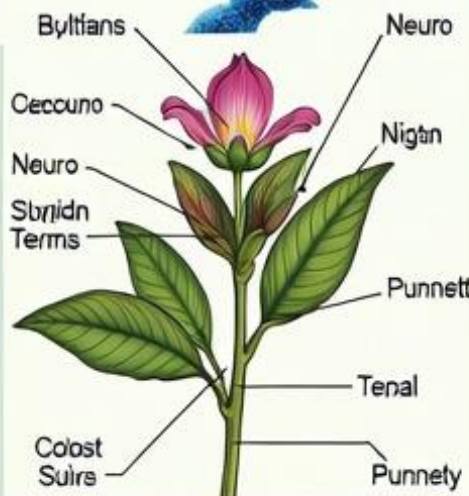
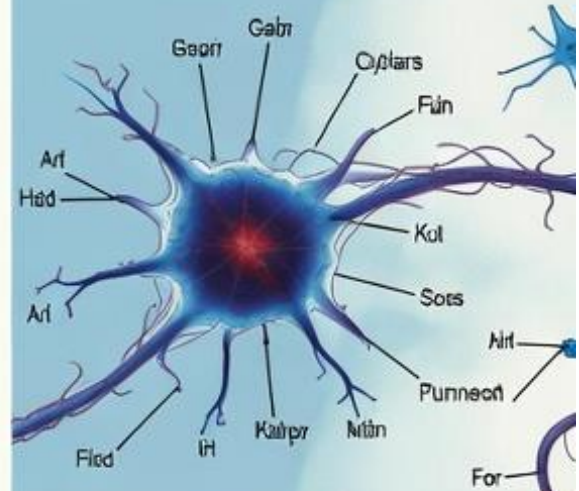
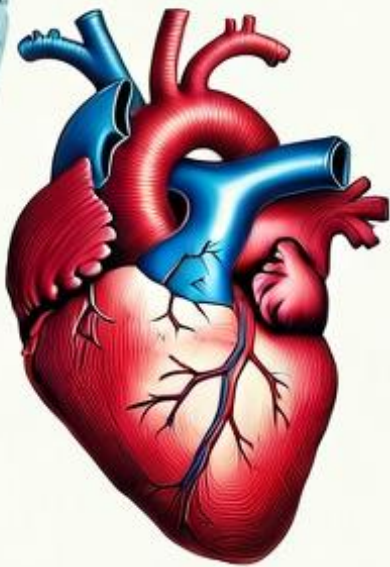


NCERT

SOLUTIONS FOR

CLASS 12

BIOLOGY



Mendelian Genetics			
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BIOLOGY SOLUTION

Class 12

CBSE, NCERT



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Chapter 1: Sexual Reproduction in Flowering Plants

Q1. Name the parts of an angiosperm flower in which development of male and female gametophyte take place.

Answer:

In a flower, the two reproductive organs are the androecium (male) and gynoecium (female).

Male Gametophyte (Pollen Grain) develops in: the Anther, which is part of the stamen (androecium).

Within the anther, there are four microsporangia (pollen sacs). The sporogenous tissue inside each microsporangium undergoes meiosis (microsporogenesis) to produce microspore tetrads. Each microspore eventually matures into a pollen grain — which IS the male gametophyte.

Female Gametophyte (Embryo Sac) develops in: the Ovule, which is present inside the Ovary (part of the pistil/gynoecium).

Inside the ovule, one of the megaspores (produced by meiosis of the megaspore mother cell) develops into the 7-celled, 8-nucleate female gametophyte, also called the embryo sac.

 **Remember:** Simple rule to remember: Male gametophyte = pollen grain (in anther). Female gametophyte = embryo sac (in ovule inside ovary). Both are the haploid (n) generation of the plant.

 **Diagram Tip:** Refer to Figure 1.1 (L.S. of a flower) in the textbook to locate the anther and ovary. Also see Figure 1.2 for detailed anther structure.

Q2. Differentiate between microsporogenesis and megasporogenesis. Which type of cell division occurs during these events? Name the structures formed at the end of these two events.

Answer:

Both processes produce spores by meiosis, but they occur in different organs and produce different structures.

Microsporogenesis	Megasporogenesis
Occurs in the microsporangia (pollen sacs) of the anther	Occurs in the nucellus of the ovule
Pollen Mother Cell (PMC) undergoes meiosis	Megaspore Mother Cell (MMC) undergoes meiosis
Produces a tetrad of 4 microspores	Produces 4 megaspores (3 degenerate, 1 functional)
Each microspore matures into a pollen grain (male gametophyte)	The functional megaspore develops into the embryo sac (female gametophyte)
Produces millions of pollen grains per anther	Typically produces one functional megaspore per ovule

Type of cell division: MEIOSIS (meiotic division) in both processes.

Structures formed:

- End of Microsporogenesis → Microspore Tetrad (cluster of 4 haploid microspores); these then mature into Pollen Grains.
- End of Megasporogenesis → 4 Megaspores (haploid); typically only 1 functional megaspore survives and develops into the Embryo Sac (female gametophyte).

 **Remember:** Why meiosis? Because meiosis reduces the chromosome number from diploid ($2n$) to haploid (n), which is necessary for the gametophyte generation. Without this reduction, chromosome numbers would double with each fertilisation.

Q3. Arrange the following terms in the correct developmental sequence: Pollen grain, sporogenous tissue, microspore tetrad, pollen mother cell, male gametes.

Answer:

The correct developmental sequence is:

Sporogenous Tissue → Pollen Mother Cell (PMC) → Microspore Tetrad → Pollen Grain → Male Gametes

Explanation of each step:

1. **Sporogenous Tissue:** A group of compactly arranged, homogenous cells in the centre of each microsporangium. Any cell in this tissue is a potential PMC.
2. **Pollen Mother Cell (PMC):** Each sporogenous cell differentiates into a PMC (also called microspore mother cell, $2n$ diploid).
3. **Microspore Tetrad:** PMC undergoes meiosis → produces a cluster of 4 haploid (n) microspores arranged as a tetrad.
4. **Pollen Grain:** Individual microspores dissociate from the tetrad as the anther matures/dehydrates, and each matures into a pollen grain (the male gametophyte). At shedding, it has 2 cells (vegetative + generative) or 3 cells in some species.
5. **Male Gametes:** The generative cell within the pollen grain divides (either before shedding or during pollen tube growth) to form 2 male gametes (haploid).

 **Remember:** Memory tip: 'Some Plants Make Pollen Grains' — Sporogenous tissue → PMC → Microspore tetrad → Pollen Grain → (male) Gametes.

Q4. With a neat, labelled diagram, describe the parts of a typical angiosperm ovule.

Answer:

A typical angiosperm ovule (megasporangium) is a small, oval structure attached to the placenta inside the ovary. It eventually develops into a seed after fertilisation.

Parts of a typical ovule:

- **Funicle:** The stalk that connects the ovule to the placenta of the ovary. It serves as a nutrient supply channel.
- **Hilum:** The region where the body of the ovule fuses with the funicle — it marks the junction between the ovule and its stalk.
- **Integuments:** One or two protective envelopes (layers) that surround the nucellus. They later harden to form the seed coat (testa).
- **Micropyle:** A small opening or pore at one end of the ovule, formed by the integuments. Pollen tube enters through it during fertilisation. It also helps in water entry during seed germination.
- **Chalaza:** The basal part of the ovule, opposite to the micropyle end. It is where the integuments and nucellus merge.
- **Nucellus:** The central mass of parenchymatous cells enclosed by the integuments. Rich in food reserves; it nourishes the developing embryo sac. The megaspore mother cell (MMC) differentiates in the micropylar region of the nucellus.
- **Embryo Sac (Female Gametophyte):** Located within the nucellus. It is the 7-celled, 8-nucleate structure that represents the female gametophyte. Contains egg cell, synergids, polar nuclei, and antipodals.

