Date: 29/01/2023

Max. Marks : 300 **Time : 2 hours**

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

Questions & Answers

for

Indian National Biology Olympiad (INBO) - 2023

INSTRUCTIONS TO CANDIDATES

(1) The question paper is divided into **Sections A** and **B**. All answers should be written in the answer booklet only which will be collected at the end of the examination. The question paper need not be submitted to the examiner.

(2) **Section A**

- Section-A consists of **32** questions carrying **1 point** each.
- All 32 questions are of multiple-choice type, with only one correct answer for each question.
- Mark the correct answer with '✓' in the answer booklet provided. The correct way of marking is shown below. Use a pen to mark your answer.

Q. No.	a	b	c	d
		✓		

- Each wrong answer will have negative marking as indicated in the scoring key.

(3) **Section B**

- Section B consists of **24** questions with a total of **68 points**.
- The points for the questions in section B vary depending on the number of answers and the complexity of the question. These points have been indicated along with the question.

SECTION-A

CELL BIOLOGY (6 points)

1. **(1 point)** Which of the following sets of chemicals and/or instrument can be used to prepare sodium phosphate buffer of approximately pH 7.0?

   I. Na_2HPO_4 salt, NaH_2PO_4 salt and water.

   II. NaH_2PO_4 salt, NaOH solution and pH meter.

   III. Na_2HPO_4 salt, water and pH meter.

   IV. Stocks of: NaH_2PO_4 solution, Na_2HPO_4 solution and water.

   (pKa values for phosphoric acid: 2.12, 7.21, 12.32)

   (a) Only I
   (b) Only IV
   (c) Only I, II and IV
   (d) I, II, III and IV

Answer (c)

Sol. Phosphoric acid is a triprotic acid which undergoes a stepwise dissociation as follows:

$$H_3PO_4 \overset{K_1}{\rightleftharpoons} H^+ + H_2PO_4^{-1} \quad \sim 2.12$$

$$H_2PO_4^- \overset{K_2}{\rightleftharpoons} H^+ + HPO_4^{-2} \quad \sim 7.21$$

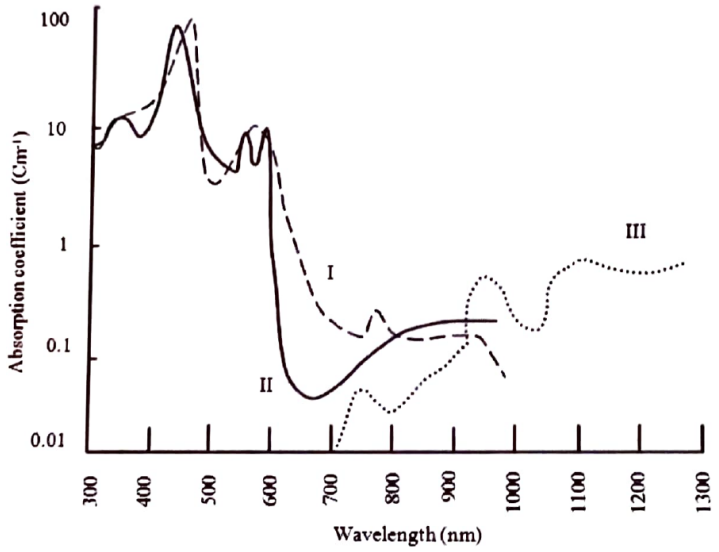
$$HPO_4^{-2} \overset{K_3}{\rightleftharpoons} H^+ + PO_4^{-3} \quad \sim 12.32$$

A buffer must have an acid/base conjugate pair as per Henderson Hasselbalch equation. Na_2HPO_4 and NaH_2PO_4 are conjugate pair. They will make buffer solution.

$$pH = pK_{a_2} + \log 10 \frac{\left[HPO_4^{-2}\right]}{\left[H_2PO_4^{-1}\right]}$$

pH of this buffer will vary from $pK_{a_2} \pm 1$

2. **(1 point)** Absorption/transmission spectrum of a compound often provides information about its physical property such as color. Absorption spectra of three compounds are shown below.



I, II and III respectively represent:

(a) hemoglobin, oxyhemoglobin and water.
(b) oxyhemoglobin, hemoglobin and water.
(c) water, hemoglobin and oxyhemoglobin.
(d) oxyhemoglobin, water and hemoglobin.

Answer (a)

Sol. I. Hb

II. HbO_2

III. Water

Plotted absorption spectral curve shows two high absorption peaks at 540 and 576 nm and an absorption valley at 560 nm, when partial pressure of oxygen is higher than 100 mm Hg (oxyhaemoglobin.) So, curve II represents absorption spectrum of oxyhaemoglon. Graph I represent haemoglobin as it mainly absorbs light, below 600 nm. Visible red light is more easily absorbed by water than other visible wave lengths.

3. **(1 point)** A student was studying transport of a solute 'X' through the erythrocyte membrane in a laboratory. She obtained the following data:

Expt.	[x] outside (mM)	Rate of Entry of X (umoles/min)
I	0	0
II	0.5	7
III	1.0	14
IV	2.0	26
V	3.0	35
VI	5.0	38

Which of the following can be deduced from the observations?

(a) The experiments I-VI were carried out at successively increasing temperatures.

(b) The nature of solute must be highly non-polar.

(c) Increase of solute concentration outside has resulted in proportional increase in rate of entry of the solute into the cell.

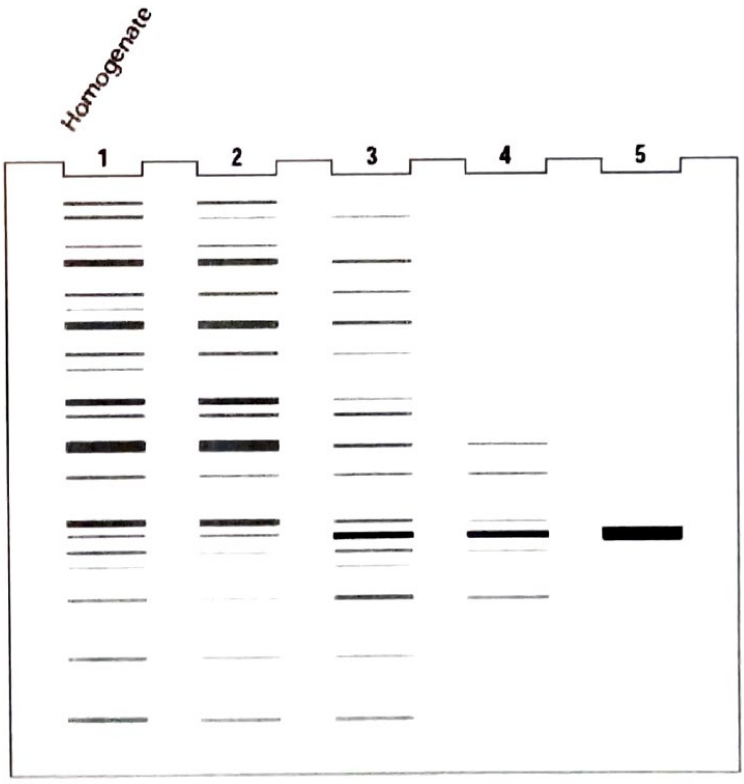
(d) The major limiting factor for the rate of entry is the carrier protein transporter.

Answer (d)

Sol. As from V – VI experiment the rate of entry of X is almost showing saturation w.r.t. [X] outside, thus, the major limiting factor for the rate of entry could be a carrier protein transport. This could be attributed to the fact that the carrier protein transport is reaching saturation leading to the saturation of 'X' molecule uptake.

These experiments cannot be carried out at increasing temperature as RBC membrane being biological is susceptible towards higher temperature.

4. **(1 point)** Biochemical purification of a protein from a cell extract often requires several purification steps involving various techniques. The purification process can be followed by gel electrophoresis of the starting protein mixture i.e., the cell homogenate and the fractions obtained from each subsequent purification step. Shown here are the schematic depictions of separation of proteins on a gel for the starting mixture of proteins (lane 1) and samples taken after each of the several purification steps.



If lanes 1 and 2 indicate the separation of proteins from the crude cell homogenate and after salt fractionation respectively, then which of the techniques are represented in lanes 3, 4 and 5 respectively?

(a) Ion exchange chromatography; affinity chromatography and gel filtration chromatography

(b) Gel filtration chromatography; ion exchange chromatography and affinity chromatography

(c) Affinity chromatography; ion exchange chromatography and gel filtration chromatography

(d) Ion exchange chromatography; gel filtration chromatography and affinity chromatography

Answer (d)

Sol. The protein purification should be done in a following manner:

1. Cell homogenate proteins
2. Proteins separated by salt fractionation
3. Percolation of the elution from step 2 to ion-exchange chromatography. Proteins with the lowest affinity for the ion-exchange resin passed directly through the column and were collected in earliest fractions eluted from the bottom of column. The remaining proteins were eluted in sequence according to their affinity for the resin. It is represented in lane 3.
4. The fraction obtained from step 3 were subjected to gel filtration and the separation will be based upon mass. It is represented in lane 4.
5. The fraction obtained from step 4 were subjected to affinity chromatography. As this chromatography is based on specific interaction between the ligand and its substrate. So, after the separation a single molecule will be present in the column as all other samples will elute out. So, it is represented in lane 5.

5. **(1 point)** One of the oxygen utilizing enzymes, cytochrome P450 catalyzes the following reaction:

$$R-H+NADPH+H^{+}+O_2 \rightleftharpoons R-OH+NADP^{+}+H_2O$$

These enzymes are also found useful in detoxification of xenobiotics (chemicals foreign to an organism). Which of the following is the most likely mode of action of these enzymes?

(a) They create a non-reducing environment by utilizing NADPH, thus nullifying the effect of the xenobiotics.

(b) They create anaerobic conditions in the cell by utilizing oxygen and thus decreasing the effect of the xenobiotics.

(c) They convert the xenobiotics to its polar form, which is easy to be excreted.

(d) They promote oxidative phosphorylation to generate ATP for detoxification of the xenobiotics.

Answer (c)

Sol. Four stages can be distinguished in the process of absorption, metabolism & cellular excretion of xenobiotics, namely

I. **Influx by transporter enzymes:** Organic Anion Transporting Polypeptide (OATP), Organic Anion Transporter (OAT) and Sodium Taurochlorate Cotransporting Polypeptide (NTCP) are involved in the influx of xenobiotics.

II. **Biotransformation in phase I and phase II mediated by drug-metabolizing enzymes:** Phase-I enzyme, which includes the cytochrome P450s (CYPs) superfamily—the major contributor, catalyzes the oxidation reduction or hydrolysis of primarily lipophilic xenobiotics into more polar molecules. The introduction of polar groups by phase I reactions provide sites that enable conjugation reactions, mediated by phase II enzymes. Phase II metabolites that are produced after phase II reactions has increased hydrophilicity and molecular weight, which in large part are not able to diffuse across phospholipid membrane.

III. Phase III xenobiotic transporters excrete hydrophilic conjugates.

By converting xenobiotics into polar forms, it can be passively transported across membrane without input of energy.

6. **(1 point)** A dichotomous key for a few cell components is given below.

1a. Found in cytosol....go to 2

1b. Found in nucleus....A

2a. Membrane-bound structure....go to 3

2b. Structure is not membrane bound....B

3a. Flattened sheet-like structure....go to 4

3b. Spherical or elongated structure....go to 6

4a. Smooth exterior....go to 5

4b. Rough exterior....C

5a. Involved in lipid metabolism....D

5b. Several spherical vesicles found in vicinity....E

6a. Bound by single membrane....go to 7

6b. Bound by double membrane....F

7a. Contains oxidative enzymes....G

7b. Contains hydrolytic enzymes....H

E, F and G respectively most likely represent:

(a) SER; Mitochondria and Lysosome
(b) Lysosome; Mitochondria and Peroxisome
(c) Golgi; Mitochondria and Peroxisome
(d) Golgi; Peroxisome and Lysosome

Answer (c)

Sol. Characteristics of E are: Found in cytosol
Membrane-bound structure
Flattened sheet-like structure
Smooth exterior
Several spherical vesicles found in vicinity

These characters are exhibited by Golgi complex.

