

CBSE Class 12 Biology Question Paper 2026 with Solution PDF-Set 57-4-2

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, C, 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. Which of the following groups of cells in the male gonad represent haploid cells?

[1 mark]

- (A) Spermatogonial cells
- (B) Germinal epithelial cells
- (C) Secondary spermatocytes
- (D) Primary spermatocytes

Correct Answer: (C) Secondary spermatocytes

Solution:

Concept:

- Haploid cells contain one set of chromosomes, denoted by n ; diploid cells contain two sets, denoted by $2n$.
- In spermatogenesis, meiosis I is the reduction division that separates homologous chromosomes.

Step 1: Locate the reduction division A primary spermatocyte is diploid. It undergoes meiosis I to produce two secondary spermatocytes. Each secondary spermatocyte has only one chromosome from every homologous pair and is therefore haploid, with 23 chromosomes in humans. Its chromosomes still have two chromatids each; this does not make the cell diploid.

Step 2: Exclude the other cell groups Spermatogonial cells and the germinal epithelial cells from which the germ-cell lineage originates are diploid. Primary spermatocytes are also diploid because they have not yet completed meiosis I. Thus options (A), (B) and (D) describe cells before the chromosome-number reduction.

Step 3: Conclusion Secondary spermatocytes are haploid cells. Hence, the correct option is (C).

Quick Tip to Solve: Place meiosis I between primary and secondary spermatocytes; cells after this division are haploid even before their chromatids separate.

2. Filiform apparatus in the embryo sac of an angiosperm is present at the micropylar tip of: [1 mark]

- (A) Central cell
- (B) Egg cell
- (C) Synergids
- (D) Antipodals

Correct Answer: (C) Synergids

Solution:

Concept:

- The egg apparatus at the micropylar end of a typical angiosperm embryo sac contains one egg cell and two synergids.
- The filiform apparatus consists of special cellular wall thickenings at the micropylar tip of each synergid and helps guide the pollen tube into a synergid.

Step 1: Identify the specialised cell structure Synergids possess the finger-like wall thickenings called the filiform apparatus. Their location at the micropyle is suited to receiving and directing the approaching pollen tube, which delivers the male gametes into the embryo sac.

Step 2: Distinguish the neighbouring cells The egg cell is part of the same egg apparatus but does not possess a filiform apparatus. The large central cell contains the polar nuclei, while the antipodals occur at the opposite, chalazal end. Therefore neither the egg, the central cell nor the antipodals is the correct location.

Step 3: Conclusion The filiform apparatus is present at the micropylar tips of the synergids. Hence, the correct option is (C).

Quick Tip to Solve: Associate the filiform apparatus with the pollen tube's guiding cells, the synergids, rather than with the egg that is fertilised.

3. A man is found to have a sperm count of less than 20 million/mL and his wife is diagnosed with blockage in the oviduct. This couple would be advised to go for which of the following techniques?

(i) ZIFT

(ii) AI

(iii) IUT

(iv) ICSI

(v) GIFT

[1 mark]

(A) (i) and (iii)

(B) (ii) and (iii)

(C) (iii) and (iv)

(D) (iv) and (v)

Correct Answer: (C) (iii) and (iv)

Solution:

Concept:

- Intracytoplasmic sperm injection (ICSI) introduces a selected sperm directly into an ovum to assist fertilisation when sperm availability is low.
- Intrauterine transfer (IUT) places an embryo with more than eight blastomeres into the uterus, bypassing the oviduct.

Step 1: Address both causes of infertility The low sperm count can be addressed by ICSI, technique (iv), in which fertilisation is achieved outside the body by injecting a sperm into the ovum. After development to an appropriate stage, the embryo can be transferred directly to the uterus by IUT, technique (iii). This avoids dependence on the blocked oviduct.

Step 2: Eliminate techniques needing a functional oviduct ZIFT transfers a zygote or early embryo into the fallopian tube, while GIFT transfers gametes there; both require a suitable functional oviduct. Artificial insemination (AI) introduces semen into the female reproductive tract but does not overcome the tubal blockage. Consequently (A) contains unsuitable ZIFT, (B) contains unsuitable AI, and (D) contains unsuitable GIFT for the combined problem.

Step 3: Conclusion The appropriate techniques are (iii) IUT and (iv) ICSI. Hence, the correct option is (C).

Quick Tip to Solve: Match each infertility factor separately: direct sperm injection assists fertilisation, and uterine embryo transfer bypasses a blocked tube.

4. Which of the following amino acid substitutions is responsible for causing sickle cell anemia?

[1 mark]

- (A) Valine is substituted by glutamic acid in the α -globin chain at the sixth position.
- (B) Valine is substituted by glutamic acid in the β -globin chain at the seventh position.
- (C) Glutamic acid is substituted by valine in the α -globin chain at the sixth position.
- (D) Glutamic acid is substituted by valine in the β -globin chain at the sixth position.

Correct Answer: (D) Glutamic acid is substituted by valine in the β -globin chain at the sixth position.

Solution:

Concept:

- Sickle-cell anaemia results from a point mutation affecting the β -globin chain of haemoglobin.
- The mutation replaces glutamic acid with valine at the sixth amino acid position of the β -globin chain.

Step 1: Specify the amino acid change In the affected globin sequence, the mRNA codon GAG, which specifies glutamic acid, becomes GUG, which specifies valine. Thus the direction of substitution is glutamic acid to valine, not valine to glutamic acid. The altered haemoglobin can polymerise at low oxygen concentration and distort red blood cells into a sickle shape.

Step 2: Check the chain and position The substitution occurs in the beta chain at position six. Options (A) and (B) reverse the amino acid replacement; (A) also gives the wrong chain and (B) the wrong position. Option (C) has the right replacement and position but incorrectly names the alpha chain. Only (D) satisfies all three conditions.

Step 3: Conclusion Glutamic acid is replaced by valine at the sixth position of the β -globin chain. Hence, the correct option is (D).

Quick Tip to Solve: Check this three-part combination together: beta chain, position six, and glutamic acid replaced by valine.

5. Name the extinct ancestor of humans who ate only fruits and hunted with stone weapons. [1 mark]

- (A) Ramapithecus
- (B) Australopithecus
- (C) Dryopithecus
- (D) Homo erectus

Correct Answer: (B) Australopithecus

Solution:

Concept:

- Human evolution questions distinguish early forms by characteristic combinations of posture, diet, brain size and use of tools.
- The NCERT account associates the australopithecines of the East African grasslands with hunting using stone weapons while essentially eating fruit.

Step 1: Match both identifying clues The combination of a fruit-based diet and hunting with stone weapons identifies *Australopithecus*. The question uses the dietary and tool-use description associated with australopithecines, so both clues must be considered together.

Step 2: Distinguish the other early forms *Ramapithecus* and *Dryopithecus* are earlier primate forms, described respectively as more man-like and more ape-like; neither is the form identified by this paired description. *Homo erectus* appeared later and is described as probably eating meat, so it does not fit the fruit-diet clue.

Step 3: Conclusion The extinct human ancestor described is *Australopithecus*. Hence, the correct option is (B).

Quick Tip to Solve: Match the combined clue of fruit eating and stone weapons to australopithecines; do not identify an ancestor from tool use alone.

6. Choose the correct statements:

(i) Polycistronic mRNA is generally found in eukaryotes.

(ii) The RNA polymerase II transcribes precursor of mRNA, the hnRNA.

(iii) The process of translation of mRNA begins when the mRNA encounters the large subunit of ribosomes.

(iv) Stop codons do not have any tRNAs.

[1 mark]

(A) (i) and (ii)

(B) (ii) and (iii)

(C) (ii) and (iv)

(D) (i), (ii) and (iv)

Correct Answer: (C) (ii) and (iv)

Solution:

Concept:

- Eukaryotic mRNAs are generally monocistronic, whereas polycistronic mRNAs are commonly found in prokaryotes.
- RNA polymerase II produces hnRNA, the precursor of mRNA. Translation begins with association of mRNA with the small ribosomal subunit and ends when a release factor recognises a stop codon.

Step 1: Test statements (i) and (ii) Statement (i) is false because it assigns the usual prokaryotic polycistronic arrangement to eukaryotes. Statement (ii) is true: RNA polymerase II transcribes heterogeneous nuclear RNA (hnRNA), which is processed by splicing, capping and tailing to form mature mRNA.

Step 2: Test statements (iii) and (iv) Statement (iii) is false because initiation involves the small ribosomal subunit; the large subunit joins subsequently. Statement (iv) is true because no tRNA corresponds to a stop codon; release factors terminate translation. Thus (A) and (D) include false statement (i), and (B) includes false statement (iii).

Step 3: Conclusion Only statements (ii) and (iv) are correct. Hence, the correct option is (C).

Quick Tip to Solve: Check the two frequent reversals here: polycistronic usually means prokaryotic, and translation starts with the small ribosomal subunit.

7. Some cyanobacteria in aquatic and terrestrial environment that enrich the soil by fixing nitrogen are: [1 mark]

- (A) Rhizobium and Azotobacter
- (B) Azospirillum and Glomus
- (C) Anabaena and Nostoc
- (D) Azospirillum and Azotobacter

Correct Answer: (C) Anabaena and Nostoc

Solution:

Concept:

- Several cyanobacteria fix atmospheric nitrogen and act as biofertilisers by enriching the soil with nitrogenous nutrients.
- *Anabaena* and *Nostoc* are nitrogen-fixing cyanobacteria; their specialised heterocysts provide sites for nitrogen fixation.

Step 1: Select the cyanobacterial pair *Anabaena* and *Nostoc* occur in aquatic and terrestrial habitats. They convert atmospheric nitrogen into forms that can enter biological nutrient cycles, thereby improving soil fertility. This satisfies both the organism-group requirement and the nitrogen-fixing function in the question.