 **Diagram Tip:** Refer to Figure 1.7(d) in the textbook — it shows a detailed labelled diagram of a typical anatropous ovule with all parts clearly marked: Hilum, Funicle, Micropyle, Outer integument, Inner integument, Nucellus, Embryo sac, and Chalazal pole. Reproduce this diagram in your answer.

 **Remember:** In an anatropous ovule (most common type in angiosperms), the ovule is inverted 180° so the micropyle is close to the funicle. This is important for pollen tube entry.

Q5. What is meant by monosporic development of female gametophyte?

Answer:

In most flowering plants, the female gametophyte (embryo sac) develops from a SINGLE functional megaspore — this is called monosporic development.

How it happens step by step:

6. The megaspore mother cell (MMC, $2n$) in the nucellus undergoes meiosis.
7. Meiosis produces 4 haploid megaspores arranged in a linear tetrad.
8. 3 of the 4 megaspores degenerate (usually the 3 towards the micropylar end).
9. Only 1 megaspore — typically the one at the chalazal end — survives as the functional megaspore.
10. This single functional megaspore undergoes 3 rounds of mitotic divisions (without cell wall formation) to produce 8 free nuclei.
11. Cell wall formation then occurs, resulting in the 7-celled, 8-nucleate embryo sac.

 **Remember:** 'Monosporic' = mono (one) + sporic (spore). So only ONE megaspore participates in embryo sac formation. This is also called the Polygonum type of embryo sac development (the most common type in angiosperms, found in about 70% of species).

Q6. With a neat diagram explain the 7-celled, 8-nucleate nature of the female gametophyte.

Answer:

The mature female gametophyte (embryo sac) in most angiosperms is 7-celled but contains 8 nuclei. This apparent contradiction is because one cell (the Central Cell) contains TWO nuclei (called polar nuclei).

Detailed structure (from micropylar to chalazal end):

At the Micropylar End — Egg Apparatus (3 cells, 3 nuclei):

- Egg Cell (1): The female gamete; 1 large haploid cell with a nucleus. This is fertilised by one male gamete to form the zygote ($2n$). Positioned between the two synergids.
- Synergids (2): Two haploid cells flanking the egg cell. They have characteristic finger-like projections of wall material called the Filiform Apparatus. They help guide the pollen tube into the embryo sac.

At the Centre — Central Cell (1 cell, 2 nuclei):

- Central Cell: The largest cell of the embryo sac. It contains 2 polar nuclei (haploid, n each). The second male gamete fuses with both polar nuclei (triple fusion) to form the triploid ($3n$) Primary Endosperm Nucleus (PEN). This is the cell with 2 nuclei — which is why the embryo sac is '7-celled but 8-nucleate'.

At the Chalazal End — Antipodal Cells (3 cells, 3 nuclei):

- Antipodal Cells (3): Three haploid cells at the end opposite the micropyle. Their exact function is not fully understood but they are thought to play a nutritive role. They degenerate after fertilisation.

Summary count: 3 (egg apparatus) + 1 (central cell with 2 nuclei) + 3 (antipodals) = 7 cells, 8 nuclei.

 **Diagram Tip:** Refer to Figure 1.13(a) in the textbook showing the fertilised embryo sac. For the unfertilised embryo sac structure, draw an oval shape, mark the 3 layers: at top (micropylar) = 2 synergids + 1 egg cell; in middle = large central cell with 2 polar nuclei; at bottom (chalazal) = 3 antipodal cells. Label all parts.

 **Remember:** Easy memory: '3-1-3 rule' — 3 cells at micropylar (egg apparatus), 1 central cell with 2 polar nuclei, 3 antipodal cells at chalazal end. Total = 7 cells, 8 nuclei.

Q7. What are chasmogamous flowers? Can cross-pollination occur in cleistogamous flowers? Give reasons for your answer.

Answer:

Chasmogamous Flowers: These are flowers that open normally (i.e., they have open, exposed anthers and stigma). They allow pollen transfer both within the same flower (self-pollination) and between different flowers (cross-pollination). Most flowers we see are chasmogamous. Examples: Rose, Hibiscus, Mustard.

Cleistogamous Flowers: These flowers NEVER open at all. They remain permanently closed. Because the flower never opens, the anthers and stigma are always enclosed within the petals. Pollination occurs within the closed flower itself (only self-pollination). Example: Commelina, Viola (some species).

Can cross-pollination occur in cleistogamous flowers?

NO. Cross-pollination CANNOT occur in cleistogamous flowers.

Reasons:

- Since cleistogamous flowers never open, no external pollen can enter from outside.
- No pollinating agents (wind, insects, water, etc.) can access the closed flower.
- Pollination is restricted to the pollen grains produced within the same flower, so only autogamy (self-pollination within the same flower) is possible.
- This guarantees seed production even in the absence of pollinators — an important adaptive advantage.

 **Remember:** Cleistogamous flowers ensure 'assured seed set' even in unfavourable conditions. However, the seeds produced lack genetic variation since no cross-pollination occurs. Some plants like Viola and Oxalis produce BOTH chasmogamous and cleistogamous flowers on the same plant to balance reproduction strategies.

Q8. Mention two strategies evolved to prevent self-pollination in flowers.

Answer:

Plants have evolved various mechanisms to prevent self-pollination and encourage cross-pollination, thereby promoting genetic diversity. Two important strategies are:

Strategy 1: Dichogamy (Maturation at Different Times)

In many flowers, the anthers (male) and stigma (female) do not mature at the same time within the same flower. This prevents self-pollination.

- Protandry: Anthers mature and release pollen BEFORE the stigma of the same flower becomes receptive. Example: Sunflower (*Helianthus*), *Salvia*.
- Protogyny: Stigma becomes receptive BEFORE the anthers of the same flower mature/release pollen. Example: *Mirabilis* (4 O'clock plant), *Magnolia*.

Strategy 2: Self-Incompatibility (SI)

This is a genetic mechanism in which a plant is unable to undergo fertilisation with its own pollen. The stigma recognises and REJECTS pollen from the same plant (or closely related plants with the same self-incompatibility alleles), preventing pollen tube growth or zygote formation. Example: Tobacco (*Nicotiana*), *Petunia*.

 **Remember:** Other strategies (for reference): *Herkogamy* — physical separation of anther and stigma within the same flower (e.g., very long style keeps stigma away from anthers); *Dioecy* — male and female flowers on separate plants (e.g., Papaya, Date Palm).

Q9. What is self-incompatibility? Why does self-pollination not lead to seed formation in self-incompatible species?

Answer:

Self-Incompatibility (SI): It is a genetically controlled mechanism in flowering plants that prevents fertilisation and seed formation when pollen from the same plant (or a plant with the same S-allele genotype) lands on the stigma. It is a natural barrier to inbreeding.

Why self-pollination does not lead to seed formation in self-incompatible species:

Self-incompatibility is controlled by the S-gene (S-locus) with multiple alleles (S₁, S₂, S₃, etc.). When pollen with an S-allele that matches the S-allele of the stigma lands on that stigma, a series of recognition and rejection responses occur:

12. The stigma recognises the 'self' nature of the pollen through biochemical interactions (the S-gene products — proteins — on the pollen wall interact with those on the stigma surface).
13. This recognition triggers an INHIBITION response. The stigma produces chemicals that either prevent pollen germination altogether, or stop pollen tube growth within the style.
14. Since the pollen tube cannot reach the ovule, fertilisation does not occur, and therefore no seed is formed.

 **Remember:** Think of it like a 'molecular password system': the stigma checks if the pollen's ID matches its own. If it does (self-pollen), it blocks entry. Only pollen with a different S-allele (non-self pollen) is allowed to germinate and fertilise. This forces cross-pollination and ensures genetic diversity.

Q10. What is bagging technique? How is it useful in a plant breeding programme?

Answer:

Bagging Technique: It is the process of covering a flower (or flower bud) with a paper or polythene bag to prevent contamination of its stigma with unwanted or foreign pollen.

Procedure:

15. The bag is placed over the emasculated flower bud (in bisexual flowers) BEFORE the flower opens.
16. The bag physically isolates the flower from the environment and any external pollen.
17. When the stigma becomes receptive, the bag is carefully removed.
18. Desired pollen (from the chosen male parent) is then dusted on the stigma artificially.
19. The flower is immediately rebagged to prevent further contamination while the pollen tube grows and fertilisation occurs.

