

CBSE Class 12 Biology Question Paper 2026 with Solution PDF-Set 57-7-3 - Compartment



Question Paper with Solutions

Conducted by the Central Board of Secondary Education (CBSE)

Time Allowed: 3 hours

Maximum Marks: 70

General Instructions

- (i) This question paper contains **33** questions. **All** questions are **compulsory**.
- (ii) Question paper is divided into **five** sections – Sections **A, B, C, D** and **E**.
- (iii) **Section A** – questions number **1** to **16** are Multiple Choice Type Questions. Each question carries **1** mark.
- (iv) **Section B** – questions number **17** to **21** are Very Short Answer Type Questions. Each question carries **2** marks.
- (v) **Section C** – questions number **22** to **28** are Short Answer Type Questions. Each question carries **3** marks.
- (vi) **Section D** – questions number **29** and **30** are Case-Based questions. Each question carries **4** marks. Each question has subparts with internal choice in one of the subparts.
- (vii) **Section E** – questions number **31** to **33** are Long Answer Type Questions. Each question carries **5** marks.
- (viii) There is no overall choice. However, an internal choice has been provided in Sections B, D and E of the question paper. A candidate has to write answer for only **one** of the alternatives in such questions.
- (ix) Kindly note that there is a separate question paper for Visually Impaired candidates.
- (x) Wherever necessary, neat and properly labelled diagrams should be drawn.

Section A (16 marks)

Questions no. 1 to 16 are Multiple Choice Type Questions, carrying 1 mark each. Choose the best option.
 $16 \times 1 = 16$

1. Identify the disease which is an inborn error of metabolism and is also inherited as the autosomal recessive trait. [1 mark]

- (A) Thalassemia
- (B) Haemophilia
- (C) Down syndrome
- (D) Phenylketonuria

Correct Answer: (D) Phenylketonuria

Solution:

Concept:

- An inborn error of metabolism results from an inherited defect in an enzyme needed for a metabolic conversion.
- An autosomal recessive disorder is expressed when both copies of the relevant autosomal gene carry the recessive allele.

Step 1: Identify the metabolic defect In phenylketonuria, the enzyme that converts phenylalanine to tyrosine is deficient. Phenylalanine therefore accumulates and is converted into phenylpyruvic acid and related substances. This is the characteristic inherited metabolic defect described in the question.

Step 2: Compare the alternatives Thalassemia is also autosomal recessive but involves reduced synthesis of globin chains, rather than this inborn error of amino-acid metabolism. Haemophilia is an X-linked recessive clotting disorder. Down syndrome results from an extra chromosome 21 and is a chromosomal disorder, not an autosomal recessive enzyme defect.

Step 3: Conclusion Phenylketonuria meets both conditions. Hence, the correct option is (D).

Quick Tip to Solve: Link phenylketonuria with failure of the phenylalanine-to-tyrosine conversion; autosomal recessive inheritance alone does not distinguish it from thalassemia.

2. The undifferentiated sheath that encloses the radicle and root cap in a monocot embryo, is known as : [1 mark]

- (A) Coleoptile
- (B) Coleorrhiza
- (C) Epiblast
- (D) Scutellum

Correct Answer: (B) Coleorrhiza

Solution:

Concept:

- A monocot embryo has an embryonal axis with a shoot end and a root end, each protected by a sheath in grasses.
- The radicle is the embryonic root, and the root cap protects its tip.

Step 1: Identify the root sheath The undifferentiated sheath surrounding the radicle together with its root cap is called the coleorrhiza. The question specifies the root end of the embryo, so the protective covering of the shoot cannot be selected.

Step 2: Distinguish the other structures The coleoptile encloses the plumule, the embryonic shoot. The scutellum is the large shield-shaped cotyledon of the grass embryo and helps absorb food from the endosperm. The epiblast is a small scale-like structure opposite the scutellum, not the sheath enclosing the root tip.

Step 3: Conclusion The sheath is the coleorrhiza. Hence, the correct option is (B).

Quick Tip to Solve: Pair coleorrhiza with radicle and root cap, and coleoptile with plumule; the root-versus-shoot distinction resolves this question immediately.

3. Choose the correct option that refers to adaptive radiation. [1 mark]

- (A) Evolution of different species from a common ancestor to other geographical areas
- (B) Migration of members of different species to a common geographical area
- (C) Power of adaptation in an individual to a variety of environments
- (D) Evolution by anthropogenic action

Correct Answer: (A) Evolution of different species from a common ancestor to other geographical areas

Solution:

Concept:

- Adaptive radiation is the evolution of several species from a common ancestral stock within a geographical region, with descendants occupying different ecological niches.
- It is a form of divergent evolution; Darwin's finches illustrate diversification associated with different feeding habits.

Step 1: Recognise diversification from an ancestor The key feature is the origin of different species from a common ancestor, with adaptation to different available habitats or ways of life. Option (A) is

the only choice that describes this ancestral diversification; its reference to other geographical areas corresponds to descendants spreading into different habitats.

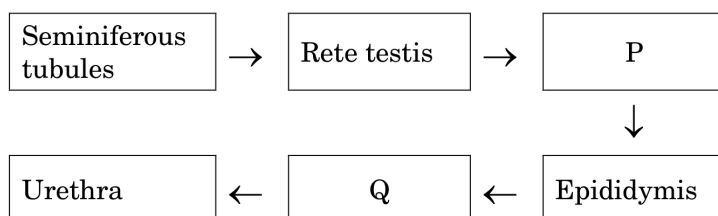
Step 2: Reject unrelated processes Migration of already different species into one area, as in (B), does not describe their origin from a common ancestor. Option (C) concerns adjustment by one individual, whereas adaptive radiation is evolutionary diversification across generations. Anthropogenic action in (D) is human influence and is not the definition of adaptive radiation.

Step 3: Conclusion Diversification of species from a common ancestor identifies adaptive radiation. Hence, the correct option is (A).

Quick Tip to Solve: Look for one common ancestor giving rise to several species; migration or adjustment by a single individual is insufficient.

4. The path of the sperm transport is shown below. Identify P and Q and select the correct option.

[1 mark]



- (A) P – Vasa efferentia, Q – Ureter
(B) P – Ejaculatory duct, Q – Vas deferens
(C) P – Vasa efferentia, Q – Vas deferens
(D) P – Vas deferens, Q – Vasa efferentia

Correct Answer: (C) P – Vasa efferentia, Q – Vas deferens

Solution:

Concept:

- Sperm formed in the seminiferous tubules travel through the male accessory ducts before entering the urethra.
- The vasa efferentia connect the rete testis with the epididymis; the epididymis continues into the vas deferens.

Step 1: Identify P from its neighbours In the diagram P lies after the rete testis and before the epididymis. These connecting ductules are the vasa efferentia. The ejaculatory duct is much farther along the pathway, so it cannot occupy P; the vas deferens also lies after the epididymis.

Step 2: Identify Q and compare the pairs Q follows the epididymis, so it represents the vas deferens. The vas deferens joins the duct from the seminal vesicle to form the ejaculatory duct, which opens into the urethra; that intermediate duct is omitted from the simplified printed pathway. The ureter carries urine from a kidney to the urinary bladder and never transports sperm. Thus (A) assigns Q a urinary duct, (B) misplaces P, and (D) reverses the two required structures.

Step 3: Conclusion P is vasa efferentia and Q is vas deferens. Hence, the correct option is (C).

Quick Tip to Solve: Use the epididymis as the landmark: vasa efferentia enter it, while the vas deferens carries sperm away from it.

5. Endosperm is completely consumed by the developing embryo in which of the following plants?

Choose the correct option.

[1 mark]

- (A) Castor and Coconut
- (B) Coconut and Groundnut
- (C) Groundnut and Pea
- (D) Castor and Pea

Correct Answer: (C) Groundnut and Pea

Solution:

Concept:

- Endosperm supplies nutrition to the developing embryo and may persist or be consumed during seed development.
- Non-albuminous seeds lack residual endosperm at maturity, whereas albuminous seeds retain endosperm.

Step 1: Identify seeds without residual endosperm In groundnut and pea, the developing embryo completely consumes the endosperm. Their mature seeds are non-albuminous, with food reserves stored mainly in the cotyledons. Both plants in option (C) therefore satisfy the stated condition.

Step 2: Exclude pairs containing albuminous seeds Castor and coconut retain endosperm in the mature seed and are albuminous. Consequently (A) contains two plants that do not meet the condition. Option (B) fails because it contains coconut, even though groundnut qualifies. Option (D) fails because it contains castor, even though pea qualifies. A correct pair must satisfy the condition for both members.

Step 3: Conclusion Endosperm is completely consumed in groundnut and pea. Hence, the correct option is (C).

Quick Tip to Solve: Classify both members of each pair: pea and groundnut are non-albuminous, while castor and coconut retain endosperm.

6. Biocontrol agents like Dragonflies are used to get rid of which of the following pests/insects?

[1 mark]

- (A) Aphids
- (B) Mosquitoes
- (C) Caterpillar of butterflies
- (D) Cotton bollworms

Correct Answer: (B) Mosquitoes

Solution:

Concept:

- Biological control uses the natural enemies of pests, such as predators, to reduce their populations.
- The predator must be matched to its appropriate prey; different biocontrol organisms target different pests.

Step 1: Identify the dragonfly's target Dragonflies are useful predators of mosquitoes and help control mosquito populations. Their action is a predator-prey interaction, so they provide biological control without acting as a chemical insecticide.

Step 2: Distinguish the alternative pests Ladybird beetles are the standard biological-control example associated with aphids, making (A) an incorrect pairing for dragonflies. Butterfly caterpillars are associated with control using the bacterium *Bacillus thuringiensis*, while Bt cotton protects against cotton bollworms. Neither (C) nor (D) is the textbook target paired with dragonflies in this question.

Step 3: Conclusion Dragonflies are used to control mosquitoes. Hence, the correct option is (B).

Quick Tip to Solve: Remember the paired examples: ladybird beetles control aphids, while dragonflies control mosquitoes.

7. Which of the following options correctly depicts the recognition site for EcoRI?

[1 mark]

- (A) G – A – A↓T – T – C
C – T – T↑A – A – G
- (B) G – T – C↓G – A – C
C – A – G↑C – T – G
- (C) G↓T – C – G – A – C
C – A – G – C – T↑G
- (D) G↓A – A – T – T – C
C – T – T – A – A↑G

Correct Answer: (D) G↓A – A – T – T – C
C – T – T – A – A↑G

Solution:**Concept:**

- EcoRI is a restriction endonuclease that recognises the palindromic sequence 5' – GAATTC – 3' in double-stranded DNA.
- Its staggered cuts occur between G and A on each strand when that strand is read in the 5' to 3' direction, producing sticky ends.