Step 2: Separate other biofertilisers from cyanobacteria *Rhizobium*, *Azotobacter* and *Azospirillum* are nitrogen-fixing bacteria but are not cyanobacteria. *Glomus* is a mycorrhizal fungus associated especially with improved phosphorus absorption. Thus options (A) and (D) contain non-cyanobacterial bacteria, and (B) includes a fungus; none is a pair of cyanobacteria.

Step 3: Conclusion The required cyanobacteria are *Anabaena* and *Nostoc*. Hence, the correct option is (C).

Quick Tip to Solve: First identify the microbial group named in the question: a nitrogen-fixing biofertiliser need not be a cyanobacterium.

8. Nicotine affects blood pressure and heart rate due to release of certain adrenal hormones. Following are some of the adrenal hormones:

- (i) Adrenaline
- (ii) Cortisol
- (iii) Noradrenaline
- (iv) Aldosterone

Select the correct option:

[1 mark]

- (A) (i) and (ii)
- (B) (i) and (iv)
- (C) (ii) and (iii)
- (D) (i) and (iii)

Correct Answer: (D) (i) and (iii)

Solution:

Concept:

- Nicotine stimulates the adrenal glands to release adrenaline and noradrenaline into the blood.
- These adrenal medullary hormones increase heart rate and blood pressure as part of a sympathetic response.

Step 1: Identify the hormones stimulated by nicotine Adrenaline, listed as (i), and noradrenaline, listed as (iii), are the catecholamines associated with the nicotine-induced rise in heart rate and blood pressure. Both are secreted by the adrenal medulla.

Step 2: Distinguish the other adrenal hormones Cortisol and aldosterone are adrenal cortical hormones. Cortisol mainly regulates metabolism and stress responses, while aldosterone regulates salt and water balance. Although aldosterone can influence blood pressure through fluid balance, it is not one of the two hormones responsible for the response to nicotine described here. Thus combinations containing (ii) or (iv) do not match.

Step 3: Conclusion The required hormones are (i) adrenaline and (iii) noradrenaline. Hence, the correct option is (D).

Quick Tip to Solve: Link nicotine with the adrenal medulla and its paired catecholamines: adrenaline and noradrenaline.

9. Elution means:

[1 mark]

- (A) making the DNA bands visible under UV radiations.
- (B) separation of DNA fragments on agarose gel.
- (C) isolating alien DNA from the choice organism.
- (D) cutting and extraction of DNA bands from the agarose gel.

Correct Answer: (D) cutting and extraction of DNA bands from the agarose gel.

Solution:

Concept:

- Agarose gel electrophoresis separates DNA fragments according to their size.
- Elution recovers the selected DNA fragment from the gel after its band has been located and cut out.

Step 1: Identify the recovery stage After electrophoresis, the required DNA band is identified, the corresponding piece of agarose gel is cut out, and the DNA is extracted from it. This recovery of DNA from the gel is called elution. The recovered fragment can then be used in constructing recombinant DNA.

Step 2: Separate elution from the earlier operations Making stained DNA bands visible under UV radiation is visualisation, not elution. Movement and separation of fragments in agarose constitute electrophoresis. Isolating DNA from a donor organism is an earlier extraction step and does not describe recovery of a selected band from a gel. Only the cutting and extraction operation matches elution.

Step 3: Conclusion Elution means cutting and extraction of DNA bands from the agarose gel. Hence, the correct option is (D).

Quick Tip to Solve: Remember the sequence: separate the DNA, locate the band, then elute the selected DNA from the gel.

10. The recombinant protein obtained from transgenic animals that could be used to treat emphysema is:

[1 mark]

- (A) Humulin
- (B) α -lactalbumin
- (C) α -1-antitrypsin
- (D) Iodothyronine

Correct Answer: (C) α -1-antitrypsin

Solution:

Concept:

- Transgenic animals can produce useful human therapeutic proteins when the corresponding human gene is introduced and expressed.
- Human α -1-antitrypsin is a protein used in the treatment of emphysema associated with its

deficiency.

Step 1: Match the disease to the therapeutic protein The NCERT example of a recombinant human protein obtained using transgenic animals for treating emphysema is α -1-antitrypsin. It inhibits proteolytic enzymes and helps protect lung tissue from excessive breakdown; its deficiency can lead to emphysema.

Step 2: Eliminate the unrelated products Humulin is recombinant human insulin used for diabetes mellitus. α -Lactalbumin is a milk protein associated with nutritionally enriched milk from a transgenic cow. Iodothyronine is a thyroid hormone. None of these is the protective protein specified for emphysema in this example.

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

Quick Tip to Solve: Keep the applications distinct: insulin for diabetes, alpha-lactalbumin for enriched milk, and alpha-1-antitrypsin for emphysema.

11. The construction of the first recombinant DNA was done by using the native plasmid of: [1 mark]

- (A) *E. coli*
- (B) *Salmonella typhimurium*
- (C) *B. thuringiensis*
- (D) *Agrobacterium*

Correct Answer: (B) *Salmonella typhimurium*

Solution:

Concept:

- Recombinant DNA is formed by joining DNA fragments from different sources using suitable enzymes.
- In the first recombinant DNA construction described in NCERT, an antibiotic-resistance gene was linked to a native plasmid of *Salmonella typhimurium*.

Step 1: Recall the source of the native plasmid Stanley Cohen and Herbert Boyer constructed the first recombinant DNA by linking a gene encoding antibiotic resistance with the native plasmid of *Salmonella typhimurium*. The question specifically asks for the bacterium supplying that native plasmid.

Step 2: Distinguish the plasmid source from other roles *E. coli* is widely used as a cloning host, but that role does not make it the answer to the plasmid-source question. *B. thuringiensis* is associated with insecticidal Bt proteins, while *Agrobacterium* is associated with gene transfer into plants. These familiar biotechnology organisms do not identify the native plasmid in this historical example.

Step 3: Conclusion The native plasmid was from *Salmonella typhimurium*. Hence, the correct option is (B).

Quick Tip to Solve: In this history question, identify the source of the native plasmid; do not substitute the familiar cloning host *E. coli*.

12. Connell's elegant field experiments on the rocky seacoast of Scotland, found that larger barnacles *Balanus* dominated the intertidal area and removed the smaller barnacles *Chthamalus*. This happened due to:

[1 mark]

- (A) Parasitism
- (B) Predation
- (C) Mutualism
- (D) Competition

Correct Answer: (D) Competition

Solution:

Concept:

- Interspecific competition occurs when different species use a common limiting resource, such as attachment space.
- A competitively superior species can exclude a weaker competitor from part of its potential habitat.

Step 1: Identify the interaction in Connell's experiment The two barnacle species occupy the rocky intertidal habitat and compete for attachment space. The larger *Balanus* is the stronger competitor and excludes the smaller barnacle from the area it dominates. This is a classic example of competitive exclusion through interspecific competition.

Step 2: Eliminate the other types of interaction Predation would require one barnacle to consume the other, which is not the interaction described. Parasitism involves a parasite obtaining nourishment from a host, while mutualism benefits both interacting species. Here the key observation is the displacement of one species by another using the same habitat resource, not feeding on it or cooperating with it.

Step 3: Conclusion The removal of the smaller barnacles occurred due to competition. Hence, the correct option is (D).

Quick Tip to Solve: In the Connell barnacle example, connect exclusion from attachment space with competition, not predation.

13. Assertion (A): After implantation, finger-like projections appear on the trophoblast called chorionic villi.

Reason (R): Chorionic villi are surrounded by the uterine tissue and the maternal blood. [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:

- After implantation, the trophoblast develops finger-like projections called chorionic villi.
- Chorionic villi are surrounded by uterine tissue and maternal blood; the villi and uterine tissue together form the placenta.

Step 1: Evaluate the assertion The assertion correctly describes an event after implantation: finger-like chorionic villi appear on the trophoblast. These projections contribute the embryonic component of the placenta. Therefore, Assertion (A) is true.

Step 2: Evaluate the reason Chorionic villi do lie within the uterine environment, surrounded by uterine tissue and maternal blood. This arrangement supports exchange between maternal and embryonic systems. Therefore, Reason (R) is also true.

Step 3: Test the explanatory relationship The reason states where the villi are situated and what surrounds them. It does not explain the developmental appearance of finger-like projections on the trophoblast after implantation. Thus the two statements are related facts about placental development, but the reason is not the correct explanation of the assertion. Options that make either statement false are also ruled out.

Step 4: Conclusion Both the assertion and the reason are true, but the reason does not correctly explain the assertion. Hence, the correct option is (B).

Quick Tip to Solve: For this pair, distinguish the formation of chorionic villi from their surroundings; location alone does not explain formation.

14. Assertion (A): Nucleopolyhedrovirus are useful, as they are good biological control agents.

Reason (R): They are species-specific narrow spectrum bioinsecticides.

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

Solution:

Concept:

- Baculoviruses, particularly those in the genus *Nucleopolyhedrovirus*, are used as biological control agents against insect pests.
- Their species specificity and narrow host range permit targeted pest control while sparing non-target organisms.

Step 1: Evaluate the assertion *Nucleopolyhedrovirus* can infect and control susceptible insect pests and therefore serve as useful biological control agents. This makes the assertion true.

Step 2: Evaluate the reason These viruses are species-specific, narrow-spectrum bioinsecticides. They act against their susceptible target insects rather than indiscriminately harming a broad range of organisms. The reason is therefore true.

Step 3: Connect specificity with usefulness Target specificity is precisely an advantage in biological control: harmful pests can be controlled while beneficial insects and other non-target organisms are spared. This makes the viruses especially useful within integrated pest management. Thus the reason explains why these viruses are good biological control agents, rather than merely stating an unrelated property.

Step 4: Conclusion Both the assertion and the reason are true, and the reason correctly explains the assertion. Hence, the correct option is (A).

Quick Tip to Solve: Link narrow-spectrum action with selective pest killing and protection of beneficial organisms to test the explanation.

15. Assertion (A): Decomposition process is slower, if detritus is rich in lignin and cutin.

Reason (R): Decomposition is largely an oxygen-requiring process.