Characteristics of Fare: Found in cytosol
Membrane-bound structure
Spherical or elongated structure
Bound by double membrane

These characters are exhibited by mitochondria

Characteristics of G are: Found in cytosol
Membrane-bound structure
Spherical or elongated structure
Bound by single membrane
Contains oxidative enzymes

These characters are exhibited by peroxisomes.

PLANT SCIENCES (7 points)

7. **(1 point)** Water movement via soil and within different parts of a plant can take place through various pathways. The major transport in the soil and through the cell walls respectively occur via:

(a) Apoplast and symplast.
(b) Symplast and apoplast.
(c) Bulk transport and apoplast.
(d) Apoplast and transmembrane pathway

Answer (c)

Sol. The apoplastic pathway involves the transportation of water from root hair to xylem through the cell wall of intervening cells.

In plant major transport of water occurs via bulk transport.

8. **(1 point)** Secondary wall thickening and lignification of tracheids and vessels is considered an important adaptation for water transport because:

(a) Lignification of the walls gives strength to tall plants.
(b) The hydrophobic nature of lignin helps plants absorb water more efficiently
(c) Strong lignin walls resist collapse of column structure which would result from high surface tension of water.
(d) Biodegradability of lignin being very low, it gives plants protection from various infections.

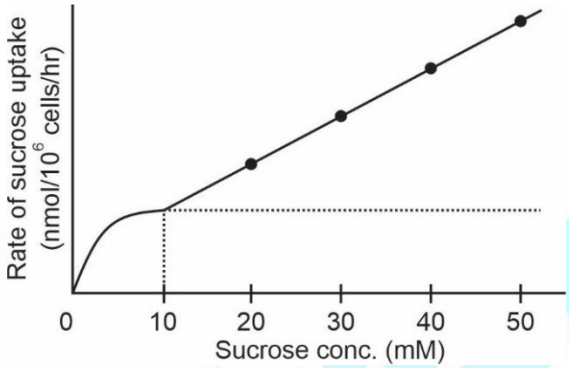
Answer (c)

Sol. The surface tension of xylem sap (due to water) plays a crucial role in plant hydraulics. It is responsible for the tensions occurring in the xylem network of vascular plants, as air-water menisci in the small cell wall pores of the leaf mesophyll do not allow air to enter the system. Transpiration at the leaf level thus causes negative pressure. The transmission of water is based on the strong cohesive and adhesive forces of water, meaning that the xylem sap is in metastable state.

Such a transport is constrained by a risk of collapse of the water column (due to metastable state of water under negative pressures) and conduit walls (due to the centripetal forces exerted on conduit walls that may implode if wall mechanical reinforcement is deficient).

Lignification of xylem walls was a mechanical adaptation to prevent vessel implosion and support plant body.

9. **(1 point)** Transport of solutes or ions into or within plant cells is regulated by the plasma membrane. When sucrose uptake by soybean cells was studied at different sucrose concentrations, the following graph was obtained.



Mark the correct interpretation.

(a) Upto 10 mM concentration of sucrose, uptake is by a carrier molecule while later it shifts to simple diffusion.

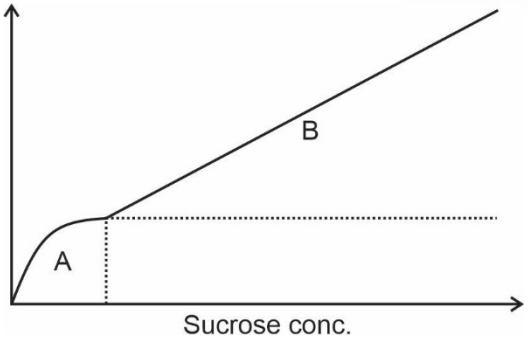
(b) It is likely that soybean cell membrane has more than one transporters that have different affinities for sucrose molecules.

(c) At initial sucrose concentration, the transport indicates typical saturation kinetics, which is indicative of active transport.

(d) Initial uptake of sucrose leads to oxidative phosphorylation leading to rise in rate of sucrose uptake.

Answer (b)

Sol.



The non-saturable phase is not a characterization of simple diffusion. As sucrose is a larger and polar molecule which cannot pass through plasma membrane. The uptake of sucrose requires transport protein. Phase A can be described being mediated by a high affinity/low-capacity mechanism and phase B can be described as a low affinity/high-capacity mechanism. Thus, it may be inferred that more than one transporter is involved in the uptake of sucrose.

10. **(1 point)** Phytoalexins are a type of oligosaccharin molecules which act as defense molecules in case of any pathogenic attack in plants. Which of the following is the correct sequence of attack and defense?

(a) Fungal invasion of plant cells → Pectinase secreted by plant cells → Phytoalexins produced by plant cells.

(b) Fungal invasion of plant cells → Chitinase secreted by plant cells → Phytoalexins produced by fungal cells.

(c) Plant cell invades fungal body → Pectinase secreted by plant cells → Phytoalexins produced by plant cells.

(d) Fungal invasion of plant cells → Pectinase secreted by fungal cells → Phytoalexins produced by plant cells.

Answer (d)

Sol. Phytoalexins are produced by plant tissue in response to contact with a parasite to inhibit the growth of that parasite.

In a case of fungal attack and defense the sequence will be, first invasion of fungal into the plant body and subsequently affect the molecular mechanism of the plant cells. In this process, the fungi secrete various type of enzymes like pectinases, proteases and cellulases which enable them to penetrate the host plant by degradation of the cell wall and facilitating the colonization of the host plant. To counteract these attacks, plant employ a complex mechanism that involves multiple physical and biochemical defense, it includes synthesis and accumulation of phytoalexins which inhibits the fungal growth.

So, the correct sequence of attack and defense will be, fungal invasion of plant cells → Pectinase secreted by fungal cells → Phytoalexins produced by plant cells.

11. **(1 point)** Which among the following physiological changes occur when plants experience drought?

(i) Accumulation of abscisic acid

(ii) Accumulation of solutes

(iii) Increased photosynthesis

(iv) Increased stomatal conductance

(v) Increased cell elongation

(a) (i) and (ii)
(b) (i) and (iii)
(c) (ii) and (v)
(d) (iii) and (iv)

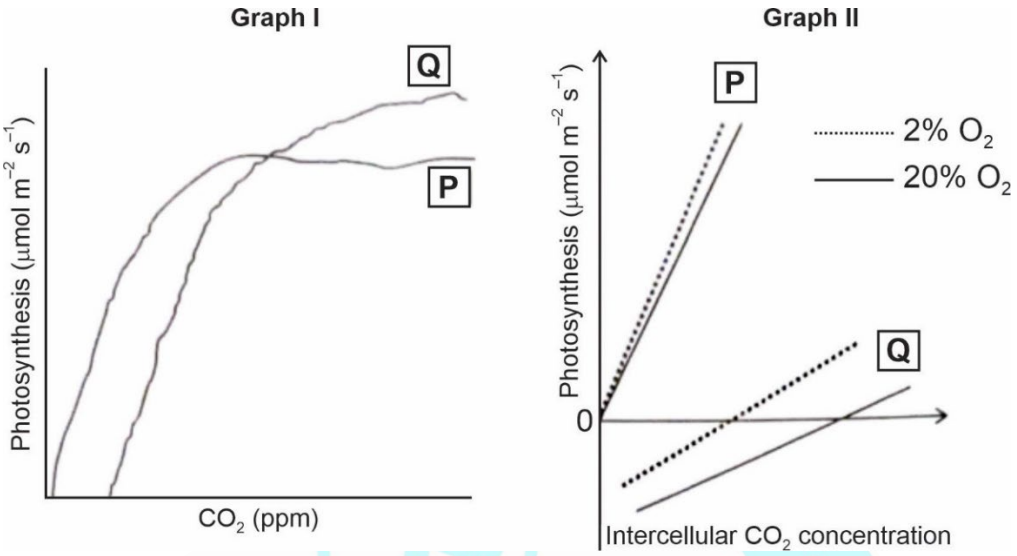
Answer (a)

Sol. Drought is one of the most severe environmental stresses affecting plant productivity. Different physiological, molecular, biochemical and ecological traits or processes of the plants are impaired under drought stress conditions.

(i) As abscisic acid is a phytohormone known as stress hormone, its synthesis increases due to increased expression of ABA responsive genes, although due to reduce translocation it results in accumulation of ABA in plants.

(ii) Accumulation of solutes occur because the condition relates to water deficit and it results in increase concentration of solute.

12. **(1 point)** A researcher was studying photosynthesis in two species of photoautotrophic diatoms **P** and **Q**. The efficiency of photosynthesis in terms of uptake of CO_2 was determined with increasing ambient CO_2 concentration (Graph I) and increasing intercellular CO_2 concentration at two different concentrations of O_2 (Graph II). Based on these experimental findings, diatoms **P** and **Q** respectively possess _____ and _____ pathway of photosynthesis.



(a) C3 and C4
(b) C4 and C3
(c) C3 and CAM
(d) C4 and CAM

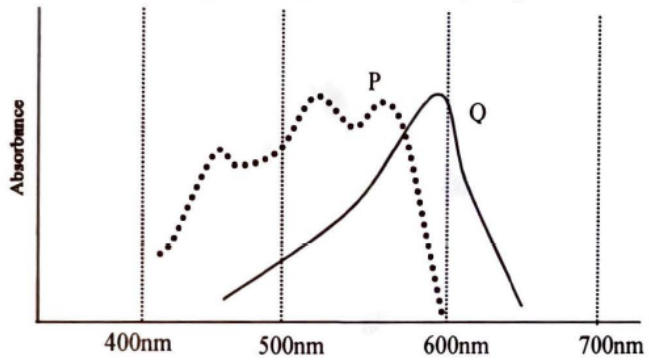
Answer (b)

Sol. The organisms that perform C_4 pathway show saturation in photosynthesis at about 360 μIL^{-1} but those organisms that perform C_3 pathway show saturation only beyond 450 μIL^{-1}.

Since, the organisms performing C_4 pathway for photosynthesis do not show photorespiration. So, the rate of photosynthesis in these organisms does not show much effect of change in concentration of O_2. On the other hand, organisms with C_3 pathway show photorespiration and the rate of photosynthesis will decrease much by increased O_2 concentration.

In this way diatoms P possess C_4 pathway and diatoms Q possess C_3 pathway of photosynthesis.

13. **(1 point)** Anika was studying pigments found in red algae. During this study, she extracted the pigments in different solvents. Following were the absorption spectra (P and Q) of the aqueous extracts. Select an option which correctly depicts the two pigments.



(a) P: Phycocyanin Q: Xanthophyll

(b) P: Chlorophyll a Q: Chlorophyll d

(c) P: Phycoerythrin Q: Phycocyanin

(d) P: Chlorophyll b Q: Phycoerythrin

Answer (c)

Sol. In red algae, containing chiefly phycoerythrin, the action spectrum closely resembles that of water-extracted pigments, with peaks corresponding to its absorption maxima at 495, 535 and 565 nm, algae included *Delesseria*, *Schizymenia* and *Porphyrella*, while in the genus *Porphyra*, there is a series *P. nereocystis*, *P. naiadum* and *P. perforate* with increasingly more phycocyanin and less phycoerythrin and shows absorption maxima at 600–620 nm.

Hence, phycoerythrin absorbs strongly in the middle of the visible spectrum (470–570 nm) and phycocyanin absorbs strongly at 600 nm.