Step 1: Locate the EcoRI cuts Write the complementary antiparallel strands and mark the cleavage positions:



The vertical bars mark cleavage of the sugar-phosphate backbone. The staggered arrangement leaves a four-base 5'-AATT overhang.

Step 2: Compare sequence and cleavage together Option (A) has the EcoRI base sequence but places both cuts centrally, between A and T on the upper strand and T and A on the lower strand. Options (B) and (C) show GTCGAC rather than GAATTC, so their recognition sequence is wrong for EcoRI regardless of the cuts. Option (D) shows both the correct sequence and the required staggered cuts between G and A.

Step 3: Conclusion EcoRI cuts G|AATTC and the complementary CTTAA|G strand. Hence, the correct option is (D).

Quick Tip to Solve: Check both the six-base GAATTC sequence and the G-A cleavage position; the right sequence with a central cut is still incorrect.

8. The human protein which is being obtained from transgenic animals and is used to treat emphysema is : [1 mark]

- (A) Alpha-lactalbumin
- (B) Thyroxine
- (C) α -1-antitrypsin
- (D) Insulin

Correct Answer: (C) α -1-antitrypsin

Solution:**Concept:**

- Transgenic animals carry an introduced gene and can produce a useful human protein encoded by that gene.
- α -1-antitrypsin is a protease inhibitor that helps protect lung tissue from damage by proteolytic enzymes.

Step 1: Connect the protein to emphysema Emphysema involves damage to the walls of the lung alveoli. Deficiency of α -1-antitrypsin allows excessive protease action and can cause such damage.

This human protein is obtained using transgenic animals for therapeutic use.

Step 2: Check the remaining options Alpha-lactalbumin is a milk protein, thyroxine is a thyroid hormone, and insulin regulates blood glucose. None is the human protein specified for treating emphysema in this application.

Step 3: Conclusion The required protein is α -1-antitrypsin. Hence, the correct option is (C).

Quick Tip to Solve: Link emphysema with protection of alveoli: the biotechnology example is α -1-antitrypsin, not a milk protein or hormone.

9. *Gambusia* is a fish which is being introduced into ponds in order to check vector-borne diseases. Select the option that indicates the correct disease. [1 mark]

- (A) Ascariasis
- (B) Malaria
- (C) Amoebiasis
- (D) Typhoid

Correct Answer: (B) Malaria

Solution:

Concept:

- Biological control uses a natural enemy to reduce the population of a pest or a disease vector.
- *Gambusia* is a larvivorous fish: it feeds on mosquito larvae in water and limits the emergence of adult mosquitoes.

Step 1: Identify the vector controlled Mosquito larvae develop in water. Introducing *Gambusia* into ponds reduces their numbers. Malaria is transmitted by infected female *Anopheles* mosquitoes, so controlling mosquito breeding helps check malaria transmission.

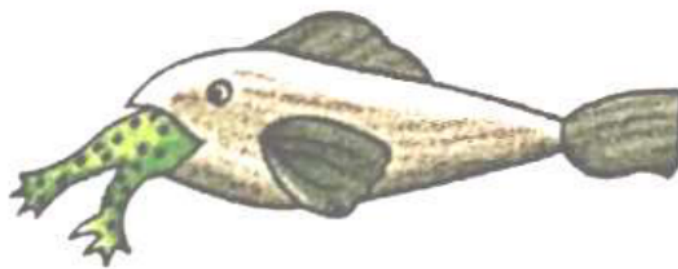
Step 2: Eliminate the other diseases Ascariasis, amoebiasis and typhoid are primarily acquired through contaminated food or water. They do not depend on a mosquito vector, so mosquito-larval control does not target their transmission in the way asked here.

Step 3: Conclusion The disease checked by introducing *Gambusia* into ponds is malaria. Hence, the correct option is (B).

Quick Tip to Solve: Trace the chain: *Gambusia* eats mosquito larvae, fewer mosquitoes develop, and malaria transmission is reduced.

10. Which type of interaction is being shown in the figure given below?

[1 mark]



- (A) Parasitism
- (B) Commensalism
- (C) Predation
- (D) Amensalism

Correct Answer: (C) Predation

Solution:

Concept:

- In predation, a predator captures and eats another organism, called its prey. The predator benefits while the prey is harmed.
- The interaction is represented as $(+, -)$, where $+$ denotes a benefit and $-$ denotes a harmful effect.

Step 1: Interpret the figure The figure shows a fish consuming another animal. The fish obtains food from the captured organism; the consumed animal is the prey and loses its life. This feeding relationship identifies the ecological interaction.

Step 2: Distinguish the other interactions Parasitism involves a parasite obtaining resources from a host, usually through a prolonged association. In commensalism one species benefits while the other is unaffected, and in amensalism one is harmed while the other is unaffected. None describes the feeding event shown.

Step 3: Conclusion The interaction shown is predation. Hence, the correct option is (C).

Quick Tip to Solve: When a figure shows one animal capturing and eating another, identify predator and prey before comparing the interaction signs.

11. Which one of the following fish is being illegally introduced for aquaculture purposes and is posing a threat to the indigenous catfishes in our rivers? [1 mark]

- (A) *Clarias gariepinus*
- (B) Nile perch
- (C) Climbing perch
- (D) *Protopterus*

Correct Answer: (A) *Clarias gariepinus*

Solution:

Concept:

- An alien species introduced outside its natural range may become invasive and threaten native biodiversity.
- The African catfish, *Clarias gariepinus*, is the introduced fish associated with a threat to indigenous catfishes in Indian rivers.

Step 1: Identify the aquaculture example The question describes the illegal introduction of African catfish for aquaculture. This species can adversely affect native aquatic fauna and is the NCERT example of a threat to indigenous catfishes.

Step 2: Compare the alternatives Nile perch is another famous introduced fish, but its textbook example concerns the decline of endemic cichlid fishes in Lake Victoria in East Africa. Climbing perch and *Protopterus* are not the illegally introduced African catfish named in this Indian-river example.

Step 3: Conclusion The fish is *Clarias gariepinus* (African catfish). Hence, the correct option is (A).

Quick Tip to Solve: Pair African catfish with Indian rivers and Nile perch with Lake Victoria to avoid confusing the two invasive-fish examples.

12. P and Q are required in the extension step of PCR to extend the primer sequences from the 3' end of each primer. Choose the option which correctly fills the blanks P and Q. [1 mark]

- (A) P – Ribonucleoside triphosphate, Q – DNA polymerase
- (B) P – Deoxyribonucleotide triphosphate, Q – Thermolabile Taq-polymerase
- (C) P – Deoxynucleotides, Q – Thermostable DNA-polymerase
- (D) P – Deoxyribonucleoside monophosphate, Q – Thermostable DNA-polymerase

Correct Answer: (C) P – Deoxynucleotides, Q – Thermostable DNA-polymerase

Solution:

Concept:

- In PCR, DNA polymerase extends an annealed primer by adding deoxyribonucleotides to its free 3'-OH end, synthesising DNA in the 5' → 3' direction.
- The enzyme used must be thermostable so that it can withstand repeated high-temperature denaturation cycles; Taq DNA polymerase has this property.

Step 1: Identify the substrates and enzyme New DNA requires deoxynucleotides, supplied as

deoxyribonucleoside triphosphates. A thermostable DNA polymerase joins these nucleotides according to the template sequence and extends each primer. The pair in option (C) gives these two requirements.

Step 2: Test the distractors Option (A) lists ribonucleoside triphosphates, which are RNA precursors. Option (B) incorrectly describes Taq polymerase as thermolabile. Option (D) supplies monophosphates rather than the triphosphate substrates needed for DNA synthesis.

Step 3: Conclusion P is deoxynucleotides and Q is thermostable DNA polymerase. Hence, the correct option is (C).

Quick Tip to Solve: For PCR extension, check both requirements together: DNA nucleotide substrates and a heat-stable DNA polymerase.

13. Assertion (A): Blastocyst becomes embedded in the endometrium of the uterus.

Reason (R): The morula divides and transforms into blastocyst.

[1 mark]

- (A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of the Assertion (A).
- (B) Both Assertion (A) and Reason (R) are true, but Reason (R) is *not* the correct explanation of the Assertion (A).
- (C) Assertion (A) is true, but Reason (R) is false.
- (D) Assertion (A) is false, but Reason (R) is true.

Correct Answer: (B) Both Assertion (A) and Reason (R) are true, but Reason (R) is *not* the correct explanation of the Assertion (A).

Solution:

Concept:

- Cleavage divisions produce a morula, which subsequently develops into a blastocyst with an outer trophoblast and an inner cell mass.
- Implantation is the embedding of the blastocyst in the uterine endometrium, following its attachment through the trophoblast.

Step 1: Evaluate the assertion The blastocyst attaches to the endometrium and becomes embedded in it as the uterine cells cover it. This is implantation, so the assertion is true.

Step 2: Evaluate the reason As embryonic development proceeds, the morula undergoes further divisions and transforms into a blastocyst. Thus, the reason correctly states the developmental sequence and is true.

Step 3: Test the explanatory link Formation of the blastocyst explains its origin, but does not explain how it attaches to and becomes embedded in the endometrium. Implantation involves the interaction of the trophoblast with the uterine lining. Therefore, the reason is not the correct explanation of the assertion.

Step 4: Conclusion Both A and R are true, but R is not the correct explanation of A. Hence, the correct option is (B).

Quick Tip to Solve: Separate blastocyst formation from implantation: a preceding developmental event need not explain attachment to the uterus.

14. Assertion (A): The two chains of DNA have antipolarity.

Reason (R): In one chain of DNA, ribose sugar at 5' end consists of a free phosphate moiety, while at the other end, the ribose sugar has free 3'-OH group. [1 mark]

- (A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of the Assertion (A).
- (B) Both Assertion (A) and Reason (R) are true, but Reason (R) is *not* the correct explanation of the Assertion (A).
- (C) Assertion (A) is true, but Reason (R) is false.
- (D) Assertion (A) is false, but Reason (R) is true.

Correct Answer: (C) Assertion (A) is true, but Reason (R) is false.

Solution:

Concept:

- The two polynucleotide strands of DNA are antiparallel: one runs in the $5' \rightarrow 3'$ direction and the complementary strand runs in the $3' \rightarrow 5'$ direction.
- DNA contains deoxyribose sugar, whereas RNA contains ribose. A DNA strand has a free phosphate at its 5' end and a free hydroxyl group at its 3' end.