[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:

- The rate of decomposition depends on both the chemical composition of detritus and environmental conditions.
- Lignin and cutin resist microbial breakdown; oxygen supports the activity of aerobic decomposers.

Step 1: Evaluate the assertion Assertion (A) is true. Detritus rich in lignin and cutin decomposes slowly because these complex, resistant substances are difficult for decomposers to break down. Detritus rich in nitrogen and water-soluble substances decomposes more rapidly.

Step 2: Evaluate the reason Reason (R) is also true. Decomposition is largely an oxygen-requiring process, and conditions that restrict oxygen availability inhibit much of the decomposer activity.

Step 3: Test the explanatory connection The reason describes an environmental requirement; it does not explain why lignin-rich and cutin-rich material resists breakdown. That slowness follows from the chemical nature of the detritus. Thus option (A) incorrectly asserts an explanatory link, while (C) and (D) incorrectly declare one of the two true statements false.

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 the chemical quality of detritus from oxygen availability before testing the assertion–reason link.

16. Assertion (A): The human blood group 'AB' exemplifies co-dominance.

Reason (R): The gene for human blood group trait exists in three allelic forms I^A , I^B and i . [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:

- Co-dominance means that both alleles express their effects in a heterozygote.
- Multiple allelism means that more than two allelic forms of a gene exist in a population; a diploid person carries only two.

Step 1: Evaluate the assertion Assertion (A) is true. An individual with blood group AB has genotype $I^A I^B$. Both alleles are expressed, so the red blood cells possess both A and B antigens. Neither allele masks the other; this is co-dominance.

Step 2: Evaluate the reason Reason (R) is true. The ABO blood-group gene exists in three allelic forms, I^A , I^B and i , in the human population. This fact illustrates multiple allelism.

Step 3: Distinguish the two genetic principles The existence of three alleles does not explain the simultaneous expression of I^A and I^B in an AB individual. Thus the reason is not the correct explanation. Option (A) confuses multiple allelism with co-dominance; options (C) and (D) wrongly treat a true statement as false.

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: For AB blood group, use expression of both antigens to recognise co-dominance and count population alleles to recognise multiple allelism.

Section B (10 marks)

17. (a) Write one way by which apomictic seeds can be developed.

(b) Why do farmers prefer apomictic seeds over hybrid seeds?

[2 marks]

Solution:

Concept:

- Apomixis is a form of asexual reproduction that produces seeds without fertilisation.
- Apomictic reproduction can preserve a desirable parental genotype, whereas sexual reproduction in subsequent hybrid generations can produce segregation of traits.

Step 1: Explain one route to apomictic seed formation (a) A diploid egg cell may be formed without reduction division (meiosis). This unreduced egg then develops directly into an embryo without fertilisation. The ovule develops into a seed containing this embryo, so seed formation has occurred without fusion of gametes.

Step 2: Explain the advantage to farmers (b) If a desirable hybrid reproduces through apomixis, its hybrid characters can be maintained in the progeny without segregation. Farmers can therefore collect and sow seeds from their crop season after season while retaining the useful hybrid combination. With ordinary hybrid seeds, seeds saved for the next generation segregate and may lose the desirable uniform hybrid performance. Farmers consequently buy fresh hybrid seed, which is expensive; apomictic seed production can avoid this repeated expense.

Step 3: Conclusion An unreduced diploid egg can form an embryo without fertilisation. Apomictic seeds preserve desirable hybrid characters and allow farmers to reuse seed, reducing recurring seed costs.

Quick Tip to Solve: Link the absence of meiosis and fertilisation to retention of hybrid characters, then state the saving from reusing seed.

18. Identify a, b, c and d in the following table with reference to birth control.

Method	Example
a	Diaphragm
Female sterilisation	b
c	Saheli
d	Cu-T

[2 marks]

Solution:

Concept:

- Contraceptive methods include barriers, surgical sterilisation, oral contraceptives and intrauterine devices (IUDs).
- Identify the method from how the named device, operation or pill prevents conception.

Step 1: Identify the barrier and sterilisation entries *a* is the **barrier method**. A diaphragm is placed over the cervix to prevent sperm from entering the uterus and meeting the ovum. *b* is **tubectomy**, the female sterilisation procedure in which a small part of each fallopian tube is removed or tied. This blocks the route through which the gametes would normally meet.

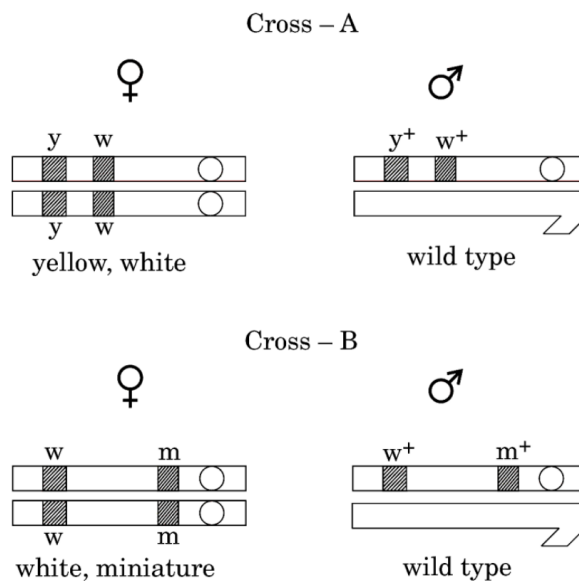
Step 2: Identify the pill and intrauterine entries *c* is the **oral contraceptive method**. Saheli is a non-steroidal oral contraceptive pill for women. *d* is an **intrauterine device (IUD)**; more specifically, Cu-T is a copper-releasing IUD inserted into the uterus. Copper ions suppress sperm motility and fertilising capacity, helping prevent conception. Saheli therefore belongs with pills, whereas Cu-T belongs with devices placed inside the uterus.

Step 3: Conclusion *a*: Barrier method; *b*: Tubectomy; *c*: Oral contraceptive method; *d*: Intrauterine device (copper-releasing IUD).

Quick Tip to Solve: Match diaphragm to barrier, tubectomy to the female tubes, Saheli to an oral pill and Cu-T to a copper IUD.

19. Study the figures given below and answer the questions.

Identify in which of the crosses the strength of linkage between the genes is higher. Give reason in support of your answer. [2 marks]



Solution:

Concept:

- Linkage is the tendency of genes on the same chromosome to be inherited together.
- Closely located genes show stronger linkage: crossing over is less likely between their loci, so fewer recombinant combinations arise.

Step 1: Compare the positions of the genes In Cross A, the loci *y* (yellow body) and *w* (white eyes) lie close together on the X chromosome. In Cross B, the loci *w* (white eyes) and *m* (miniature wings) are farther apart on the X chromosome. The figure therefore shows a shorter intergenic distance for the genes in Cross A.

Step 2: Relate distance to linkage strength A shorter distance between loci gives a smaller chance that crossing over in a heterozygote will separate the linked alleles during meiosis. Thus the yellow-body and white-eye alleles are transmitted together more often and produce a lower proportion of recombinants than the more widely separated white-eye and miniature-wing alleles. Simply being on the same chromosome establishes linkage; the relative distance between the loci determines which pair is more strongly linked.

Step 3: Conclusion Linkage is stronger in **Cross A**, because the *y* and *w* loci are closer together and are separated by crossing over less frequently than the *w* and *m* loci in Cross B.

Quick Tip to Solve: Compare the gap between the labelled loci: the smaller gap indicates stronger linkage and fewer recombinants.

20. A laboratory assistant collected three water samples, namely river water, untreated sewage water and secondary effluent discharged from a sewage treatment plant. But the laboratory attendant did not note which was which. The samples were labelled A, B and C and subjected to a BOD test. The BOD values of the three samples A, B and C were recorded as 30 mg/L, 8 mg/L and 400 mg/L respectively.

(a) Which sample of the water is most polluted?

(b) Can you assign the correct label to each, assuming the river water is relatively clean? [2 marks]

Solution:

Concept:

- Biochemical oxygen demand (BOD) is the amount of oxygen consumed by microorganisms in decomposing the biodegradable organic matter in a water sample under specified test conditions.
- A higher BOD indicates a larger biodegradable organic load and hence greater organic pollution. Secondary sewage treatment lowers BOD by microbial breakdown of organic matter.

Step 1: Compare the oxygen demands The measured values are $A = 30 \text{ mg/L}$, $B = 8 \text{ mg/L}$, and $C = 400 \text{ mg/L}$. Thus their BOD order is $C > A > B$. Sample C requires the most oxygen for decomposition and is the most polluted sample in part (a).

Step 2: Match each sample to its source For part (b), untreated sewage has the greatest biodegradable organic load, so it is C. The relatively clean river water has the lowest BOD, so it is B. The remaining sample, A, is the secondary effluent: treatment has reduced its organic load substantially below that of untreated sewage, although its BOD is still above that of the relatively clean river water.

Step 3: Conclusion (a) Sample C is most polluted. (b) A is secondary effluent, B is river water, and C is untreated sewage water.

Quick Tip to Solve: Rank the BOD values first: the largest identifies untreated sewage, the smallest identifies the relatively clean river, and the intermediate value identifies treated effluent.

21(a). Biodiversity must be conserved as it plays an important role in many ecosystem services that nature provides. Explain any two ecosystem services. [2 marks]

Solution:

Concept:

- Ecosystem services are benefits obtained from the natural activities of organisms and the functioning of ecosystems. Conserving biodiversity helps maintain these services.
- Different organisms perform complementary functions, such as primary production and pollination, which support both natural communities and human well-being.

Step 1: Explain oxygen production Green plants and other photosynthetic organisms release oxygen during photosynthesis. This replenishes atmospheric oxygen used in aerobic respiration by humans and other organisms. Conserving forests and other vegetation therefore protects a vital life-support service supplied by biodiversity.