Absorption spectra, P $\Rightarrow$ Phycoerythrin

Q $\Rightarrow$ Phycocyanin

ANIMAL SCIENCES (6 points)

14. **(1 point)** Among various types of digestive systems, horse exhibits a modified monogastric type of stomach and digestive system. The correct path of food in this type of digestive system is:

(a) Mouth $\rightarrow$ esophagus $\rightarrow$ stomach $\rightarrow$ small intestine $\rightarrow$ large colon $\rightarrow$ small colon $\rightarrow$ cecum $\rightarrow$ rectum $\rightarrow$ anus

(b) Mouth $\rightarrow$ esophagus $\rightarrow$ stomach $\rightarrow$ small intestine $\rightarrow$ cecum $\rightarrow$ large colon $\rightarrow$ small colon $\rightarrow$ rectum $\rightarrow$ anus

(c) Mouth $\rightarrow$ esophagus $\rightarrow$ cecum $\rightarrow$ stomach $\rightarrow$ small intestine $\rightarrow$ large colon $\rightarrow$ rectum $\rightarrow$ anus

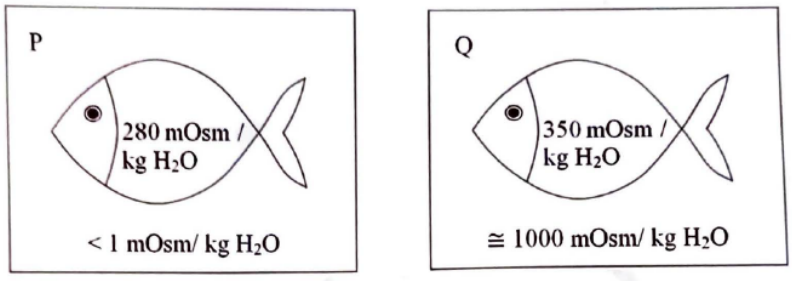
(d) Mouth $\rightarrow$ esophagus $\rightarrow$ cecum $\rightarrow$ small intestine $\rightarrow$ large colon $\rightarrow$ small colon $\rightarrow$ rectum $\rightarrow$ anus

Answer (b)

Sol. The correct answer is option (b) as horses are modified monogastric herbivores.

Food digestion starts at the mouth, then goes through the esophagus, stomach, small intestine and large intestine *i.e.*, caecum, large colon and then to small colon. The caecum is the place where fermentation occurs. Here, nutrients are taken from the food and then it goes through the rectum and out of the body *via* anus.

15. **(1 point)** Balance of internal environment or homeostasis is maintained in fish by different mechanisms. Two species of fish P and Q are shown in the figures. Which of the following correctly describes homeostasis in them?



(a) Fish P loses salt by diffusion and gains water by osmosis.

(b) Fish Q gain salt and water by diffusion and osmosis respectively.

(c) In fish P, active transport across skin helps recover the salts.

(d) In fish Q, active transport in kidneys helps to recover Mg^{+2}, SO_4^{-2} and other divalent cations.

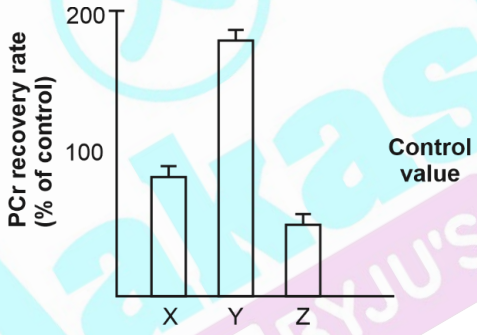
Answer (a)

Sol. The correct answer is option (a) as

Figure (P) represents fish in a fresh water environment whose osmolarity is much less than 50 $mOsmL^{-1}$ and the animal have blood osmolarity about 280 $mOsmL^{-1}$. The body fluid of animal is hypertonic to their surrounding environment so there is loss of body salt to the outside and entry of H_2O by osmosis.

Figure (Q) represents fish in a marine water environment where the body fluid of animal is hypotonic to seawater and thereby they tend to lose water from the body through permeable surfaces (gill membranes, oral and anal membranes).

16. **(1 point)** Requirement of energy during muscle contraction can be readily supplied by transfer of high energy phosphate bond from phosphocreatine (PCr) to generate ATP. However, resynthesis of used up PCr involves the rephosphorylation of creatine by aerobically produced ATP. PCr recovery rate in three individuals X, Y and Z is shown.



X, Y and Z most likely respectively represent:

(a) a sprinter, a distance runner and an individual with mitochondrial disease.

(b) a marathon runner, a sprinter and a healthy individual.

(c) a person above 80 years of age, a young adult and a child below 15 years.

(d) an old person with sedentary lifestyle, a young individual with active lifestyle and a young individual with sedentary lifestyle.

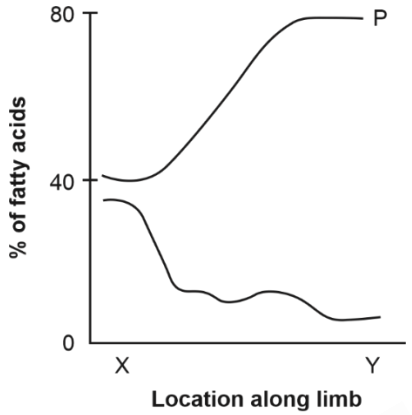
Answer (a)

Sol. The correct answer is option (a) as phosphocreatine recovery rate is faster in endurance track athletes than in middle distance runners and sprinters. A person with mitochondrial disease will have low phosphocreatine recovery rate because ATP production rate will be less.

Option (b) is incorrect as phosphocreatine recovery rate of healthy individual would be higher than that of a sprinter.

Option (c) is incorrect as phosphocreatine recovery rate of a person above 80 years of age will be lower than a child below 15 years.

17. Variations in the amount of fatty acids P and Q in the bone marrow lipids in the legs of an Arctic reindeer are shown below. X and Y indicate two locations along the limb.



P, Q, X and Y respectively represent:

(a) oleic acid, stearic acid, proximal part and distal part.

(b) palmitic acid, stearic acid, distal part and mid part.

(c) stearic acid, oleic acid, distal part and proximal part.

(d) stearic acid, palmitic acid, mid part and distal part.

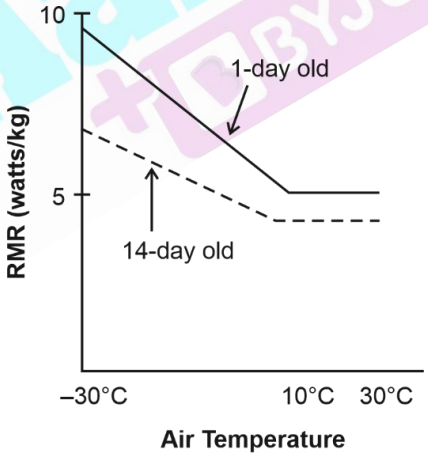
Answer (a)

Sol. The correct answer is option (a) as oleic acid is the most abundant fatty acid in deer's bone marrow, represented by P.

Mammals in the Arctic region (e.g., reindeer) have higher levels of unsaturated fatty acids in their legs and hooves than in the rest of their body.

Oleic acid will be less in proximal part than in distal part.

18. **(1 point)** Resting metabolic rates (RMR) as a function of ambient temperature for an animal, 1-day old and 14-day old, are shown.



Select the correct statement from the following.

(a) The continuous decrease in RMR upto 10°C shows that the animal is a heterotherm.

(b) The cost for thermoregulation decreases as the animal grows older.

(c) The body temperature of newborn is much higher than the older animal.

(d) As the animal grows older, the metabolic requirements of the animal decrease.

Answer (b)

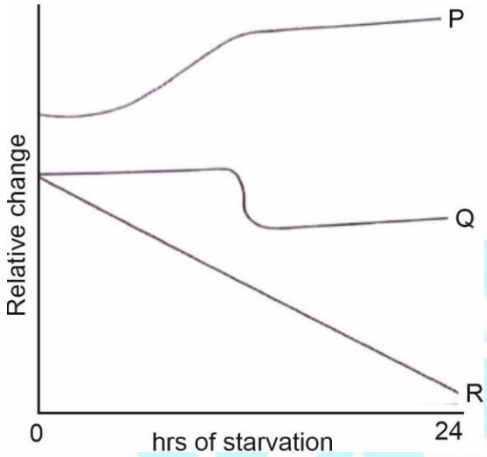
Sol. The correct answer is option (b) as cost for thermoregulation decreases as the animal grows older. Smaller the animal more will the BMR and more cost for thermoregulation because when animal grows older from day 1 to day 14, its size increases and cost for thermoregulation decreases.

Option (a) is incorrect as heterotherms can exhibit characters of both poikilotherms and homeotherms. The continuous decrease in RMR up to 10°C shows that animal is poikilotherm and not a heterotherm.

Option (c) is incorrect because body temperature of new born is lower than the older animal as in new born BMR is more, to regulate body temperature.

Option (d) is incorrect because animal's activity increases to increase energy requirement of the body so the metabolic requirement of animal also increases.

19. **(1 point)** Plasma levels of three biomolecules (P, Q and R) were measured during starvation of 24 hours and the following graph was obtained.



P, Q and R respectively are

(a) Free fatty acids, glucose and insulin
(b) Insulin, liver glycogen and free fatty acids
(c) Ketone bodies, glucagon and insulin
(d) Glucagon, glucose and liver glycogen

Answer (d)

Sol. (d) is the answer, Where R = liver glycogen, Q = glucose and P = glucagon

- Prolonged starvation leads to continued depletion of liver (storehouse of energy) glycogen to increase the availability of glucose.
- Glucagon levels increase initially and then become linear to maintain glucose levels (homeostasis).
- Glucose levels follow the declining trend (midway) followed by linear levels.

GENETICS AND EVOLUTION (6 points)

20. **(1 point)** Assume that independent orientation of chromosomes in meiosis and random union of gametes produced by male and female of a species are the only responsible factors for genetic variations in their offspring. If the diploid chromosome number of this species is 40, the number of possible combinations of chromosomes for their sperm/ovum is A^P and number of possible combinations of chromosomes for their offspring is B^Q, then values of A, B, P and Q would be

(a) A = 20, B = 20, P = 40, Q = 40
(b) A = 40, B = 40, P = 20, Q = 20
(c) A = 2, B = 2, P = 20, Q = 40
(d) A = 2, B = 2, P = 40, Q = 40

Answer (c)

Sol. The possible combination of chromosomes in gametes = 2^n

Here, n = haploid number of chromosomes.

In the question, diploid number is 40.

Therefore, haploid number, i.e., P = 20 and A = 2.

Similarly, the possible combination in offspring would be $(2^n)^2$.

Therefore, Q = 2 × n = 2 × 20 = 40

and B = 2

21. **(1 point)** Consider the genome of a diploid organism. The palindromic recognition site for the restriction enzyme P occurs once in a certain intergenic region of this genome. A mutation arises in the recognition site of P in this region of the genome that makes the new palindromic site susceptible to restriction enzyme Q but not to P anymore. This mutation spreads in the population. Consider (i) random mating and (ii) absence of any correlation of this mutation with fitness and (iii) P and Q are identical to each other except for the site they recognize. After a long time in evolutionary terms, most of the genomes in the population will be cleaved by

(a) Only P
(b) Only Q
(c) Neither P nor Q
(d) Both P and Q

Answer (d)

Sol. As mentioned in the question that population is in Hardy-Weinberg equilibrium.

As random mating occurs and that individuals with 'P' type genome are not completely eliminated, hence both P and Q restriction enzymes can act on their respective targets. Also, this mutation lies in intergenic region, thereby it does not affect the fitness levels.

22. **(1 point)** Consider a hypothetical species where meiotic cell division occurs after zygote formation. This organism is likely to be

(a) Sexual diploid
(b) Asexual diploid
(c) Sexual haploid
(d) Asexual haploid

Answer (c)

Sol. The organism mentioned in the question is showing zygotic meiosis. Zygote is formed in sexually reproducing organisms and the dominant stage of life cycle that shows zygotic meiosis is haploid.

23. **(1 point)** Considering the extant animals with flight, what is the minimum number of independent migration events to land assuming that life originated in oceans?

(a) 1
(b) 2
(c) 3
(d) 4

Answer (a)

Sol. Considering the extant (existing) animals with flight, the minimum number of independent migration event is one. As life originated in oceans, the first migration event was from water to land and second event was from land to air.