Usefulness in Plant Breeding:

- Ensures pure hybridisation: Only the selected/desired pollen is used for pollination, guaranteeing the intended genetic cross.
- Prevents accidental self-pollination: In emasculated bisexual flowers, if not bagged, wind or insects could bring self pollen back — bagging prevents this.
- Controlled crossing: Enables plant breeders to combine traits from two specific parent varieties to develop new, improved hybrid varieties with desired characteristics (e.g., disease resistance, high yield).
- Used in conjunction with emasculation: Together these two techniques form the basis of artificial hybridisation programmes.

 **Remember:** In unisexual (dioecious) female flowers, emasculation is not needed (no stamens), but bagging is still necessary to control which pollen reaches the stigma.

Q11. What is triple fusion? Where and how does it take place? Name the nuclei involved in triple fusion.

Answer:

Triple Fusion: It is the fusion of ONE male gamete with the TWO polar nuclei (or the secondary nucleus) present in the central cell of the embryo sac. It is called 'triple' because three haploid nuclei (1 male gamete + 2 polar nuclei) are involved in the fusion.

Where it takes place: Inside the embryo sac (female gametophyte), specifically in the Central Cell of the ovule, which is located within the nucellus of the ovule inside the ovary.

How it takes place:

20. After the pollen tube enters the embryo sac through the micropyle, it bursts open in one of the synergids and releases two male gametes into the cytoplasm.
21. One male gamete fuses with the egg cell → this is syngamy → forms the diploid (2n) Zygote.
22. The second male gamete moves towards the central cell and fuses with the two polar nuclei simultaneously.
23. This fusion of 1 male gamete (n) + 2 polar nuclei (n + n) produces the triploid (3n) Primary Endosperm Nucleus (PEN).
24. The PEN then develops into the endosperm tissue that nourishes the growing embryo.

Nuclei involved in Triple Fusion:

- One male gamete nucleus (haploid, n) — from the pollen tube
- Two polar nuclei (each haploid, n) — from the central cell of the embryo sac

Result: 3n (triploid) Primary Endosperm Nucleus (PEN)

 **Remember:** Triple fusion is part of the larger phenomenon called Double Fertilisation, which is UNIQUE to angiosperms. Double fertilisation = Syngamy (male gamete + egg) + Triple fusion (male gamete + 2 polar nuclei). Both fusions happen almost simultaneously in the same embryo sac.

Q12. Why do you think the zygote is dormant for sometime in a fertilised ovule?

Answer:

The zygote remains dormant (inactive) for some time after fertilisation. This dormancy is an important biological adaptation. The reasons are:

- **Ensuring Nutritional Support:** The primary function of dormancy is to WAIT for the endosperm to develop first. The endosperm is the nutritive tissue that will feed the growing embryo. If the

zygote started dividing immediately without endosperm being available, the embryo would lack nutrients and could not survive.

- **Endosperm First Principle:** In angiosperms, endosperm development ALWAYS precedes embryo development. The Primary Endosperm Cell (PEC) begins dividing and forming endosperm tissue before the zygote begins developing into an embryo. This is an adaptation to ensure assured nutrition.
- **Physiological Readiness:** The ovule must reach a certain physiological state (appropriate hormone levels, enzyme activity, etc.) before the zygote can successfully divide and undergo embryogenesis.
- **Resource Allocation:** Dormancy allows the plant to channel initial resources into endosperm formation, which serves as the nutrient reservoir, rather than premature embryo development.

 **Remember:** Analogy: Think of the endosperm as 'setting up the kitchen' before the embryo (chef) starts working. The zygote waits for the food store (endosperm) to be ready before it starts the complex process of embryo development. This ensures the embryo never runs out of nutrition during its early critical stages.

Q13. Differentiate between: (a) hypocotyl and epicotyl; (b) coleoptile and coleorrhiza; (c) integument and testa; (d) perisperm and pericarp.

Answer:

(a) Hypocotyl vs. Epicotyl

Hypocotyl	Epicotyl
Part of embryonal axis BELOW the level of cotyledon attachment	Part of embryonal axis ABOVE the level of cotyledon attachment
Terminates at its lower end in the Radicle (root tip)	Terminates at its upper end in the Plumule (shoot tip / stem tip)
Gives rise to the ROOT system on germination	Gives rise to the SHOOT system on germination
Present in both dicot and monocot embryos	Present in both dicot and monocot embryos

(b) Coleoptile vs. Coleorrhiza

Coleoptile	Coleorrhiza
A hollow, foliar (leaf-like) sheath that encloses and protects the shoot apex (plumule) and young leaf primordia	An undifferentiated sheath that encloses the radicle and root cap
Found in monocot embryos (grass family)	Found in monocot embryos (grass family)
Located at the UPPER end of the embryonal axis (epicotyl region)	Located at the LOWER end of the embryonal axis (hypocotyl region)
Protects the SHOOT during germination as it pushes through soil	Protects the ROOT (radicle) during germination

 **Remember:** Both coleoptile and coleorrhiza are protective sheaths unique to monocotyledons (grasses). Think: Coleoptile = protection for Plumule/Shoot. Coleorrhiza = protection for Radicle/Root.

(c) Integument vs. Testa

Integument	Testa
Protective covering(s) of the OVULE (one or two layers)	Protective covering of the SEED (seed coat)
Present in the unfertilised/developing ovule	Present in the mature seed after fertilisation
Is a soft, living layer surrounding the nucellus	Hard, tough, dried layer — integuments harden and form testa after fertilisation and maturation
Before fertilisation / seed maturation	After fertilisation — it IS the mature form of the integument

 **Remember:** Simply put: Integument (in ovule) → after maturation → becomes Testa (in seed). Testa = hardened integument.

(d) Perisperm vs. Pericarp

Perisperm	Pericarp
Residual, persistent nucellus tissue that remains in some mature seeds	The wall of the fruit — develops from the ovary wall after fertilisation
Found INSIDE the seed — it is part of the seed	Surrounds the seeds — it is the fruit wall, outside the seed
Represents leftover nucellus not consumed during embryo/endosperm development	Develops from the ovary wall
Examples: Black pepper (<i>Piper nigrum</i>), Beet (<i>Beta vulgaris</i>)	Examples: Mango (fleshy pericarp), Groundnut (dry pericarp), Coconut (fibrous pericarp)

 **Remember:** Memory tip: 'Peri-sperm' = around the seed (it's inside the seed). 'Peri-carp' = around the carpel/fruit. Perisperm is RARE; pericarp is present in ALL fruits.

Q14. Why is apple called a false fruit? Which part(s) of the flower forms the fruit?

Answer:

False Fruit: In a TRUE fruit, only the OVARY wall (pericarp) develops to form the fruit wall. However, in apple (and also in strawberry and cashew), the fleshy edible part of the 'fruit' that we eat develops NOT from the ovary alone, but MAINLY from the THALAMUS (the receptacle/floral axis, i.e., the swollen stem tip that bears all the floral parts).

In apple specifically:

- The edible fleshy part is derived primarily from the THALAMUS (which swells and becomes fleshy).
- The actual true fruit (the ovary) is the small, papery, core-like structure in the centre of the apple that contains the seeds.
- Since most of the edible material is from a floral part other than the ovary (i.e., the thalamus), it is called a FALSE FRUIT or Pseudocarp.

Parts of the flower that form the fruit in apple:

- Thalamus (receptacle) — forms the bulk of the fleshy edible portion
- Ovary wall — forms the core/inner dry portion

 **Remember:** True fruits (like mango, tomato) are formed entirely from the ovary. False fruits (like apple, strawberry, cashew) have significant contribution from non-ovary floral parts — mainly the thalamus. The 'cashew apple' is similarly a false fruit formed from the swollen peduncle/thalamus, while the actual cashew nut is the true fruit.