Step 2: Explain pollination Insects such as bees and butterflies, and animals such as birds and bats,

transfer pollen between flowers. This transfer permits fertilisation and subsequent seed and fruit formation in many wild plants and crops. Conserving pollinator diversity supports plant reproduction, maintains plant populations and contributes to agricultural food production.

Step 3: Conclusion Two ecosystem services are oxygen production by photosynthetic organisms and pollination by animals; conserving biodiversity helps sustain both.

Quick Tip to Solve: For each ecosystem service, name the organisms involved, state their activity and link it to a benefit, such as oxygen supply or seed and fruit production.

OR

21(b). (i) State, what does 'standing crop' of a trophic level represent.

(ii) List any two ways of measuring the standing crop of a trophic level.

[2 marks]

Solution:

Concept:

- Each trophic level contains a certain quantity of living material at a particular time. This quantity is its standing crop.
- Standing crop is a stock measured at a given instant, whereas productivity describes a rate of production of biomass over time.

Step 1: State what standing crop represents For part (i), the standing crop represents the mass of living material present in a trophic level at a given time. For example, the living grass present in a sampled grassland at the time of observation forms part of the standing crop of its producer trophic level.

Step 2: List the two ways of measuring it For part (ii), standing crop can be measured as the number of organisms per unit area, or as their biomass per unit area. For example, plant abundance may be expressed as individuals per square metre, while biomass may be expressed as g m^{-2} . Biomass may be reported as fresh mass or dry mass, but dry mass is more accurate for comparisons because varying water content is excluded.

Step 3: Conclusion Standing crop is the quantity of living material in a trophic level at a given time. It is measured by the number of organisms or by their biomass, commonly per unit area.

Quick Tip to Solve: Include both the trophic level and the time in the definition; list number and biomass as the two measures, with no time-rate unit.

Section C (21 marks)

22. Differentiate between wind-pollinated and insect-pollinated flowers. Give an example of each type. [3 marks]

Solution:

Concept:

- Pollination is the transfer of pollen grains from an anther to a stigma. Wind pollination is called anemophily, while insect pollination is called entomophily.
- Floral adaptations facilitate pollen transport by the appropriate agent: wind dispersal favours easily carried pollen, while insect transport requires attraction and attachment.

Step 1: Compare floral attraction and rewards Wind-pollinated flowers are usually small and inconspicuous, without a bright display, fragrance or nectar reward. They do not need to attract an animal. Insect-pollinated flowers commonly have conspicuous colours, fragrance and nectar or edible pollen that attract and reward visiting insects; small flowers may be grouped into conspicuous inflorescences.

Step 2: Compare the pollen grains Wind-pollinated flowers produce large quantities of light, non-sticky pollen that air currents can carry, compensating for the large amount lost during dispersal. In insect-pollinated flowers, pollen is generally sticky or has a sculptured surface, so that it adheres to the insect's body and can be transferred during another floral visit.

Step 3: Compare anthers and stigmas and give examples Wind-pollinated flowers have well-exposed stamens that release pollen into the air and often large, feathery stigmas that intercept airborne pollen. In insect-pollinated flowers, anthers and sticky stigmas are positioned so that a visiting insect brushes against them, promoting pollen pickup and deposition. Maize is an example of wind pollination, and sunflower is an example of insect pollination.

Step 4: Conclusion Wind-pollinated flowers, such as maize, have inconspicuous flowers, abundant light pollen and exposed pollen-catching structures. Insect-pollinated flowers, such as sunflower, attract insects and have pollen and floral arrangements suited to transport on their bodies.

Quick Tip to Solve: Compare matching features in pairs: attraction, pollen and reproductive structures. Link light pollen and feathery stigmas to wind, and rewards and adhesive pollen to insects.

23. Explain the three different ways in which natural selection operates. Explain with the help of graphs. [3 marks]

Solution:

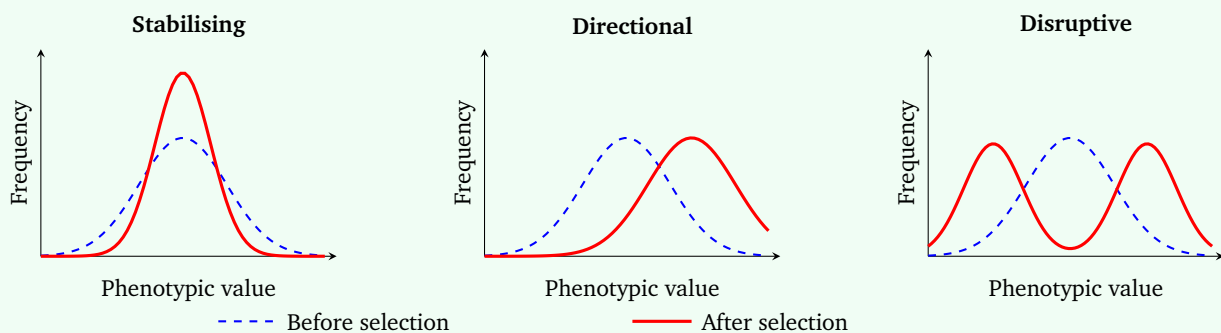
Concept:

- Natural selection is differential survival and reproduction of individuals with heritable variations. Favourable phenotypes contribute more offspring to subsequent generations.
- A frequency distribution shows how common each phenotypic value is. Selection may favour the average phenotype, one extreme, or both extremes.

Step 1: Explain stabilising selection Stabilising selection favours individuals with intermediate or average characters and selects against both extremes. More individuals acquire the mean character over generations, while fewer occupy the extremes. The distribution becomes narrower and taller around approximately the same mean; variation decreases. In the first graph, the solid curve is therefore concentrated around the original central peak.

Step 2: Explain directional selection Directional selection favours individuals at one extreme of the phenotypic range. These individuals leave more offspring, so the population mean shifts towards that favoured extreme. The second graph shows selection favouring larger phenotypic values: the peak shifts to the right. If smaller values were favoured, the peak would shift to the left instead.

Step 3: Explain disruptive selection and compare the graphs Disruptive selection favours individuals at both extremes and selects against intermediate individuals. Consequently, two peaks develop, one near each extreme, and the intermediate class becomes less frequent. This increases phenotypic divergence within the population. In all three schematic graphs below, the horizontal axis shows phenotypic value and the vertical axis shows frequency of individuals. The dashed curve is the distribution before selection and the solid curve is the distribution after selection.



Changes in phenotypic frequency under the three modes of natural selection.

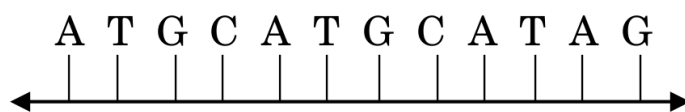
Step 4: Conclusion Natural selection operates through stabilising selection (average favoured), directional selection (one extreme favoured) and disruptive selection (both extremes favoured).

Quick Tip to Solve: Identify the favoured phenotype first: average gives a narrower central peak, one extreme shifts the peak, and both extremes produce two peaks.

24. (a) Construct a complete transcription unit with promoter and terminator on the basis of the hypothetical coding strand given below:

(b) Write the RNA strand transcribed from the above transcription unit along with its polarity.

[3 marks]

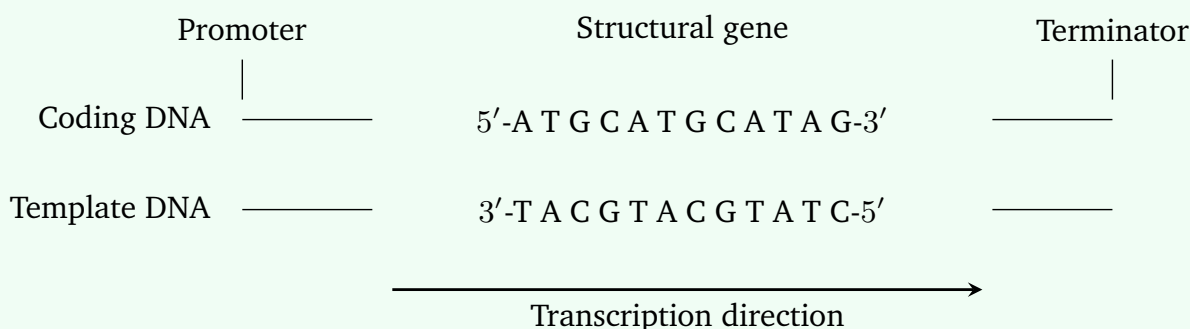


Solution:

Concept:

- A transcription unit consists of a promoter, a structural gene and a terminator. The promoter determines the template strand and the direction of transcription.
- The template and coding DNA strands are complementary and antiparallel. RNA polymerase reads the template in the $3' \rightarrow 5'$ direction and synthesises RNA in the $5' \rightarrow 3'$ direction.
- The RNA sequence matches the coding strand when both are written $5' \rightarrow 3'$, except that uracil (U) replaces thymine (T).

Step 1: Construct the transcription unit in part (a) Write the given coding strand from left to right as $5' \rightarrow 3'$. Using A–T and G–C pairing gives the complementary template $3'$ -TACGTACGTATC- $5'$, antiparallel to the coding strand. Place the promoter upstream, towards the coding strand's $5'$ end, and the terminator downstream, towards its $3'$ end. The supplied sequence forms the structural-gene segment. RNA polymerase binds at the promoter and moves along the template towards the terminator.



Complete transcription unit with strand polarities and transcription direction.

Step 2: Transcribe the RNA in part (b) RNA is complementary to the template: U pairs with A, A with T, G with C and C with G. RNA elongates only in the $5' \rightarrow 3'$ direction. Thus, copying the coding sequence in that direction and replacing every T with U gives the twelve-nucleotide RNA corresponding to the supplied segment.

Step 3: Conclusion The complete unit is promoter–structural gene–terminator, with antiparallel coding and template strands as shown. The RNA transcribed from the given segment is $5'$ -AUGCAUGCAUAG- $3'$.