24. **(1 point)** Genetic drift is a random fluctuation in allelic frequencies owing to the variations in reproductive fitness in populations. The chance of drift causing gene fixation is highest

(a) In small populations

(b) In large populations

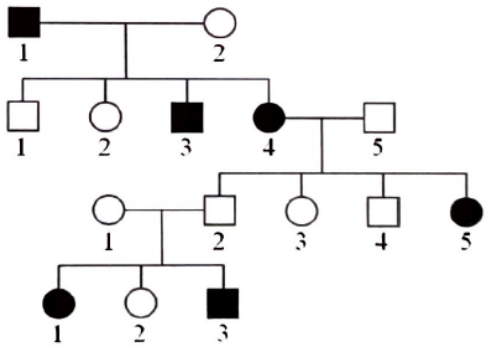
(c) When neutral genes are located near genes under selection

(d) When genes are under negative selection

Answer (a)

Sol. Genetic drift occurs in all populations of non-infinite size, but its effects are strongest in small population predominantly. Therefore, the chance of drift causing gene fixation is highest in small population.

25. **(1 Point)** A family pedigree for a rare body trait is shown below. The affected persons are shown as filled symbols.



The inheritance pattern of the trait is most likely to be:

(a) X-linked recessive

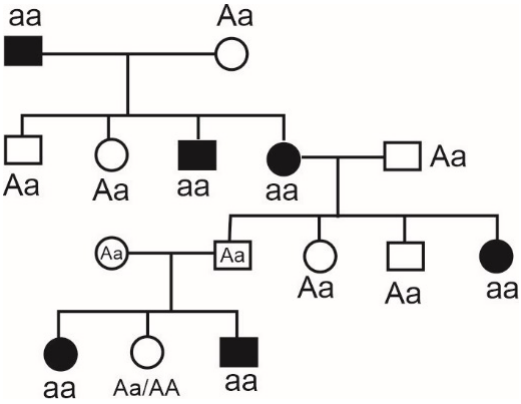
(b) Autosomal recessive

(c) X-linked dominant

(d) Autosomal dominant with incomplete penetrance

Answer (b)

Sol. The trait inherited in the given pedigree is an autosomal recessive trait.



ECOLOGY (5 points)

26. **(1 point)** Field capacity can be defined as the water content of a soil after it has been saturated with water and the excess water has been allowed to drain away. The field capacity of soil depends on the type of soil particles that make up the soil. The physical characteristics of different types of soils (I – IV) are given below.

Soil	Particle diameter (μm)	Surface area per gm (m^2)
I	20 – 2	10 – 100
II	200 – 20	< 1 – 10
III	< 2	100 – 1000
IV	2000 – 200	< 1 – 10

Mark the correct statement.

(a) III could be clayey soil with the maximum field capacity among I – IV.

(b) I could be sandy soil with maximum field capacity among I – IV.

(c) II could be sandy soil with least water retention capacity among I – IV.

(d) IV could be silty soil with least water retention capacity among 1 – IV.

Answer (a)

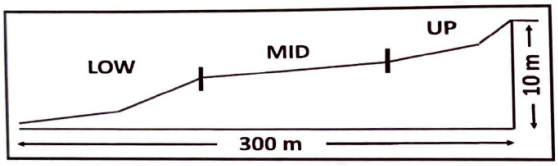
Sol.

Particle diameter (μm)	Soil
<2	Clay
2 – 20	Silt
200-2000	Sand

The particles that make up the soil are broadly categorized into three groups:

- Clay particles – Smallest particle – Maximum field capacity
- Sand particle – Largest particle size – Least field capacity and least water retention
- Silt particle – Medium sized particle

27. (1 point) In the following diagram, a rocky inter tidal area is sub divided into three zones; UP: Upper, MID: Middle and LOW: Lower inter tidal area based on geomorphology and tidal exposure.



Which of the following statements is/are correct?

i. The inhabitants of LOW region will be plankton feeders and swift swimmers like pelagic animals since this area will remain under water during high and low tides.

ii. In the MID region, during low tide exposure period, maximum photosynthesis will occur hence the diversity of algae will be more. Therefore, in this region, only herbivores will be found.

iii. In the UP region, animals resistant to desiccation stress (dry, hot & direct sunlight during low tides) are more likely to be found.

iv. An animal having its fundamental niche in MID and UP regions may have its realized niche in the MID region due to inter-specific competition.

Options:

(a) i and ii only
(b) iii and iv only
(c) i, ii and iii
(d) iv only

Answer (c)

Sol. Upper zone of intertidal area is completely covered with water only during high tide mark. It is driest zone and is sparsely populated. The inhabitants of this area can remain wet even if exposed to sun and wind. They have developed attachment devices to help them resist force of waves and are resistant to desiccation stress (Supports point (iii))

The inhabitants of low regions always remain under water. They are swift swimmers and have large mouth and increased surface area of plankton capturing sieves which permits greater volumes of water to be filtered i.e. plankton feeders.

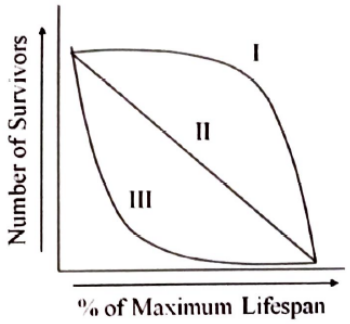
(Supports point (i))

Mid intertidal area is covered with water during high tides and is completely exposed during low tides. This provides favourable conditions for algal growth.

(Supports point (ii))

An animal having fundamental niche in mid and up intertidal zone may have realised niche in up reason to avoid inter-specific competition (point (iv).

28. **(1 Point)** Following graph shows different types of idealized survivorship curves I, II and III of natural populations.



Which of the following statements is correct?

(a) Type III curve represents fish and Type I curve represents frog since adult frogs are prey species for many predators and hence the mortality rate for adults will be high.

(b) Both fish and frog will show Type III curve.

(c) Mosquito and frog lay their eggs in water but adults live on land. The rate of mortality and survivorship for both the species in water and on land will respectively be curves III and II.

(d) Both mosquito and frog pass through metamorphosis stages where high mortality occurs, hence they both will show curve type I.

Answer (b)

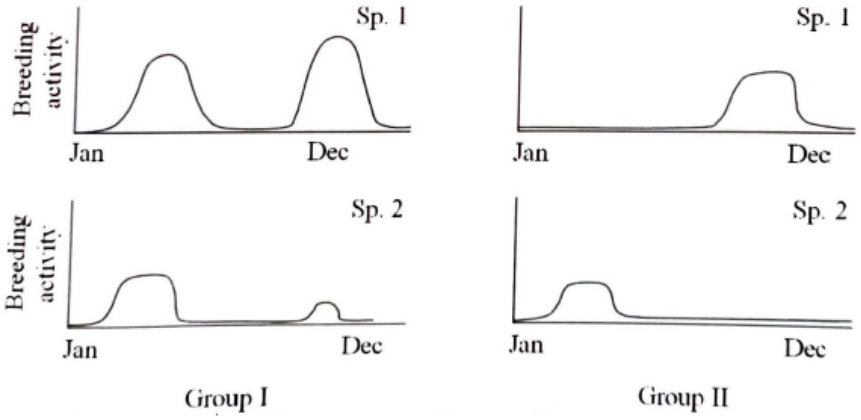
Sol. Survivorship curves can be of three types:

Type I: Organisms tend not to die when they are young or middle aged but die instead when they are old. They have small number of offsprings and provide lots of parental care to offsprings e.g., Humans and most primates.

Type II: Organism die more or less equally at each age interval. Mortality does not depend on age e.g., rodents, adult birds and certain turtle species.

Type III: Few organisms survive their younger years. Species with this type of curve usually have lots of offsprings but do not provide much parental care to them e.g., seeds, marine invertebrates and most fishes and frogs.

29. **(1 point)** Breeding seasons of two closely related frog species *Rana berlandeieri* (Sp. 1) and *Rana sphenocephala* (Sp. 2), from two different habitats within the same geographical region were recorded independently by two research groups (group I and group II). The data obtained is shown below.



What can be the most plausible explanation for these findings?

(a) The two habitats must be very different from each other in terms of temperature and humidity.

(b) The two species observed by group I must have been physically isolated from each other.

(c) Species observed by group 2 must have experienced post-zygotic barrier.

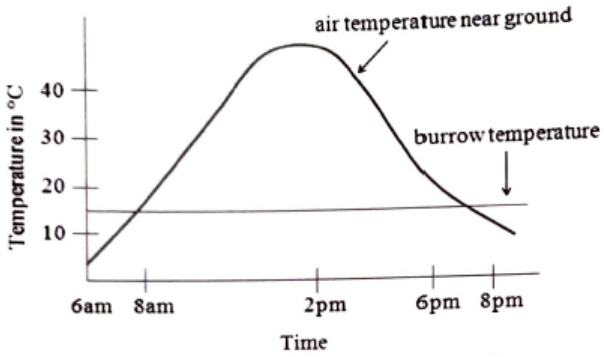
(d) Pre-zygotic barrier is stronger in species studied by group 2 than that studied by group 1.

Answer (b/d*)

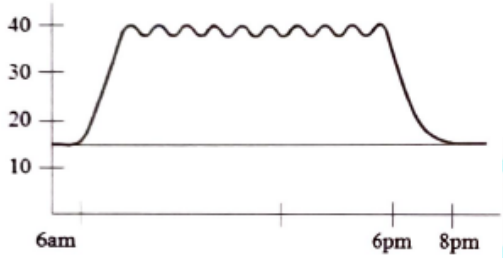
Sol. The correct answer is option (b) as the peak breeding seasons of two species of *Rana* overlap when the species are physically separated (allopatry).

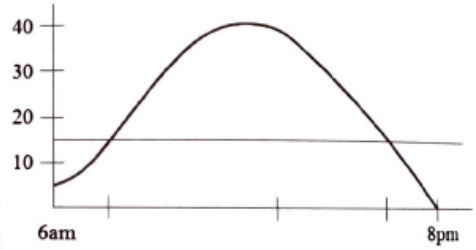
Option (c) is incorrect as species observed by group 2 may be the case of sympatry, overlap between their peak breeding seasons is greatly reduced or eliminated. Sympatric populations have few opportunities to hybridise.

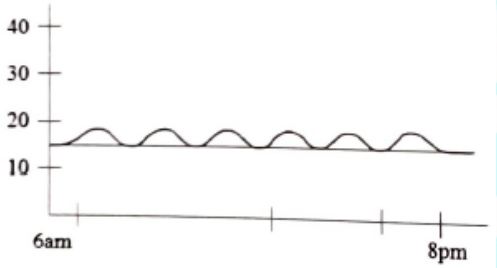
30. **(1 Point)** Diurnal variation of environment temperatures in a desert habitat is shown below.



Which of the following profiles match the variation of body temperature of a moderately active lizard dwelling in this habitat?

(a)


(b)


(c)


(d)


Answer (c)

Sol. Desert lizards lack the physiological ability to cope with extreme temperature but manage the body temperature by behavioural means. Since these animals are conformers, their body temperature changes with the ambient temperature. At the higher temperatures that can be lethal, the lizard maintains the optimal body temperature by any behavioural means.

ETHOLOGY (2 points)

31. **(1 point)** Alclock (1979) while studying reproductive strategies of Digger Bees (*Centris pallida*) identified two different strategies, patrolling and hovering. Patrolling involves activities such as finding virgin females buried in the nest, excavating them and mating with them. Excavation takes a few minutes during which there is a chance that other males might arrive resulting in violent fights. Hovering males, on the other hand, hover near flowering trees and wait receptive females to fly by. Mating success is more in patrolling as compared to hovering. Which of the following statements is correct?

(a) Smaller males may prefer patrolling and larger males may prefer hovering at give tough competition for reproduction.

(b) Larger males may prefer patrolling and smaller males may prefer hovering for better reproductive success.