Step 1: Evaluate the assertion The two chains of a DNA double helix have opposite polarity. If one chain has $5' \rightarrow 3'$ polarity, the other has $3' \rightarrow 5'$ polarity. Thus, the assertion about antipolarity is true.

Step 2: Evaluate the printed reason The reason specifically calls the sugar in DNA ribose. This is incorrect: the sugar in DNA is deoxyribose. Although the stated free phosphate and 3'-OH end groups describe strand polarity, the claim about ribose makes the reason false as written.

Step 3: Assess whether the reason explains the assertion A false reason cannot explain a true assertion. Moreover, describing the two ends of a single strand alone does not state that the two complementary strands run in opposite directions.

Step 4: Conclusion The assertion is true, but the reason is false. Hence, the correct option is (C).

Quick Tip to Solve: Check the sugar before judging DNA statements: DNA has deoxyribose, and antiparallel refers to the opposite directions of two strands.

15. Assertion (A): Mucosa-associated lymphoid tissues are specialised immune barriers located on the skin.

Reason (R): MALT constitutes about 50 percent of the lymphoid tissue in a human body. [1 mark]

(A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of the Assertion (A).

(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is *not* the correct explanation of the Assertion (A).

(C) Assertion (A) is true, but Reason (R) is false.

(D) Assertion (A) is false, but Reason (R) is true.

Correct Answer: (D) Assertion (A) is false, but Reason (R) is true.

Solution:

Concept:

- Mucosa-associated lymphoid tissue (MALT) is lymphoid tissue associated with the mucosal lining of major body tracts.
- The skin is a physical barrier of innate immunity; it is not the location specified by the term MALT.

Step 1: Evaluate the assertion MALT occurs within the lining of the respiratory, digestive and urogenital tracts. The assertion incorrectly places this tissue on the skin. Therefore, Assertion (A) is false.

Step 2: Evaluate the reason MALT constitutes about 50 percent of the lymphoid tissue in the human body. This is the standard proportion stated for this tissue, so Reason (R) is true.

Step 3: Check the explanation and codes The correct proportion does not justify the incorrect location in the assertion. Codes (A) and (B) require both statements to be true, while code (C) requires a true assertion and a false reason. None matches these evaluations.

Step 4: Conclusion The assertion is false, but the reason is true. Hence, the correct option is (D).

Quick Tip to Solve: In MALT, associate the word mucosa with the linings of body tracts, then assess the percentage separately.

16. Assertion (A): ELISA is based on the principle of antigen antibody interaction.

Reason (R): ELISA can detect the proteins/glycoproteins only when present in high concentration.

[1 mark]

- (A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of the Assertion (A).
- (B) Both Assertion (A) and Reason (R) are true, but Reason (R) is *not* the correct explanation of the Assertion (A).
- (C) Assertion (A) is true, but Reason (R) is false.
- (D) Assertion (A) is false, but Reason (R) is true.

Correct Answer: (C) Assertion (A) is true, but Reason (R) is false.

Solution:

Concept:

- ELISA stands for enzyme-linked immunosorbent assay and uses the specificity of antigen–antibody binding.
- An enzyme-linked detection reaction produces a measurable signal, allowing sensitive detection of a target antigen or antibody.

Step 1: Evaluate the assertion An antibody specifically recognises and binds its corresponding antigen. ELISA uses this antigen–antibody interaction to detect the target in a sample. Thus, Assertion (A) is true.

Step 2: Evaluate the reason ELISA can detect very small amounts of the relevant proteins or glycoproteins. It does not require the target to be present only at high concentration. The word “only” makes Reason (R) false.

Step 3: Check the explanation and codes A false statement about the concentration requirement cannot explain the true principle of ELISA. Codes (A) and (B) incorrectly treat the reason as true, and code (D) incorrectly treats the assertion as false.

Step 4: Conclusion The assertion is true and the reason is false. Hence, the correct option is (C).

Quick Tip to Solve: For ELISA, remember specific binding and sensitive detection; a claim that only high concentrations can be detected is false.

Section B (10 marks)

17(a). How is it possible in *Oxalis* and *Viola* plants, to produce assured seed sets even in the absence of pollinators?

[2 marks]

Solution:

Concept:

- Cleistogamous flowers remain closed and undergo autogamy, the transfer of pollen to the stigma of the same flower.
- Pollinators are unnecessary when pollen is deposited directly on a receptive stigma within a closed

flower.

Step 1: Identify the flower type *Oxalis* and *Viola* produce cleistogamous flowers in addition to open, chasmogamous flowers. The cleistogamous flowers do not open, and their anthers and stigma lie close to each other within the closed flower.

Step 2: Explain assured pollination and seed formation When the anthers dehisce, their pollen comes in contact with the stigma of the same flower. Pollen germinates there and the pollen tubes carry male gametes towards the embryo sac, allowing fertilisation and subsequent seed formation. Because this self-pollination takes place inside the closed flower, it is independent of visiting insects or any other pollinating agent. It is this cleistogamous mechanism that ensures seed set even when pollinators are absent.

Step 3: Conclusion *Oxalis* and *Viola* obtain assured seed set through autogamy in their closed, cleistogamous flowers, where anthers and stigma remain in close proximity.

Quick Tip to Solve: Link assured seed set to closed flowers, close anther–stigma contact and automatic self-pollination.

OR

17(b). Write the ploidy of the cells of the nucellus, MMC (Megaspore Mother Cell), the functional megaspore and female gametophyte. [2 marks]

Solution:

Concept:

- Ploidy is the number of chromosome sets: n denotes haploid and $2n$ denotes diploid.
- Meiosis reduces the chromosome number from $2n$ to n , whereas mitosis maintains the chromosome number.

Step 1: Identify the sporophytic cells The nucellus is part of the diploid sporophyte, so its cells have ploidy $2n$. A megaspore mother cell (MMC) differentiates within the nucellus and is also diploid, $2n$. The MMC has not yet undergone the reduction division that produces megaspores.

Step 2: Follow meiosis and gametophyte development The MMC undergoes meiosis to produce haploid megaspores. Therefore, the functional megaspore has ploidy n . Its nucleus undergoes mitotic divisions to form the female gametophyte or embryo sac, which is the haploid generation, n . The egg, synergids and antipodals are haploid. The two haploid polar nuclei in the central cell can fuse to form a diploid secondary nucleus; this special fusion does not change the designation of the female gametophyte as haploid.

Step 3: Conclusion Nucellus: $2n$; MMC: $2n$; functional megaspore: n ; female gametophyte: n .

Quick Tip to Solve: Place the reduction in ploidy at MMC meiosis: the sequence is $2n, 2n, n, n$.

18. How can childless couples get help by the following assisted reproductive technologies?

(a) GIFT

(b) ICSI

[2 marks]

Solution:

Concept:

- Assisted reproductive technologies help overcome specific difficulties in gamete production, fertilisation or early development.
- GIFT introduces gametes into a fallopian tube; ICSI assists fertilisation by placing a sperm directly inside an ovum.

Step 1: Explain how GIFT helps (a) **GIFT: Gamete intra-fallopian transfer.** An ovum collected from a donor is transferred into the fallopian tube of a woman who cannot produce ova but can provide a suitable environment for fertilisation and further development. The transferred ovum can be fertilised by sperm within her reproductive tract. Thus, a deficiency in ovum production can be overcome when the recipient has a functional reproductive environment.

Step 2: Explain how ICSI helps (b) **ICSI: Intra-cytoplasmic sperm injection.** A single sperm is directly injected into the cytoplasm of an ovum in the laboratory to achieve fertilisation. This bypasses difficulty in the sperm reaching or penetrating the ovum and can help in male-factor infertility. The resulting embryo is subsequently transferred to the female reproductive tract for further development and establishment of pregnancy.

Step 3: Conclusion GIFT supplies a donor ovum to a suitable fallopian tube for fertilisation in the body, while ICSI achieves assisted fertilisation by direct injection of a sperm into an ovum before embryo transfer.

Quick Tip to Solve: Distinguish the transfer sites: GIFT places a gamete in the fallopian tube; ICSI places a sperm inside the ovum.

19(a). (i) Name the source plant of heroin drug. How is it obtained from the plant?

(ii) Write the effects of heroin on the human body.

[2 marks]

Solution:

Concept:

- Heroin is an opioid drug, chemically called diacetylmorphine; it is commonly known as smack.
- Opioids bind to specific opioid receptors in the central nervous system and gastrointestinal tract. Heroin acts as a depressant.

Step 1: Identify the plant and the precursor (i) The source plant is the opium poppy, *Papaver somniferum*. Morphine is extracted from the latex of this plant. Heroin is then obtained by acetylation of morphine. Thus, the plant supplies morphine as the precursor; heroin is the chemically modified product.

Step 2: State the effect on the body (ii) Heroin depresses the central nervous system and slows down body functions. Its action at opioid receptors produces sedative effects. Repeated use can produce dependence, but the principal effect asked here is the slowing of body functions rather than

stimulation of nervous activity.

Step 3: Conclusion Heroin is obtained by acetylating morphine extracted from the latex of *Papaver somniferum*. It is a depressant that slows down body functions.

Quick Tip to Solve: Remember the sequence: opium-poppy latex → morphine → acetylation → heroin.

OR

19(b). What is ‘withdrawal syndrome’? List any two symptoms it is characterised by.

[2 marks]

Solution:

Concept:

- Drug dependence develops when the body becomes accustomed to the regular presence of a drug or alcohol.
- Abruptly discontinuing the substance in a dependent person can produce a characteristic set of unpleasant physical and psychological responses.

Step 1: Define withdrawal syndrome Withdrawal syndrome is the characteristic set of symptoms that appears when the regular dose of a drug or alcohol is abruptly discontinued in a dependent individual. These symptoms reflect the body’s dependence on the substance; the defining event is stopping its regular intake.

Step 2: List two characteristic symptoms Two symptoms are **anxiety** and **sweating**. Anxiety is a state of marked uneasiness or apprehension, whereas sweating is a physical response. These illustrate that withdrawal can affect both the person’s mental state and bodily functions; both are recognised features of the syndrome.

Step 3: Conclusion Withdrawal syndrome is the response to abrupt discontinuation of a regularly used substance in a dependent person. Two symptoms are anxiety and sweating.

Quick Tip to Solve: Link withdrawal to stopping the regular dose, then give two specific symptoms such as anxiety and sweating.

20. If a person is having karyotype 47, XXY, name the genetic disorder he is suffering from. Write down symptoms of such a genetic disorder.

