

CBSE Class 12 Biology Question Paper 2009 with Solution PDF-Set 57/1/1

Question Paper with Solutions

Conducted by the Central Board of Secondary Education (CBSE)



Time Allowed: 3 hours

Maximum Marks: 70

General Instructions

- (i) Please check that this question paper contains **12** printed pages.
- (ii) Code number given on the right hand side of the question paper should be written on the title page of the answer-book by the candidate.
- (iii) Please check that this question paper contains **30** questions.
- (iv) **Please write down the serial number of the question before attempting it.**
- (v) 15 Minutes time has been allotted to read this question paper. The question paper will be distributed at 10.15 a.m. From 10.15 a.m. to 10.30 a.m., the student will read the question paper only and will not write any answer on the answer script during this period.
- (vi) All questions are compulsory.
- (vii) This question paper consists of four Sections A, B, C and D. Section A contains 8 questions of one mark each, Section B is of 10 questions of two marks each, Section C is of 9 questions of three marks each and Section D is of 3 questions of five marks each.
- (viii) There is no overall choice. However, an internal choice has been provided in one question of 2 marks, **one** question of 3 marks and **all the three** questions of 5 marks weightage. A student has to attempt **only one** of the alternatives in such questions.
- (ix) Wherever necessary, the diagrams drawn should be neat and properly labelled.

Section A (8 marks)

1. Why hnRNA is required to undergo splicing?

[1 mark]

Solution:

Concept:

- In eukaryotes, heterogeneous nuclear RNA (hnRNA) is the primary transcript and contains both exons and introns.
- Splicing removes introns, the intervening non-coding sequences, and joins the exons in their correct order.

Step 1: Identify why the primary transcript needs processing The newly transcribed hnRNA contains introns between its exons. These introns must be removed before the RNA can serve as the proper template for protein synthesis.

Step 2: Explain the role of splicing During splicing, introns are excised and the remaining exons are joined. This produces the continuous exon sequence of mature messenger RNA, which can be translated after the other maturation steps are completed.

Step 3: Conclusion hnRNA must undergo splicing to remove introns and join exons, thereby forming a functional mature mRNA for translation.

Quick Tip to Solve: Link splicing specifically to intron removal and exon joining; capping and tailing are different processing steps.

2. The microscopic pollen grains of the past are obtained as fossils. Mention the characteristic of the pollen grains that makes it happen.

[1 mark]

Solution:

Concept:

- The outer wall of a pollen grain, called the exine, is composed of sporopollenin.
- Sporopollenin is exceptionally resistant to physical, chemical and biological degradation.

Step 1: Identify the protective wall material Pollen grains have a tough exine made of sporopollenin. This wall material can resist high temperatures and strong acids and alkalis.

Step 2: Connect resistance with fossil preservation No enzyme is known to degrade sporopollenin. Consequently, the resistant exine can persist in deposits long after the living contents disappear, allowing ancient pollen grains to be recovered as fossils.

Step 3: Conclusion Pollen grains are preserved as fossils because their exine contains highly resistant, non-degradable sporopollenin.

Quick Tip to Solve: For pollen fossil questions, name both the wall layer (exine) and its resistant material (sporopollenin).

3. How does colostrum provide initial protection against diseases to new born infants? Give one reason. [1 mark]

Solution:

Concept:

- Colostrum is the early milk secreted by the mother after childbirth and is rich in protective antibodies.
- Transfer of ready-made maternal antibodies provides naturally acquired passive immunity to the infant.

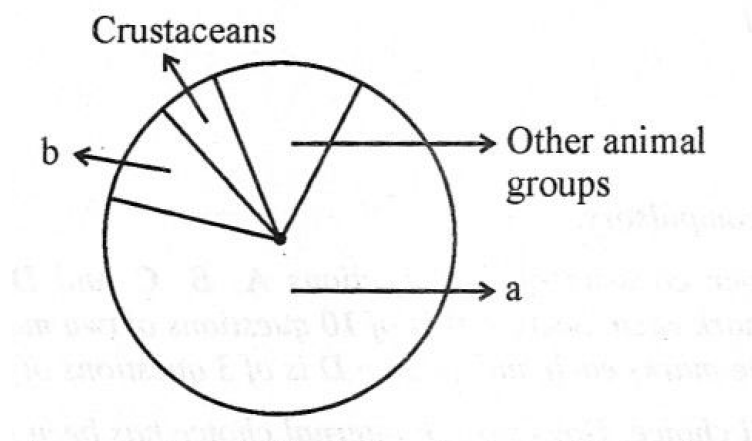
Step 1: Identify the protective component Colostrum supplies maternal antibodies, especially immunoglobulin A (IgA), to the newborn through breastfeeding.

Step 2: Explain the immediate protection These ready-made antibodies help protect the infant against pathogens, particularly at mucosal surfaces, while its own immune system is still developing. The infant does not have to produce these antibodies first, so the protection is initially available through passive immunity.

Step 3: Conclusion Colostrum provides initial protection because it contains abundant maternal antibodies, especially IgA, which confer passive immunity.

Quick Tip to Solve: Use the term passive immunity because the newborn receives ready-made antibodies rather than producing them in response to an antigen.

4. Name the unlabelled areas 'a' and 'b' of the pie chart (given above) representing the global biodiversity of invertebrates showing their proportionate number of species of major taxa. [1 mark]



Solution:

Concept:

- A biodiversity pie chart represents each major taxon by a sector proportional to its recorded number of species.
- Insects form the largest group of invertebrate species; molluscs form another prominent group.

Step 1: Identify the largest sector The arrow labelled a points into the very large sector occupying

most of the chart. In the global distribution of invertebrate species, this dominant sector represents insects.

Step 2: Identify the smaller unlabelled sector The arrow labelled b points into the sector adjacent to the explicitly labelled crustaceans sector. In this standard chart of major invertebrate taxa, that sector represents molluscs. The other printed sectors are already identified as crustaceans and other animal groups.

Step 3: Conclusion a: Insects; b: Molluscs.

Quick Tip to Solve: Identify insects from the dominant sector first, then distinguish the mollusc sector from the separately labelled crustaceans.

5. Mention the type of evolution that has brought the similarity as seen in potato tuber and sweet potato. [1 mark]

Solution:

Concept:

- Convergent evolution produces similar functional adaptations in organs that differ in their origin.
- Analogous organs perform similar functions but have different developmental or anatomical origins.

Step 1: Compare the origins of the two storage organs A potato tuber is a modified underground stem, recognizable by its buds or eyes. The swollen edible part of sweet potato is a modified adventitious root.

Step 2: Relate their similarity to evolution Both organs store food, even though one arose from a stem and the other from a root. Their common storage function with different origins makes them analogous organs and illustrates convergence.

Step 3: Conclusion The similarity between potato tuber and sweet potato is due to convergent evolution.

Quick Tip to Solve: Check origin before classifying similar organs: potato is a stem, sweet potato a root, so their storage function indicates analogy.

6. Name the group of organisms and the substrate they act on to produce biogas. [1 mark]

Solution:

Concept:

- Methanogens are anaerobic methane-producing microorganisms, commonly exemplified by Methanobacterium.
- Biogas is generated during anaerobic digestion of organic material such as the cellulose-rich material in cattle dung.

Step 1: Name the methane-producing group The group is methanogens, such as Methanobacterium. These organisms occur in anaerobic environments, including cattle rumen, and are present in cattle

dung.

Step 2: State the substrate used in biogas production The substrate is cellulosic organic matter in cattle dung and other plant residues. During anaerobic digestion, microbes break down this material and methanogens use the resulting products to generate methane, a major constituent of biogas.

Step 3: Conclusion Methanogens, for example *Methanobacterium*, act in the anaerobic digestion of cellulose-rich material such as cattle dung to produce biogas.

Quick Tip to Solve: Give both requested components: methanogens are the group, and cellulosic organic matter in cattle dung is the substrate.

7. Mention the pollinating agent of an inflorescence of small dull coloured flowers with well exposed stamens and large feathery stigma. Give any one characteristic of pollen grains produced by such flowers. [1 mark]

Solution:

Concept:

- Anemophily is pollination by wind; exposed stamens release pollen into moving air.
- Large feathery stigmas efficiently intercept airborne pollen, which is typically light and non-sticky.

Step 1: Infer the pollinating agent from the floral features The small, dull flowers do not require conspicuous colours to attract animals. Their exposed stamens release pollen readily, and the large feathery stigmas provide a broad surface for catching airborne grains. These features indicate wind pollination.

Step 2: Give a suitable pollen characteristic The pollen grains are light in weight, allowing air currents to carry them from the anthers to the stigmas. They are also generally non-sticky and produced in large numbers, although any one of these suitable characteristics answers the second part.

Step 3: Conclusion The pollinating agent is wind. One characteristic is that the pollen grains are light in weight.

Quick Tip to Solve: Use the combination of exposed stamens and a feathery stigma to identify wind pollination; then state light pollen as the requested trait.