Quick Tip to Solve: When a coding strand is given, copy its $5' \rightarrow 3'$ sequence with T replaced by U; complementing it directly would give the wrong RNA.

25. (a) What is primary productivity? Why does it vary in different types of ecosystems?

(b) Why is the assimilation of energy at the herbivore level called secondary productivity? [3 marks]

Solution:

Concept:

- Productivity is a rate of biomass or organic-matter production, expressed per unit area per unit time. Primary producers fix energy into organic matter; consumers obtain organic matter from other organisms.
- Primary productivity is commonly expressed as $\text{g m}^{-2} \text{yr}^{-1}$ or $\text{kcal m}^{-2} \text{yr}^{-1}$. The time component distinguishes productivity from the biomass present at a particular instant.

Step 1: Define primary productivity in part (a) Primary productivity is the amount of biomass or organic matter produced per unit area per unit time by plants during photosynthesis. Plants capture solar energy and use it to synthesise organic food from inorganic raw materials. This production is primary because it introduces newly fixed organic matter and energy into the ecosystem's food chains.

Step 2: Explain why ecosystems differ in primary productivity Primary productivity depends on the plant species inhabiting an area and their photosynthetic capacity. It also depends on environmental factors, including light, temperature and water availability, and on the availability of nutrients. These conditions differ among ecosystems, so the amount of organic matter produced per unit area per unit time also differs. For example, limited water restricts photosynthesis in a desert, whereas favourable moisture and temperature can support much greater productivity in a tropical forest.

Step 3: Explain secondary productivity in part (b) Herbivores are consumers. They obtain already formed organic matter by feeding on primary producers and assimilate part of its energy into their own tissues. The rate of formation of this new organic matter by consumers is called secondary productivity. It is termed secondary because the organic matter and energy originate in primary production and are subsequently incorporated into consumer biomass. Energy expended in respiration does not become new consumer biomass.

Step 4: Conclusion Primary productivity is the rate of organic-matter production by plants and varies with plant species, photosynthetic capacity, environmental conditions and nutrient availability. New biomass formed by herbivores from producer-derived food constitutes secondary productivity.

Quick Tip to Solve: Include both area and time in the definition of productivity; distinguish producers fixing energy from herbivores converting ingested organic matter into biomass.

26. There are many animals, which have become extinct in the wild, but continue to be maintained in zoological parks. Answer the questions that follow:

- (a) What type of bio-diversity conservation is observed in this case?
(b) Explain any other two ways which help in this type of conservation.
(c) Besides zoological parks, mention one place that serves this purpose.

[3 marks]

Solution:

Concept:

- Ex-situ conservation protects threatened organisms or their genetic material outside their natural habitats under human care.
- Conservation can maintain whole living organisms, or preserve viable cells, gametes and tissues from which organisms can later be obtained.

Step 1: (a) Identify the conservation method The animals survive in zoological parks even though they have disappeared from the wild. Since they are maintained outside their natural habitats, this is **ex-situ conservation**. Protected care and captive breeding help maintain populations that can no longer survive unaided in their original surroundings.

Step 2: (b) Explain cryopreservation and tissue culture **Cryopreservation:** Gametes of threatened species can be stored in a viable and fertile condition for long periods at very low temperatures, commonly in liquid nitrogen at -196°C . Their biological activity is greatly reduced during storage, and they can subsequently be used for reproduction to help conserve the species.

Tissue culture: Small pieces of plant tissue are grown aseptically on a suitable nutrient medium. Owing to the totipotency of plant cells, complete plants can be regenerated and multiplied. This enables large numbers of rare or threatened plants to be propagated and maintained outside their natural habitats.

Step 3: (c) Give another place for ex-situ conservation A **botanical garden** is another such place. It maintains living collections of plant species under managed conditions outside their natural habitats, including rare and threatened species.

Step 4: Conclusion (a) Ex-situ conservation; (b) cryopreservation of gametes and propagation by tissue culture; (c) a botanical garden.

Quick Tip to Solve: Use the location test: care outside the natural habitat is ex-situ. Pair each conservation method with what it preserves or propagates.

27. (a) How is insulin different from proinsulin?

(b) Explain all the stages of how human insulin is produced through rDNA technology.

[3 marks]

Solution:

Concept:

- Mature human insulin has an A chain of 21 amino acids and a B chain of 30 amino acids, linked by disulphide bridges.
- Recombinant DNA technology introduces DNA encoding the required polypeptide into a host so

that the host produces that polypeptide.

Step 1: (a) Distinguish insulin from proinsulin **Proinsulin** is the inactive precursor of insulin. It is a single polypeptide containing the future A and B chains joined by an extra connecting segment called the **C peptide**. During maturation, the C peptide is removed. **Mature, active insulin** therefore contains only the A and B chains linked by disulphide bridges; it does not contain the C peptide.

Step 2: (b) Prepare and introduce the coding DNA In the method developed by Eli Lilly in 1983, two DNA sequences corresponding to the A and B chains of human insulin were prepared separately. Each sequence was inserted into a plasmid vector. The recombinant plasmids were introduced into separate cultures of *Escherichia coli*, producing bacterial hosts carrying the DNA for the respective insulin chains.

Step 3: Express and isolate the two chains The genetically engineered bacteria were cultured so that they expressed the introduced DNA and produced the A chain and B chain separately. The two polypeptides were extracted from their respective bacterial cultures and purified. Producing the chains separately avoids relying on bacteria to remove the C peptide from human proinsulin.

Step 4: Assemble mature human insulin The purified A and B chains were combined under suitable conditions that allowed the correct disulphide bridges to form between them. This joining produced mature, biologically active human insulin with the required two-chain structure.

Step 5: Conclusion Proinsulin contains the C peptide, whereas mature insulin lacks it. Recombinant production involves preparing A- and B-chain DNA, plasmid insertion, expression in separate *E. coli* cultures, chain purification and joining by disulphide bridges.

Quick Tip to Solve: Recall the sequence: two coding DNAs, two bacterial cultures, two purified chains, then disulphide linkage. The C peptide is removed during natural maturation.

28(a). Name the cells of the human body attacked by HIV first, when it gains entry into a human body. How does this virus replicate further to cause immunodeficiency in the body? [3 marks]

Solution:

Concept:

- Human immunodeficiency virus (HIV) is a retrovirus with an RNA genome. Reverse transcriptase produces viral DNA using viral RNA as the template.
- Helper T lymphocytes coordinate immune responses. Their progressive depletion weakens both cellular and antibody-mediated protection against infections.

Step 1: Identify the first cells attacked After gaining entry into the body, HIV first attacks **macrophages**. The virus enters these cells and releases its RNA genome along with the enzymes required for replication.

Step 2: Convert viral RNA into DNA and integrate it Inside the macrophage, the viral enzyme **reverse transcriptase** synthesises a DNA copy from the viral RNA. The resulting viral DNA becomes integrated into the host cell's DNA. The host cell machinery then transcribes viral RNA and synthesises viral proteins, which assemble into new virus particles.

Step 3: Explain continued virus production and T-cell loss Infected macrophages continue to produce and release HIV particles, acting as a source of infection. HIV also enters **helper T lymphocytes**, repeats its replication cycle and produces progeny viruses. These infect further helper T cells. Repeated infection and destruction cause a progressive decline in the number of helper T lymphocytes in the body.

Step 4: Relate T-cell depletion to immunodeficiency As helper T cells become depleted, their ability to coordinate the activation of other immune cells and effective antibody responses decreases. The person consequently becomes susceptible to opportunistic infections, including those caused by microbes that a healthy immune system would normally control. Severe immune suppression characterises AIDS.

Step 5: Conclusion Macrophages are attacked first. HIV undergoes reverse transcription, integrates its DNA and produces new viruses; subsequent progressive destruction of helper T lymphocytes causes immunodeficiency.

Quick Tip to Solve: Keep the sequence clear: macrophage entry, RNA-to-DNA conversion, integration, virus production, helper T-cell depletion, then opportunistic infections.

OR

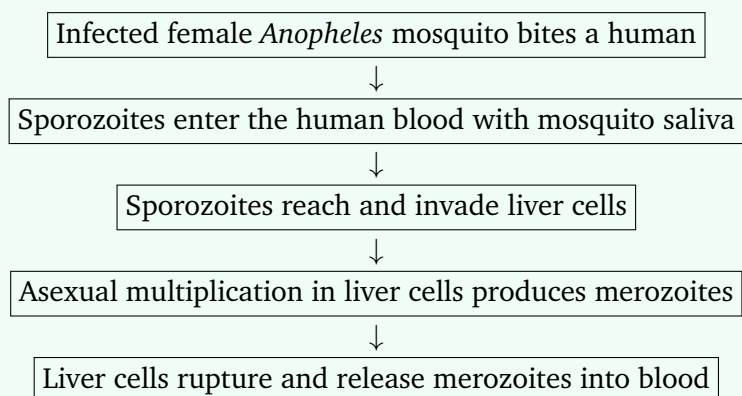
28(b). Show with the help of a flow chart only, the life-cycle of malarial parasite in human. [3 marks]

Solution:

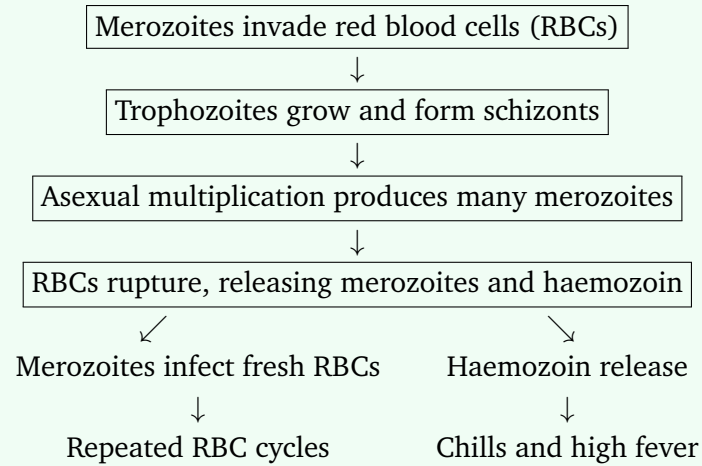
Concept:

- Infected female *Anopheles* bite → human infection by *Plasmodium*
- Liver stage → red blood cell stage → gametocytes

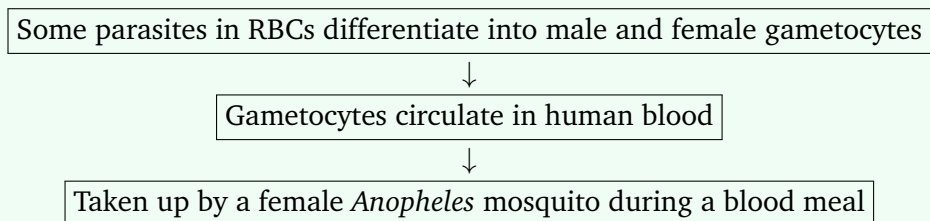
Step 1: Trace entry and the liver stage



Step 2: Continue through red blood cells



Step 3: Conclusion



Quick Tip to Solve: Keep the human stages in order: sporozoites, liver, RBC cycles, then gametocytes; show fever as a consequence of RBC rupture.