[2 marks]

Solution:

Concept:

- A normal human male has 46 chromosomes with the sex-chromosome constitution XY.
- Klinefelter’s syndrome is a sex-chromosomal aneuploidy caused by an additional X chromosome in a male, giving the karyotype 47, XXY.

Step 1: Interpret the chromosome constitution The given total is 47 rather than 46, and the sex chromosomes are XXY rather than XY. The extra chromosome is therefore an X chromosome. This

constitution identifies **Klinefelter's syndrome**. The presence of a Y chromosome accounts for the individual's male development.

Step 2: Describe the characteristic features The individual has overall masculine development but also develops some feminine characteristics, notably enlargement of the breasts (gynaecomastia). The testes are underdeveloped, and the individual is usually sterile because normal sperm formation is impaired. These features distinguish the syndrome from a simple variation in chromosome number without an effect on sexual development.

Step 3: Conclusion The disorder is Klinefelter's syndrome. Characteristic features include male development with gynaecomastia, underdeveloped testes and sterility.

Quick Tip to Solve: In 47, XXY, identify the extra X first: an XXY male points to Klinefelter's syndrome and sterility.

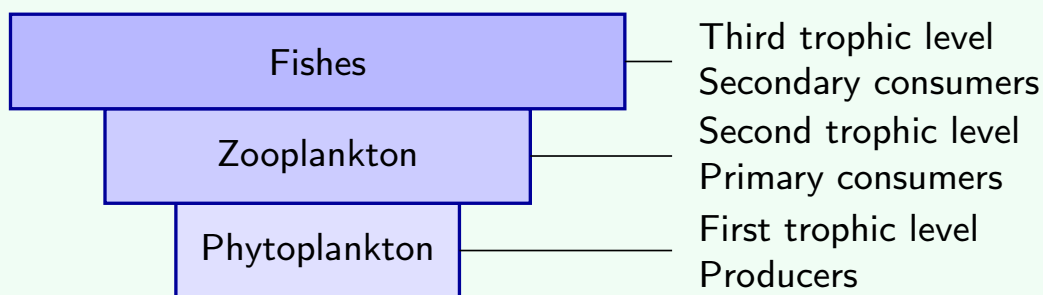
21(a). Construct a pyramid of biomass starting with Phytoplanktons and label three trophic levels. Is the pyramid upright or inverted? [2 marks]

Solution:

Concept:

- A pyramid of biomass compares the total standing biomass of organisms at successive trophic levels at a particular time.
- In an aquatic food chain, phytoplankton are producers, zooplankton are primary consumers and fishes feeding on zooplankton are secondary consumers.

Step 1: Arrange and label the trophic levels Place phytoplankton at the first trophic level, zooplankton at the second, and zooplankton-eating fishes at the third. The feeding sequence is phytoplankton → zooplankton → fishes. In the biomass pyramid, the producers form the lowest tier even though that tier has the smallest width.



Inverted aquatic pyramid of biomass (schematic, not to scale)

Step 2: Explain the shape of the pyramid The aquatic pyramid of biomass is **inverted**. The standing biomass of phytoplankton at a given instant can be smaller than the consumer biomass it supports. Phytoplankton reproduce and are consumed rapidly, so their biomass is repeatedly renewed. A small standing crop can therefore sustain larger consumer biomass over time. The tier widths indicate this inverted pattern schematically.

Step 3: Conclusion The three labelled levels are phytoplankton (producers), zooplankton (primary

consumers) and fishes (secondary consumers); the pyramid of biomass is inverted.

Quick Tip to Solve: Keep phytoplankton at the bottom but make their biomass tier narrow; the diagram represents standing biomass, not energy flow.

OR

21(b). Differentiate between grazing food chain and detritus food chain.

[2 marks]

Solution:

Concept:

- A food chain shows the transfer of food and energy through successive groups of organisms.
- Grazing and detritus food chains differ in their starting material and in the organisms that first use that material as food.

Step 1: Describe the grazing food chain A grazing food chain begins with **living green plants or other photosynthetic producers**. Herbivores feed directly on this living plant material, and carnivores feed on the herbivores. An example is grass → grasshopper → frog. Thus, the first consumers obtain energy by grazing on living producers.

Step 2: Contrast the detritus food chain A detritus food chain begins with **dead organic matter**, such as fallen leaves and animal remains. Its initial consumers include decomposers, mainly bacteria and fungi; detritivores also feed on and fragment detritus. Decomposers secrete enzymes externally and absorb the soluble products. The contrast is therefore living producer biomass used by herbivores versus dead organic material used by decomposers and detritivores.

Step 3: Conclusion The grazing food chain starts with living producers and passes to herbivores; the detritus food chain starts with dead organic matter and is initially used by decomposers and detritivores.

Quick Tip to Solve: Compare the starting material first: living green plants indicate grazing, whereas dead organic matter indicates detritus.

Section C (21 marks)

22. Define test cross. How does test cross help to determine the genotype of an individual? Explain with the help of an example.

[3 marks]

Solution:

Concept:

- A dominant phenotype can be produced by either a homozygous dominant or a heterozygous genotype; the phenotype alone does not distinguish them.
- In a test cross, an individual showing the dominant phenotype but having an unknown genotype is crossed with a homozygous recessive individual for the same character.

Step 1: Select a recessive tester Consider plant height in pea, where T determines tallness and t determines dwarfness. An unknown tall plant may be TT or Tt . Cross it with a dwarf plant, tt . The dwarf tester produces only t -bearing gametes, so the offspring directly reveal the alleles contributed by the tall parent.

Step 2: Examine the homozygous possibility If the tall plant is homozygous, the cross is

$$TT \times tt \longrightarrow \text{all } Tt \text{ (tall)}.$$

The tall parent produces only T -bearing gametes, and every offspring receives one T and one t . Thus, an all-tall progeny is the expected result for a homozygous dominant parent.

Step 3: Examine the heterozygous possibility If the tall plant is heterozygous, it produces T - and t -bearing gametes in equal proportions. Therefore,

$$Tt \times tt \longrightarrow \frac{1}{2}Tt \text{ (tall)} + \frac{1}{2}tt \text{ (dwarf)}.$$

The expected phenotypic and genotypic ratios are both 1 : 1. A dwarf offspring demonstrates that the tall parent carries the recessive allele. The ratios are interpreted using a sufficiently large progeny; a small sample may deviate by chance.

Step 4: Conclusion A test cross uses a homozygous recessive tester to identify the genotype of a dominant-looking individual: $TT \times tt$ gives all tall offspring, whereas $Tt \times tt$ gives tall and dwarf offspring in an expected 1 : 1 ratio.

Quick Tip to Solve: Choose the recessive tester: because it supplies only the recessive allele, any recessive offspring reveals heterozygosity in the dominant parent.

23. (a) Draw a labelled diagram of a human sperm. (Label any four parts)

(b) Define spermiogenesis and spermiation.

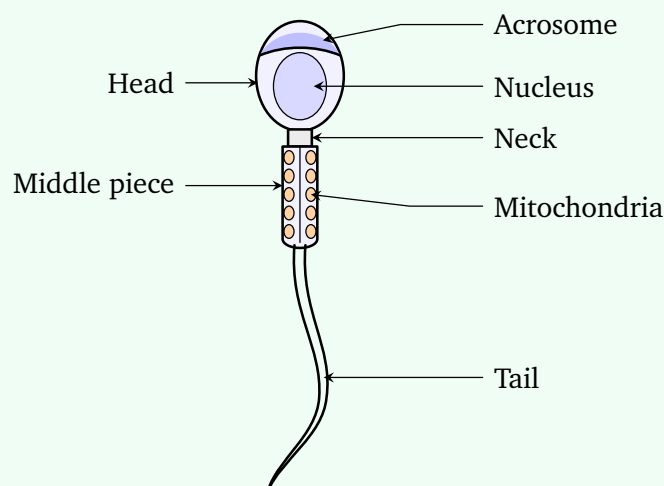
[3 marks]

Solution:

Concept:

- A human sperm is a motile male gamete enclosed by a plasma membrane. Its main regions are the head, neck, middle piece and tail.
- Spermiogenesis changes the form of a spermatid, whereas spermiation releases a spermatozoon from its association with a Sertoli cell.

Step 1: (a) Label the structure of a human sperm The head contains the haploid nucleus. Its anterior end bears an acrosomal cap containing enzymes that assist entry into the ovum. The short neck connects the head to the middle piece. Numerous mitochondria in the middle piece supply energy for movement of the tail, which propels the sperm. The labelled drawing shows these regions and organelles; any four of the indicated parts satisfy the labelling requirement.



Human sperm showing the head, neck, middle piece and tail, with acrosome, nucleus and mitochondria labelled.

Step 2: (b) Define spermiogenesis Spermiogenesis is the transformation of haploid spermatids into spermatozoa (sperms). During this differentiation, the nucleus becomes compact, the acrosome and tail develop, and excess cytoplasm is shed. It is a change in cellular form, not another meiotic division; the haploid chromosome number is retained.

Step 3: (b) Define spermiation Following spermiogenesis, the sperm heads remain embedded in the Sertoli cells of the seminiferous tubules. Spermiation is the process by which spermatozoa are released from the Sertoli cells into the lumen of the seminiferous tubules. It therefore follows sperm formation and is distinct from ejaculation, which is the expulsion of semen from the male reproductive tract.

Step 4: Conclusion Spermiogenesis forms spermatozoa from spermatids; spermiation releases the formed spermatozoa from Sertoli cells into the seminiferous-tubule lumen. The labelled sperm is shown above.

Quick Tip to Solve: Remember the sequence: spermatid changes shape in spermiogenesis, then the formed sperm is released from the Sertoli cell in spermiation.

24. Explain any three different approaches used in the treatment of a person suffering from Adenosine Deaminase deficiency. [3 marks]

Solution:

Concept:

- Adenosine deaminase (ADA) is an enzyme crucial for normal immune-system function. A defect in the gene encoding ADA can cause severe immune deficiency.
- Treatment can provide functional blood-forming cells, supply the missing enzyme, or introduce a functional ADA gene into the patient's cells.

Step 1: Bone marrow transplantation Bone marrow from a suitable healthy donor can be transplanted into the patient. The donor's blood-forming stem cells carry a functional ADA gene and can give rise to functional immune cells. This approach has been used to treat ADA deficiency in some children by

replacing the defective blood-cell-forming system with donor-derived cells.