8. Name the organism commercially used for the production of single cell protein. [1 mark]

Solution:

Concept:

- Single cell protein (SCP) is protein-rich microbial biomass used as a food or feed supplement.
- Microorganisms that grow rapidly on inexpensive nutrient sources can be cultivated commercially for their biomass.

Step 1: Identify the commercial organism *Spirulina*, a cyanobacterium, is commercially cultivated as a source of single cell protein. The harvested microbial biomass provides the protein supplement.

Step 2: Relate the organism to its use It can be grown on suitable nutrient media using materials such as waste water from potato-processing plants or straw. Rapid biomass production and a high protein content make such cultivation useful for supplementing diets.

Step 3: Conclusion *Spirulina* is commercially used for the production of single cell protein.

Quick Tip to Solve: For SCP questions, remember the product is microbial biomass itself; name *Spirulina* rather than a microbial enzyme.

Section B (20 marks)

9. Explain the contribution of *Thermus aquaticus* in the amplification of a gene of interest. [2 marks]

Solution:

Concept:

- PCR (polymerase chain reaction) amplifies a selected DNA segment through repeated cycles of denaturation, primer annealing and extension.
- *Thermus aquaticus* is a heat-tolerant bacterium that supplies the thermostable DNA polymerase called Taq polymerase.

Step 1: Identify the enzyme supplied The contribution of *Thermus aquaticus* is its thermostable Taq DNA polymerase. This enzyme catalyses the synthesis of a new DNA strand from deoxyribonucleotides, using the existing strand as a template and extending an annealed primer.

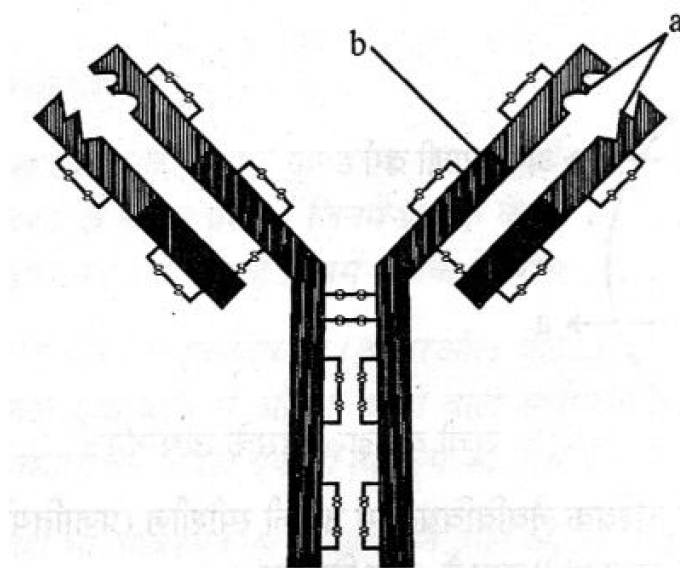
Step 2: Explain its role in repeated PCR cycles During PCR, high temperature, around 94–95 °C, separates the two template strands. Taq polymerase remains active despite this repeated heating. After primers anneal, it extends them at about 72 °C. Newly formed DNA becomes template in subsequent cycles, producing many copies of the gene of interest without adding fresh polymerase after each denaturation step.

Step 3: Conclusion *Thermus aquaticus* provides heat-stable Taq DNA polymerase, which withstands PCR denaturation and repeatedly synthesises DNA to amplify the gene of interest.

Quick Tip to Solve: Link *Thermus* to thermostability: the enzyme survives denaturation and extends primers during PCR.

10. (i) What does the above diagram illustrate?
(ii) Name the parts labelled 'a' and 'b'.
(iii) Name the type of cells that produce this molecule.

[2 marks]



Solution:

Concept:

- An antibody (immunoglobulin) is a Y-shaped protein with two identical heavy chains and two identical light chains, linked by disulphide bonds.
- Antigen-binding sites occur at the tips of its arms; antibody secretion is a function of plasma cells formed from activated B lymphocytes.

Step 1: Identify the illustrated molecule (i) The diagram illustrates the structure of an antibody or immunoglobulin molecule. Its paired arms and stem produce the characteristic Y shape. The heavy chains extend through the stem and arms, while the shorter light chains occur along the outer portions of the arms.

Step 2: Identify the labelled parts (ii) Label *a* indicates the antigen-binding sites at the tips of the arms. These sites recognise and bind a specific antigen. Label *b* indicates a heavy polypeptide chain, which extends into the stem as well as an arm of the molecule.

Step 3: Name the producing cells (iii) Antibodies are produced by B lymphocytes, specifically their differentiated effector forms called plasma cells. On activation by the appropriate antigen, B cells multiply and differentiate into plasma cells that secrete antibodies.

Step 4: Conclusion The molecule is an antibody; *a* denotes antigen-binding sites and *b* a heavy chain. It is produced by plasma cells derived from B lymphocytes.

Quick Tip to Solve: Trace a chain towards the stem to identify a heavy chain; the two tips of the arms carry antigen-binding sites.

11. Banana is a parthenocarpic fruit whereas oranges show polyembryony. How are they different from each other with respect to seeds? [2 marks]

Solution:

Concept:

- Parthenocarpy is fruit development without fertilisation and normally produces a seedless fruit.
- Polyembryony is the presence of more than one embryo in a single seed.

Step 1: Explain the seeds in banana In banana, the fruit develops without fertilisation. As fertilisation does not occur, normal mature seeds are not formed in the edible parthenocarpic fruit. Thus banana is seedless; parthenocarpy describes how the fruit develops, rather than the number of embryos in a seed.

Step 2: Explain the embryos in orange seeds Orange fruits contain seeds, and polyembryonic seeds contain more than one embryo within the same seed. In Citrus, some nucellar cells surrounding the embryo sac can develop into additional embryos, alongside the embryo formed through sexual reproduction. Thus the extra embryos are within a seed; polyembryony does not mean that several separate seeds are fused together.

Step 3: Conclusion Banana is seedless because its fruit is parthenocarpic, whereas orange has seeds that may contain more than one embryo because of polyembryony.

Quick Tip to Solve: Separate the two levels: parthenocarpy concerns fruit formation without fertilisation; polyembryony concerns embryo number within a seed.

OR

11. Where are fimbriae present in a human female reproductive system? Give their function. [2 marks]

Solution:

Concept:

- Each human oviduct begins near the ovary as a funnel-shaped infundibulum.
- Fimbriae are finger-like projections at the free margin of the infundibulum, associated with collecting the released oocyte.

Step 1: Locate the fimbriae Fimbriae are present along the fringed margin of the infundibulum, the funnel-shaped ovarian end of each fallopian tube or oviduct. They lie close to the ovary. They are not projections inside the uterus or at the uterine end of the oviduct.

Step 2: Explain their function at ovulation At ovulation, the ovary releases a secondary oocyte. The fimbriae help collect this released oocyte and guide it into the funnel-shaped opening of the infundibulum. It can then travel along the oviduct towards the region where fertilisation may occur. This collecting role helps transfer the oocyte from the vicinity of the ovary into the female reproductive tract.

Step 3: Conclusion Fimbriae occur at the margin of the infundibulum of each oviduct and help collect the ovulated oocyte and guide it into the oviduct.

Quick Tip to Solve: Remember the sequence from the ovary: fimbriae collect the oocyte into the infundibulum, followed by the ampulla and isthmus.

12. How is the translation of mRNA terminated? Explain.

[2 marks]

Solution:

Concept:

- Translation synthesises a polypeptide by reading the codons of mRNA on a ribosome.
- UAA, UAG and UGA are termination or stop codons. They do not specify an amino acid and are recognised by release factors.

Step 1: Recognise the termination signal During elongation, the ribosome moves along the mRNA and aminoacyl-tRNAs bring the amino acids specified by successive codons. When one of the stop codons, UAA, UAG or UGA, reaches the ribosome's A site, no corresponding aminoacyl-tRNA binds there. Thus no further amino acid is added to the growing chain.

Step 2: Release the completed polypeptide A release factor binds at the stop codon. It promotes hydrolysis of the bond linking the completed polypeptide to the tRNA in the ribosome, freeing the polypeptide. The ribosome, mRNA and tRNA then dissociate, and the ribosomal subunits can participate in another round of translation.

Step 3: Conclusion Translation terminates when the ribosome encounters a stop codon and a release factor causes the completed polypeptide to be released.

Quick Tip to Solve: Link termination to two events: recognition of UAA, UAG or UGA, followed by release-factor-mediated release of the polypeptide.

13. Explain accelerated eutrophication. Mention any two consequences of this phenomenon.

[2 marks]

Solution:

Concept:

- Eutrophication is the enrichment of a water body with nutrients and its gradual ageing. Human activities can greatly accelerate this natural process.
- Nutrients, especially nitrogen and phosphorus, stimulate excessive growth of algae and aquatic plants; decomposition of their dead biomass consumes dissolved oxygen.