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:

Immunity in our body is of two types (i) Innate immunity, and (ii) Acquired immunity. Innate immunity is a non-specific defence mechanism, whereas Acquired immunity is pathogen specific. Acquired immunity is characterised by memory. Antibodies are specific to antigens and there are four types of antibodies produced in our body — IgA, IgE, IgG and IgM. It shows primary response where it encounters the pathogen for the first time and secondary response during the subsequent encounters with the same antigen/pathogen. These immune responses are carried out with the help of two special types of lymphocytes present in the blood. [4 marks]

29(a). Name the two types of specialised cells which carry out the primary and secondary responses. [1 mark]

Solution:

Concept:

- Acquired immunity is antigen specific and shows memory after the first encounter with an antigen.
- B-lymphocytes and T-lymphocytes are the specialised lymphocytes of acquired immunity.

Step 1: Identify the cells for antibody responses B-lymphocytes give rise to plasma cells that produce antigen-specific antibodies. They therefore participate in humoral immune responses to a pathogen.

Step 2: Identify the other specialised lymphocytes T-lymphocytes mediate cell-mediated immunity and helper T cells assist B-cell responses. Memory B and T cells formed after antigen exposure contribute to a stronger response on subsequent encounters.

Step 3: Conclusion The two specialised cell types are **B-lymphocytes (B cells) and T-lymphocytes (T cells)**.

Quick Tip to Solve: When asked for the two lymphocyte types in acquired immunity, name B cells and T cells, rather than antibodies or phagocytes.

29(b)(i). Name any two barriers present in our body that provide innate immunity. [1 mark]

Solution:

Concept:

- Innate immunity is present from birth and provides non-specific defence against pathogens.
- Innate barriers prevent entry of pathogens or create conditions that inhibit their survival.

Step 1: Name a physical barrier **Skin** forms a physical barrier that prevents the entry of microbes into the body. Mucus coating the respiratory, digestive and urogenital tracts also traps microbes.

Step 2: Name a physiological barrier **Acid in the stomach** is a physiological barrier: the acidic environment inhibits or destroys many microbes that enter with food and water. Its action does not

depend on prior exposure to a particular antigen.

Step 3: Conclusion Two innate barriers are **physical barriers (skin)** and **physiological barriers (stomach acid)**.

Quick Tip to Solve: Give a barrier category with its example: skin is physical, while stomach acid is physiological.

OR

29(b)(ii). The organ transplants (grafts) are often rejected if not taken from suitable compatible persons. Mention the characteristic of our immune system that is responsible for the rejection.

[1 mark]

Solution:

Concept:

- The immune system can distinguish the body's own cells (self) from foreign material (non-self).
- Cell-mediated immunity, involving T-lymphocytes, is responsible for immune rejection of an incompatible graft.

Step 1: Recognise the incompatible graft Cells in a graft from an incompatible donor carry surface antigens that differ from those of the recipient. The recipient's immune system recognises these antigens as non-self.

Step 2: Relate recognition to rejection This recognition activates an immune response against the transplanted tissue, particularly a T-cell-mediated response. The resulting damage can cause graft rejection even though the transplanted organ is useful to the patient.

Step 3: Conclusion The responsible characteristic is the immune system's **ability to distinguish self from non-self**.

Quick Tip to Solve: For the characteristic behind graft rejection, write self–non-self discrimination; T cells describe the mechanism.

29(c). How is active immunity different from passive immunity? Write any two differences. [2 marks]

Solution:

Concept:

- Active and passive immunity differ in the source of the protective antibodies and in the time needed to provide protection.
- An antigen stimulates an immune response, whereas ready-made antibodies can provide protection without waiting for the recipient to produce them.

Step 1: Compare the source of antibodies **Active immunity:** The individual's own immune system produces antibodies after exposure to an antigen, as during an infection or vaccination. The person actively develops an immune response.

Passive immunity: Ready-made antibodies are transferred to the individual from another source, as with maternal antibodies received by a baby or injected antiserum. The recipient need not produce these transferred antibodies.

Step 2: Compare the onset of protection **Active immunity:** Protection develops relatively slowly during the first exposure because antigen recognition, activation and multiplication of lymphocytes, and antibody production take time.

Passive immunity: Protection is immediate because the transferred antibodies are already available to act against the relevant antigen.

Step 3: Conclusion The two differences are **antibodies made by the individual versus ready-made antibodies received**, and **slow onset versus immediate protection**, respectively, for active and passive immunity.

Quick Tip to Solve: Use two matched comparisons: who makes the antibodies, and how soon protection starts after the first exposure or transfer.

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

Gene expresses itself in a cell system as a protein/enzyme. How an expression of gene occurs in a cell system, when it needs to occur and how the gene expression is regulated in prokaryotic cell system was studied by the combined efforts of Francois Jacob, a geneticist and Jacques Monod, a biochemist. For their work on lactose metabolism in *E. coli* and introducing the concept of 'lac operon', they were awarded the Nobel Prize in 1965.

[4 marks]

30(a). It is said that 'lac operon' has to be operational at a very low level in the bacterial cell all the time. Justify.

[1 mark]

Solution:

Concept:

- Basal expression means that the lac operon produces small amounts of its gene products even before full induction.
- Permease, encoded by the structural gene *y*, facilitates entry of lactose into the bacterial cell.

Step 1: Identify the need for an initial supply of permease Lactose must enter the cell before it can bring about induction of the lac operon. A small amount of permease must therefore already be present in the membrane to allow lactose uptake when it becomes available outside the bacterium.

Step 2: Connect basal expression with subsequent induction Continuous expression at a very low level supplies this initial permease. Once lactose enters, it can induce the operon by inactivating the repressor, enabling increased production of the proteins needed for lactose uptake and metabolism.

Step 3: Conclusion The lac operon must function at a low basal level to provide permease, which allows lactose to enter the cell and induce the operon.

Quick Tip to Solve: Link the low basal activity specifically to permease: lactose must first enter before it can induce greater expression.

30(b)(i). How are the structural genes activated in the lac operon in *E. coli*?

[1 mark]

Solution:

Concept:

- The lac operon is an inducible system in which an active repressor normally prevents transcription of its structural genes.
- Lactose acts as the inducer; binding of the inducer inactivates the repressor so that it cannot bind the operator.

Step 1: Inactivate the repressor When lactose becomes available in *E. coli*, the inducer binds to the repressor and changes its conformation. The repressor therefore loses its ability to occupy the operator.

Step 2: Permit transcription of the structural genes With the operator free, RNA polymerase can transcribe the structural genes *z*, *y* and *a*. Their messenger RNA is translated to produce the proteins involved in lactose metabolism.

Step 3: Conclusion The structural genes are activated when the lactose inducer inactivates the repressor, freeing the operator and allowing their transcription by RNA polymerase.

Quick Tip to Solve: Explain activation in this order: inducer binds repressor, operator becomes free, structural genes are transcribed.

OR

30(b)(ii). Why is the regulation of operon called negative regulation?

[1 mark]

Solution:

Concept:

- Negative regulation means that a regulatory protein inhibits gene expression by blocking transcription.
- In the lac operon, the regulatory gene produces a repressor that can bind to the operator.

Step 1: Identify the inhibitory action In the absence of the inducer, the active repressor binds to the operator and prevents RNA polymerase from transcribing the structural genes. Thus the regulatory protein acts as a brake on gene expression.

Step 2: Explain how the inhibition is removed When the inducer is present, it inactivates the repressor and allows transcription to proceed. This response depends on removing an inhibitory influence: the repressor does not act as an activator of transcription.

Step 3: Conclusion Lac operon regulation is called negative regulation because the repressor negatively controls expression by binding to the operator and preventing transcription.

Quick Tip to Solve: To justify the word negative, name the repressor and state the transcription-blocking action of its operator binding.

30(c). Why is lac operon said to be a transcriptionally regulated system?

[2 marks]

Solution:

Concept:

- Transcription is the synthesis of RNA from a DNA template by RNA polymerase. Controlling this step controls whether a gene's messenger RNA is available for protein synthesis.
- The lac structural genes *z*, *y* and *a* are transcribed together under the control of a common promoter and operator.

Step 1: Locate the control point without lactose In the absence of lactose, the active repressor binds to the operator. It prevents RNA polymerase from transcribing the structural genes, so production of the corresponding messenger RNA is strongly suppressed. The control therefore acts before the enzymes are made.

Step 2: Trace the change when lactose is present Lactose acts as an inducer and inactivates the repressor. The operator becomes available, permitting RNA polymerase to transcribe the structural genes into a polycistronic messenger RNA. Translation of this RNA then produces the proteins needed for lactose metabolism. The regulatory switch determines RNA formation, rather than directly switching the activity of already-made enzymes.