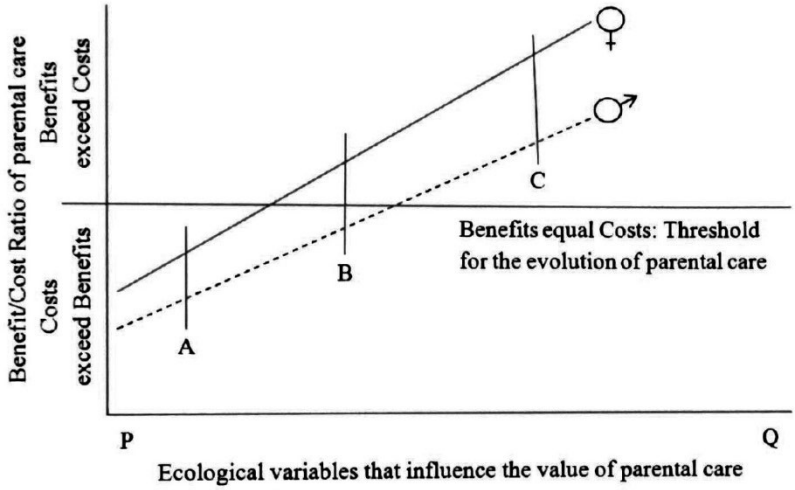
(c) All males irrespective of their size would prefer patrolling strategy for better reproductive success.

(d) Larger and smaller males both may prefer hovering to avoid violent fights.

Answer (b)

Sol. Option (b) is the correct statement because the size of the male is related to which of given strategies he adopts. It is usually observed that the larger males more commonly choose patrolling and digging whereas the smaller males more commonly indulge in hovering. Larger males are superior in competitive disputes over digging sites and appear to enjoy much greater reproductive success than males at the lower end of the spectrum of size.

32. **(1 point)** Parental care in animals becomes advantageous only if certain ecological factors raise the benefit/cost ratio of the trait above 1. A graph depicting the benefits for male and female parents at various values of certain ecological variables is shown.



Which of the following could be true?

i. Females have a higher threshold for parental care than males because of their increased reliability of parentage.

ii. Predation on young decreases in the direction from P to Q.

iii. Food availability becomes abundant in the direction of Q to P.

iv. Competition for nesting sites increases from P to Q.

Options:

(a) i and iii

(b) ii and iii

(c) iii and iv

(d) Only iv

Answer (d)

Sol. (d) is the answer as statement (iv) is correct because,

In the direction from P to Q, the benefits exceed costs hereby increasing the offspring survival. This leads to the competition among the offsprings for nesting sites.

- Statement (i) is incorrect as, it is clear from the graph that females have a lower threshold for parental care than males.
- Statement (ii) is incorrect as, predation on young increases in the direction from P to Q.
- Statement (iii) is incorrect as, benefits are exceeding costs.

SECTION-B

CELL BIOLOGY (17 points)

33. **(4 points)** A single copy 500 bp regions was PCR amplified using human genomic DNA as the template. If after 30 cycles of PCR, the amount of DNA amplified in that amplicon was 2.16 ng, calculate the number DNA molecules that were initially present in the sample. Also, indicate from how many cells the DNA would have been obtained. Assume molecular weight of 1 bp as 650 and Avogadro's number is 6.023×10^{23}.

Note that the final answer will be given marks only if calculations are shown in the box given and final answer is filled in the blank.

Sol. [Note = 1 ng = 10^{-9} gm]

$$x \times 2^{30} = \frac{2.16 \times 10^{-9}}{650} \times \frac{6.023 \times 10^{23}}{500}$$

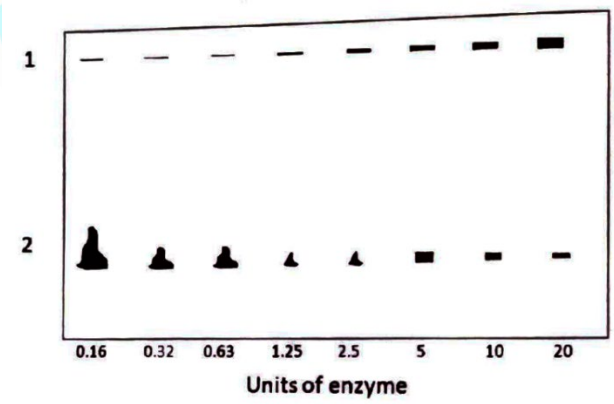
$$x = \frac{2.16 \times 10^{-9} \times 6.023 \times 10^{23}}{650 \times 500 \times 2^{30}}$$

$$= \frac{2.16 \times 6.023 \times 10^{14}}{650 \times 500 \times 2^{30}}$$

= 4 molecules

DNA was obtained from 4 cells to begin with.

34. **(2.5 points)** In an experiment, autoradiography technique was used to study as enzyme catalyzed reaction. A set of 8 tubes were used for the experiment. To each tube, a fixed concentration of Y^{32} p-labelled ATP and $(dT)_8$ oligonucleotide were added. Increasing units of enzyme 'X' was then added to the tubes and the tubes were incubated. The contents of each tube were then electrophoresed on 20% PAGE, 7 M urea gel. The autoradiograph obtained is shown below:



Based on the results, indicate whether each of the following is true or false by putting tick marks (✓) in the approximate boxes.

a. Row 1 indicates enzyme bands.

b. Row 2 indicates reducing length of $(dT)_8$ oligonucleotide.

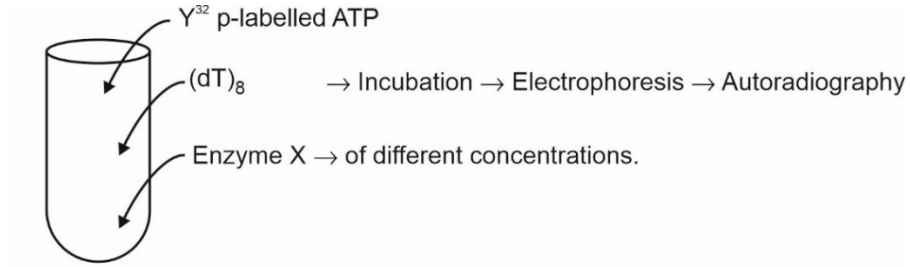
c. The enzyme is most likely a kinase.

d. Row 2 indicates amount of radioactive decay in the ATP molecules.

e. Row 1 indicates increasing radioactivity in oligonucleotide molecule.

Answer (a, c)

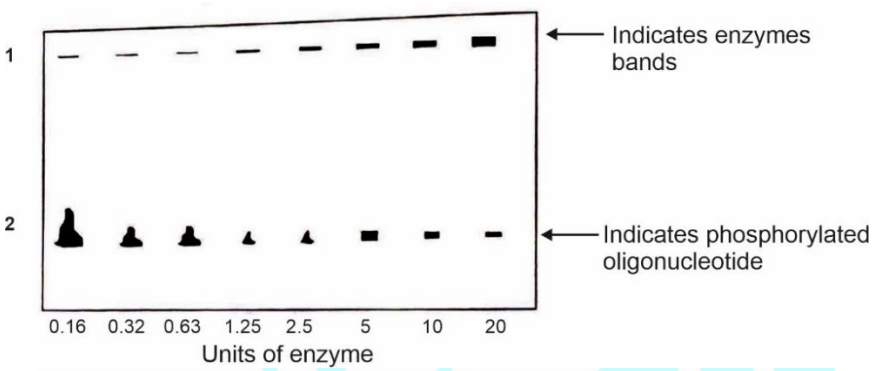
Sol.



Reaction:

$$dT + ATP \xrightarrow{X} dT - (p)$$

X is most likely kinase enzyme with increasing concentration of X, the amount of phosphorylated oligonucleotide will increase.



35. **(2 points)** An experiment was being carried out using partially differentiated (Sample S1) and undifferentiated (Sample S2) erythroblast cells. Nuclei from S1 and S2 were isolated and exposed to increasing concentration of DNase 1. The nuclear DNA was then extracted from both these samples and treated with BamHI, which cleaves the DNA around the globin sequence and normally releases a 4.6 kb globin fragment. The DNase 1 and BamHI digested DNA was subjected to Southern blot analysis with a probe of labelled cloned adult globin DNA, which hybridizes to the 4.6 kb BamHI fragment. The results of the Southern blot analysis are shown below.

Based on the results, indicate whether each of the following statements is true or false by putting tick marks (✓) in the appropriate boxes.

a. DNA from S_2 cells is in a more condensed form of a chromatin in which the globin gene is shielded from DNase digestion.

b. Absence of 4.6 kb band at higher concentration of DNase suggests that globin synthesizing S1 cells were resistant to BamHI digestion.

c. Transcriptionally active DNA is sensitive to DNase digestion.

d. If the globin gene is susceptible to initial DNase digestion, it is expected to show the 4.6 kb fragment.

Answer (a, c)

Sol. <u>Erythropoiesis</u>

Normoblast
↓
Reticulocytes
↓
Erythrocytes

The nuclear material in normoblast is much condensed as compared to reticulocytes as it progressively vanishes off with maturation.

The DNA in normocytes is transcriptionally active so resistant to DNase activity.

	True	False
a	✓	
b		✓
c	✓	
d		✓

36. **(4.5 points)** The ability of molecules to diffuse through the phospholipid bilayer depends on the properties of the molecule. Complete the table in the answer sheet by correlating the property of the molecule with the name of the molecule/s and its ability to diffuse through the phospholipid bilayer.

Choose from the options given below and fill in the appropriate number or alphabet in the table in the answer sheet.

Options for molecules:

i. Calcium

ii. Carbon dioxide

iii. Bicarbonate

iv. Glycine

v. Glucose

Options for ability to diffuse through phospholipid bilayer:

a. Permeable

b. Impermeable

Sol. Permeable : (ii) Carbon dioxide (CO_2)

Impermeable: (i) Calcium

(iii) Bicarbonate

(iv) Glycine

(v) Glucose

37. **(4 points)** Methylation of cytosine in DNA and lysine residues in histones are the two important epigenetic marks on the chromatin that determine majority of the biological processes, such as embryonic development, stem cell differentiation and cell division cycles. Also, indiscriminate hypermethylation is often associated with tumorigenesis. These methyl marks are removed by enzymes known as dioxygenases. TET (Ten-Eleven Translocation and Jumonji domain containing histone demethylases (JHDM) remove methyl groups from DNA and histones, respectively. (His K represents histones with lysine.)

Tow reaction are shown below:

Histone lysyl demethylation:

$$\text{His K} - \text{H}^{+}_{2}\text{N} - \text{CH}_3 \xrightarrow[\alpha\text{–ketoglutarate} + \text{O}_2]{\text{JHDM} + \text{Fe(II)}} \text{His K} - \text{NH}_3^{+} + \text{Succinate} + \text{CO}_2 + \text{HCHO}$$

DNA demethylation:

$$\text{DNA-5 methyl C} \xrightarrow[\alpha\text{–ketoglutarate} + \text{O}_2]{\text{TET} + \text{Fe(II)}} \text{DNA-5-hydroxymethyl cytosines} + \text{Succinate} + \text{CO}_2$$

In light of the above, indicate whether each of the following is true or false by putting tick marks (✓) in the appropriate boxes.

a. Loss of function mutation in the gene that codes for isocitrate dehydrogenase will lead to hypermethylation of DNA and histones.

b. Translocation of specific chromosome regions between chromosome 10 and 11 can lead to formation of tumor.

c. Overexpression of JHDM in a cell will lead to metabolic imbalance and oxidative stress.

d. Krebs cycle operates in the mitochondrial matrix and chromatin modifications take place in the nucleus and hence the two processes are independent.

Sol. a. Loss of function mutation in the gene that codes for isocitrate dehydrogenase will lead to hypermethylation of DNA and histone → True.

Explanation:-

$$\text{Isocitrate} \xrightarrow{\text{Isocitrate dehydrogenase}} \alpha\text{-ketoglutarate}$$

α-ketoglutarate is a cofactor for JHDM.