 **Diagram Tip:** Refer to Figure 1.15(b) in the textbook, which shows the L.S. of apple clearly labelling the Thalamus, Seed, Endocarp, and Mesocarp, making it easy to identify which parts come from the ovary vs. the thalamus.

Q15. What is meant by emasculation? When and why does a plant breeder employ this technique?

Answer:

Emasculation: It is the manual removal of anthers (stamens) from a bisexual flower bud BEFORE they mature and dehisce (release pollen). It is done using forceps or fine scissors. After emasculation, the flower is immediately covered with a bag (bagging technique) to prevent any contamination.

When it is employed: Emasculation is carried out on the FEMALE PARENT plant when it has bisexual (hermaphrodite) flowers. It must be done at the flower BUD stage — before the anthers mature and shed their pollen — to ensure no self-pollination has occurred.

Why it is employed:

25. To PREVENT SELF-POLLINATION in bisexual flowers: If a plant breeder wants to cross two plants (A x B), but the female parent (A) has both stamens and pistil, the anthers of plant A must be removed so that it cannot fertilise itself.
26. To ensure CONTROLLED CROSS-POLLINATION: After emasculation and bagging, only the desired pollen from the chosen male parent (B) will be used to pollinate the stigma of plant A at the right time.
27. For ARTIFICIAL HYBRIDISATION: This is one of the most important tools in crop improvement programmes to create new hybrid varieties with desirable traits.

 **Remember:** Emasculation is NOT needed when: (1) The female parent has unisexual female flowers (no stamens, so no self-pollination risk) — just bag before it opens. (2) The flowers are cleistogamous. **Remember:** Always emasculate at BUD stage — if done after flower opens, pollen may have already been shed.

Q16. If one can induce parthenocarpy through the application of growth substances, which fruits would you select to induce parthenocarpy and why?

Answer:

Parthenocarpy: Development of fruit WITHOUT fertilisation, resulting in SEEDLESS fruits. It can be artificially induced by applying plant growth regulators (hormones) such as Auxin (IAA, IBA), Gibberellins (GA), or Cytokinins.

Fruits I would choose to induce parthenocarpy:

28. Tomato (*Solanum lycopersicum*) — Reason: Seedless tomatoes would be very consumer-friendly as seeds can be unpleasant in texture when eating/processing. Already widely used in food industry. Auxin application has been experimentally shown to induce parthenocarpy in tomato.
29. Watermelon (*Citrullus lanatus*) — Reason: Seedless watermelons are already commercially popular (though currently produced by polyploidy). Seedless watermelon is easier to eat and has better commercial value. Application of growth hormones could simplify production.

30. Grapes (*Vitis vinifera*) — Reason: Seedless grape varieties (like Thompson seedless) are among the most commercially valuable fruits worldwide. Gibberellin application is already used commercially to enhance berry size and seedlessness in grapes.
31. Orange/Citrus — Reason: Seedless oranges (like Navel oranges) are preferred by consumers. Seeds in citrus fruits reduce eating convenience. Parthenocarpic induction would increase consumer appeal and market value.

General reasoning for selection: Fruits are selected based on:

- High consumer demand for seedless varieties
- Commercial/economic importance
- Ease of eating (seeds cause inconvenience)
- Industrial/processing use where seeds are unwanted

 **Remember:** Banana is a natural parthenocarpic fruit — it develops without fertilisation and is naturally seedless. The wild banana has seeds but the cultivated banana is parthenocarpic. This is why cultivated bananas cannot be propagated by seeds and are grown vegetatively (from suckers).

Q17. Explain the role of tapetum in the formation of pollen-grain wall.

Answer:

Tapetum: The tapetum is the innermost wall layer of the microsporangium (pollen sac). It directly surrounds the sporogenous tissue (microspore mother cells and developing microspores/pollen grains).

Characteristics of Tapetum:

- Cells are nutritive in function, with dense cytoplasm, large nuclei, and often bi-nucleate or polyploid.
- It is metabolically very active.
- It gets gradually broken down and absorbed as the pollen grains mature.

Role in Pollen Wall Formation:

32. **Primary Nutritive Role:** Tapetal cells provide nutrients (carbohydrates, lipids, proteins) to the developing microspores. This supports the growth and wall formation of pollen grains.
33. **Sporopollenin Precursors:** Tapetal cells synthesise and secrete sporopollenin precursors. Sporopollenin is the extremely resistant polymer that forms the outer wall (exine) of the pollen grain. Without tapetal secretions, the exine cannot be properly constructed.
34. **Pollen Coat Formation:** Tapetal cells contribute to the formation of the pollen coat (pollenkitt) — a sticky, lipid-rich coating on the exine surface that helps pollen adhere to pollinators and the stigma.
35. **Ubish Bodies:** Tapetum produces small spherical organelles called Ubish bodies (orbicules) that are believed to help in transferring sporopollenin to the developing pollen wall.
36. **Enzyme secretion:** Tapetum releases enzymes like callase that help in the separation of microspore tetrads into individual microspores.

 **Remember:** In simple terms: The tapetum is like a 'supplier factory' for pollen grain wall construction. It provides the raw materials (sporopollenin precursors, proteins, lipids) and enzymes needed to build the tough, complex, and beautifully patterned exine wall of pollen grains. Absence or dysfunction of tapetum leads to MALE STERILITY.

 **Diagram Tip:** Refer to Figure 1.3(b) in the textbook — the enlarged microsporangium cross-section clearly shows the position of the Tapetum as the innermost wall layer, just surrounding the microspore mother cells.

Q18. What is apomixis and what is its importance?

Answer:

Apomixis: It is a special type of reproduction in which seeds are formed **WITHOUT** fertilisation. It is essentially a form of **ASEXUAL** reproduction that mimics sexual reproduction (seed formation occurs but without the union of male and female gametes). The offspring produced are genetically identical to the parent plant (clones).

How apomixis occurs (types):

- **Diplospory:** The diploid egg cell develops into the embryo **WITHOUT** meiosis and without fertilisation. The egg cell retains the $2n$ chromosome number and develops parthenogenetically (without fertilisation) into an embryo.
- **Adventive Embryony:** In many Citrus and Mango varieties, the nucellar cells (diploid, $2n$) surrounding the embryo sac start dividing, protrude into the embryo sac, and develop into additional embryos. This results in polyembryony (multiple embryos per seed).

Importance of Apomixis:

37. **Hybrid Seed Industry — MOST IMPORTANT:** Hybrid varieties have superior traits (heterosis/hybrid vigour) but hybrid seeds must be produced **EVERY** year because seeds from hybrids segregate in F_2 generation and lose hybrid characters. If hybrids are made apomictic, their superior traits are maintained across generations without segregation. Farmers can save seeds year after year without buying new hybrid seeds — reducing cost dramatically.
38. **Preservation of Superior Genotypes:** Apomixis fixes superior genotypes, ensuring that advantageous combinations of genes are maintained intact across generations (since no meiosis/random gamete formation occurs).
39. **Assured Seed Production:** Apomixis ensures seed formation even without pollinators or in adverse conditions.
40. **Reduces Cost of Hybrid Seed Production:** Producing hybrid seeds is expensive and labour-intensive. Apomixis would eliminate the need to produce hybrid seeds every season, making agriculture more economical for farmers.
41. **Research and Breeding:** Understanding apomixis genetics helps in transferring apomictic genes into important crop hybrids.

 **Remember:** Current Status: Active research is underway worldwide to understand the genetics of apomixis and to transfer apomictic genes into hybrid crop varieties (rice, maize, wheat, etc.). If successful, this could revolutionise agriculture by providing farmers with affordable, stable hybrid seeds that maintain vigour indefinitely.