Step 3: Conclusion The lac operon is transcriptionally regulated because repressor binding or release at the operator controls transcription of the structural genes, and hence the synthesis of their messenger RNA.

Quick Tip to Solve: Identify the stage being controlled: operator occupancy affects RNA synthesis, so the regulation is at transcription.

Section E (15 marks)

31(a). (i) EcoR I has played a very important role in rDNA technology.

(I) Explain the convention for naming EcoR I.

(II) Write the recognition site of this endonuclease restriction enzyme.

(ii) Name the overhanging stretches of DNA produced by these restriction enzymes. Describe their role in the formation of rDNA.

[5 marks]

Solution:

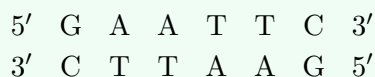
Concept:

- Restriction endonucleases recognise specific DNA sequences and cut the phosphodiester backbone at defined positions within DNA.
- EcoR I recognises a palindromic sequence: the two complementary strands have the same sequence when each is read in the 5' to 3' direction.
- Complementary sticky ends associate by hydrogen bonding; DNA ligase seals the sugar-phosphate backbones to form stable recombinant DNA.

Step 1: Decode the name EcoR I in part (i) (I) The first letter **E** comes from the genus *Escherichia*,

and the next two letters **co** come from the species *coli*, the bacterium from which the enzyme was isolated. The letter **R** identifies the bacterial strain RY13. The Roman numeral **I** indicates that this was the first restriction endonuclease isolated from that strain. Thus each part of the name records the enzyme's bacterial origin or order of isolation.

Step 2: Write the recognition site for part (i)(II) EcoR I recognises the following six-base-pair DNA sequence. Both strands and their polarities are shown:



Reading either strand in the 5' to 3' direction gives GAATTC, confirming the palindromic recognition sequence.

Step 3: Identify the overhangs in part (ii) EcoR I makes staggered cuts between G and A on each strand when read in its own 5' to 3' direction. The cut positions are:



These cuts produce short, single-stranded overhanging stretches called **sticky ends** or cohesive ends. In this case, the protruding 5' sequence is AATT.

Step 4: Explain how the ends help form recombinant DNA Cutting the vector DNA and the DNA containing the desired gene with the same restriction enzyme generates compatible sticky ends. On mixing the fragments, complementary bases of these ends pair through hydrogen bonds, holding the insert and vector together. DNA ligase then forms phosphodiester bonds between adjacent nucleotides in the sugar-phosphate backbones, sealing the remaining breaks. This covalent joining produces a stable recombinant DNA molecule containing DNA from the two sources; base pairing alone does not seal the backbone.

Step 5: Conclusion EcoR I is the first restriction endonuclease isolated from *Escherichia coli* strain RY13 and recognises 5'-GAATTC-3'. Its sticky ends allow complementary vector and insert ends to pair, after which DNA ligase seals them into recombinant DNA.

Quick Tip to Solve: Decode EcoR I as genus, species, strain and isolation order; then distinguish sticky-end hydrogen bonding from the phosphodiester bonds made by ligase.

- 31(b).** (i) Insertional inactivation is a method to detect the recombinant DNA. Explain this method.
 (ii) Name the commonly used vector for transferring genes in plants from bacteria.
 (iii) How is this able to transform a normal plant cell into a tumour? [5 marks]

Solution:

Concept:

- Insertional inactivation identifies a recombinant by the loss of activity of a marker gene into which foreign DNA has been inserted.
- The Ti (tumour-inducing) plasmid of *Agrobacterium tumefaciens* naturally transfers a segment of DNA, called T-DNA, into a plant cell.

Step 1: (i) Explain how inserting DNA disrupts a marker A cloning vector is cut at a suitable restriction site within a marker gene, and the foreign DNA is ligated into that site. The insertion interrupts the coding sequence, so the recombinant vector cannot produce a functional marker product. In contrast, a non-recombinant vector retains the intact gene and its activity. Thus, after introduction into host cells, the loss of marker activity distinguishes recombinants from non-recombinants.

Step 2: (i) Apply the colour-screening example A commonly used marker encodes β -galactosidase. The foreign DNA is inserted into the relevant coding sequence and inactivates it. Transformed bacteria are grown on a suitable medium containing a chromogenic substrate. Non-recombinant colonies have functional β -galactosidase, which acts on the substrate and produces blue colonies. Recombinant colonies lack this activity and remain white or colourless. The white colonies are therefore selected as putative recombinants; an independent selectable marker can first distinguish transformed cells from cells that received no vector.

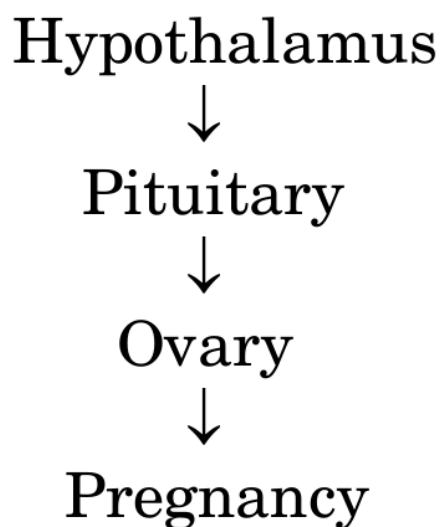
Step 3: (ii) Identify the bacterial vector used in plants The commonly used vector is the Ti plasmid of *Agrobacterium tumefaciens*. For gene transfer in biotechnology, its tumour-causing function is disarmed while the ability to deliver DNA into plant cells is retained. A desired gene is introduced into the transferable DNA region.

Step 4: (iii) Explain tumour formation by the natural plasmid In the natural, tumour-inducing system, the bacterium delivers T-DNA from its Ti plasmid into a susceptible plant cell. T-DNA integrates into the plant genome and its genes are expressed. The transferred genes alter the production of plant growth regulators, including auxins and cytokinins, causing uncontrolled cell division and a crown-gall tumour. The normal plant cell is therefore genetically transformed into a tumour cell; the disarmed vector used for engineering does not retain this tumour-inducing activity.

Step 5: Conclusion Insertional inactivation detects recombinants through loss of marker function, such as white colonies instead of blue colonies. The plant-transfer vector is the Ti plasmid of *A. tumefaciens*; its natural T-DNA transforms plant cells and induces tumour growth.

Quick Tip to Solve: Link an inserted foreign gene to an inactive marker and a white colony. For Ti plasmids, distinguish natural tumour induction from the disarmed vector used in gene transfer.

32(a). Study the flow chart given below. Name the hormones involved at each stage and explain their functions. [5 marks]



Solution:

Concept:

- The hypothalamus controls the anterior pituitary through gonadotropin-releasing hormone (GnRH); pituitary gonadotropins control ovarian activity.
- Ovarian oestrogens and progesterone regulate the uterine endometrium, preparing it for implantation and supporting pregnancy.

Step 1: Identify the hypothalamic hormone The hypothalamus secretes gonadotropin-releasing hormone (GnRH). Its pulsatile release stimulates the anterior pituitary to synthesise and secrete the gonadotropins, follicle-stimulating hormone (FSH) and luteinising hormone (LH). GnRH therefore provides the hormonal link from the hypothalamus to the pituitary in the flow chart.

Step 2: Explain the pituitary hormones acting on the ovary FSH stimulates growth and maturation of ovarian follicles and, together with LH, promotes their development and oestrogen secretion. A sharp mid-cycle rise in LH, the LH surge, induces rupture of the mature Graafian follicle and ovulation. LH also promotes formation of the corpus luteum from the ruptured follicle and supports its secretion of progesterone. Thus FSH prepares the follicle, whereas the LH surge releases the secondary oocyte and initiates the luteal phase.

Step 3: Explain the ovarian hormones preparing the uterus The growing ovarian follicles secrete oestrogens. These stimulate proliferation and regeneration of the uterine endometrium after menstruation. Following ovulation, the corpus luteum secretes large amounts of progesterone along with oestrogens. Progesterone maintains the thick, vascular, secretory endometrium required for implantation and nourishment of the developing embryo. These ovarian hormones provide the link between the ovary and the uterine conditions needed for pregnancy.

Step 4: Relate the hormonal sequence to maintenance of pregnancy If fertilisation and implantation occur, human chorionic gonadotropin (hCG), secreted by the developing trophoblast and placenta, maintains the corpus luteum in early pregnancy. Continued progesterone and oestrogen secretion

prevents breakdown of the endometrium and supports pregnancy. The placenta subsequently becomes an important source of these hormones. Progesterone also helps keep the uterus quiescent. Hormones therefore prepare and maintain the maternal tissues, while fertilisation and implantation establish pregnancy.

Step 5: Conclusion The main sequence is hypothalamic GnRH, pituitary FSH and LH, followed by ovarian oestrogens and progesterone. These hormones coordinate follicular growth, ovulation and maintenance of the endometrium; hCG maintains the corpus luteum during early pregnancy.

Quick Tip to Solve: Read each arrow as a source, hormone and target: hypothalamus–GnRH–pituitary; pituitary–FSH/LH–ovary; ovary–oestrogens/progesterone–uterus.

OR

32(b). (i) Draw a diagram of L.S. of maize grain and label its any six parts.

(ii) Differentiate between perisperm and endosperm giving one example of each.