Loss of function of isocitrate dehydrogenase will lead to decrease in formation of α-ketoglutarate and thus function of JHDM and TET will decrease leading to hypermethylation of histone and DNA respectively.

b. Translocation of specific chromosome region between chromosome 10 and 11 can lead to formation of tumor → False.

Active TET enzyme will cause demethylation. Tumorigenesis is associated with hypermethylation. Thus, the statement is false.

c. Overexpression of JHDM in a cell will lead to metabolic imbalance and oxidative stress → True

Overexpression of JHDM will lead to excess of succinate and HCHO.

HCHO can induce oxidative stress.

d. Krebs cycle operates in the mitochondrial matrix and chromatin modifications take place in the nucleus and hence the two processes are independent → False.

These processes are inter-dependent because a-ketoglutarate is an intermediate of Krebs cycle as well as co-factor for dioxygenases.

PLANT SCIENCES (10 Points)

38. **(2 points)** Various elements required by plants for growth and metabolism can be broadly divided into four major groups. These groups and four elements are listed below. Match them appropriately.

I. Mineral nutrients that are part of carbon compounds

II. Mineral nutrients important for structural integrity

III. Nutrients that remain in ionic forms

IV. Nutrients involved in redox reactions

Elements: P: Silicon Q: Copper R: Manganese S: Sulfur

Choose the correct option and put a tick mark (✓) in the appropriate box.

a. I: S II: P III: R IV: Q

b. I: P II: R III: Q IV: S

c. I: S II: R III: Q IV: P

d. I: R II: S III: P IV: Q

Answer (a)

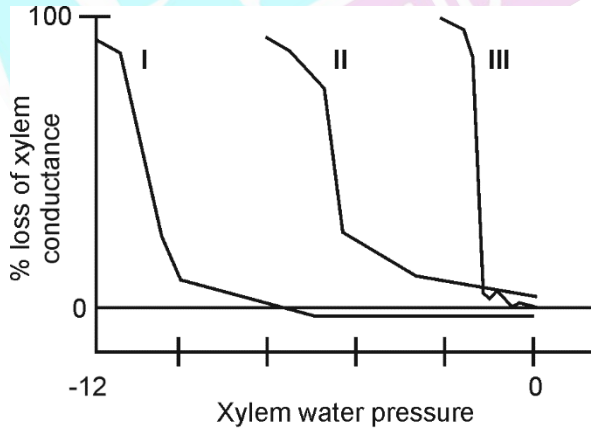
Sol. I. Mineral nutrients that are part of carbon compound are nitrogen and sulphur.

II. Nutrients important for maintaining structural integrity are phosphorus, silicon and boron.

III. Nutrient that remain in ionic form is manganese.

IV. Nutrient involved in redox reaction is copper.

39. **(2 points)** Cavitation or air bubble formation in the xylem conduits can lead to break in the continuity of water columns and prevent transport. Plants native to different habitats show varying susceptibility to cavitation and its impact on flow. The graph depicts this property for three plant species I, II and III.



Indicate whether each of the following statements is a correct or incorrect interpretation by putting tick marks (✓) in the appropriate boxes.

a. Plant II is more sensitive to cavitation than plant III.

b. Among the three plants, plants I is most vulnerable to water loss due to cavitation.

c. Plant III is the most drought tolerant plant.

d. Plant II is found in wetter habitats as compared to plants I.

Sol. Conductivity falls as cavitation knocks out more and more conduits, so this curve shows how vulnerable the xylem is to cavitation.

Plant species I and II are resistant and III is vulnerable.

a. False, Plant III is most sensitive to cavitation.

b. False, Plant III is most vulnerable to water loss due to cavitation.

c. False, Plant I is more drought tolerant.

d. True

40. **(6 points)** Representative values of water potential and its components at various points in the transport pathway from the soil through the plant to the atmosphere is tabulated.

Location	Water potential and its components (in MPa)				
	Water potential (ψ_w)	Pressure potential (ψ_p)	Osmotic potential (ψ_s)	Gravity (ψ_s)	Water potential in gas phase
A	–0.8	–0.8	–0.1	0.1	
B	–0.8	0.2	–1.1	0.1	
C	–95.2				–95.2
D	–0.6	–0.5	–0.1	0.0	
E	–0.5	–0.4	–0.1	0.0	
F	–0.8				–0.8

Based on the values tabulated, identify the various locations (A – F) along the pathway.

Choose from the options and fill in the blanks with the appropriate option number.

Options for the locations:

I. Soil adjacent to root

II. Root xylem (near surface)

III. Leaf xylem

IV. Leaf internal air space

V. Vacuole of mesophyll cell (at 10 m)

VI. Outside air

Sol. I. Soil adjacent to root = It has maximum water potential, *i.e.* E with ψ_w = –0.5 MPa

II. Root xylem near surface = D with ψ_w = –0.6 MPa

III. Leaf xylem = A with ψ_w = –0.8 MPa

IV. Leaf internal air space = It will have water vapours and show water potential in gas phase, *i.e.* F = ψ_w = –0.8 MPa

V. Vacuole of mesophyll cell = Vacuole maintain turgidity of cell and pressure potential will be positive, *i.e.* B = ψ_w = –0.8 MPa

VI. Outside Air = It has water vapours and maintain water potential in gas phase, *i.e.* C = ψ_w = –95.2 MPa

I – E

II – D

III – A

IV – F

V – B

IV – C

ANIMAL SCIENCES (10.5 Points)

41. **(2 points)** Hemoglobin and myoglobin are the molecules that are responsible for transport and storage of oxygen respectively. During evolution, some mammals underwent land to aquatic or semi-aquatic habitat transition. The properties and electrophoretic mobilities of myoglobin from six mammals are shown below. Note that $[Mb]_{max}$ is the maximum myoglobin concentration while Z_{Mb} in the graph indicates the charge on the molecule.

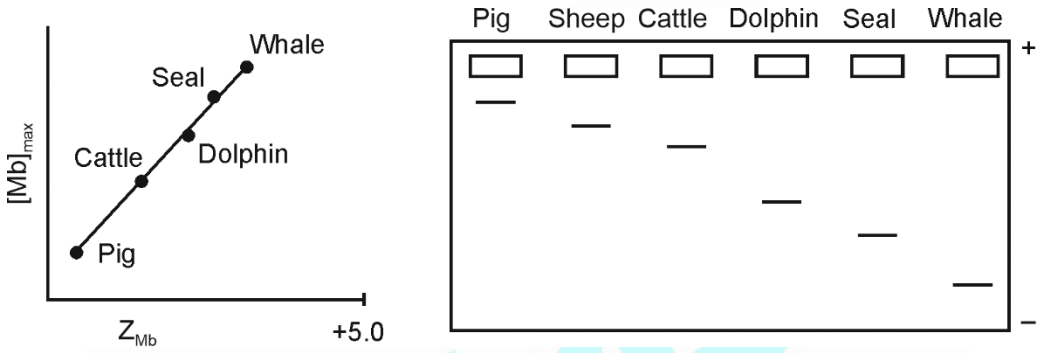


Fig. Electrophoretic mobility of myoglobin

Indicate whether each of the following statements is correct or incorrect by putting tick marks (✓) in the appropriate boxes.

a. Diving mammals are likely to have higher concentration of muscle myoglobin as compared to non divers.

b. Myoglobin protein of divers is likely to have more leucine residues in place of histidine residues.

c. The net surface charge indicates that all mammals, diving and non diving, share the same primary structure of myoglobin.

d. Greater the similar surface charge on the myoglobin molecule, greater is the repulsion between molecules and hence greater is the oxygen binding capacity.

Sol.

	T	F
a	✓	
b		✓
c		✓
D	✓	

- Statement (a) is correct as myoglobin is highly concentrated in the tissues of deep-diving animals, whereas its concentration is significantly lower in land animals.
- Statement (b) is incorrect as myoglobin protein of divers have greater positive net charges on surface than the terrestrial mammals. Leucine is a neutral amino acid and histidine is a basic amino acid.
- Statement (c) is incorrect as the myoglobin from terrestrial to subterranean to semi-aquatic species, genetic changes took place that would diminish the ability for the proteins to stick to each other.
- Statement (d) is correct as high positive myoglobin net charge in mammalian divers increases intermolecular electrostatic repulsion, permitting higher muscle oxygen storage capacities.

42. **(6 points)** Several organs such as lungs and kidneys play an important role in blood pH homeostasis. The major buffer system that contributes to this is the bicarbonate buffer system.

$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$

Thus levels of blood bicarbonates and pCO_2 are key indicators of blood homeostasis. Due to several reasons, the homeostasis can be temporarily disturbed leading to acidemia or alkalemia. In such situations, the body tries to compensate by alternative methods to restore the original values. Acidosis or alkalosis can be due to respiratory reasons as indicated by CO_2 levels, or metabolic reasons as indicated by HCO_3^- levels. For a healthy person, normal values of blood pH, $pHCO_3^-$ and p_aCO_2 are as follows :

Blood pH 7.4; Tolerated limits : 7.35 – 7.45

$pHCO_3^-$: 22 – 26 mEq / L

p_aCO_2 : 35 – 45 mmHg

These parameters were tested for two cases (I and II) who were admitted to a clinic and the values are tabulated below.

	I	II
pH	7.44	7.33
p_aCO_2	28	25
$pHCO_3^-$	20	12
p_aO_2	54	89

Hints :

1. *The causative factor will lead lo change in pH that will be reflected in the blood pH*
2. *The compensatory factor will try to change the direction of this change but there will never be overcompensation.*

Fill in the table with the primary process underway, the compensatory mechanism and the symptoms that they show for each of the cases I and II.

(Choose from the options given and fill in the table with the appropriate alphabets or numbers as applicable.)

Options for Primary process under way:

a. Respiratory acidosis

b. Respiratory alkalosis

c. Metabolic acidosis

d. Metabolic alkalosis

Options for compensatory mechanisms :

a. Uncompensated respiratory alkalosis

b. Compensated respiratory alkalosis

c. Uncompensated metabolic acidosis

d. Uncompensated metabolic alkalosis

e. Uncompensated respiratory acidosis

f. Compensated respiratory acidosis

g. Compensated metabolic acidosis

h. Compensated metabolic alkalosis

Options for Symptoms:

I. Person on anti-anxiety medication. Often gets anxiety attacks during which shallow rapid breathing occurs. Complains of shortness of breath.

II. Patient reports cyanosis (bluing) of lips, shortness of breath, case of pneumonia with productive cough present.

III. Person with severe diarrhoea over the past several days.

IV. Person with severe nausea, known case of peptic ulcers and heavy consumption of milk and $CaCO_3$ tablets.

Sol.

- Case I represents the situation of respiratory alkalosis while case II represents the situation of metabolic acidosis as there is deficiency of bicarbonate that causes the blood to be overly acidic.
- Since, the case I has a primary respiratory alkalosis, leading to alkalemia; the compensatory process is a metabolic acidosis and since, the case II has a primary metabolic acidosis leading to acidemia, the compensatory process is a respiratory alkalosis.
- Symptoms for case I is option (I) *i.e.*, the person on anti-anxiety medication, often gets anxiety during which shallow and rapid breathing occurs.
- Symptoms for case II is option (III) *i.e.*, person with severe diarrhoea over the past several days.

	Case I	**Case II**
Primary process	(b)	(c)
Compensatory process	(g)	(b)
Symptoms	I	III

43. **(2.5 points)** Intravenous fluids (IVs) are supplemental fluids that perform different functions such as restoring normal fluid volume or electrolyte balance when the oral route is compromised in humans. A few solutions and a few descriptions are given below.

Intravenous Fluids:

I. Normal saline solution (Isotonic)

II. Dextrose 5% solution (Isotonic)

III. Dextrose 2.5% solution (Hypotonic)

Descriptions:

(A) Initially acts as isotonic and then hypotonic solution.

(B) Used to replace sodium losses in burn injuries.

(C) Used to treat cellular dehydration but should not be used with blood products.

(D) Should not be used in pulmonary oedema.

(E) Used to treat hypernatremia.