Step 1: Explain accelerated eutrophication Sewage, agricultural runoff containing fertilisers, and other nutrient-rich wastes add large quantities of nitrogen and phosphorus to lakes and other water bodies. This human-induced nutrient enrichment speeds up the natural ageing of the water body and is called accelerated or cultural eutrophication.

Step 2: State two consequences First, the nutrient supply causes excessive algal growth, producing algal blooms that deteriorate water quality and reduce light penetration. Second, when algae and other aquatic organisms die, decomposer microbes consume dissolved oxygen while breaking down their remains. The resulting oxygen depletion can cause the death of fish and other oxygen-dependent aquatic animals.

Step 3: Conclusion Accelerated eutrophication is rapid, human-induced nutrient enrichment of water. Two consequences are algal blooms and oxygen depletion leading to fish mortality.

Quick Tip to Solve: Remember the chain: nutrient-rich runoff, algal bloom, decomposition, oxygen depletion and fish death.

14. List the specific symptoms of amoebiasis. Name the causative organism.

[2 marks]

Solution:

Concept:

- Amoebiasis, also called amoebic dysentery, is an intestinal infection caused by a protozoan parasite.
- The parasite lives in the large intestine, and infection produces characteristic digestive disturbances and abnormal stools.

Step 1: List the characteristic symptoms The specific symptoms of amoebiasis are constipation, abdominal pain and cramps, and stools containing excess mucus and blood clots. Mentioning the mucus and blood clots in the stools is especially useful for identifying the intestinal disease, rather than describing it only as a general stomach upset.

Step 2: Name the causative organism Amoebiasis is caused by the protozoan parasite *Entamoeba histolytica*, which inhabits the large intestine of humans. Infection is acquired by ingesting its cysts in contaminated food or water. Houseflies may mechanically carry the parasite from the faeces of an infected person to food, but they are carriers rather than the causative organism.

Step 3: Conclusion Amoebiasis causes constipation, abdominal pain and cramps, and stools with excess mucus and blood clots. Its causative organism is *Entamoeba histolytica*.

Quick Tip to Solve: Associate amoebiasis with the NCERT symptom cluster: constipation, abdominal cramps, and mucus and blood clots in stools.

15. A crane had DDT level as 5 ppm in its body. What would happen to the population of such birds? Explain giving reasons.

[2 marks]

Solution:

Concept:

- DDT is a persistent pesticide that accumulates in organisms. Its concentration increases at successive trophic levels, a process called biomagnification.
- In birds, high DDT concentrations disturb calcium metabolism and cause eggshell thinning, which reduces successful reproduction.

Step 1: Relate the DDT level to biomagnification The crane has accumulated DDT in its body through contaminated food. DDT is not readily broken down and is not efficiently eliminated, so it remains in tissues. When a bird feeds on many contaminated prey organisms, the pesticide accumulates and becomes concentrated at the higher trophic level. The stated level of 5 ppm indicates this accumulated contamination.

Step 2: Explain the effect on reproduction A high DDT concentration interferes with calcium metabolism in the birds. This produces thin, fragile eggshells that can break prematurely and reduces the number of eggs that hatch successfully. Consequently, fewer young birds enter the population. If such contamination persists, reduced reproductive success causes the population of these cranes to decline.

Step 3: Conclusion The population of such birds would decline because accumulated DDT disturbs calcium metabolism, thins eggshells and reduces successful hatching and recruitment of young birds.

Quick Tip to Solve: For DDT in birds, connect biomagnification to disturbed calcium metabolism, thin eggshells, reduced hatching and population decline.

16. Describe the responsibility of GEAC, set up by the Indian Government.

[2 marks]

Solution:

Concept:

- GEAC, the Genetic Engineering Approval Committee, is the government body responsible for examining the acceptability and biosafety of activities involving genetic modification.
- Genetically modified organisms must be assessed before their use or release because their effects can extend to humans, other organisms and the environment.

Step 1: Assess genetic modification research GEAC makes decisions regarding the validity of research involving genetically modified organisms. It examines whether proposed genetic engineering work is acceptable and meets the required safety considerations.

Step 2: Assess safety before public use It evaluates the safety of introducing genetically modified organisms for public services, including their proposed use and environmental release. This scrutiny is needed to prevent harmful effects on people and ecological systems before such organisms are approved for wider use.

Step 3: Conclusion GEAC decides on the validity of genetic modification research and the safety of introducing genetically modified organisms for public use.

Quick Tip to Solve: Remember the two responsibilities together: validity of GM research and safety of GM organisms for public use.

17. During the secondary treatment of the primary effluent how does the significant decrease in BOD occur?

[2 marks]

Solution:

Concept:

- Biochemical oxygen demand (BOD) is the oxygen required by aerobic microorganisms to break down the biodegradable organic matter in a water sample.
- Secondary sewage treatment uses microbial activity to remove dissolved and suspended organic matter remaining in the primary effluent.

Step 1: Promote aerobic microbial growth The primary effluent is passed into large aeration tanks, where it is constantly agitated mechanically and air is pumped into it. The oxygen supply allows useful aerobic microbes to grow vigorously as flocs: masses of bacteria associated with fungal filaments to form mesh-like structures.

Step 2: Consume the biodegradable organic matter As these microbes grow, they consume the major part of the organic matter in the effluent and oxidise it through aerobic metabolism. Consequently, much less biodegradable material remains to be broken down in a subsequent BOD test. The oxygen demand of the treated effluent therefore decreases significantly.

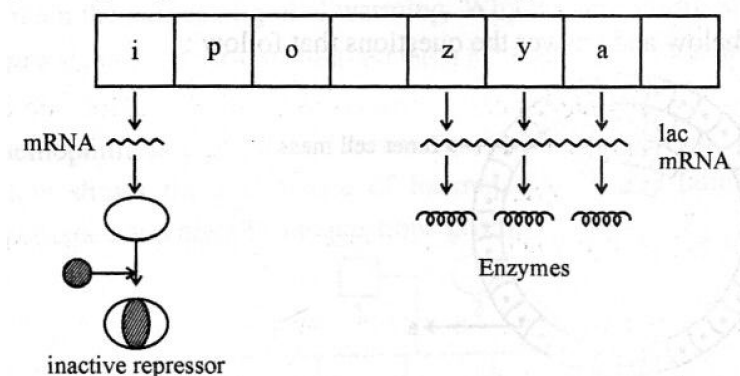
Step 3: Conclusion BOD falls because the actively growing aerobic microbial flocs consume and oxidise most of the organic matter in the aerated primary effluent.

Quick Tip to Solve: Link lower BOD to removal of organic food for microbes; pumping air supports the microbes but does not itself remove BOD.

18. Study the figure given below and answer the questions:

- (a) How does the repressor molecule get inactivated?
(b) When does the transcription of lac mRNA stop?
(c) Name the enzyme transcribed by the gene 'Z'.

[2 marks]



Solution:

Concept:

- The lac operon is an inducible system: the repressor controls transcription by binding to the operator when the inducer is absent.
- The structural gene *z* encodes β -galactosidase, which participates in lactose metabolism.

Step 1: (a) Inactivation of the repressor The inducer, lactose or its isomer allolactose, binds to the repressor protein and changes its conformation. The resulting inactive repressor cannot bind to the operator. RNA polymerase can therefore transcribe the structural genes, as shown in the figure.

Step 2: (b) Stopping lac mRNA transcription Transcription stops when lactose is absent or has been used up, so that the inducer is no longer available to keep the repressor inactive. The active repressor binds to the operator and prevents RNA polymerase from transcribing the structural genes of the operon.

Step 3: (c) Product of gene Z Gene *z* codes for β -galactosidase. Strictly, the gene is transcribed into mRNA and that mRNA is translated into the enzyme; the enzyme itself is not a product of transcription. It hydrolyses lactose into glucose and galactose.

Step 4: Conclusion (a) Inducer binding inactivates the repressor. (b) Transcription stops when the

inducer is absent and the repressor binds the operator. (c) Gene z encodes β -galactosidase.

Quick Tip to Solve: Track the operator: inducer present means repressor off the operator; inducer absent means repressor on it.

Section C (27 marks)

19. Name the pioneer species on a bare rock. How do they help in establishing the next type of vegetation? Mention the type of climax community that will ultimately get established. [3 marks]

Solution:

Concept:

- Primary succession begins on a previously unoccupied surface without developed soil. On bare rock this is a lithosere, a form of xerarch succession.
- Pioneer organisms change the physical and chemical conditions of the habitat, making it suitable for later communities that gradually replace them.

Step 1: Identify the pioneers Lichens are the pioneer organisms on bare rock, with crustose lichens typically forming the first colonising stage. They can attach to the exposed rock and survive where a developed soil layer is absent, unlike most rooted plants.

Step 2: Explain establishment of the next vegetation Lichens secrete acids that dissolve and weather the rock, releasing mineral particles. Their action gradually produces a thin layer of soil. Dead and decaying lichen material adds organic matter, while the developing soil holds more moisture. These changes create conditions suitable for small plants such as bryophytes, especially mosses, which form the next vegetation stage.