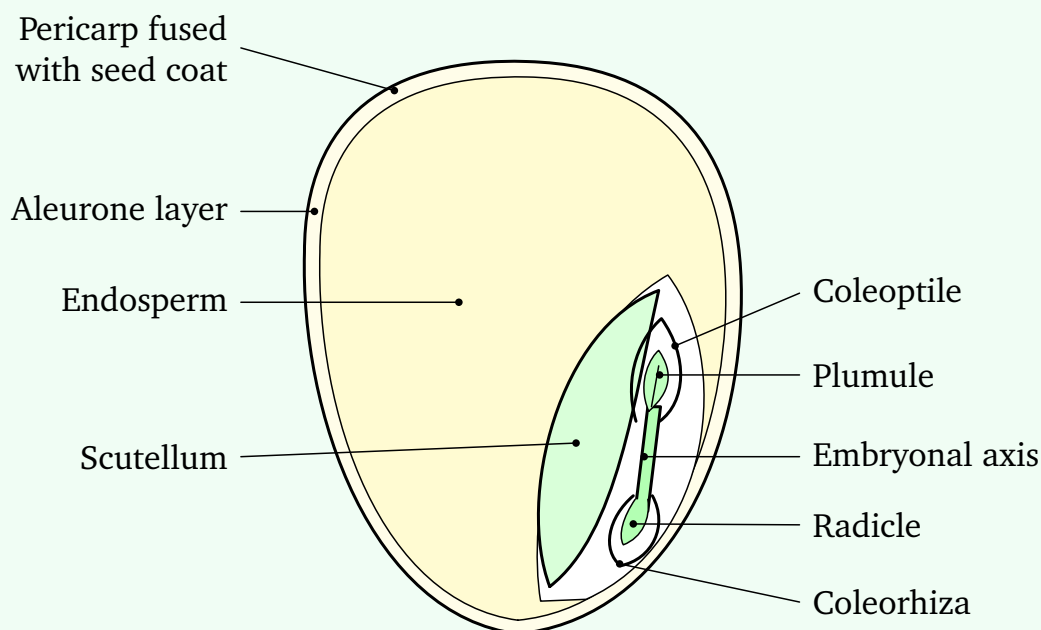
[5 marks]

Solution:

Concept:

- Maize grain is a caryopsis: its fruit wall (pericarp) is fused with the seed coat. It is an albuminous seed with a large persistent endosperm and a small embryo situated laterally.
- The monocot embryo has one shield-shaped cotyledon, the scutellum. The plumule and radicle are protected by the coleoptile and coleorhiza, respectively.
- Perisperm is the persistent remnant of the nucellus, whereas endosperm develops from the primary endosperm nucleus formed by triple fusion during double fertilisation.

Step 1: (i) Draw and label the longitudinal section Show the fused pericarp and seed coat as the outer covering. Immediately within the covering, mark the aleurone layer around the large starchy endosperm. Place the embryo towards one side of the grain, with the scutellum facing the endosperm. In the labelled L.S. below, the embryonal axis bears a plumule at its upper end and a radicle at its lower end. The coleoptile encloses the plumule, while the coleorhiza surrounds the radicle. These distinct labelled parts identify the characteristic monocot seed structure.



L.S. of maize grain (schematic)

Step 2: (ii) Compare the origin and nature of the two tissues **Perisperm:** This is the part of the maternal nucellus that remains in the mature seed instead of being completely consumed during seed development. It is therefore a pre-existing maternal tissue, ordinarily diploid, $2n$; it is not a product of triple fusion. A standard example is **black pepper** (also seen in beet).

Endosperm: This nutritive tissue develops after triple fusion, when one male gamete fuses with the two polar nuclei (or the diploid secondary nucleus) of the central cell. The resulting primary endosperm nucleus is generally triploid, $3n$, and divides to form the endosperm. It supplies nourishment to the developing embryo. A standard example of persistent endosperm is **maize** (also seen in castor). Thus, the decisive distinctions are nucellar versus fertilisation-derived origin and usually diploid versus triploid constitution. Both tissues may remain in mature seeds, so persistence alone does not distinguish them.

Step 3: Conclusion The labelled L.S. shows the outer fused covering, aleurone layer, endosperm, scutellum and the protected embryonal axis. Perisperm is persistent nucellus, as in black pepper; endosperm is the usually triploid nutritive tissue formed after triple fusion, as in maize.

Quick Tip to Solve: In the maize sketch, keep the scutellum between the endosperm and embryonal axis. Pair plumule with coleoptile and radicle with coleorhiza; distinguish perisperm from endosperm by origin first.

33(a). Write the types and locations of the genes causing thalassemia in humans. State the cause and symptoms of the disease. How is sickle-cell anemia different from this disease? [5 marks]

Solution:

Concept:

- Adult haemoglobin contains two α -globin and two β -globin chains. Its normal production requires adequate synthesis of both kinds of chain.
- Thalassemia is an inherited, autosomal recessive blood disorder in which the synthesis of one type of globin chain is reduced or absent. It is therefore a quantitative defect of haemoglobin production.
- Sickle-cell anaemia involves a structural alteration of the β -globin chain, so it is a qualitative defect of haemoglobin.

Step 1: Identify the types and locate their genes **α -thalassemia:** The affected genes encode α -globin. Two closely linked genes, *HBA1* and *HBA2*, are present on chromosome 16. Thus, a diploid individual normally has four copies of the α -globin genes in total. Mutation or deletion affecting these genes reduces α -chain production; severity depends on how many gene copies are affected.

β -thalassemia: The affected gene encodes β -globin. The *HBB* gene lies on chromosome 11, with one copy on each homologous chromosome. Mutations in this gene reduce or prevent β -chain production.

Step 2: Explain the cause and symptoms of thalassemia Inherited mutations or deletions in the globin genes impair the synthesis of the corresponding globin chain. The imbalance between α and β chains interferes with the formation of normal haemoglobin and damages developing red blood cells. Many cells are destroyed before maturation, and circulating red blood cells also have a shortened life span. The resulting anaemia reduces the oxygen-carrying capacity of blood. Common symptoms include pallor, tiredness, weakness and breathlessness. Severe forms may also show jaundice, an enlarged spleen, poor growth and bone changes due to expansion of the blood-forming marrow. The severity varies with the genetic defect; carriers may have only mild anaemia or no obvious symptoms.

Step 3: Distinguish sickle-cell anaemia from thalassemia In sickle-cell anaemia, a point mutation in the β -globin gene changes the sixth amino acid of its chain from glutamic acid to valine. The corresponding coding-DNA triplet changes from *GAG* to *GTG*, producing abnormal haemoglobin *HbS*. Under low oxygen conditions, *HbS* polymerises and red blood cells become sickle-shaped. These cells are fragile and can obstruct small blood vessels.

Thus, sickle-cell anaemia primarily changes the **structure** of a globin chain, whereas thalassemia primarily reduces the **quantity** of an α - or β -globin chain. Both can cause anaemia, but their underlying molecular defects differ.

Step 4: Conclusion α -thalassemia involves *HBA1* and *HBA2* on chromosome 16; β -thalassemia involves *HBB* on chromosome 11. Reduced globin-chain synthesis causes anaemia and associated weakness and pallor. Sickle-cell anaemia instead results from the glutamic-acid-to-valine substitution in β -globin, producing structurally abnormal *HbS*.

Quick Tip to Solve: Link alpha with chromosome 16 and beta with chromosome 11. Then contrast thalassemia's reduced chain quantity with sickle-cell anaemia's altered chain quality.

33(b). (i) Enlist any four prime goals of the Human Genome Project (HGP).

(ii) List the two methodologies which were involved in the human genome project. Mention how they were used.

(iii) Expand 'YAC' and mention what it was used for.

[5 marks]

Solution:

Concept:

- The Human Genome Project (HGP) aimed to obtain and analyse the complete DNA sequence of the human genome and identify its genes.
- The two main approaches described for HGP are expressed sequence tags (ESTs) and sequence annotation. They differ in whether the starting material represents expressed genes or the entire genome.
- Cloning vectors allow large genomic DNA fragments to be maintained and multiplied in host cells for subsequent analysis and sequencing.

Step 1: List four prime goals of HGP for part (i) Any four of the following prime goals can be stated. Here are four distinct goals:

1. Identify all the approximately 20,000–25,000 genes in human DNA.
2. Determine the sequence of the approximately three billion chemical base pairs that make up human DNA.
3. Store the resulting information in databases so that it can be accessed and compared.
4. Improve tools for analysing the large amount of genomic data generated by the project.

Gene identification establishes which DNA regions are genes, whereas whole-genome sequencing establishes the order of bases throughout the genome, including non-coding regions. Database storage and analytical tools make this sequence information usable.

Step 2: Explain the two methodologies for part (ii) **Expressed sequence tags (ESTs):** This approach focused on identifying the genes that are expressed as RNA. RNA transcripts, especially messenger RNA, could be represented as complementary DNA (cDNA), and short sequences from these expressed sequences served as tags for identifying genes. It therefore concentrated on the expressed portion of the genome.

Sequence annotation: This approach sequenced the entire genome, including both coding and non-coding regions. Functions were then assigned to different regions of the DNA sequence using sequence analysis and other information. Thus, the genome sequence was obtained first and its regions were subsequently identified and interpreted.

The key difference is that ESTs begin with expressed genes, while sequence annotation considers the whole genomic sequence and then assigns functions to its different regions.

Step 3: Expand YAC and state its use for part (iii) YAC stands for **Yeast Artificial Chromosome**. It was used as a cloning vector to carry large fragments of human genomic DNA in yeast cells. The human DNA was fragmented and inserted into suitable vectors; multiplication of the yeast host produced many copies of the inserted DNA. These clones provided sufficient DNA for mapping and

sequencing during the Human Genome Project.

A YAC can maintain a large DNA insert as an artificial chromosome in yeast, making it useful for handling genomic fragments that are too large for ordinary plasmid vectors.

Step 4: Conclusion Four HGP goals were gene identification, determination of the complete base sequence, database storage and improvement of analytical tools. Its two methodologies were ESTs for identifying expressed genes and sequence annotation for sequencing and interpreting the entire genome. YAC means Yeast Artificial Chromosome and was used to clone large human DNA fragments in yeast.

Quick Tip to Solve: Keep the two methodologies distinct: ESTs start from expressed RNA, while sequence annotation starts from the whole genome. For YAC, give both its expansion and its role as a large-insert cloning vector.