Match the descriptions to the appropriate solution and fill in the blanks with the appropriate number of the fluid (I – III).

Sol. (Multiple answer)

	Intravenous Fluids		**Descriptions**
I.	Normal saline solution (Isotonic)	(B)	Used to replace sodium losses in burn injuries
II.	Dextrose 5% solution	(E)	Used to treat hypernatremia
III.	Dextrose 2.5% solution (Hypotonic)	(A)	Initially acts as Isotonic and then hypotonic solution
		(C)	Used to treat cellular dehydration but should not be used with blood products
		(D)	Should not be used in pulmonary oedema

I	B
II	E
III	A, C, D

GENETICS & EVOLUTION (12.5 points)

44. **(2.5 points)** If the operator region of lac operon in *E. coli* is replaced with that of operator from trp operon, predict what will happen to the expression of lac operon genes in the medium that contains :

i. Only Glucose, no lactose, no tryptophan

ii. No glucose, no lactose, only tryptophan

iii. No glucose, no tryptophan, only lactose

iv. Tryptophan and lactose, no glucose

v. Tryptophan, IPTG (analogue of lactose), no glucose

Indicate whether lac operon will be expressed or will not be expressed by putting tick marks (✓) in the appropriate boxes.

Sol. If the operator of lac-operon is replaced with that of operator of trp-operon, it will activate only in absence of tryptophan. In the presence of tryptophan,

(i) only glucose, no lactose, no tryptophan

→ will be expressed (✓)

(ii) No glucose, no lactose, only tryptophan

→ will not be expressed (×)

(iii) No glucose, no tryptophan, only lactose

→ will be expressed (✓)

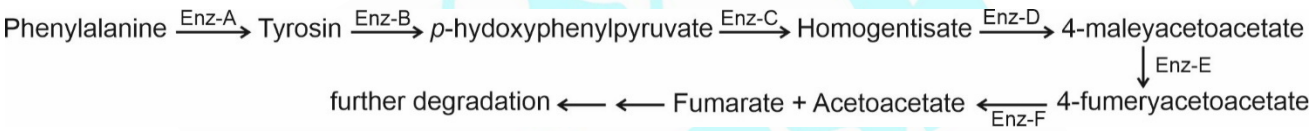
(iv) Tryptophan and lactose, no glucose

→ will not be expressed (×)

(v) Tryptophan, IPTG (analogue of lactose), no glucose

→ will not be expressed (×)

45. **(3 points)** Given below is the pathway for breakdown of phenylalanine to fumarate and acetoacetate. This involves six enzymes (marked Enz-A to Enz-F). Each enzyme is encoded by a single gene and the 6 genes are present on different chromosomes.



PKU is an autosomal recessive genetic disorder caused by a defect in the enzyme acting on phenylalanine. Alkaptonuria is another autosomal recessive genetic disorder characterized by the accumulation of homogentisate. A female with PKU, who is also a carrier for Alkaptonuria, marries a male with Alkaptonuria, who is a carrier for PKU. What is the probability (in%) that their child will show both PKU and Alkaptonuria phenotypes? Fill in the blank with the correct answer.

Note that the final answer will be given marks only if calculation/explanation is written in the box given and the final answer is filled in the blank.

Answer (25%)

Sol. a – allele for phenylketonuria

c – allele for alkaptonuria

- Genotype of a F with PKU, who is also a carrier of alkaptonuria = aaCc
- Genotype of a M with alkaptonuria, who is a carrier of PKU = Aacc

aaCc × Aacc

	Ac	ac
aC	AaCc	aaCc
ac	Aacc	aacc

The probability of a child with both PKU and Alkaptonuria i.e., aacc will be 25%.

46. **(3 points)** Consider a single mutation in wheat that causes grains to turn black. Black is recessive to the wild-type brown grains. In a population of wheat plants, 56 out of 10000 plants bore black grains. If the population is in Hardy-Weinberg equilibrium, how many of the plants are heterozygous for the mutation locus?

Fill in the blank with the correct answer.

Note that the final answer will be given marks only if calculations are shown in the box given and the final answer is filled in the blank.

Sol. 1387 individuals are heterozygous out of 10000

56 out of 10000 are recessive

$$q^2 = \frac{56}{10000} = 0.0056$$

q = 0.075

p + q = 1

Frequency of dominant allele p = 1 – 0.075 = 0.925

Heterozygous individuals = 2pq = 2(0.925 × 0.075)

= 0.1387

0.1387 × 10000 = 1387 individuals are heterozygous.

47. **(2 points)** In *Drosophila*, red eye colour is a dominant X-linked trait. A reciprocal cross involves a pair of crosses between a male of one phenotype and a female of another phenotype for a given trait, and vice versa. Usually the cross is represented in such a way that the first parent is female and the second parent is male. All parent organisms are true breeding in such experiments.

If reciprocal crosses between white-eyed, and red-eyed Drosophila adults were carried out, then mark each of the following statements as true or false by putting tick marks (✓) in the appropriate boxes.

(a) Use of a red-eyed female parent results in four phenotypic groups of progeny in the F2 generation.

(b) The probability of producing a red-eyed female in the F2 progeny in a cross using a white-eyed male parent is 25%.

(c) A cross with a red-eyed male parent yields F2 progeny in the ratio 1:1:1:1

(d) A white-eyed female is only obtained in the F2 progeny of a cross with a red-eyed male parent.

Sol.

Reciprocal cross

Cross A

$\frac{w^+}{w^+}$ (Red eyed ♀) × $\frac{w}{}$ (White eye ♂)

Gametes: (w^+) (w) (Y)

F1: $\frac{w^+w, w^+w,}{\text{Red eyed females}}$ $\frac{w^+Y, w^+Y}{\text{Red eyed males}}$

F2:

	w^+	Y
w^+	w^+w^+ Red eyed female	w^+Y Red eyed male
w	w^+w Red eyed females	wY White eyed male

Cross B

$\frac{w}{w}$ (White eyed ♀) × $\frac{w^+}{}$ (Red eye ♂)

Gametes: (w) , (w^+) (Y)

F1: $\frac{ww^+, ww^+,}{\text{Red females}}$ $\frac{wY, wY}{\text{White eyed males}}$

F2:

	w	Y
w^+	w^+w Red eyed female	w^+Y Red eyed male
w	ww White eyed female	wY White eyed male

(a) False, only two phenotypes regarding eye colour that are seen red eyed and white eyed.

(b) False, 100% females are red eyed.

(c) True, four phenotypes are obtained, red eyed and white eyed female and red eyed and white eyed males.

(d) True, yes when male is red eyed then only females are white eyed in F2 generation.

48. **(2 points)** When a pure line of wheat plant with coloured kernel was crossed to a plant with white kernel and resulting F_1, were selfed, the coloured kernels were found in 93.75% of the plants. The correct pathway for the kernel pigment synthesis is:

Choose the correct option and put a tick mark (✓) in the appropriate box.

T : inhibition

a. Gene A → enzyme A; Gene B → enzyme B; Precursor → Intermediate → Coloured Product

b. Gene B → enzyme B; Gene A → enzyme A; Precursor → Intermediate → Coloured Product

c. Gene A → enzyme A OR Gene B → enzyme B; Precursor → Coloured Product

d. Gene B → protein B → Gene A → enzyme A; Precursor → Coloured Product

Answer (c)

Sol. A modification of dihybrid 9 : 3 : 3 : 1 ratio is produces from the given cross in the question.

Coloured kernel were found in 93.75% of the total plant.

Therefore,

9 A_B_ – Coloured kernel

3 A_bb – Coloured kernel

3 aaB_ – Coloured kernel

1 aabb – Colourless kernel

Here we achieve a 15 : 1 ratio. Because either of the genes can provide wild type phenotype. This interaction is called duplicate gene interaction.

Gene A → Enzyme A
Precursor → Product
OR
Enzyme B ← Gene B

For this type of pathway a functional enzyme A or B can produce a product from common precursor. The product gives colour to the wheat kernel. Therefore, only one dominant allele at either of the two loci is required to generate the product.

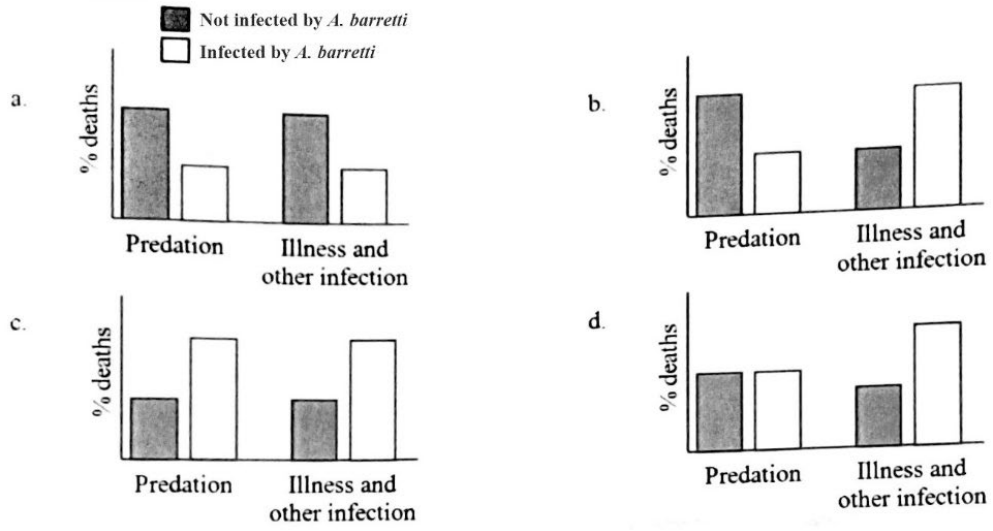
ECOLOGY (10 points)

49. **(2 points)** In Northern American swamps, predatory adult mosquito *Toxorhynchites rutilus* (*T. rutilus*) preys on the larvae of *Aedes triseriatus* (*A. triseriatus*) that are foraging for food. Larvae forage for food by thrashing the water around it, but this makes them more vulnerable to detection by *T. rutilus*. Data has shown that thrashing behaviour is strongly correlated with larval health and fitness.

The parasite *Ascogregarina barrette* (*A. barretti*) infects *A. triseriatus* in the larval stage and completes its life cycle in the pupal stage. This results in weakening of the larval muscles causing the larvae to thrash less for food–thus making them unhealthy.

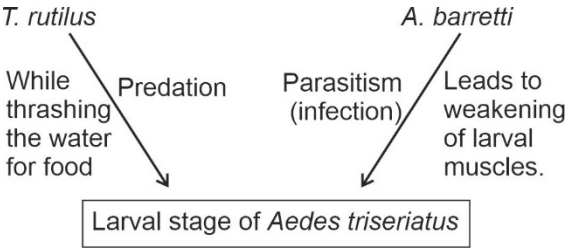
Larval deaths were recorded and categorized into two causes – (i) predation by *T. rutilus* and (ii) illness and other infections. Which graph is most likely to represent the scenario described above?

Choose the correct option and put a tick mark (✓) in the appropriate box.



Answer (b)

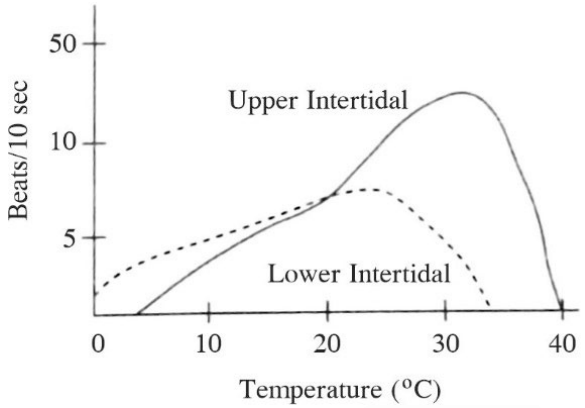
Sol.



It is clear that if larval death is more due to predation then larvae available for parasitism is less and if larvae are parasitised by *A. barretti* then larval death due to illness will be less.

Hence (b) graph correctly explains the situation.