Step 2: Enzyme replacement therapy Functional ADA enzyme is administered to the patient by injection. It compensates for the missing enzyme activity and helps improve immune function. The injected enzyme is eventually broken down, so repeated administration is needed. This treatment supplies the gene product; it does not correct the defective ADA gene in the patient's cells.

Step 3: Gene therapy using lymphocytes Lymphocytes are taken from the patient's blood and grown in culture outside the body. A functional ADA complementary DNA (cDNA) is introduced into these lymphocytes using a retroviral vector. The genetically modified lymphocytes are then returned to the patient, where they express functional ADA. Since these lymphocytes are not immortal, periodic infusions of modified cells are required. Thus, the lymphocyte-based procedure compensates for the deficiency without permanently correcting every affected cell in the body.

Step 4: Conclusion Three approaches are bone marrow transplantation, repeated ADA enzyme replacement, and gene therapy in which a functional ADA cDNA is introduced into cultured patient lymphocytes before their reinfusion.

Quick Tip to Solve: Distinguish the three treatments by what is supplied: donor marrow cells, the ADA enzyme itself, or a functional ADA gene in modified lymphocytes.

25. What are sacred groves? Name any four sacred groves and mention the places where they are found in India. [3 marks]

Solution:

Concept:

- Sacred groves are patches of natural forest protected by local communities because of religious beliefs and cultural traditions.
- They conserve biodiversity in its natural habitat and are therefore examples of in-situ conservation; the entire local community of organisms is protected.

Step 1: Define sacred groves and explain their protection A sacred grove is a forest patch regarded as sacred, often associated with a deity or ancestral tradition. Local people traditionally refrain from cutting trees and disturbing or killing the animals within it. Such community protection allows plants and animals to survive in their original surroundings, together with their ecological interactions. Sacred groves can therefore act as refuges for rare and threatened plants even when forests outside them have been disturbed.

Step 2: List four sacred-grove regions with their locations Four examples of sacred groves in India, identified by the regions in which they occur, are:

1. Sacred groves of the Khasi and Jaintia Hills: Meghalaya.
2. Sacred groves of the Aravalli Hills: Rajasthan.
3. Sacred groves of the Western Ghats: Karnataka and Maharashtra.
4. Sacred groves of the Sarguja, Chanda and Bastar areas: central India, principally Chhattisgarh and Maharashtra.

These are forest areas preserved through traditional community practices; they retain native species

within their natural habitats rather than maintaining them in botanical gardens or other artificial collections.

Step 3: Conclusion Sacred groves are traditionally protected sacred forest patches. Examples occur in the Khasi and Jaintia Hills, Aravalli Hills, Western Ghats, and Sarguja–Chanda–Bastar areas, at the Indian locations listed above.

Quick Tip to Solve: Pair each sacred-grove region with its location, and use the phrase “protected in the natural habitat” to identify in-situ conservation.

26. (a) How does the human body respond to an allergen? Which type of antibody is produced during allergic reactions?

(b) Name the types of drugs that help in reducing the symptoms of allergic reactions.

(c) Name the chemicals released in the body during an allergic reaction.

[3 marks]

Solution:

Concept:

- Allergy is an exaggerated response of the immune system to certain substances in the environment, called allergens, such as pollen or dust.
- Allergic reactions involve immunoglobulin E (IgE) antibodies and the release of chemical mediators from mast cells.

Step 1: Explain the response to an allergen in part (a) The body of a susceptible individual responds to an allergen with an exaggerated immune response. During sensitisation, the immune system produces IgE antibodies against the allergen; these antibodies bind to mast cells. On subsequent exposure, the allergen interacts with the IgE attached to these cells and triggers the release of inflammatory chemicals. These chemicals produce symptoms such as sneezing, watery eyes, a running nose, or difficulty in breathing. Thus, the antibody associated with allergic reactions is **IgE**, not the antibodies of the IgG class that are abundant in blood.

Step 2: Name the drugs for part (b) The symptoms can be reduced by **antihistamines, adrenaline and steroids**. Antihistamines oppose the effects of histamine, steroids suppress inflammation, and adrenaline is used in severe allergic reactions to rapidly counter dangerous effects such as airway narrowing and a fall in blood pressure. These drugs reduce the allergic response or its effects; they are not antibiotics directed against the allergen.

Step 3: Identify the released chemicals in part (c) The chemicals released from mast cells during an allergic reaction are **histamine and serotonin**. They contribute to the inflammatory response and the characteristic allergic symptoms. Distinguish these released chemicals from IgE: IgE is the antibody involved in recognising the allergen and initiating the mast-cell response.

Step 4: Conclusion (a) An allergen elicits an exaggerated immune response involving IgE antibodies. (b) Antihistamines, adrenaline and steroids reduce symptoms. (c) Mast cells release histamine and serotonin.

Quick Tip to Solve: Keep three categories separate: IgE is the antibody, histamine and serotonin are released mediators, and antihistamines, adrenaline and steroids are drugs.

Solution:**Concept:**

- The Hardy–Weinberg principle states that allele frequencies in a population remain constant from generation to generation in the absence of evolutionary influences. The gene pool remains in genetic equilibrium.
- For a gene with two alleles, A and a , let their frequencies be p and q , respectively. Since these are the only alleles at that locus, $p + q = 1$.

Step 1: State the conditions for genetic equilibrium Consider a very large population with random mating. If mutation, migration (gene flow), natural selection and random genetic drift do not alter its allele frequencies, the relative frequencies of A and a remain unchanged across generations. The ideal equilibrium also assumes normal Mendelian segregation and the absence of other evolutionary disturbances. This gives a reference against which evolutionary change can be recognised.

Step 2: Derive the genotype-frequency equation Both male and female gamete pools contain allele A with probability p and allele a with probability q . Under random fertilisation, multiply the corresponding gamete probabilities. The frequency of AA is $p \times p = p^2$, and the frequency of aa is $q \times q = q^2$. A heterozygote can arise from A in the male gamete and a in the female gamete, or from the reverse combination; therefore its frequency is $pq + qp = 2pq$. All genotype frequencies sum to one:

$$(p + q)^2 = p^2 + 2pq + q^2 = 1.$$

Here p^2 , $2pq$ and q^2 represent the frequencies of AA , Aa and aa , respectively.

Step 3: Relate the equation to unchanged allele frequencies Each heterozygote contributes one copy of each allele. Hence, the frequency of A in the offspring generation is

$$p^2 + \frac{1}{2}(2pq) = p(p + q) = p.$$

Similarly, the frequency of a remains q . Thus, random mating by itself does not change allele frequencies. A change in allele frequency indicates a disturbance of genetic equilibrium and constitutes evolutionary change.

Step 4: Conclusion Hardy–Weinberg equilibrium is expressed as $p^2 + 2pq + q^2 = 1$, with $p + q = 1$. Under the stated conditions, the allele frequencies p and q remain constant from generation to generation.

Quick Tip to Solve: Define p and q as allele frequencies first; then label p^2 , $2pq$, and q^2 as genotype frequencies, with both gamete combinations included in $2pq$.

28. (a) Name the type of interaction seen in each of the following examples.

(i) An orchid growing on branch of mango tree

(ii) Wasp pollinating fig inflorescence

(b) Also explain the above interactions shown by (i) and (ii).

[3 marks]

Solution:

Concept:

- In commensalism, one species benefits while the other is neither benefited nor harmed; the interaction is represented as $(+, 0)$.
- In mutualism, both interacting species benefit, so the interaction is represented as $(+, +)$. The type of interaction depends on the effects on both partners.

Step 1: Identify the orchid–mango interaction (a)(i) The interaction is commensalism. The orchid is an epiphyte that grows on the mango tree's branch for physical support. Its elevated position helps it obtain light, but it does not draw food from the mango tree as a parasite would.

Step 2: Explain the effects on the two plants (b)(i) The orchid benefits from the supporting surface, whereas the mango tree receives no corresponding benefit and is not harmed. Thus the orchid is the positive partner and the mango tree is the unaffected partner in this $(+, 0)$ association.

Step 3: Identify and explain the fig–wasp interaction (a)(ii) The association is mutualism. (b)(ii) The female wasp uses the fig inflorescence as an egg-laying site, and the developing seeds provide nourishment for its larvae. In return, the wasp pollinates the fig inflorescence while seeking suitable sites for egg laying. The fig gains pollination and the wasp gains a breeding site and food for its young, so both partners benefit.

Step 4: Conclusion Orchid on mango: commensalism $(+, 0)$. Wasp pollinating fig: mutualism $(+, +)$.

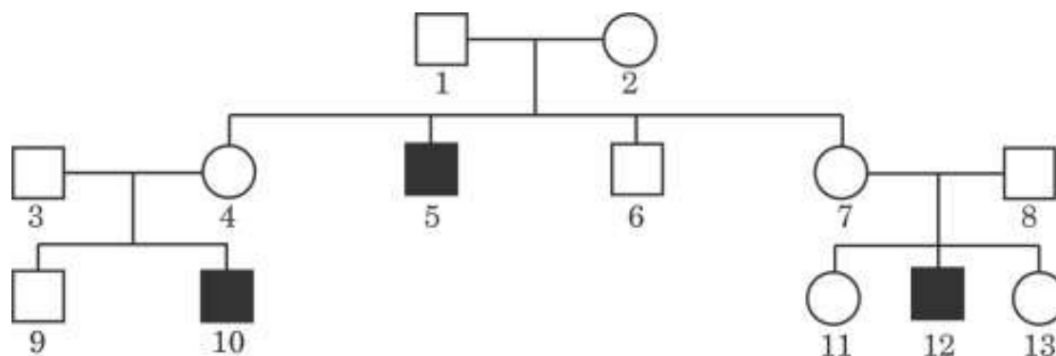
Quick Tip to Solve: Check the effect on each partner: support without harm gives commensalism; pollination exchanged for a breeding site and larval food gives mutualism.

Section D (8 marks)

Questions No. 29 and 30 are case-based questions. Each question has 3 sub-questions with internal choice in one sub-question.

29. Read the following passage and answer the questions that follow :

Haemophilia is a sex-linked recessive disease. Study the pedigree analysis given below showing the inheritance of the disease in a family and answer the questions that follow : [4 marks]



29(a). Analyse the given pedigree chart to explain why Haemophilia is considered a sex-linked recessive disorder. [1 mark]

Solution:

Concept:

- Haemophilia is caused by a recessive allele on the X chromosome. A male expresses it with one affected X, whereas a heterozygous female is a carrier.
- An unaffected carrier mother can transmit the affected X chromosome to her sons; a father transmits his Y chromosome to his sons.