Step 3: Follow succession to the climax Mosses further increase soil formation and organic matter. With progressively deeper soil and improved moisture availability, herbs, shrubs and then trees can establish, each community modifying the site for its successors. The dry bare-rock starting point thus develops towards mesic conditions and a stable climax community adapted to the regional climate.

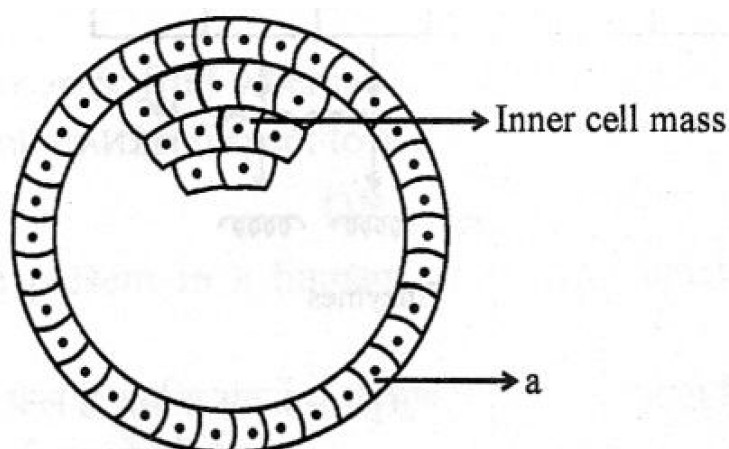
Step 4: Conclusion Lichens are the pioneers; their rock-weathering acids and accumulated organic matter prepare soil for bryophytes. Ultimately, a mesic forest climax community becomes established in the usual bare-rock succession sequence.

Quick Tip to Solve: Use the chain lichens, weathering and soil, mosses, then a mesic forest; connect each replacement to habitat improvement.

20. Study the figure given below and answer the questions that follow:

- (a) Name the stage of human embryo the figure represents.
- (b) Identify 'a' in the figure and mention its function.
- (c) Mention the fate of the inner cell mass after implantation in the uterus.
- (d) Where are the stem cells located in this embryo?

[3 marks]



Solution:

Concept:

- A blastocyst is a hollow early embryo with an outer trophoblast, a fluid-filled cavity and an inner cell mass at one pole.
- The trophoblast assists implantation, whereas the inner cell mass gives rise to the embryo proper and contains embryonic stem cells.

Step 1: (a) Identify the embryonic stage The figure represents a blastocyst. Its hollow cavity and the compact group of cells at one side distinguish it from the solid ball of blastomeres called the morula. The blastocyst develops after cleavage and rearrangement of the cells of the morula.

Step 2: (b) Identify the outer layer and state its function Label 'a' indicates the trophoblast, the outer layer of cells surrounding the blastocyst cavity. It attaches to the uterine endometrium and helps the blastocyst become embedded in the uterine lining during implantation. It subsequently contributes to the chorion and the foetal component of the placenta.

Step 3: (c) State the fate of the inner cell mass After implantation, the inner cell mass differentiates to form the embryo proper. During further development, its cells give rise to the embryonic germ layers, from which the various tissues and organs of the developing individual arise. Thus it has a different developmental role from the outer trophoblast.

Step 4: (d) Locate the stem cells Embryonic stem cells occur in the inner cell mass of the blastocyst. These cells can differentiate into the different tissues and organs of the body; they are not located in the surrounding fluid-filled cavity.

Step 5: Conclusion (a) Blastocyst; (b) 'a' is the trophoblast, which helps attachment and implantation in the uterine endometrium; (c) the inner cell mass forms the embryo proper; (d) embryonic stem cells lie in the inner cell mass.

Quick Tip to Solve: Identify the hollow blastocyst first: its outer trophoblast helps implantation, while its inner cell mass forms the embryo and contains stem cells.

21. Give the scientific name of the parasite that causes malignant malaria in humans. At what stage does this parasite enter the human body? Trace its life cycle in human body. [3 marks]

Solution:

Concept:

- Malignant malaria is caused by the protozoan parasite *Plasmodium falciparum*, transmitted by an infected female *Anopheles* mosquito.
- Sporozoites infect humans; asexual multiplication occurs first in liver cells and then in red blood cells, while sexual reproduction occurs in the mosquito.

Step 1: Name the parasite and its infective stage The scientific name is *Plasmodium falciparum*. An infected female *Anopheles* injects sporozoites with its saliva while taking a blood meal. Thus the parasite enters the human body as a sporozoite, rather than as a gametocyte or merozoite.

Step 2: Trace multiplication in the liver The sporozoites reach the liver through the bloodstream and invade liver cells. They multiply asexually there by schizogony, producing numerous merozoites. When the infected liver cells rupture, merozoites are released into the blood and invade red blood cells.

Step 3: Trace the red blood cell cycle In a red blood cell the parasite passes through a ring stage and a growing trophozoite stage, then forms a schizont that divides to produce more merozoites. The infected red blood cell ruptures, releasing the merozoites and the toxic substance haemozoin. This release is associated with the chills and high fever of malaria. The newly released merozoites invade fresh red blood cells and repeat the cycle.

Step 4: Describe the stage available to the mosquito Some parasites in red blood cells develop into male and female gametocytes instead of continuing asexual multiplication. These are taken up by another female *Anopheles* during a blood meal. Fertilisation and the subsequent formation of sporozoites occur in the mosquito, not in the human body.

Step 5: Conclusion *Plasmodium falciparum* causes malignant malaria and enters humans as sporozoites. Its human cycle is liver-cell multiplication, merozoite invasion of red blood cells, repeated red-cell multiplication and rupture, followed by formation of gametocytes.

Quick Tip to Solve: Keep the stages separate: sporozoites enter humans, merozoites invade red blood cells, and gametocytes leave humans in a mosquito's blood meal.

22. Draw a labelled schematic sketch of replication fork of DNA. Explain the role of the enzymes involved in DNA replication. [3 marks]

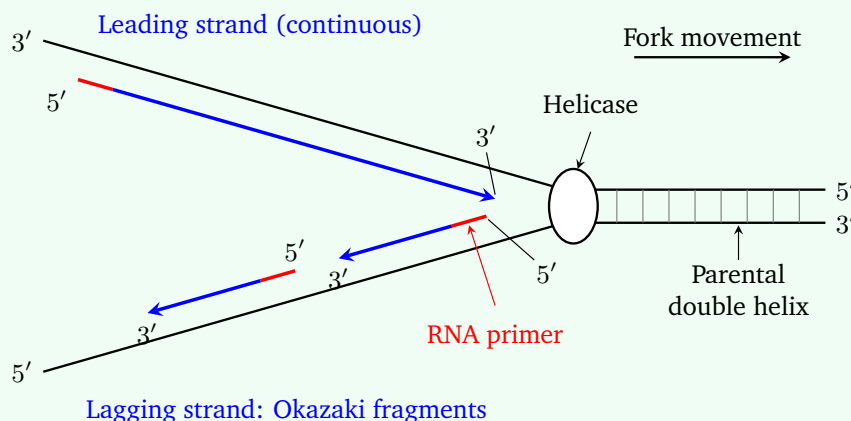
Solution:

Concept:

- DNA replication is semiconservative: each daughter DNA molecule contains one parental strand and one newly synthesised strand.
- DNA polymerase reads the template in the $3' \rightarrow 5'$ direction and synthesises DNA only in the $5' \rightarrow 3'$ direction. Antiparallel templates therefore produce a continuous leading strand and a

discontinuous lagging strand.

Step 1: Draw and interpret the replication fork The diagram shows a fork advancing to the right. On the upper template, synthesis proceeds continuously towards the advancing fork. On the lower template, synthesis proceeds away from the fork in short Okazaki fragments. Arrows indicate $5' \rightarrow 3'$ synthesis; each fragment starts from a primer.



Replication fork advancing rightwards. Black lines are parental templates; blue arrows are newly synthesised DNA; red segments are RNA primers.

Step 2: Explain unwinding and initiation Helicase unwinds the parental double helix by breaking the hydrogen bonds between complementary bases. Topoisomerase relieves the torsional strain generated ahead of the fork. Primase synthesises short RNA primers, providing the free $3'$ -OH ends needed by DNA polymerase. A primer starts the leading strand, while repeated primers are needed for the lagging-strand fragments.

Step 3: Explain elongation and joining DNA-dependent DNA polymerase adds complementary deoxyribonucleotides to the growing $3'$ end, using parental DNA as template. RNA primers are removed and the gaps are filled with DNA by the appropriate enzymes. DNA ligase seals the remaining nicks by forming phosphodiester bonds, joining the fragments into one continuous daughter strand.

Step 4: Conclusion The replication fork has antiparallel templates, a continuous leading strand and discontinuous Okazaki fragments on the lagging strand. Helicase opens DNA, primase provides primers, DNA polymerase synthesises new DNA, and ligase joins the fragments; topoisomerase relieves strain ahead of the fork.