50. **(2 points)** Intertidal invertebrates can avoid overheating by evaporative cooling, combined with circulation of body fluids. Studies were carried out on two species of intertidal filter feeding barnacles to investigate the effect of temperature on the beating of cirri (feeding appendages). The findings are shown in the graph below:



Indicate whether each of the following statements is correct or incorrect by putting tick marks (✓) in the appropriate boxes.

(a) Movement of the cirri in intertidal barnacles increases with increasing temperature but declines near an upper thermal limit indicating a specific threshold value for both lower and upper intertidal barnacles.

(b) Lower intertidal barnacles do not require a mechanism for high temperature tolerance since they have closely shut plates and are not desiccated for a long duration.

(c) Barnacles inhabiting upper intertidal region feed more efficiently at all temperatures as compared to the barnacles in the lower intertidal region.

(d) Upper intertidal barnacles tend to maintain greater coordinated ciliary motion leading to greater fluid movements at higher temperatures as compared lower temperatures. Therefore they are more resistant to desiccation.

Answer (a, d)

Sol. In the given graph of two species of intertidal feeding barnacles the effect of temperature on the beating of cirri shows that with increase in temperature movement of cirri increases.

But after they reaches their threshold value of temperature the movement of cirri decreases for both upper and lower intertidal barnacles.

Barnacles inhabiting upper intertidal region feed efficiently maximum at 35°C (approx.) and lower intertidal barnacle at 25°C (approx.).

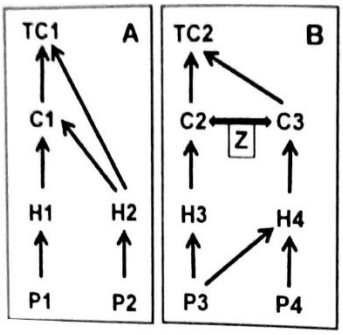
As their cirri movement is affected with temperature, they do not feed constantly in all the temperature ranges.

Barnacles which are in the high tidal zone of a rocky intertidal community are well adapted to avoid desiccation.

Barnacles at upper intertidal region possess a close fitting shells which helps them to resist desiccation and tissues tolerant to high temperature and low salinity.

Therefore, statements (a) and (d) are correct.

51. **(2 points)** In the following flow chart, the vertical interlinking of trophic levels Producers (P), Herbivores (H). Primary Carnivores (C) and Top Carnivore (TC) is shown. Within a trophic level, horizontal interactions are also seen which are marked here as Z interactions.



Indicate whether each of the following statements is correct or incorrect by putting tick marks (✓) in the appropriate boxes.

(a) Amount of energy transferred to TC2 through C2 involves a total of three organisms and through C3 involves four organisms. Therefore, if food chain through C3 is prominently operative then TC2 will receive more energy than the food chain through C2.

(b) The dependency of TC2 on the previous trophic level for energy is more than TCI.

(c) Interaction Z is interspecific competition for resources other than for food.

(d) Since TCI can receive energy from more than one lower trophic levels, the net energy available to TCI is greater than that available to TC2.

Sol. (a) False, Energy transferred to TC2 through C2 & C3 involve total three organisms only.

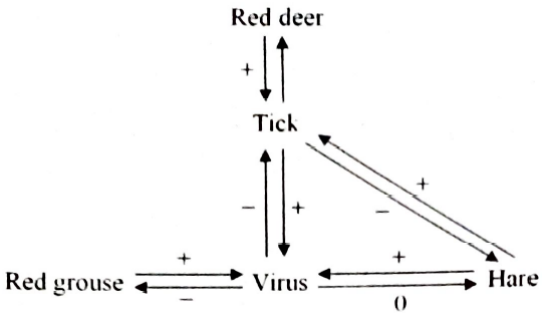
(b) False, Both TC2 & TC1 are dependent on previous trophic levels for their food.

(c) True, C2 and C3 show interspecific competition.

(d) True, Net energy available to TC1 is greater than that available to TC2.

52. **(2 points)** Interspecific interactions can effect community structure as well as biodiversity. One such community structure is shown where parasites can play an important role. “Louping ill virus” is a tick borne virus and can infect red grouse (small sized bird). If amplified in grouse, it can cause substantial mortality. The virus is transmitted by a tick (*Ixodida vicinus*) which can feed on many vertebrates but can complete its life cycle only on large mammals. Red deer can amplify the tick but not virus. Hares can amplify both while grouse can amplify only the virus.

Assume: No measurable cost to hare from virus and no fitness cost to deer/hare due to low intensity tick infestation.



Mark each of the following statements as true or false by putting tick marks (✓) in the appropriate boxes.

(a) Deer and grouse can independently maintain the virus.

(b) Hare-grouse community can maintain the virus.

(c) In deer-grouse community only grouse will suffer from virus mediated apparent complication.

(d) At very high deer densities, the probability of viral infection in the grouse population is reduced.

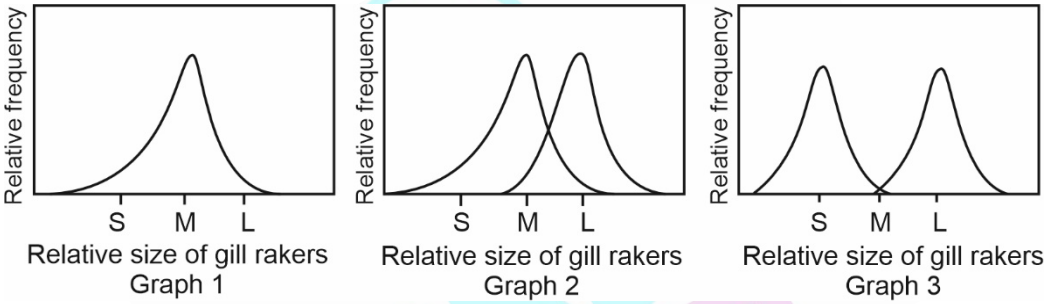
Sol. Statement (a) : False – Red deer can amplify the tick but not virus.

Statement (b) : True – In both hare and grouse virus can amplify and can be maintained in their community.

Statement (c) : True – Red deer can amplify the tick but not virus.

Statement (d) : False – High deer density does not affect the viral infection in the grouses. Deer amplify ticks but not virus. In grouse direct virus can amplify and cause substantial mortality.

53. **(2 points)** The size of gill rakers in fish varies with the type of diet and habitat that they dwell in. The relative frequency of the size of gill rakers in a certain fish species A is shown in Graph 1. Graph 2 depicts the introduction of another species B which is a limnetic (surface-dwelling) species and graph 3 shows the relative distribution of the characters after many generations post-introduction of species B. Relative sizes of the gill rakers are denoted as S, M and L corresponding to small, medium and large in the graphs.



Mark each of the following statements as true and false by putting tick marks (✓) in the appropriate boxes.

(a) Introduction of species B most likely resulted in a shift in distribution of species A from exclusively benthic to limnetic habitat.

(b) Species A and B seem to co-exist and share an amensalistic relationship with each other.

(c) The interaction between species A and B leads to character displacement in species A.

(d) Introduction of species B causes species A to shift to a diet dominated by invertebrates found only at the bottom of the lake.

Sol. Statement (a): False – The size of gill rakers in the dentlic fishes are smaller as compare to limnetic fishes. Introduction of species B result in shift of species A from limnetic to benthic zone.

Statement (b): False – In amensalism, one species is harmed whereas other is unaffected. Here species A is not harmed but shifted to other zone and species B remain unaffected.

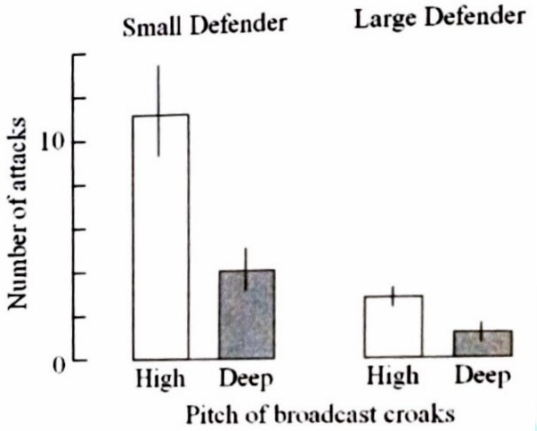
Statement (c): True – The interaction between species A and B lead to character displacement in species A. The size of gill rakers in species A shifted from medium sized to small size.

Statement (d): True – Species A is shifted to benthic zone dominated by invertebrates due to introduction of species B.

a – False; b – False; c – True; d – True

ETHOLOGY (2 Points)

54. **(2 points)** An experiment to assess fighting behavior in male toads *Bufo bufo* was being carried out. Medium-sized males (attackers) were allowed to attack either small or large paired males (defenders). These paired males who were physically associated with the females were silenced by means of a band tied around their vocal sacs. During an attack, tape-recorded croaks were broadcast from a loudspeaker just next to the pair. The number of attacks, when two types of pitches (high and deep) of broadcast croaks were played, was recorded as shown below.



Based on the findings, mark each of the following statements as true or false by putting tick marks (✓) in the appropriate boxes.

(a) Croak pitch is the only assessment cue used to assess the body strength of rivals.

(b) High pitch along with visual cues could be a strong predictor that the viral has better fighting abilities.

(c) Large males, being difficult to displace, are attacked by rivals only when they croak at high pitches.

(d) In absence of visual cues, weak individuals could evade attacks by mimicking sound.

Answer (b, c)

	True	False
a		✓
b	✓	
c	✓	
d		✓

Sol. (b) High pitch along with visual cues could be a strong predictor that the rival has better fighting abilities because larger defenders are not attacked much even on high pitch as compared to small defenders.

(c) Large males, being difficult to displace, are attacked by rivals only when they croak at higher pitches.

Because in the graph you can easily observe the trend that number of attack on large defender is higher at high pitch than on low pitch.

BIOSYSTEMATICS (6 points)

55. **(2 points)** Most frogs lack teeth on the lower jaw. One genus, *Amphignathodon*, shows teeth on the lower jaw. None of the ancestral frogs had teeth on the lower jaw. In this context, state whether each of the following statements is true or false by putting tick marks (✓) in the appropriate boxes.

(a) 'Absence of teeth' is a synapomorphic feature for all the frogs if chose from the genus *Amphignathodon* are excluded in the classification.

(b) Absence of teeth in birds and most frogs is an example of convergent evolution.

(c) Microphagous food habit might have led to evolutionary reversal of the trait in frogs.

(d) Presence of teeth in frogs belonging to the genus *Amphignathodon* and higher vertebrates is an example of homoplasy.

Sol.

	True	False
a	✓	
b	✓	
c	✓	
d	✓	

(a) Synapomorphy is an advance character state shared among two or more taxa inherited from most recent common ancestor.

In this case, absence of teeth is common among different genera of frogs.

(b) Convergent evolution is an evolutionary process in which unrelated organisms (No common recent ancestor among birds and most frogs) evolves structures (absence of teeth) or morphological features that have the same function.

(c) Having teeth in the jaw to capture and hold on food habits *i.e.*, they at were eating really small invertebrates that they can just bring into their mouth with their highly modified tongue. This seems to relax the selection pressure hereby leads to loss of teeth.

(d) Homoplasy is the development of organs or other bodily structures (presence of teeth within different species in *Amphignathodon* and higher vertebrates) which resemble each other and have the same functions but did not have a common ancestral origin.

56. **(4 points)** A list of evolutionary features found in vertebrates is given below. Place them correctly in the cladogram given in the answer sheet.

Features:

A. Gizzard
B. Feathers
C. Claws/nails
D. Keratinous scales
E. Jaws
F. Lungs
G. Continuously growing incisors
H. Fur

Sol.

		Character	Taxonomic origin
E	–	Jaws	Pisces
F	–	Lungs	Amphibians
D	–	Keratinous scales	Reptiles
C	–	Claws/nails	Reptiles
A and B	–	Gizzard and feathers	Birds (Aves)
G and H	–	Continuously growing incisors and furs	Mammals

❑ ❑ ❑