— End of Solutions —

Chapter 2: Human Reproduction

Q1. Fill in the blanks:

Here are all the blanks filled with answers and brief explanations for each:

#	Statement	Answer
(a)	Humans reproduce _____	sexually
(b)	Humans are _____	viviparous
(c)	Fertilisation is _____ in humans	internal
(d)	Male and female gametes are _____	haploid
(e)	Zygote is _____	diploid
(f)	The process of release of ovum from a mature follicle is called _____	ovulation
(g)	Ovulation is induced by a hormone called _____	Luteinising Hormone (LH)
(h)	The fusion of male and female gametes is called _____	fertilisation
(i)	Fertilisation takes place in _____	the ampulla of the fallopian tube (oviduct)
(j)	Zygote divides to form _____ which is implanted in uterus.	blastocyst
(k)	The structure which provides vascular connection between foetus and uterus is called _____	placenta

 **Note:** Key concept: Humans are viviparous (give birth to young ones, NOT eggs) and fertilisation is internal (inside the female body). Gametes are haploid (n) because they are formed by meiosis; when they fuse, the zygote becomes diploid (2n). The LH surge (LH peak) just before ovulation is the most important hormonal trigger for ovulation.

Q2. Draw a labelled diagram of the male reproductive system.

Answer:

The male reproductive system consists of the following structures that should be clearly labelled in your diagram:

Structures to label (from inside to outside):

- Testes (pair) — primary sex organs that produce sperms and androgens; located in scrotal sacs outside the abdominal cavity (temperature 2–2.5° C lower than body temp for sperm production)
- Seminiferous tubules — highly coiled tubes inside testes; site of sperm formation
- Epididymis — comma-shaped structure on the posterior surface of testis; site of sperm maturation and storage
- Vas deferens (Ductus deferens) — a long muscular tube that carries mature sperm from epididymis towards the urethra
- Seminal vesicles (pair) — accessory glands that secrete a fluid rich in fructose (energy for sperm) and prostaglandins
- Prostate gland — surrounds the urethra; secretes slightly alkaline fluid that activates sperm and neutralises acidity of urine

- Bulbourethral glands (Cowper's glands, pair) — secrete a clear fluid that lubricates the urethra and neutralises residual urine
- Urethra — carries both urine and semen (at different times) to the exterior through the penis
- Penis — male external genitalia; contains erectile tissue; deposits semen in female reproductive tract during coitus
- Scrotum — external pouch housing the testes; maintains temperature lower than body temperature

 **Diagram:** Refer to Figure 2.1(a) in the textbook — it shows a clear side-view (sagittal section) of the male reproductive system with all structures labelled. Reproduce this diagram showing the testis, epididymis, vas deferens, seminal vesicle, prostate, bulbourethral gland, urethra, and penis. Use arrows from labels to structures.

Q3. Draw a labelled diagram of the female reproductive system.

Answer:

The female reproductive system consists of the following structures that must be labelled in your diagram:

Structures to label:

- Ovaries (pair) — primary female sex organs; produce ova (eggs) and ovarian hormones (estrogen, progesterone); located in the pelvic cavity
- Fallopian tubes / Oviducts (pair) — carry ova from ovary to uterus; site of fertilisation (specifically in the ampulla region)
- Infundibulum — funnel-shaped opening of the oviduct near the ovary; has finger-like fimbriae that sweep the released ovum into the tube
- Ampulla — wider, middle portion of oviduct; site where fertilisation occurs
- Isthmus — narrow portion of oviduct that joins the uterus
- Uterus (womb) — pear-shaped muscular organ; site of implantation, foetal development; has three layers: perimetrium (outer), myometrium (middle, smooth muscle), endometrium (inner, shed during menstruation)
- Cervix — narrow, lower part of uterus that opens into the vagina
- Vagina — muscular tubular canal that opens to the exterior; receives penis during coitus; birth canal during parturition
- External genitalia — mons pubis, labia majora, labia minora, clitoris, hymen
- Mammary glands — accessory reproductive structures; produce milk after childbirth

 **Diagram:** Refer to Figure 2.2 in the textbook — it shows the female reproductive system in frontal view clearly labelling ovaries, fallopian tubes (infundibulum, ampulla, isthmus), uterus, cervix, and vagina. This is a standard exam diagram — practise drawing it with all labels.

Q4. Write two major functions each of testis and ovary.

Answer:

Functions of TESTIS	Functions of OVARY
1. Spermatogenesis: Production of male gametes (spermatozoa) in the seminiferous tubules through the process of meiosis and mitosis.	1. Oogenesis: Production of female gametes (ova/eggs) in the ovarian follicles through the process of meiosis.
2. Steroidogenesis (Endocrine function): Secretion of male sex hormones called androgens (mainly testosterone) by the Leydig cells (interstitial cells).	2. Steroidogenesis (Endocrine function): Secretion of female sex hormones — estrogen (by granulosa cells of developing follicles) and progesterone (by

Testosterone is responsible for development of male secondary sexual characteristics, spermatogenesis, and male behaviour.

corpus luteum). These regulate the menstrual cycle, secondary sexual characteristics, and maintain pregnancy.

 **Note:** Memory tip: Both gonads (testis and ovary) have the SAME two categories of function: (1) Gamete production (gametogenesis) and (2) Hormone production (steroidogenesis). Testis = sperm + testosterone. Ovary = ova + estrogen/progesterone.

Q5. Describe the structure of a seminiferous tubule.

Answer:

Seminiferous tubules are the functional units of sperm production in the testis. Here is a detailed structural description:

Location and Number:

- Each testis is divided into about 250 compartments called testicular lobules.
- Each lobule contains 1–3 highly coiled seminiferous tubules.
- The tubules open into the rete testis, which connects to the epididymis via efferent ducts.

Wall structure (from outside to inside):

1. Fibrous tissue wall: The outer boundary of each tubule is made of a basement membrane lined by germinal epithelium.
2. Spermatogonia (Germ cells): These are diploid ($2n$) male germ cells that line the inner wall. They are the precursor cells that undergo spermatogenesis. They divide by mitosis to maintain their population and some undergo meiosis to form spermatocytes.
3. Sertoli cells (Nurse cells / Sustentacular cells): These are large, non-dividing columnar cells that extend from the basement membrane to the lumen of the tubule. They surround and protect the developing sperm cells. Key functions: provide nutrition (lactate, pyruvate) to developing germ cells; form the blood-testis barrier; secrete Androgen Binding Protein (ABP); respond to FSH; secrete inhibin.
4. Lumen: The central hollow space of the tubule where mature spermatids are released after spermiogenesis.

Surrounding tissue (outside the tubule):

- Interstitial tissue (connective tissue) fills the space between tubules.
- Leydig cells (Interstitial cells): Present in the interstitial tissue outside the tubules. These are large, polygonal cells that synthesise and secrete androgens (mainly testosterone) in response to LH (ICSH). They are NOT part of the tubule wall itself but are crucial for spermatogenesis.

 **Diagram:** Refer to Figure 2.1(b) in the textbook — it shows a transverse section through a seminiferous tubule, clearly showing the arrangement of spermatogonia, Sertoli cells, spermatocytes at different stages, spermatids, and Leydig cells in the interstitium. Reproduce this circular cross-section diagram with all labels.

 **Note:** Key distinction: Sertoli cells are INSIDE the seminiferous tubule (provide nutrition). Leydig cells are OUTSIDE the tubule in the interstitial space (produce testosterone). Both are essential for spermatogenesis.

Q6. What is spermatogenesis? Briefly describe the process of spermatogenesis.

Answer:

Spermatogenesis: It is the process of formation of mature male gametes (spermatozoa) from the diploid germ cells (spermatogonia) in the seminiferous tubules of the testis. It begins at puberty and continues throughout adult life.

Process of Spermatogenesis (step by step):

Step 1 — Multiplication Phase:

- Spermatogonia ($2n$) line the inner wall of the seminiferous tubule.
- Some spermatogonia (Type A) undergo repeated mitotic divisions to maintain the germ cell population.
- Others (Type B spermatogonia) are committed to become sperm — they grow in size to form Primary Spermatocytes ($2n$, diploid).

Step 2 — Meiotic Phase (Meiosis I):

- Each Primary Spermatocyte ($2n$) undergoes Meiosis I (reductive division).
- This produces 2 Secondary Spermatocytes, each haploid (n).
- Note: Primary spermatocytes are the largest germ cells in the seminiferous tubule.

