	
R		2	-3

Solution:

Cell	Ψ_s (MPa)	$\Psi_p(MPa)$	$\Psi_w(MPa)$
P	-8	2	**-6**
R	**-5**	2	-3

2.0

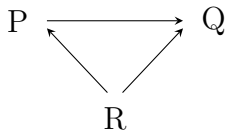
(b) At a stage when the system is at equilibrium and there is no external solute being added or pressure acting on above three cells, the water potential of the system is close to -7. What would be the Ψ_w of Q at time zero?

Solution:
Thus, the initial Ψ_w for Q will be
$-7 \times 3 - (-6) - (-3) = -12$

2.0

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

Solution:



2.0

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

Solution:
Q. As it has most negative value of ψ_w

1.0

34. (5 marks) 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
Grant'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?

Solution:

Species	kg	h	$P = \frac{E}{h}$	s	$P_s = \frac{E}{(h+s)}$
Wildebeest	85	12.5	6.8	2.6	5.6
Zebra	80	11.3	7.0	4.1	5.1
Pig	37	6.8	5.8	17.8	1.5
Grant's Gazelle	27	8.0	3.4	10	1.5

Since P of wildebeest is 6.8 and that of zebra is 7.0, hunting the zebra is more profitable.

(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?

Solution:

As P_s of wildebeest is 5.6 and P for gazelle is 3.4, it is still profitable to ignore the gazelle and search for wildebeest.

(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?

Solution:

No preference to either of them as profitability is same 1.5 in both cases.

Note: As most of the data available has only two significant digits, the profitability value should also be rounded to two significant digits. After rounding, both values are 1.5.

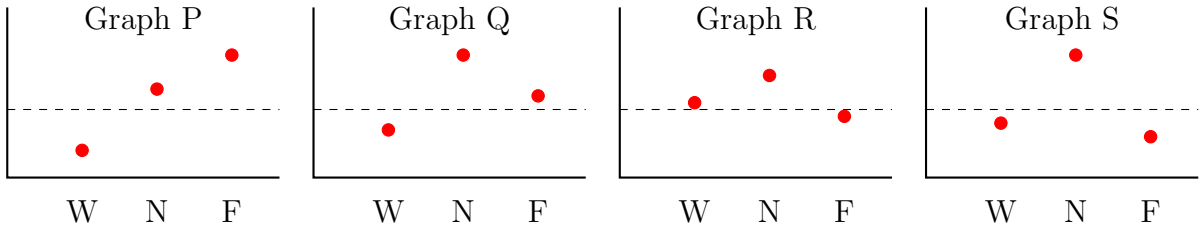
35. (8 marks) Any change in an environmental parameter can have a large effect on an ecosystem. Consider a pond ecosystem. Some researchers designed an experiement to study the effect of certain treatments on food webs in pond ecosystems.
Four artificial identical ponds (P, Q, R and S) were created and 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.

Solution:

First thing to note is that no numerical values have been specified on y-axis and hence changes can only be discussed in qualitative terms.
In all four graphs, addition of nutrients leads to rise in number. Smaller rise in some cases, larger rise in other cases. So treatment N may not be a good discriminator.
We note that component 4 is "number of bacterial **species**", i.e. we are more interested in diversity of species and not necessarily the total count of all bacteria. The diversity of species in an artificial pond will not be significantly affected by any of these treatments. Thus, in all three cases, we expect the dots to be relatively close to baseline.
When you warm the water slightly, one may expect that slightly more number of bacterial species may find the conditions thriving. On the other hand, when the predator fish are introduced, they might consume complex life forms on which some bacterial species can thrive and hence there may be slight reduction in the diversity. Thus, **Graph R** will be best representation for **component iv**.
Introduction of predator fish increases numbers significantly in graph P and decreases numbers significantly in graph S. In a food chain, plants at the bottom of the pond are food for invertebrates and the same invertebrates are food for predator fish. When invertebrates numbers go down, number of plants at the bottom of the pond will go up. Thus, **Graph P** will be best representation for **component iii** and **Graph S** will be best representation for **component ii**. As an additional confirmation, warming of water reduces dissolved oxygen in water, which will affect bottom-dwelling plants more than it

would affect the invertebrates. Hence, for W treatment, one sees a bigger reduction in graph P as compared to graph S.
Lastly, we look at graph Q. Even slight warming of water adversely affects dissolution capacity of oxygen in water. So it is possible that some of the floating plants will not able to thrive in warmer water and numbers may go down. Thus, **Graph Q** will be best representation for **component i**.