Quick Tip to Solve: Label both template polarities before drawing new strands: all synthesis arrows must run from $5'$ to $3'$, with lagging fragments pointing away from the fork.

23. Explain the causes of global warming. Why is it a warning to mankind?

[3 marks]

Solution:

Concept:

- Global warming is the rise in the average temperature of the Earth's surface and lower atmosphere due to an enhanced greenhouse effect.

- Greenhouse gases absorb outgoing terrestrial infrared radiation and re-radiate energy, reducing heat loss to space. Excess accumulation intensifies this natural warming process.

Step 1: Explain the causes Burning coal, petroleum and natural gas in power plants, industries and vehicles increases atmospheric carbon dioxide. Deforestation adds carbon dioxide through burning and decomposition of vegetation and also reduces its removal by photosynthesis. Methane released from cattle, rice fields and waste, nitrous oxide from agricultural activities, and industrial chlorofluorocarbons also contribute to the greenhouse effect. As these gases accumulate, more outgoing infrared radiation is absorbed, raising the Earth's average temperature.

Step 2: Explain why it warns mankind Rising temperatures accelerate melting of glaciers and polar ice and cause thermal expansion of seawater. The resulting sea-level rise can inundate low-lying coastal areas and displace people. Changes in rainfall and other climatic patterns can increase droughts, floods and disruption of agriculture, threatening water supplies and food production. Altered habitats also threaten biodiversity and ecological balance. These consequences affect human settlements, health and livelihoods, so global warming is a warning that unchecked human disturbance of the atmosphere can undermine the conditions on which human life depends.

Step 3: Conclusion Human-driven accumulation of greenhouse gases causes enhanced greenhouse warming. Its threats to coasts, climate, agriculture and ecosystems make it a serious warning to mankind.

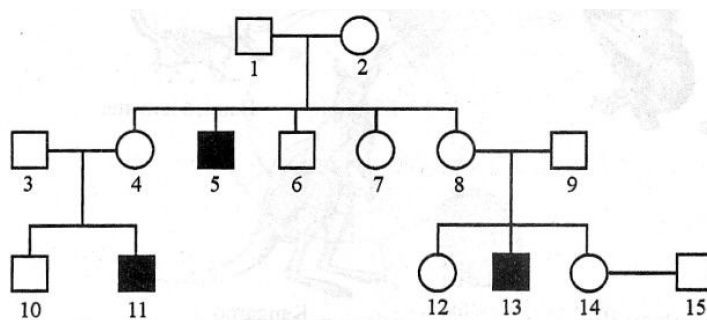
Quick Tip to Solve: Link each cause to greenhouse-gas accumulation, then connect warming to sea-level rise and changed rainfall to explain the warning.

24. Haemophilia is a sex linked recessive disorder of humans. The pedigree chart given below shows the inheritance of haemophilia in one family. Study the pattern of inheritance and answer the questions given.

(a) Give all the possible genotypes of the members 4, 5 and 6 in the pedigree chart.

(b) A blood test shows that the individual 14 is a carrier of haemophilia. The member numbered 15 has recently married the member numbered 14. What is the probability that their first child will be a haemophilic male?

[3 marks]



Solution:

Concept:

- Let X^H carry the normal blood-clotting allele and X^h the recessive haemophilia allele. A male is affected if his genotype is X^hY ; a heterozygous female $X^H X^h$ is an unaffected carrier.
- A son receives his X chromosome from his mother and his Y chromosome from his father. The probability of an affected male child includes both the probability of being male and of receiving X^h .

Step 1: (a) Identify the genotypes of members 4, 5 and 6 Member 4 is an unaffected female, but her son 11 has haemophilia. Son 11 must have received X^h from her because his father supplies only the Y chromosome to a son. Since member 4 herself is unaffected, she also possesses X^H . Thus member 4 is necessarily $X^H X^h$, not $X^H X^H$. Member 5 is a shaded square, representing an affected male, so his genotype is X^hY . Member 6 is an unshaded square, representing an unaffected male, so his genotype is X^HY . Males cannot be unaffected carriers of this recessive X-linked disorder because they have only one X chromosome.

Step 2: (b) Calculate the probability for the first child The blood test establishes member 14 as $X^H X^h$, while the unshaded male 15 is X^HY . Their cross is

$$X^H X^h \times X^HY.$$

The mother's gametes are X^H and X^h , and the father's are X^H and Y . The four equally likely offspring genotypes are $X^H X^H$, $X^H X^h$, X^HY and X^hY . Only the last is a haemophilic male. Hence the probability is $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$. The value $\frac{1}{2}$ would apply only if the child were already known to be a son.

Step 3: Conclusion (a) Member 4: $X^H X^h$; member 5: X^hY ; member 6: X^HY . (b) The probability that their first child is a haemophilic male is $\frac{1}{4} = 25\%$.

Quick Tip to Solve: Trace an affected son's X chromosome to his mother, and include the probability of a son when the question asks about a child.

OR

24. Inheritance pattern of ABO blood groups in humans shows dominance, codominance and multiple allelism. Explain each concept with the help of blood group genotypes. [3 marks]

Solution:

Concept:

- The ABO blood-group gene has three alleles in the human population: I^A , I^B and i . A diploid individual carries only two of these alleles.
- Alleles I^A and I^B determine A and B antigens on red blood cells, respectively; i produces neither antigen. Their interactions illustrate dominance, codominance and multiple allelism.

Step 1: Explain dominance over the recessive allele Dominance means that one allele expresses its

effect in a heterozygote while the alternative allele's effect is masked. Both I^A and I^B are dominant over i . Thus $I^A I^A$ and $I^A i$ both give blood group A, while $I^B I^B$ and $I^B i$ both give blood group B. Blood group O is expressed only by the homozygous recessive genotype ii , whose red blood cells have neither A nor B antigen.

Step 2: Explain codominance of the A and B alleles Codominance means that both alleles express their effects together in a heterozygote. In genotype $I^A I^B$, both A and B antigens are present on the red blood cells, producing blood group AB. Neither allele masks the other, and their products do not blend to form an intermediate antigen. Thus I^A and I^B are codominant with each other even though each is dominant over i .

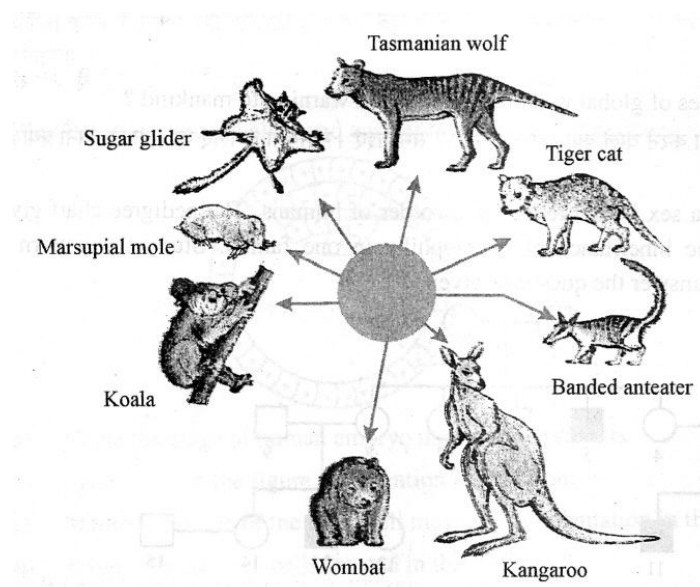
Step 3: Explain multiple allelism Multiple allelism is the occurrence of more than two alternative alleles of a gene at the same locus within a population. The ABO system qualifies because its population contains I^A , I^B and i . Any one person still has only two alleles, one inherited from each parent. These three alleles form six possible genotypes, giving the four phenotypes A, B, AB and O described above.

Step 4: Conclusion ABO inheritance shows dominance in $I^A i$ and $I^B i$, codominance in $I^A I^B$, and multiple allelism through the three population-level alleles I^A , I^B and i .

Quick Tip to Solve: Use A_i and B_i for dominance, AB for codominance, and count the three alleles in the population for multiple allelism.

25. (a) Mention the specific geographical region where these organisms are found.
 (b) Name and explain the phenomenon that has resulted in the evolution of such diverse species in the region.
 (c) Explain giving reasons the existence of placental wolf and Tasmanian wolf sharing the same habitat.

[3 marks]



Solution:

Concept:

- Adaptive radiation is the evolution of different species from a common ancestral stock within a geographical region, each adapted to a different ecological niche.
- Divergent evolution produces different adaptations among related organisms; convergent evolution produces similar adaptive features independently in different ancestral lineages.

Step 1: (a) Identify the geographical region These marsupials are characteristic of Australia. The kangaroo, koala, wombat, marsupial mole and Tasmanian wolf shown in the figure represent the Australian marsupial radiation.

Step 2: (b) Explain the origin of the diverse species The phenomenon is adaptive radiation. A common ancestral marsupial stock diversified within the Australian geographical region. Descendant populations became adapted to different habitats, foods and modes of life, producing distinct species. For example, the marsupial mole became adapted to burrowing, whereas the kangaroo became adapted to hopping on land. Thus, one ancestral lineage gave rise to many forms occupying different ecological niches. This is an example of divergent evolution.