Step 1: Recognise the recessive pattern Unaffected parents 1 and 2 have an affected son, 5. Similarly, unaffected females 4 and 7 have affected sons 10 and 12. The allele can therefore be carried without being expressed in the mothers.

Step 2: Relate the pattern to sex linkage All affected individuals shown, 5, 10 and 12, are males. Each receives his only X chromosome from his mother; its recessive allele is expressed because the Y chromosome has no corresponding normal allele to mask it. Females 2, 4 and 7 are unaffected carriers.

Step 3: Conclusion Transmission through unaffected carrier females to affected sons is consistent with X-linked recessive inheritance.

Quick Tip to Solve: In this pedigree, trace affected sons 5, 10 and 12 back to their unaffected mothers to identify the carrier line.

29(b). (i) The possibility of a human female becoming a haemophilic is extremely rare. Explain.

(ii) Why do the sons of a haemophilic father never suffer from this disease?

[2 marks]

Solution:

Concept:

- Let X^H carry the normal allele and X^h carry the recessive haemophilia allele. An affected female is X^hX^h , while a carrier female is X^HX^h .
- A son receives his X chromosome from his mother and his Y chromosome from his father. Thus X-linked alleles do not pass directly from father to son.

Step 1: Explain why affected females are rare (i) A female must inherit X^h from both parents to become haemophilic. Her father must therefore be haemophilic (X^hY), and her mother must be at least a carrier (X^HX^h) or herself affected. This combination is rare. A female receiving just one affected X is usually an unaffected carrier because the normal allele on her other X masks the recessive allele.

Step 2: Trace the paternal chromosome to sons (ii) A haemophilic father gives his sons his Y chromosome, not his affected X^h . Sons therefore never inherit haemophilia directly from their father. With a homozygous normal mother (X^HX^H), all sons are X^HY and unaffected. If the mother is a carrier or affected, however, a son can receive X^h from her and be haemophilic; the father's condition alone does not guarantee unaffected sons.

Step 3: Conclusion Haemophilic females are rare because two affected X-linked alleles are required. There is no direct father-to-son transmission of haemophilia; a son's risk depends on his mother's X chromosome.

Quick Tip to Solve: Track one chromosome from each parent: daughters need two affected X alleles, while sons get the relevant X only from their mother.

29(c)(i). Write the possible genotype of the individuals 2 and 5.

[1 mark]

Solution:

Concept:

- Let X^H denote an X chromosome carrying the normal allele and X^h one carrying the recessive haemophilia allele.
- A male receives his only X chromosome from his mother. An unaffected female carrying one recessive allele has genotype X^HX^h .

Step 1: Determine the genotype of individual 5 Individual 5 is a shaded square, representing an affected male. A male has one X and one Y chromosome, so his genotype must be X^hY . He received X^h from his mother, individual 2.

Step 2: Identify the carrier mother Individual 2 is an unshaded circle, representing an unaffected female. Since she has an affected son, she must possess X^h . Her unaffected phenotype shows that her other X carries the normal allele, so she is a carrier with genotype X^HX^h .

Step 3: Conclusion Individual 2: X^HX^h , an unaffected carrier; individual 5: X^hY , a haemophilic

male.

Quick Tip to Solve: Start with the shaded son: his affected X must come from his mother, identifying her as a carrier if she is unaffected.

OR

29(c)(ii). Why is haemophilia categorised as a Mendelian disorder?

[1 mark]

Solution:

Concept:

- A Mendelian disorder results from an alteration or mutation in a single gene and is inherited according to Mendelian principles.
- Haemophilia is an X-linked recessive disorder: the mutant allele is carried on the X chromosome, and its inheritance can be traced by pedigree analysis.

Step 1: Identify the genetic basis Haemophilia results from a mutation in a gene controlling a blood-clotting factor. The defective allele impairs normal blood coagulation. It is a single-gene disorder, rather than a disorder caused by a change in the number of whole chromosomes.

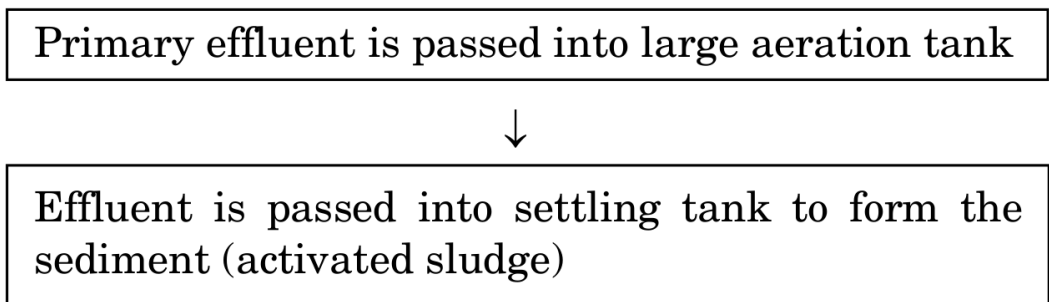
Step 2: Relate transmission to Mendelian principles The normal and mutant alleles segregate during gamete formation. A carrier female can pass either X-linked allele to her offspring. The normal allele masks the recessive allele in a carrier, whereas a male expresses the recessive allele on his single X chromosome. This predictable segregation explains its transmission through the family.

Step 3: Conclusion Haemophilia is categorised as a Mendelian disorder because it is caused by a single-gene mutation and follows Mendelian inheritance as an X-linked recessive trait.

Quick Tip to Solve: For a Mendelian-disorder question, state both the single-gene cause and the predictable inheritance of its alleles.

30. Read the following passage and answer the questions that follow :

Sewage is generated in large quantities in the urban areas. It is treated in sewage treatment-plants (STPs) to make it less polluted before discharging into any natural water body. Observe the flow chart given below and answer the questions that follow : [4 marks]



30(a). Name the two products obtained after primary treatment of sewage.

[1 mark]

Solution:

Concept:

- Primary treatment removes suspended solids from sewage by physical processes such as filtration and sedimentation.
- Sedimentation separates sewage into a settled solid fraction and a liquid fraction above it.

Step 1: Identify the settled fraction After floating debris and grit have been removed, suspended solids settle in the sedimentation tank. The deposited solids form the primary sludge.

Step 2: Identify the liquid fraction The supernatant liquid remaining above the settled material is the primary effluent. It passes to secondary biological treatment in aeration tanks. Activated sludge forms later, during secondary treatment, and is therefore not a product of primary treatment.

Step 3: Conclusion The two products are **primary sludge** and **primary effluent**.

Quick Tip to Solve: Remember the physical separation: settled solids give primary sludge; the liquid above them is primary effluent.

30(b). What happens to the activated sludge when it is passed into an anaerobic sludge digester ? Explain. [2 marks]

Solution:

Concept:

- Activated sludge is the sediment of microbial flocs formed after the biologically treated effluent enters a settling tank.
- Anaerobic digestion breaks down organic material in the absence of oxygen; methanogenic bacteria contribute to biogas formation.

Step 1: Describe digestion of the sludge A small portion of activated sludge is returned to the aeration tank as inoculum, while most is pumped into an anaerobic sludge digester. In this tank, anaerobic

bacteria grow without oxygen and digest the organic matter, including the bacteria and fungi present in the sludge. This reduces and stabilises the organic material in the sludge.

Step 2: Explain the gaseous products During anaerobic digestion, the microbial community produces a mixture of gases, chiefly methane, carbon dioxide and hydrogen sulphide. Methanogens are responsible for methane formation. This gas mixture is called biogas; its methane content makes it useful as a fuel.

Step 3: Conclusion Anaerobic bacteria digest the bacteria, fungi and other organic matter in activated sludge, producing biogas containing methane, carbon dioxide and hydrogen sulphide.

Quick Tip to Solve: Link the digester to absence of oxygen, digestion of microbial sludge and production of methane-containing biogas.

30(c)(i). Name the two groups of microbes present in the primary effluent after it is passed into large aeration tanks. [1 mark]

Solution:

Concept:

- Aeration supplies oxygen and encourages vigorous growth of useful aerobic microbes in primary effluent.
- Flocs are masses of bacteria associated with fungal filaments, forming mesh-like structures.

Step 1: Identify the bacterial group Air is pumped into the aeration tank and the effluent is agitated. Aerobic bacteria grow rapidly and consume much of the organic matter present in the effluent.

Step 2: Identify the associated filamentous group Fungi provide filaments with which the bacterial masses associate. Together, bacteria and fungal filaments form flocs. The microbial consumption of organic matter lowers the biochemical oxygen demand of the effluent.

Step 3: Conclusion The two groups are **aerobic bacteria and fungi**.

Quick Tip to Solve: Recall the composition of a floc: bacterial masses associated with fungal filaments.

OR

30(c)(ii). Define BOD. What happens to the BOD when organic matter present in the wastewater increases ? [1 mark]

Solution:

Concept:

- Biochemical oxygen demand (BOD) measures the oxygen required by aerobic microorganisms to oxidise biodegradable organic matter in water.
- A greater load of biodegradable organic matter supports greater microbial decomposition and therefore greater oxygen demand.

Step 1: Define the measure BOD is the amount of oxygen required by bacteria to oxidise all the organic matter in one litre of water under specified test conditions. It indicates the load of biodegradable organic pollutants in the water.

Step 2: Relate organic matter to oxygen demand When wastewater contains more biodegradable organic matter, aerobic microbes need more oxygen to decompose it. Therefore, its BOD increases. BOD is oxygen demand, so a high BOD does not mean that the water contains more dissolved oxygen.

Step 3: Conclusion BOD is the oxygen required for microbial oxidation of organic matter in a water sample; it **increases when the organic-matter load increases**.

Quick Tip to Solve: Read the D in BOD as demand: more biodegradable organic material means more oxygen needed for decomposition.

Section E (15 marks)

31(a)(I)(i). State the role of selectable markers in rDNA technology.

[1 mark]

Solution:

Concept:

- Transformation is the introduction of foreign DNA into a host cell.
- A selectable marker is a gene in the vector whose expression enables identification and selection of transformed cells.

Step 1: Distinguish the host cells After introducing a cloning vector into a population of host cells, only some cells acquire it. These cells are transformants; cells that do not take up the vector are non-transformants.

Step 2: Apply the selection condition The marker allows transformants to survive under a selective condition while non-transformants are eliminated. For example, a vector carrying an antibiotic-resistance gene permits its host to grow on medium containing that antibiotic, whereas sensitive non-transformants cannot grow.

Step 3: Conclusion Selectable markers help identify and select transformants and eliminate non-transformants in recombinant DNA technology.