Step 3 — Meiosis II:

- Each Secondary Spermatocyte (n) undergoes Meiosis II (equational division).
- This produces 2 Spermatids each (total 4 spermatids from one primary spermatocyte).
- All spermatids are haploid (n).

Step 4 — Spermiogenesis (Differentiation Phase):

- Each spermatid undergoes spermiogenesis — a complex metamorphosis/differentiation to transform into a mature spermatozoon (sperm).
- Changes include: formation of acrosome from Golgi complex, development of flagellum from centriole, condensation of nucleus, loss of cytoplasm, mitochondria aggregate in the midpiece.

Step 5 — Spermiation:

- The process by which fully formed spermatozoa are released from the Sertoli cells into the lumen of the seminiferous tubule is called spermiation.

Net result: 1 spermatogonium ($2n$) → 4 spermatozoa (n each)

 **Note:** Hormonal regulation: FSH stimulates Sertoli cells which secrete ABP (Androgen Binding Protein) that concentrates testosterone near the spermatogonia. LH stimulates Leydig cells to secrete testosterone. Both FSH and testosterone are essential for spermatogenesis to proceed.

Q7. Name the hormones involved in the regulation of spermatogenesis.

Answer:

The following hormones regulate spermatogenesis:

Hormone	Source	Role in Spermatogenesis
GnRH (Gonadotropin Releasing Hormone)	Hypothalamus	Stimulates anterior pituitary to release FSH and LH. The master trigger for the whole process.
FSH (Follicle Stimulating Hormone)	Anterior Pituitary	Acts on Sertoli cells → stimulates them to secrete Androgen Binding Protein (ABP), which concentrates testosterone in the

		tubules and supports sperm development.
LH (Luteinising Hormone) / ICSH	Anterior Pituitary	Acts on Leydig cells (interstitial cells) → stimulates synthesis and secretion of testosterone (androgens).
Testosterone (Androgens)	Leydig cells of testis	Essential for the meiotic divisions of spermatocytes and for spermiogenesis (sperm differentiation). Also maintains male secondary sexual characters.
Inhibin	Sertoli cells of testis	Provides negative feedback to anterior pituitary to suppress FSH secretion when sperm production is adequate — a self-regulatory mechanism.

 **Note:** Regulation pathway (simple): Hypothalamus → GnRH → Anterior Pituitary → FSH + LH → Testis → Testosterone (+ inhibin feedback). Without both FSH AND testosterone, spermatogenesis cannot occur. This is why anabolic steroid abuse (excess testosterone) paradoxically suppresses sperm production — it suppresses GnRH/FSH via negative feedback.

Q8. Define spermiogenesis and spermiation.

Answer:

Spermiogenesis:

It is the process of transformation (differentiation/metamorphosis) of non-motile, round spermatids into mature, motile spermatozoa (sperms). It is the FINAL PHASE of spermatogenesis.

Changes that occur during spermiogenesis:

5. The Golgi complex transforms into the acrosome — a cap-like structure on the head of the sperm containing hydrolytic enzymes (hyaluronidase, acrosin) needed to penetrate the egg.
6. The nucleus condenses and elongates to form the compact sperm head.
7. The centriole elongates to form the axoneme (axial filament) of the flagellum (tail).
8. Mitochondria migrate and coil around the proximal part of the flagellum to form the midpiece — this is the energy-producing region of the sperm.
9. Excess cytoplasm is shed as residual bodies, which are phagocytosed by Sertoli cells.

Spermiation:

It is the process by which the fully formed, mature spermatozoa (sperm cells) are released from the cytoplasm of the Sertoli cells into the lumen (central cavity) of the seminiferous tubule.

After spermiation, sperms pass into the rete testis → efferent ducts → epididymis, where they undergo further maturation and gain motility.

 **Note:** Simple distinction: Spermiogenesis = the MAKING/SHAPING of sperm (spermatid → spermatozoon). Spermiation = the RELEASE of finished sperm from Sertoli cells into the tubule lumen. Both are final steps after meiosis is complete.

Q9. Draw a labelled diagram of a sperm.

Answer:

A human sperm is approximately 60 micrometres long and has four distinct regions:

Parts of a Sperm — detailed description for diagram:**1. Head:**

- Contains the highly condensed haploid nucleus (with DNA).
- Covered at the front by the acrosome — a cap derived from the Golgi complex containing hydrolytic enzymes essential for penetrating the zona pellucida of the egg during fertilisation.
- Plasma membrane covers the entire head.

2. Neck (connecting piece):

- Very short region connecting head and middle piece.
- Contains the centrioles (proximal centriole connects to the nucleus; distal centriole gives rise to the axoneme of flagellum).

3. Middle piece:

- Contains the axoneme (central microtubule arrangement: 9+2 pattern).
- Mitochondria are spirally arranged around the axoneme — they provide energy (ATP) for sperm motility.
- This is the POWERHOUSE of the sperm.

4. Tail (flagellum):

- The longest part — gives the sperm its characteristic motility (swimming movement).
- Contains the axoneme throughout its length.
- The whip-like movement of the tail propels the sperm forward.

 **Diagram:** Refer to Figure 2.4 in the textbook — it shows a detailed labelled diagram of a human sperm with all four regions (head with acrosome and nucleus, neck, middle piece with mitochondria, and tail/flagellum) clearly marked. Draw an elongated sperm shape and label all four parts with arrows.

 **Note:** Exam tip: Always label (1) Acrosome, (2) Nucleus in the head, (3) Mitochondria in the middle piece, (4) Flagellum/tail. These are the most commonly asked parts. The acrosome contains enzymes — hyaluronidase and acrosin — which help the sperm penetrate the egg.

Q10. What are the major components of seminal plasma?**Answer:**

Seminal plasma: It is the fluid component of semen (the male reproductive fluid). Semen = Sperms + Seminal plasma. Sperms make up only about 2–5% of semen volume; the rest is seminal plasma.

Major components of seminal plasma and their sources:

Component	Source Gland	Function / Role
Fructose (sugar)	Seminal vesicles (~60% of volume)	Primary energy source for sperm motility (sperm use fructose for ATP production via glycolysis)
Prostaglandins	Seminal vesicles	Stimulate uterine contractions to help transport sperm upward through female tract

Fibrinogen (forms semen clot)	Seminal vesicles + Prostate	Causes temporary coagulation of semen after ejaculation, keeping sperm in vagina
Citric acid, proteolytic enzymes, acid phosphatase, zinc	Prostate gland (~30% of volume)	Alkaline fluid that neutralises acidic vaginal secretions; zinc stabilises sperm DNA; enzymes liquify the semen clot after ~20 min
Mucus / Lubricating fluid	Bulbourethral glands (Cowper's glands)	Lubricates the urethra before ejaculation; neutralises residual urine acidity in the urethra
Overall — alkaline pH (~7.2–7.8)	Mixture from all glands	Neutralises the acidic environment of the vagina, protecting sperm from acid damage

 **Note:** Why is seminal plasma important? Sperm are produced in the testis but cannot fertilise an egg on their own — they need the seminal plasma for energy (fructose), protection from acidity (alkaline secretions), lubrication, and signalling. The seminal plasma is essentially the 'life-support system' for sperm outside the testis.

Q11. What are the major functions of male accessory ducts and glands?

Answer:

A. Functions of Male Accessory Ducts:

Duct	Major Functions
Rete testis	Network of channels in the testis that collect sperms from the ends of seminiferous tubules and channel them to the efferent ducts.
Vasa efferentia (Efferent ducts)	Connect rete testis to epididymis; lined with ciliated cells that help move sperm from testis to epididymis.
Epididymis	1. Site of sperm MATURATION — sperm gain motility and fertilising capacity here (takes ~2–3 weeks). 2. STORAGE of mature sperms (up to several weeks). 3. Absorption and secretion of fluid that modifies the sperm surface proteins.
Vas deferens (ductus deferens)	1. Transports mature sperms from epididymis to the ejaculatory duct (and urethra) during ejaculation by peristaltic contractions. 2. Serves as a storage duct for sperm. (Note: This duct is cut in vasectomy — male sterilisation)
Ejaculatory duct	Formed by the union of vas deferens and duct of seminal vesicle; opens into the urethra; carries semen to the urethra.
Urethra	Common passage for both urine and semen (not simultaneously); carries semen to the exterior during ejaculation.