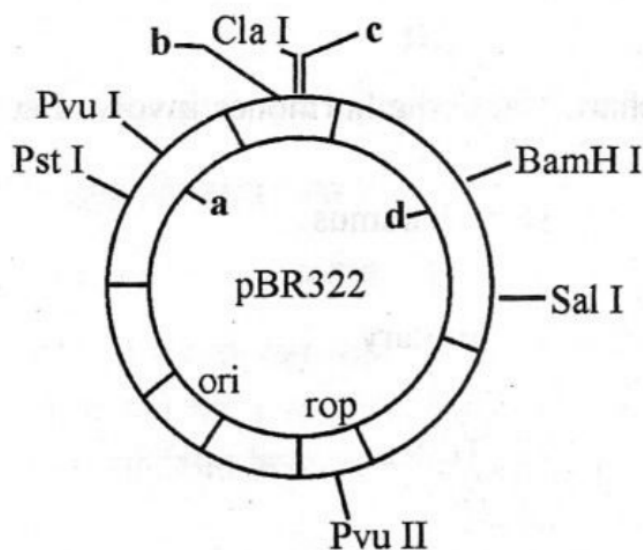
Step 3: (c) Explain the similarity between the two wolves The placental wolf and Tasmanian wolf belong to different mammalian ancestral lineages: one is placental and the other marsupial. Similar environmental conditions and carnivorous habits selected similar functional adaptations, such as a wolf-like body and predatory dentition. Their independent acquisition of similar features is convergent evolution. Thus, the similarity associated with comparable habitats reflects similar selection pressures rather than descent from a recent common wolf ancestor.

Step 4: Conclusion (a) Australia. (b) Adaptive radiation of an ancestral marsupial stock into species occupying different niches. (c) The placental wolf and Tasmanian wolf show convergent evolution under similar habitat and feeding pressures.

Quick Tip to Solve: Use one ancestral stock producing many Australian marsupials for adaptive radiation; use placental wolf versus Tasmanian wolf for convergence between different lineages.

26. (a) Identify the selectable markers in the diagram of *E. coli* vector shown above.

(b) How is the coding sequence of α -galactosidase considered a better marker than the ones identified by you in the diagram? Explain. [3 marks]



Solution:

Concept:

- Selectable markers distinguish transformed cells from non-transformants; insertional inactivation can also distinguish recombinant clones from non-recombinant clones.
- The plasmid pBR322 carries ampicillin-resistance and tetracycline-resistance genes. Disruption of a marker gene by foreign DNA removes its normal function.
- Blue-white screening uses insertional inactivation of the lacZ coding sequence and a chromogenic substrate to distinguish colonies by colour.

Step 1: (a) Identify the two selectable markers The selectable markers are the ampicillin-resistance gene, amp^R , labelled a, and the tetracycline-resistance gene, tet^R , labelled d. The Pst I site lies in the ampicillin-resistance region, whereas the BamH I and Sal I sites lie in the tetracycline-resistance region. The origin of replication and rop are not the two antibiotic-resistance selectable markers.

Step 2: (b) Explain screening by insertional inactivation In the standard blue-white screening system, foreign DNA is inserted into the lacZ marker sequence and inactivates its enzyme-producing function. On a medium containing a suitable chromogenic substrate, such as X-gal, non-recombinant colonies with a functional marker produce blue colour. Recombinant colonies, whose marker is interrupted by the insert, remain white. Thus, white colonies are selected as candidate recombinants. The enzyme involved in this standard system is β -galactosidase; the question names it α -galactosidase.

Step 3: Compare this method with antibiotic markers In pBR322, insertion into one resistance gene is detected by comparing growth on different antibiotic plates, commonly by replica plating. For example, insertion into the tetracycline-resistance gene produces ampicillin-resistant but tetracycline-sensitive recombinants. The colour-based system permits recombinant and non-recombinant colonies to be distinguished directly on the same indicator plate, avoiding this extra comparison and making screening simpler.

Step 4: Conclusion (a) a is amp^R and d is tet^R . (b) Insertional inactivation in blue-white screening gives white recombinant colonies and blue non-recombinant colonies, enabling easier identification than comparison on separate antibiotic plates.

Quick Tip to Solve: Link Pst I to the ampicillin-resistance region and BamH I to the tetracycline-resistance region; in blue-white screening, pick white colonies as candidate recombinants.

27. Construct an ideal pyramid of energy when 1,000,000 joules of sunlight is available. Label all its trophic levels. [3 marks]

Solution:

Concept:

- In the ideal terrestrial energy pyramid, producers capture about 1 percent of incident solar energy and convert it into chemical energy.
- According to Lindeman's ten percent law, approximately 10 percent of the energy at one trophic level passes to the next trophic level; the remainder is used in life processes or dissipated as heat.

Step 1: Calculate the energy fixed by producers The incident sunlight supplies 1,000,000 J. Taking the ideal capture by green plants as 1 percent, the energy present at the first trophic level is

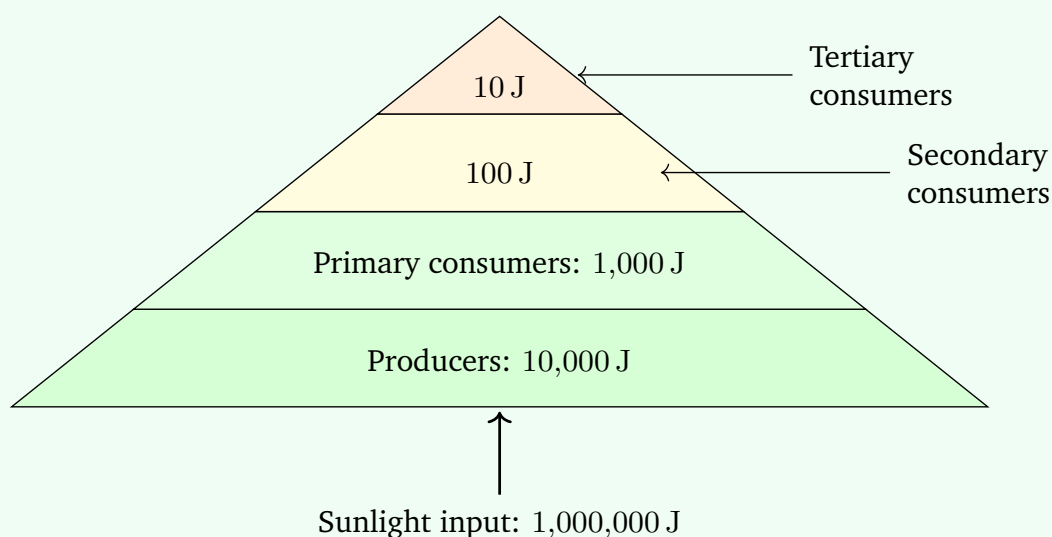
$$E_{\text{producers}} = \frac{1}{100} \times 1,000,000 = 10,000 \text{ J.}$$

Sunlight is the external energy input; it is not itself a trophic level.

Step 2: Apply the ten percent law successively Each consumer level receives one-tenth of the energy of the level immediately below it:

$$\begin{aligned} E_{\text{primary consumers}} &= 0.10 \times 10,000 = 1,000 \text{ J,} \\ E_{\text{secondary consumers}} &= 0.10 \times 1,000 = 100 \text{ J,} \\ E_{\text{tertiary consumers}} &= 0.10 \times 100 = 10 \text{ J.} \end{aligned}$$

Draw the producers as the broad base and place progressively narrower consumer levels above them. The pyramid of energy is always upright because energy decreases at each successive trophic transfer; energy lost as heat is not recycled to the preceding level.



Ideal upright pyramid of energy; each band is labelled with its trophic level and available energy.

Step 3: Conclusion The labelled energy pyramid has producers at 10,000 J, primary consumers at 1,000 J, secondary consumers at 100 J, and tertiary consumers at 10 J, for an incident sunlight input of 1,000,000 J.

Quick Tip to Solve: First take 1 percent of the sunlight to obtain producer energy; only then divide by 10 for each successive consumer level.