Quick Tip to Solve: Link a selectable marker to survival on selective medium: vector uptake gives the host the marker's selectable trait.

31(a)(I)(ii). Name two such selectable markers which are considered to be useful for *E. coli* cloning vector.

[1 mark]

Solution:

Concept:

- Antibiotic-resistance genes are useful selectable markers in cloning vectors for *E. coli*.
- A resistance gene allows a transformed host to grow in the presence of the corresponding antibiotic.

Step 1: Identify the first marker The ampicillin-resistance gene, written as amp^R , is one suitable marker. Cells carrying a vector with this functional gene can grow on medium containing ampicillin.

Step 2: Identify the second marker The tetracycline-resistance gene, written as tet^R , is another suitable marker. It permits growth in the presence of tetracycline. Both genes are found in the familiar *E. coli* cloning vector pBR322; the selectable markers are the resistance genes, rather than the antibiotics themselves.

Step 3: Conclusion Two useful selectable markers are the ampicillin-resistance gene amp^R and the tetracycline-resistance gene tet^R .

Quick Tip to Solve: Recall pBR322 and name its two resistance genes; write “resistance gene” after each antibiotic name.

31(a)(I)(iii). State two significances of ‘Ori’ in *E. coli* cloning vector.

[1 mark]

Solution:

Concept:

- The origin of replication, or ori, is the DNA sequence from which replication starts in a cloning vector.
- The vector’s origin influences the number of copies of linked DNA maintained in a host cell.

Step 1: Explain replication of linked DNA Ori provides the site where replication begins. A piece of foreign DNA joined to a vector containing a functional origin can therefore replicate within the *E. coli* host along with the vector.

Step 2: Explain control of copy number Ori is also responsible for controlling the copy number of the linked DNA. Choosing an appropriate origin enables the desired number of vector copies, and hence copies of the inserted DNA, to be obtained in each host cell.

Step 3: Conclusion Ori enables initiation of replication of the vector and its linked DNA, and controls their copy number in the host cell.

Quick Tip to Solve: Remember ori with two phrases: “replication begins here” and “copy number is controlled here.”

31(a)(II). How have biotechnologists effectively used *Agrobacterium tumefaciens* in plants and retroviruses in animals? Explain.

[2 marks]

Solution:

Concept:

- A cloning vector carries a desired foreign gene into a recipient cell. Natural gene-transfer systems can be modified into vectors by removing their disease-causing properties.
- A disarmed vector retains the ability to deliver genetic material while the genes responsible for pathogenic effects are removed or inactivated.

Step 1: Use of *Agrobacterium* in plants *Agrobacterium tumefaciens* naturally transfers a segment of its tumour-inducing (Ti) plasmid into plant cells, causing tumour formation. Biotechnologists disarm the Ti plasmid by removing its tumour-inducing genes and introduce the desired foreign gene into the transferable region. The modified system delivers the desired gene into plant cells without causing tumours and is used to produce transgenic plants.

Step 2: Use of retroviruses in animals Retroviruses naturally infect animal cells and can integrate a DNA copy of their genetic material into the host genome. Biotechnologists disarm these viruses by removing or inactivating their disease-causing genes and insert a desired gene. The modified retrovirus then acts as a vector to introduce that gene into animal cells without producing the original disease.

Step 3: Conclusion Biotechnologists use a disarmed Ti plasmid of *A. tumefaciens* as a plant gene-transfer vector and disarmed retroviruses as animal gene-transfer vectors.

Quick Tip to Solve: For each vector, state its natural gene-transfer ability, the removal of pathogenic genes, and the delivery of the desired gene.

OR

31(b). Name and describe the technique that helps in separation and isolation of DNA fragments after cutting of DNA by restriction endonucleases. [5 marks]

Solution:

Concept:

- Agarose gel electrophoresis separates DNA fragments according to their size. DNA carries a negative charge because of the phosphate groups in its backbone.
- Agarose, a natural polymer extracted from seaweeds, forms a porous matrix that acts as a molecular sieve. Smaller DNA fragments move through its pores more readily than larger fragments.
- After separation, a selected DNA band can be cut from the gel and its DNA recovered by elution for further use in recombinant DNA technology.

Step 1: Name the technique and prepare the gel The technique is **agarose gel electrophoresis**, followed by **elution** to isolate the desired DNA fragment. Prepare an agarose gel with wells near one end and place it in a suitable electrophoresis buffer. Load the mixture of DNA fragments obtained after restriction-endonuclease digestion into the wells, which are positioned toward the negative electrode, the cathode.

Step 2: Apply an electric field DNA fragments are negatively charged. On applying an electric field, they move through the gel toward the positive electrode, the anode. The buffer supports the passage of electric current and maintains suitable conditions during separation. The gel matrix resists the movement of the DNA molecules.

Step 3: Separate the fragments by size The porous agarose matrix produces a sieving effect. Smaller fragments move faster and travel farther from the wells in a given time, whereas larger fragments move more slowly and remain closer to the wells. Fragments of a particular size collect in a distinct

band, so the original mixture is resolved into bands at different distances from the loading end.

Step 4: Visualise the separated DNA DNA cannot be seen directly in visible light. The separated fragments are stained with ethidium bromide and viewed under ultraviolet radiation. Ethidium bromide associated with DNA makes the DNA bands appear bright orange. These visible bands allow the desired fragment to be located in the gel.

Step 5: Isolate the selected fragment by elution Cut out the gel region containing the required DNA band and extract the DNA from that gel piece. This recovery of the separated DNA fragment is called **elution**. The purified fragment can subsequently be joined to a cloning vector using DNA ligase to construct recombinant DNA.

Step 6: Conclusion Agarose gel electrophoresis separates restriction-generated DNA fragments by size; ethidium-bromide staining and ultraviolet illumination reveal the bands, and elution isolates the desired fragment from the gel.

Quick Tip to Solve: Recall the sequence: load near the cathode, run toward the anode, locate the stained band under UV light, cut the band out, and elute the DNA.

32(a). (i) How and why is charging of tRNA essential in the process of translation?

(ii) State the function of ribosome as a catalyst in translation in bacteria.

(iii) Explain the process of binding of ribosomal units to mRNA during protein synthesis.

(iv) Where are untranslated regions located in mRNA? Mention their role.

[5 marks]

Solution:

Concept:

- Translation reads the codon sequence of mRNA to assemble amino acids into a polypeptide. Each tRNA acts as an adaptor between an mRNA codon and its corresponding amino acid.
- Aminoacylation (charging) attaches an amino acid to its specific tRNA using ATP and an aminoacyl-tRNA synthetase. The ribosome positions the charged tRNAs and catalyses peptide-bond formation.
- A translation unit contains a coding region bounded by a start codon and a stop codon, along with untranslated regions (UTRs) that assist efficient translation.

Step 1: (i) Explain how tRNA is charged A specific aminoacyl-tRNA synthetase first activates an amino acid using ATP. The enzyme then attaches the activated amino acid to the acceptor end, the 3'-CCA end, of its corresponding tRNA. The product is aminoacyl-tRNA, also called charged tRNA. Thus ATP supplies energy, while the specificity of the enzyme ensures that the correct amino acid is linked to the correct tRNA.

Step 2: (i) Explain why charging is essential The charged tRNA carries its amino acid to the ribosome, where its anticodon pairs with the complementary codon on mRNA. This connects the genetic message with the amino-acid sequence. Peptide-bond formation requires energy; activation during charging provides energy stored in the amino acid-tRNA linkage. Consequently, when adjacent charged tRNAs are correctly positioned, their amino acids can be joined to extend the polypeptide. An uncharged tRNA cannot supply an amino acid for this process.

Step 3: (ii) Identify the catalytic role of the bacterial ribosome The ribosome catalyses peptide-bond formation between successive amino acids during translation. In bacteria, the 23S rRNA of the large 50S ribosomal subunit provides the peptidyl-transferase activity. Since the catalytic component is RNA, the ribosome acts as a ribozyme. Its role is therefore both to position the reacting molecules and to catalyse their joining.

Step 4: (iii) Describe assembly of the ribosome on mRNA Before translation, the small and large ribosomal subunits are separate. The small subunit binds to mRNA and positions the initiation codon, usually AUG. The initiator tRNA pairs with this codon through its anticodon. The large subunit then joins to form the complete initiation complex; in bacteria the 30S and 50S subunits form the functional 70S ribosome. The large subunit has binding sites that bring adjacent aminoacyl-tRNAs close enough for peptide-bond formation. Subsequent codons are read as the ribosome moves along mRNA in the 5' to 3' direction.

Step 5: (iv) Locate the untranslated regions and state their role The 5' UTR lies at the 5' end of mRNA before the start codon. The 3' UTR lies after the stop codon towards the 3' end. These regions are present in the mRNA but do not encode the amino-acid sequence of the protein. They are required for efficient translation, helping regulate how effectively the coding region is used for protein synthesis.

Step 6: Conclusion Charging supplies the correct amino acids and the activation energy needed for their joining. Bacterial 23S rRNA catalyses peptide-bond formation; the small subunit initiates binding to mRNA before the large subunit joins. UTRs flank the coding region and support efficient translation.

Quick Tip to Solve: Keep the sequence clear: charge tRNA, bind the small ribosomal subunit and initiator tRNA to mRNA, then join the large subunit. Place the UTRs outside the start-to-stop coding region.

OR

32(b). (i) State the arrangement of different genes, that in bacteria is referred to as 'operon'.

(ii) Draw a schematic labelled illustration of *lac* operon in a switched on state.

(iii) Describe the role of lactose in *lac* operon.