B. Functions of Male Accessory Glands:

Gland	Major Functions
Seminal vesicles (pair)	Secrete ~60% of seminal plasma volume. Provide fructose (energy for sperm), prostaglandins (stimulate female tract contractions), and proteins. Fluid is slightly alkaline.
Prostate gland	Secretes ~30% of seminal plasma volume. Secretes a slightly alkaline, milky fluid containing citric acid, zinc, enzymes (PSA — prostate specific antigen, used in cancer screening). Helps neutralise vaginal acidity, activates sperm motility, liquifies semen clot.
Bulbourethral glands (Cowper's glands, pair)	Secrete a clear, alkaline, mucus-like fluid before ejaculation. Lubricates the urethra; neutralises residual acidity of urine in urethra to protect sperm.

 **Note:** Overall function of accessory ducts and glands together: To transport sperm from testis to the outside, to nourish and protect sperm, to activate sperm motility, to neutralise acids, and to ensure delivery of sperm into the female reproductive tract.

Q12. What is oogenesis? Give a brief account of oogenesis.

Answer:

Oogenesis: It is the process of formation and development of a mature female gamete (ovum/egg) from the diploid germ cells (oogonia) in the ovary. Unlike spermatogenesis (which begins at puberty), oogenesis BEGINS during foetal development (before birth) but is completed only after fertilisation.

Process of Oogenesis (chronological account):

Phase 1 — During Foetal Development (before birth):

10. Primordial germ cells in the foetal ovary proliferate by mitosis to form a large number of oogonia ($2n$).
11. Oogonia enter Meiosis I but STOP at the Prophase I stage — they are now called Primary oocytes ($2n$).
12. Each primary oocyte gets surrounded by a single layer of granulosa cells to form a Primordial follicle.
13. A baby girl is born with approximately 2 million primary oocytes — arrested in Prophase I.

Phase 2 — At Puberty (during each menstrual cycle):

14. At puberty, some primordial follicles start maturing under FSH influence → primary follicle → secondary follicle → Graafian follicle (mature follicle).
15. Just before ovulation, the primary oocyte RESUMES meiosis I and completes it — producing a large Secondary oocyte (n) and a tiny First Polar Body (n).
16. The secondary oocyte immediately enters Meiosis II but STOPS again at Metaphase II.
17. Ovulation occurs — the secondary oocyte (arrested at Meiosis II) is released from the Graafian follicle.

Phase 3 — Only if fertilisation occurs:

18. If a sperm penetrates the secondary oocyte, Meiosis II is COMPLETED → producing the mature Ovum (n) + Second Polar Body (n).
19. If fertilisation does NOT occur, the secondary oocyte degenerates.

Summary: 1 Oogonium (2n) → 1 functional Ovum (n) + 3 polar bodies (n, all degenerate)

 **Note:** Key differences from spermatogenesis: (1) Oogenesis is ASYMMETRIC — one large ovum + 3 tiny polar bodies (vs. 4 equal sperms). (2) Oogenesis begins before birth; spermatogenesis begins at puberty. (3) Meiosis in oogenesis is arrested TWICE (prophase I and metaphase II). (4) Only 1 egg/month is released; millions of sperm are produced daily.

 **Diagram:** Refer to Figure 2.6 in the textbook — it shows the complete process of oogenesis from oogonia to mature ovum with all stages (primary oocyte, Graafian follicle, ovulation, secondary oocyte, polar bodies) clearly illustrated.

Q13. Draw a labelled diagram of a section through an ovary.

Answer:

A section through a mammalian ovary would show follicles at various stages of development. Label the following structures:

Structures to label in an ovary section:

20. Germinal epithelium — outermost layer covering the ovary surface (single layer of cuboidal cells)
21. Tunica albuginea — fibrous capsule just beneath the germinal epithelium
22. Cortex — outer region containing follicles at various developmental stages
23. Stroma — connective tissue framework embedded with follicles
24. Primordial follicles — smallest; primary oocyte surrounded by a single flat layer of granulosa cells
25. Primary follicles — primary oocyte with multiple layers of granulosa cells
26. Secondary follicles — fluid-filled spaces (antrum) beginning to form; zona pellucida visible around oocyte
27. Graafian follicle (mature follicle) — large, fluid-filled (antrum); contains the secondary oocyte surrounded by zona pellucida and corona radiata; bulges from ovary surface
28. Corpus luteum — yellowish glandular structure formed after ovulation from remnants of Graafian follicle; secretes progesterone
29. Corpus albicans — white scar tissue; degenerated corpus luteum
30. Medulla — inner region with blood vessels, nerves, and lymphatic vessels

 **Diagram:** Refer to Figure 2.5 in the textbook — it shows a diagrammatic section through a mammalian ovary with all stages of follicular development arranged in a clear developmental sequence. This is a high-value exam diagram. Draw an oval shape, place follicles at different stages around the cortex, and show the corpus luteum and corpus albicans as well.

Q14. Draw a labelled diagram of a Graafian follicle.

Answer:

A Graafian follicle is the large, mature ovarian follicle just before ovulation. It is the final stage of follicular development.

Structures to label in a Graafian follicle:

31. Theca externa — outer fibrous layer of the follicle wall
32. Theca interna — inner cellular layer; secretes androgens (converted to estrogen by granulosa cells)

33. Basement membrane — separates theca from granulosa cells
34. Granulosa cells — multiple layers of cells lining the follicle; secrete estrogen (aromatase converts androgens to estrogen); become luteal cells after ovulation
35. Antrum — large, fluid-filled cavity within the follicle; filled with follicular fluid (liquor folliculi) rich in estrogen
36. Corona radiata — innermost layer of granulosa cells that directly surround the secondary oocyte; they travel with the egg after ovulation
37. Zona pellucida — transparent, glycoprotein layer between the oocyte and corona radiata; sperm must penetrate this during fertilisation
38. Secondary oocyte (with first polar body) — the female gamete; arrested at Metaphase II; located eccentrically in the follicle on a mound called cumulus oophorus
39. Cumulus oophorus — mound of granulosa cells on which the secondary oocyte sits, projecting into the antrum

 **Diagram:** Refer to Figure 2.5 in the textbook (Graafian follicle detail). Draw a large oval representing the follicle, show the central antrum, place the secondary oocyte (with zona pellucida and corona radiata) eccentrically on the cumulus oophorus, and label the granulosa cells, theca layers, and antrum.

 **Note:** Why is the Graafian follicle important? It is the source of the egg that is released during ovulation, AND it is the source of estrogen during the follicular phase of the menstrual cycle. After ovulation, it transforms into the corpus luteum.

Q15. Name the functions of the following: (a) Corpus luteum, (b) Endometrium, (c) Acrosome, (d) Sperm tail, (e) Fimbriae

Answer:

Structure	Functions
(a) Corpus luteum	1. Secretes progesterone (primary function) — which maintains and thickens the endometrium to prepare it for implantation of the blastocyst. 2. Also secretes small amounts of estrogen. 3. If fertilisation occurs → corpus luteum persists (maintained by hCG from embryo) and continues secreting progesterone throughout early pregnancy. 4. If fertilisation does NOT occur → corpus luteum degenerates into corpus albicans (white scar tissue) → progesterone falls → menstruation occurs.
(b) Endometrium	1. Innermost, glandular mucous membrane lining the uterus. 2. Site of IMPLANTATION of the blastocyst (embryo). 3. Provides nutrition to the early embryo before placenta is formed. 4. The endometrium undergoes cyclical changes during the menstrual cycle — proliferates under estrogen, becomes secretory under progesterone, and is shed during menstruation when hormone levels fall.
(c) Acrosome	1. Cap-like structure on the head of the sperm, derived from the Golgi complex. 2. Contains hydrolytic enzymes — hyaluronidase (dissolves hyaluronic acid in corona radiata), acrosin (protease that digests zona pellucida proteins). 3. During fertilisation, the ACROSOMAL REACTION occurs — the acrosome ruptures and releases these enzymes, allowing the sperm to penetrate the zona pellucida and reach the egg plasma membrane.