Section D (15 marks)

28. Explain with the help of a diagram the development of a mature embryo sac from a megaspore mother cell in angiosperm. [5 marks]

Solution:

Concept:

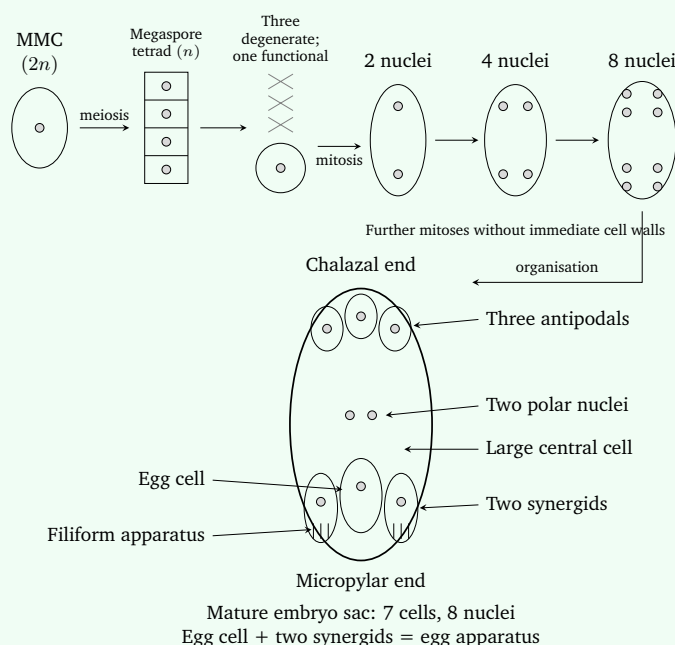
- The embryo sac is the female gametophyte of an angiosperm. In the common monosporic, Polygonum-type development, it arises from one functional haploid megaspore.
- Megasporogenesis is the meiotic formation of megaspores from the diploid megaspore mother cell (MMC). Megagametogenesis is the development of the functional megaspore into the embryo sac by mitotic divisions.
- The typical mature embryo sac contains seven cells and eight nuclei: an egg apparatus, three antipodal cells and a large central cell containing two polar nuclei.

Step 1: Form a tetrad of haploid megaspores In the nucellus of a young ovule, a hypodermal cell differentiates into a large megaspore mother cell with dense cytoplasm and a prominent nucleus. The MMC is diploid, $2n$. It undergoes meiosis to produce four haploid megaspores, usually arranged in a linear tetrad. Thus, the chromosome number is reduced from $2n$ in the MMC to n in each megaspore.

Step 2: Select the functional megaspore and multiply its nucleus Usually the three megaspores towards the micropylar end degenerate, while the chalazal megaspore remains functional. Its nucleus

divides mitotically to form two nuclei, which move to opposite poles. The developing embryo sac enlarges, and a large central vacuole separates the nuclei. Two further successive mitotic divisions produce first four and then eight nuclei, with four nuclei at each pole. These are free-nuclear divisions: nuclear division is not immediately followed by cell-wall formation. Only one of the four meiotic megaspores contributes to the embryo sac, hence this development is called monosporic.

Step 3: Organise the mature embryo sac One nucleus from each pole moves towards the centre; these two nuclei are called the polar nuclei and lie in the large central cell. The remaining three nuclei at the micropylar pole become organised into an egg apparatus comprising one egg cell and two synergids. The synergids possess a filiform apparatus at the micropylar end, which helps guide the pollen tube into the embryo sac. The three nuclei at the chalazal pole become enclosed in three antipodal cells. Consequently, cellular organisation produces a seven-celled, eight-nucleate embryo sac. The two polar nuclei may subsequently fuse to form the diploid secondary nucleus.

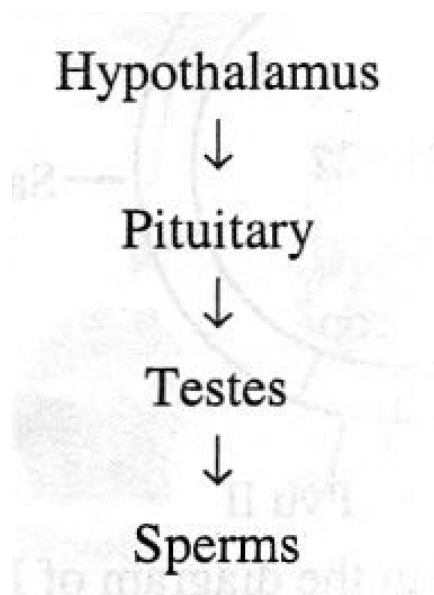


Monosporic embryo-sac development; the mature sac is shown enlarged. All nuclei after meiosis are haploid before any polar-nuclear fusion.

Step 4: Conclusion A diploid MMC undergoes meiosis to form four haploid megaspores. One functional megaspore then undergoes three mitotic divisions and cellular organisation to produce the typical seven-celled, eight-nucleate mature embryo sac, with the egg apparatus at the micropyle and antipodals at the chalazal end.

Quick Tip to Solve: Track the two counts separately: meiosis gives four megaspores, but only one survives; three mitoses of its nucleus give eight nuclei organised into seven cells.

28. Study the following flow chart. Name the hormones involved at each stage. Explain their functions. [5 marks]



Solution:

Concept:

- Spermatogenesis is regulated by the hypothalamus, anterior pituitary and testes acting as an endocrine axis. A hormone released at one level stimulates specific target cells at the next level.
- Gonadotropin-releasing hormone (GnRH) stimulates pituitary gonadotropin secretion. The two gonadotropins are luteinising hormone (LH) and follicle-stimulating hormone (FSH); they act on different cells of the testes.
- Testicular androgens, chiefly testosterone, and the supporting action of Sertoli cells together maintain sperm formation in the seminiferous tubules.

Step 1: Hypothalamus to pituitary: GnRH At puberty the hypothalamus increases secretion of gonadotropin-releasing hormone (GnRH). It reaches the anterior pituitary and stimulates the synthesis and release of the gonadotropins LH and FSH. Thus the first arrow in the chart represents stimulation by GnRH, rather than the direct production of sperm by the hypothalamus.

Step 2: Pituitary to testes: LH and FSH LH acts on the interstitial cells, or Leydig cells, situated between the seminiferous tubules of the testes. It stimulates these cells to synthesise and secrete androgens, mainly testosterone. In males, LH is also called interstitial cell-stimulating hormone (ICSH).

FSH acts on the Sertoli cells within the seminiferous tubules. It stimulates Sertoli cells to secrete factors that support the developing germ cells and help the process of spermiogenesis, the transformation of spermatids into spermatozoa. These cells also provide nourishment and support to the developing germ cells.

Step 3: Testes to sperms: androgen action with Sertoli-cell support Testosterone and other androgens stimulate and maintain spermatogenesis in the seminiferous tubules. Spermatogonia proliferate and

give rise to spermatocytes; meiotic divisions produce haploid spermatids, which differentiate into spermatozoa with Sertoli-cell support. Therefore, the final arrow represents the action of testicular androgens, together with the FSH-dependent support of Sertoli cells, in producing sperm. Testosterone is a hormone, whereas spermatozoa are the cellular products of this process.

Step 4: Conclusion The sequence is: hypothalamic GnRH stimulates the anterior pituitary; pituitary LH stimulates Leydig cells to secrete androgens, chiefly testosterone, while FSH stimulates Sertoli cells to support spermiogenesis; testicular androgens stimulate spermatogenesis, resulting in sperm formation.

Quick Tip to Solve: Pair LH with Leydig cells and testosterone; pair FSH with Sertoli cells and support of spermiogenesis. Put GnRH above both pituitary hormones.

29. (a) Explain the experiment performed by Griffith on *Streptococcus pneumoniae*. What did he conclude from this experiment?

(b) Name the three scientists who followed up Griffith's experiments.

(c) What did they conclude and how?

[5 marks]

Solution:

Concept:

- Bacterial transformation is a heritable change in a bacterium caused by uptake of genetic material from another bacterial cell.
- In *Streptococcus pneumoniae*, smooth (S) bacteria possess a polysaccharide capsule and are virulent; rough (R) bacteria lack the capsule and are non-virulent.
- The chemical identity of a transforming substance can be tested by selectively destroying proteins, RNA or DNA and checking whether transformation still occurs.

Step 1: (a) Griffith's experimental observations Griffith injected mice with different preparations of *S. pneumoniae* and observed the following results:

1. Living S-strain bacteria killed the mice.
2. Living R-strain bacteria did not kill the mice.
3. Heat-killed S-strain bacteria did not kill the mice.
4. A mixture of living R-strain bacteria and heat-killed S-strain bacteria killed the mice. Living S-strain bacteria were recovered from these dead mice.

Thus, the mixture caused death even though each of its components, when injected separately, did not. Recovery of living S bacteria showed that the living R bacteria had changed into the virulent S form; heat-killed S cells had not simply become alive again.

Step 2: (a) Interpretation of transformation Griffith inferred that a transforming principle from the heat-killed S bacteria entered the living R bacteria. It enabled the R bacteria to synthesise the smooth polysaccharide capsule and become virulent S bacteria. This change was heritable: the transformed bacteria retained the S character in subsequent generations. Griffith demonstrated transformation, but did not identify the chemical nature of the transforming principle.

Step 3: (b) Scientists who investigated the transforming principle Oswald Avery, Colin MacLeod

and Maclyn McCarty followed up Griffith's experiments to determine which substance carried the information responsible for transformation.

Step 4: (c) Biochemical identification of the transforming principle They purified the biochemical constituents of heat-killed S bacteria and tested their ability to transform living R bacteria. The DNA fraction could produce transformation. They then used specific enzymes to test which molecule was essential:

1. Protease destroyed proteins, but transformation still occurred; protein was therefore not the transforming principle.
2. RNase destroyed RNA, but transformation still occurred; RNA was therefore not the transforming principle.
3. DNase destroyed DNA and abolished transformation; the R bacteria were no longer transformed into S bacteria.