[5 marks]

Solution:

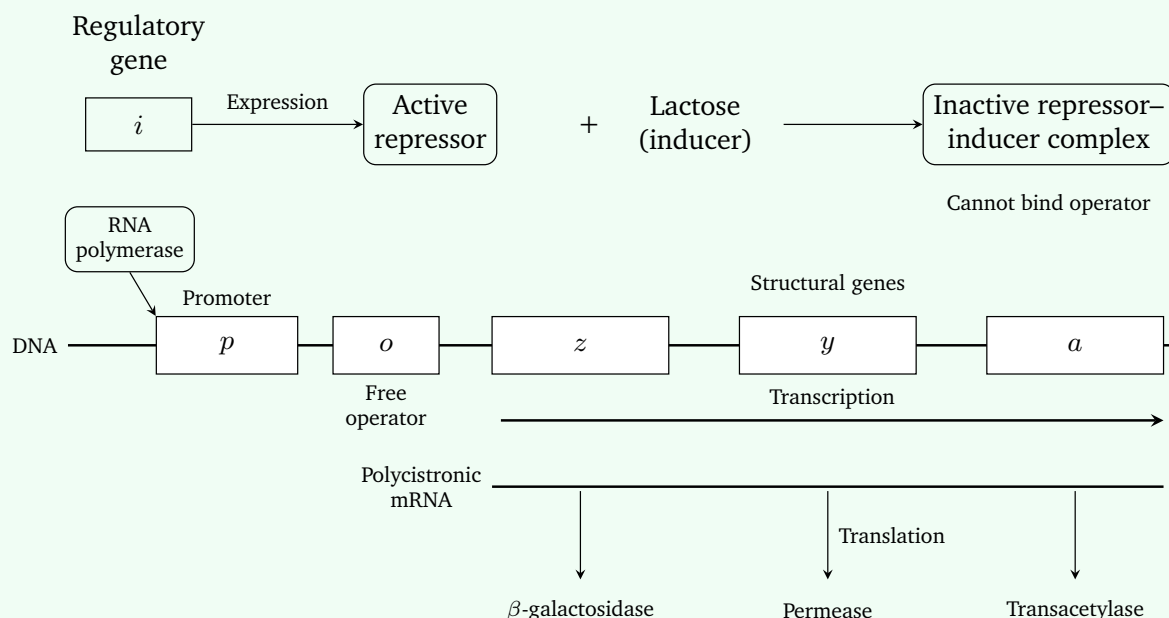
Concept:

- An operon is a group of structural genes controlled together by a common promoter and operator. They are transcribed as one polycistronic mRNA.
- The *lac* operon is an inducible system: the repressor normally blocks transcription, while the inducer inactivates the repressor.
- The structural genes *z*, *y* and *a* encode β -galactosidase, permease and transacetylase, respectively.

Step 1: (i) State the arrangement of an operon In bacteria, several structural genes concerned with related functions are arranged together under the control of a common promoter and operator. RNA polymerase binds to the promoter, and the operator controls access for transcription. The structural genes form a single transcription unit, producing a polycistronic mRNA. In the *lac* system, the order

is promoter-operator- z - y - a . A regulatory gene, i , produces the repressor protein; it has its own promoter and is expressed independently of the structural genes.

Step 2: (ii) Show the switched-on state The labelled scheme below shows the inducer bound to the repressor. This inactive repressor cannot bind to the operator, leaving the operator free. RNA polymerase can therefore transcribe z , y and a into a common mRNA, which is translated into the three enzymes. β -galactosidase hydrolyses lactose into glucose and galactose; permease increases the entry of lactose into the cell; transacetylase is the product of gene a .



Switched-on lac operon: the inactive repressor cannot bind the free operator.

Step 3: (iii) Explain the role of lactose Lactose acts as both the substrate and the inducer of the *lac* operon. A small basal amount of permease allows lactose to enter the cell. The inducer interacts with the repressor and inactivates it, so the repressor no longer binds to the operator. This removes the block on RNA polymerase, permitting transcription of the structural genes and synthesis of enzymes for lactose utilisation. Thus, the presence of lactose switches the operon on. When lactose is exhausted, the repressor becomes active again, binds to the operator and switches transcription off. Induction therefore regulates enzyme synthesis according to the availability of the substrate.

Step 4: Conclusion The *lac* operon coordinates z , y and a under a common promoter and operator. Lactose inactivates the repressor, freeing the operator and allowing transcription and enzyme production.

Quick Tip to Solve: For the switched-on diagram, show the inducer bound to the repressor, an unoccupied operator, and arrows from z , y , a to mRNA and their enzyme products.

33(a). Draw a flow chart to show hormonal control of the human male reproductive system. [5 marks]

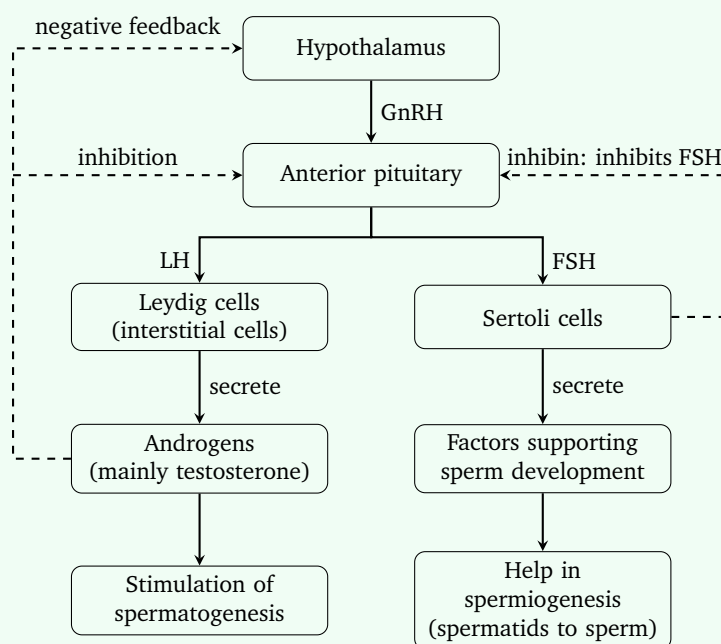
Solution:

Concept:

- The hypothalamus, anterior pituitary and testes form a hormonal control system. Gonadotropin-releasing hormone (GnRH) stimulates the pituitary to release the gonadotropins LH and FSH.
- Luteinising hormone (LH) acts on the interstitial or Leydig cells, whereas follicle-stimulating hormone (FSH) acts on the Sertoli cells of the seminiferous tubules.
- Testicular androgens support spermatogenesis. Sertoli-cell secretions support sperm development, including spermiogenesis, the transformation of spermatids into spermatozoa.

Step 1: Start with hypothalamic stimulation At puberty, increased secretion of GnRH from the hypothalamus initiates increased gonadotropin secretion. GnRH reaches the anterior pituitary and stimulates it to release both LH and FSH. Thus the first part of the flow chart is hypothalamus, followed by GnRH, followed by anterior pituitary; the pathway then divides into two coordinated branches.

Step 2: Trace both pituitary-to-testis branches In the LH branch, LH stimulates Leydig cells to synthesise and secrete androgens, chiefly testosterone. Androgens stimulate spermatogenesis and maintain the male reproductive organs and secondary sexual characters. In the FSH branch, FSH acts on Sertoli cells and stimulates secretion of factors that help spermiogenesis. Sertoli cells also nourish and support the developing germ cells. The flow chart below distinguishes the two target cell types and their effects. Solid arrows indicate stimulation; dashed arrows indicate negative feedback.



Hormonal control of the human male reproductive system.

Step 3: Include regulation by negative feedback Testosterone feeds back negatively on the hypothalamus and anterior pituitary, reducing further GnRH and LH secretion when androgen levels are sufficient. Sertoli cells secrete inhibin, which inhibits FSH secretion from the anterior pituitary. This feedback regulates the hormonal drive to the testes while the LH-androgen and FSH-Sertoli pathways

work together to support sperm production and maturation.

Step 4: Conclusion Hormonal control proceeds through GnRH from the hypothalamus, LH and FSH from the anterior pituitary, and their actions on Leydig and Sertoli cells respectively. Androgens and Sertoli-cell factors support spermatogenesis and spermiogenesis; testosterone and inhibin provide negative feedback.

Quick Tip to Solve: Split the pituitary output into two branches: LH to Leydig cells to testosterone, and FSH to Sertoli cells to factors helping spermiogenesis. Keep the two target cells distinct.

OR

33(b). Explain the changes that the primary oocyte undergoes while in different follicular stages before ovulation. [5 marks]

Solution:

Concept:

- Oogenesis is the formation and maturation of the female gamete. A primary oocyte is diploid, $2n = 46$, and begins meiosis I during foetal life but remains arrested in prophase I until its further maturation.
- Follicular development provides the growing oocyte with supporting cells and a suitable environment. The stages are primary follicle, secondary follicle, tertiary follicle and mature Graafian follicle.
- The first meiotic division is reductional and has unequal cytokinesis: it produces a large haploid secondary oocyte and a small first polar body, each with $n = 23$ chromosomes.

Step 1: Identify the primary oocyte in the primary follicle During foetal development, oogonia enter meiosis I and become primary oocytes. Each primary oocyte becomes surrounded by a layer of granulosa cells, forming a primary follicle. The oocyte remains arrested in prophase I; it has not yet become a haploid secondary oocyte. Many follicles degenerate between birth and puberty, while the surviving follicles form the reserve from which subsequent maturation occurs.

Step 2: Follow development into the secondary follicle From puberty onwards, selected follicles develop under the influence of gonadotropins. Additional layers of granulosa cells surround the primary oocyte, and a new thecal layer develops around the follicle. This forms a secondary follicle. The granulosa cells support and nourish the oocyte as it grows. A secondary follicle still contains a primary oocyte; the word secondary here describes the follicle, not the stage of meiosis of the oocyte.

Step 3: Explain the changes in the tertiary follicle The secondary follicle develops into a tertiary follicle with a fluid-filled cavity called the antrum. Its thecal layer differentiates into an inner theca interna and an outer theca externa. At this stage the primary oocyte grows in size and completes meiosis I. Unequal division produces one large haploid secondary oocyte and one tiny first polar body. Most of the nutrient-rich cytoplasm is retained in the secondary oocyte, providing resources for the early stages of development after fertilisation.

Step 4: Trace maturation into the Graafian follicle The tertiary follicle further matures into a Graafian

follicle. The secondary oocyte is surrounded by the zona pellucida, a non-cellular glycoprotein covering, and an outer layer of follicular cells called the corona radiata. The secondary oocyte enters meiosis II but arrests at metaphase II. Thus, meiotic maturation is still incomplete immediately before ovulation; completion of meiosis II requires fertilisation.

Step 5: Relate these changes to ovulation The mid-cycle surge of luteinising hormone (LH) brings about rupture of the mature Graafian follicle. At ovulation it releases the secondary oocyte with its protective coverings. The released cell is therefore haploid but has not yet completed its second meiotic division. The first polar body, formed by the earlier unequal division, contains very little cytoplasm.

Step 6: Conclusion Before ovulation, the diploid primary oocyte grows within the developing follicle and completes meiosis I in the tertiary follicle, producing a large haploid secondary oocyte and a small first polar body. The secondary oocyte is released from the mature Graafian follicle while arrested in metaphase II.

Quick Tip to Solve: Keep follicle names separate from oocyte names: a secondary follicle contains a primary oocyte, whereas the tertiary follicle is the stage at which meiosis I produces the secondary oocyte.