Persistence of transformation after protein or RNA digestion, together with its loss after DNA digestion, established DNA as the substance responsible for the heritable change.

Step 5: Conclusion Griffith demonstrated heritable transformation of living R bacteria into virulent S bacteria by material from heat-killed S bacteria. Avery, MacLeod and McCarty identified that transforming principle as DNA, thereby providing evidence that DNA is the genetic material.

Quick Tip to Solve: Recall the decisive controls: heat-killed S alone does not kill mice, but heat-killed S plus living R does; only DNase abolishes transformation.

OR

29. Two blood samples A and B picked up from the crime scene were handed over to the forensic department for genetic fingerprinting. Describe how the technique of genetic fingerprinting is carried out. How will it be confirmed whether the samples belonged to the same individual or to two different individuals?

[5 marks]

Solution:

Concept:

- DNA fingerprinting identifies individuals using highly variable repetitive DNA sequences, especially variable number tandem repeats (VNTRs). Individuals differ in the number of repeat units at these loci, producing restriction fragments of different lengths.
- A labelled VNTR probe hybridises with complementary DNA on a membrane. The resulting band pattern can be compared between samples processed by the same method; many independent variable loci provide much greater discrimination than a single locus.

Step 1: Isolate and cut DNA from each sample Extract and purify DNA separately from blood samples A and B, avoiding contamination or mixing. In human blood, the nuclear DNA is obtained principally from white blood cells, because mature red blood cells lack nuclei. Digest each DNA preparation with the same restriction endonuclease. The enzyme cuts at specific recognition sequences, yielding fragments of different lengths; fragments containing VNTR regions vary in length according to the number of repeats.

Step 2: Separate and transfer the fragments Load the digested samples into separate lanes of the same agarose gel and perform electrophoresis. Negatively charged DNA moves towards the positive electrode, with smaller fragments travelling farther than larger ones. Treat the separated DNA with alkali to denature the double strands into single strands. Transfer the DNA fragments, preserving their positions, from the gel onto a nylon or nitrocellulose membrane. This is Southern blotting.

Step 3: Reveal the variable DNA bands Incubate the membrane with a radioactively labelled probe complementary to the selected VNTR sequences. The probe binds by complementary base pairing to its matching sequences, a process called hybridisation. Wash away unbound probe and expose the membrane to photographic film. Autoradiography reveals bands at the positions of DNA fragments carrying the complementary VNTR sequences. These bands form the DNA fingerprint. Several variable loci are examined to make the comparison reliable.

Step 4: Compare fingerprints A and B Compare corresponding bands in the two lanes, using the same probes and experimental conditions. Matching band positions across the tested variable loci indicate matching fragment lengths and support the conclusion that A and B came from the same individual. Reproducible differences in the band pattern indicate different individuals. Ordinary VNTR fingerprinting cannot distinguish identical twins, whose inherited DNA profiles are normally the same; thus a match is interpreted with that exception and with proper laboratory controls.

Step 5: Conclusion Genetic fingerprinting proceeds through DNA isolation, restriction digestion, gel electrophoresis, Southern blotting, hybridisation with labelled VNTR probes and autoradiography. Matching fingerprints of A and B support a common individual source; different fingerprints establish different sources, provided the samples are uncontaminated and the comparison is technically valid.

Quick Tip to Solve: Remember the order: isolate, cut, separate, blot, probe and reveal; compare band positions at several variable loci, not merely the number of bands.

30. One of the main objectives of biotechnology is to minimize the use of insecticides on cultivated crops. Explain with the help of a suitable example how insect resistant crops have been developed using techniques of biotechnology. [5 marks]

Solution:

Concept:

- An insect-resistant transgenic crop contains a gene introduced by recombinant DNA technology that enables the plant to produce an insecticidal protein. Bt cotton is a suitable example.
- The soil bacterium *Bacillus thuringiensis* (Bt) produces insecticidal crystal proteins encoded by *cry* genes. Different Cry proteins act against particular groups of insects.
- The Bt protein is initially an inactive protoxin. The alkaline conditions in a susceptible insect's gut convert it into an active toxin that damages the gut epithelium.

Step 1: Identify the useful insect-resistance gene Certain strains of *Bacillus thuringiensis* produce protein crystals during sporulation. These crystals contain insecticidal protoxins. Scientists identify and isolate the appropriate *cry* gene for the target insect pest. For example, *cryIAc* and *cryIIAb* encode proteins effective against cotton bollworms, whereas *cryIAb* encodes a protein effective

against corn borer. Thus, the gene must be selected according to the crop and the insect to be controlled.

Step 2: Introduce the gene into the crop plant The isolated Bt toxin gene is incorporated into a suitable DNA construct and transferred into cotton cells using genetic engineering. Transformed cells containing the introduced gene are selected and regenerated into complete plants by tissue culture. The resulting transgenic cotton plants express the Bt gene and produce its insecticidal protein in their tissues. These plants are called Bt cotton; their protection is therefore produced within the plant itself.

Step 3: Explain how the insect is killed When a susceptible bollworm feeds on Bt cotton, it ingests the Bt protein. The alkaline pH of its gut solubilises the crystals and activates the inactive protoxin. The active toxin binds to receptors on the surface of midgut epithelial cells and creates pores in their membranes. This causes swelling and lysis of the cells, damages the gut and ultimately kills the insect. In the bacterium the protein remains an inactive protoxin, which explains why its production does not kill the bacterium itself.

Step 4: Relate the example to reduced insecticide use Because Bt cotton itself produces a protein active against its target bollworms, the crop suffers less damage from these insects and needs fewer external chemical insecticide applications for their control. The action is specific to susceptible target insects; the presence of one Bt gene does not make the crop resistant to every insect pest. Introducing the appropriate pest-specific gene is the essential biotechnology step.

Step 5: Conclusion Insect-resistant crops such as Bt cotton are developed by introducing selected *cry* genes from *Bacillus thuringiensis* into plants. The expressed Bt protein becomes active in the susceptible insect's alkaline gut, damages its midgut cells and kills it, thereby reducing the need for chemical insecticides against the target pest.

Quick Tip to Solve: Link the example in order: Bt bacterium, selected cry gene, transgenic cotton, alkaline insect gut, pore formation and insect death.

OR

30. (a) How is mature insulin different from proinsulin secreted by pancreas in humans?

(b) Explain how was human functional insulin produced using rDNA technology.

(c) Why is the functional insulin thus produced considered better than the ones used earlier by diabetic patients?

[5 marks]

Solution:

Concept:

- Human insulin is a protein hormone that regulates blood glucose. Mature functional insulin consists of two polypeptide chains, A and B, linked by disulphide bonds.
- Proinsulin is the precursor of mature insulin. It contains an additional connecting segment, the C-peptide, which is removed during maturation.
- Recombinant DNA technology allows bacteria to manufacture the human insulin chains from

introduced DNA sequences; the chains are subsequently purified and assembled into functional insulin.

Step 1: (a) Compare proinsulin with mature insulin Proinsulin is a single polypeptide precursor in which the future A and B chains are joined through an extra connecting segment called the C-peptide. During maturation in pancreatic beta cells, this C-peptide is removed. The resulting mature insulin contains only the A and B chains held together by disulphide bonds and is biologically functional. Thus, the presence of C-peptide in proinsulin and its absence in mature insulin is the key structural difference.

Step 2: (b) Produce the A and B chains using recombinant DNA In 1983, the American company Eli Lilly prepared two DNA sequences corresponding to the A and B chains of human insulin. Each sequence was introduced separately into a plasmid vector of the bacterium *Escherichia coli*. The recombinant bacteria were cultured so that the inserted human sequences directed production of the respective insulin chains. The A and B chains were therefore manufactured separately, then extracted and purified. The purified chains were combined under suitable conditions to form the correct disulphide bonds between them, producing mature, functional human insulin.

Step 3: (c) Explain the advantage over earlier insulin preparations Earlier, insulin for diabetic patients was extracted from the pancreas of slaughtered cattle and pigs. Because animal insulin differs slightly from human insulin, it could cause allergy or other immune reactions in some patients. Recombinant insulin has the human insulin sequence and therefore avoids the reactions caused by those animal-protein differences. Thus, human recombinant insulin is better tolerated than the earlier animal-derived preparations.

Step 4: Conclusion Mature insulin lacks the C-peptide present in proinsulin. Recombinant human insulin is obtained by producing its A and B chains separately in *E. coli*, purifying them and joining them through disulphide bonds. Its human structure makes it preferable to animal-derived insulin, which could provoke allergic or immune reactions.

Quick Tip to Solve: Remember the sequence: remove C-peptide in humans; produce A and B separately in bacteria; join by disulphide bonds. Compare recombinant human insulin with cattle or pig insulin when explaining its advantage.