(d) Sperm tail (Flagellum)	1. The longest part of the sperm; provides MOTILITY to the sperm. 2. Contains the axoneme (9+2 arrangement of microtubules) — generates the whip-like beating movement. 3. ATP produced by mitochondria in the midpiece powers the dynein motor proteins in the axoneme, causing the flagellar beat. 4. Enables sperm to swim through the female reproductive tract to reach the egg.
(e) Fimbriae	1. Finger-like projections at the open, infundibular end of the fallopian tube (oviduct). 2. Primary function: to COLLECT the released egg (secondary oocyte) from the surface of the ovary after ovulation and sweep it into the fallopian tube. 3. Lined with ciliated cells whose beating motion and muscular contractions of the fimbriae direct the egg into the tube. 4. This is critical because the ovary and the fallopian tube are NOT directly connected — the egg must be 'caught' by the fimbriae.

 **Note:** Exam tip: All five structures have very specific, examinable functions. Remember: Corpus luteum = progesterone = maintains pregnancy. Acrosome = enzymes = penetrates egg. Fimbriae = collects egg from ovary surface.

Q16. Identify True/False statements. Correct each false statement to make it true.

Answer:

Statement	T / F	Correction (if False)
(a) Androgens are produced by Sertoli cells.	FALSE	Androgens are produced by LEYDIG CELLS (interstitial cells), not Sertoli cells. Sertoli cells secrete ABP, inhibin, and nutrients.
(b) Spermatozoa get nutrition from Sertoli cells.	TRUE	— (Already correct. Sertoli cells are called 'nurse cells' because they provide lactate, pyruvate, and other nutrients to developing germ cells.)
(c) Leydig cells are found in ovary.	FALSE	Leydig cells are found in the TESTIS (in the interstitial tissue between seminiferous tubules), NOT in the ovary.
(d) Leydig cells synthesise androgens.	TRUE	— (Already correct. Leydig cells produce testosterone and other androgens in response to LH stimulation.)
(e) Oogenesis takes place in corpus luteum.	FALSE	Oogenesis takes place in the OVARY (specifically in the ovarian follicles within the cortex of the ovary). Corpus luteum is the post-ovulatory structure that secretes progesterone.
(f) Menstrual cycle ceases during pregnancy.	TRUE	— (Already correct. During pregnancy, rising progesterone

		and estrogen suppress GnRH/FSH/LH, preventing follicular development and ovulation, so menstrual cycles stop.)
(g) Presence or absence of hymen is not a reliable indicator of virginity or sexual experience.	TRUE	— (Already correct. The hymen can be absent, torn, or remain intact due to various physical activities (sports, tampon use, etc.) unrelated to sexual activity. It is NOT a reliable indicator of virginity.)

Q17. What is menstrual cycle? Which hormones regulate the menstrual cycle?

Answer:

Menstrual Cycle: It is the cyclical, rhythmic series of physiological changes that occur in the reproductive tract of female primates (including humans) approximately every 28–29 days, from puberty to menopause (~13–45 years of age). It prepares the uterus for pregnancy each month. If fertilisation does not occur, the thickened endometrium is shed as menstrual flow (the period).

Phases of the Menstrual Cycle:

40. Menstrual Phase (Day 1–5): Shedding of the endometrium (blood, mucus, cells). Caused by fall in progesterone and estrogen. Day 1 is the first day of bleeding.
41. Follicular / Proliferative Phase (Day 1–13): FSH stimulates follicle growth → estrogen rises → endometrium proliferates/rebuilds. Culminates in the LH surge on Day 13.
42. Ovulatory Phase (Day 14): LH surge triggers ovulation — the secondary oocyte is released from the Graafian follicle.
43. Luteal / Secretory Phase (Day 15–28): Corpus luteum forms → secretes progesterone + estrogen → endometrium becomes thick and glandular (secretory). If no pregnancy → corpus luteum degenerates → hormones fall → cycle repeats.

Hormones regulating the Menstrual Cycle:

Hormone	Source	Role
GnRH	Hypothalamus	Stimulates pituitary to release FSH and LH — the master regulator
FSH (Follicle Stimulating Hormone)	Anterior Pituitary	Stimulates follicle growth and estrogen secretion by granulosa cells
LH (Luteinising Hormone)	Anterior Pituitary	LH surge triggers ovulation; stimulates corpus luteum formation and progesterone secretion
Estrogen (Estradiol)	Ovarian follicle / Corpus luteum	Causes endometrial proliferation; at high levels causes LH surge (positive feedback); develops secondary sexual characters
Progesterone	Corpus luteum (mainly)	Maintains secretory endometrium for implantation; prevents further

		ovulation during luteal phase; inhibits uterine contractions during pregnancy
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 **Note:** Simple flow: Hypothalamus → GnRH → Pituitary → FSH+LH → Ovary → Estrogen+Progesterone → Uterus changes. Rising estrogen causes the LH surge (positive feedback) → ovulation. Then corpus luteum forms → progesterone rises → if no pregnancy, corpus luteum dies → progesterone falls → menstruation.

Q18. What is parturition? Which hormones are involved in induction of parturition?

Answer:

Parturition: It is the process of delivery (expulsion) of the fully developed foetus from the uterus to the outside world at the end of gestation (pregnancy). In humans, normal gestation lasts approximately 9 months (38–40 weeks). Parturition is also called **CHILDBIRTH** or **LABOUR**.

How parturition is triggered — the neuroendocrine mechanism:

44. At the end of pregnancy, the fully mature foetus signals readiness for birth. This is initiated by signals from the mature foetus itself.
45. The foetal signals cause mild uterine contractions (called foetal ejection reflex).
46. These contractions stimulate the release of oxytocin from the posterior pituitary of the mother.
47. Oxytocin causes stronger uterine contractions → more oxytocin released → even stronger contractions (a positive feedback loop).
48. This builds up to the intense, coordinated contractions of labour that expel the baby, followed by the placenta.

Hormones involved in induction of parturition:

Hormone	Role in Parturition
Oxytocin (from posterior pituitary)	PRIMARY hormone of parturition. Causes strong, rhythmic uterine contractions (myometrium). A positive feedback loop amplifies contractions. Oxytocin receptor number in uterus increases dramatically near term. (Note: Synthetic oxytocin — Pitocin/Syntocinon — is used medically to induce labour.)
Cortisol (from foetal adrenal cortex)	Rising foetal cortisol signals foetal maturity and triggers the onset of parturition. It initiates the shift in placental hormone production from progesterone to estrogen, which sensitises the uterus to oxytocin.
Estrogens (from placenta)	As pregnancy nears term, estrogen levels rise. Estrogen: (1) increases uterine sensitivity to oxytocin by upregulating oxytocin receptors; (2) promotes prostaglandin synthesis; (3) softens the cervix (cervical ripening).
Prostaglandins (local hormones)	Produced by uterine tissues near term. Stimulate powerful uterine muscle contractions, work synergistically with oxytocin. Also involved in cervical ripening.
Relaxin (from corpus luteum/placenta)	Relaxes the pubic symphysis and softens/dilates the cervix to allow passage of the foetus.

 **Note:** Summary: Foetal cortisol → shifts placenta to make more estrogen → more oxytocin receptors → oxytocin released → uterine contractions → positive feedback loop → stronger contractions → delivery. Parturition is one of the few examples of a POSITIVE FEEDBACK mechanism in the body (contractions cause more oxytocin, which causes more contractions).

Q19. In our society women are often blamed for giving birth to daughters. Can you explain why this is not correct?

Answer:

This social belief is completely scientifically incorrect. The sex of the baby is determined by the genetic contribution of the FATHER, not the mother.

Scientific explanation:

49. Human cells have 46 chromosomes (23 pairs). Of these, 44 are autosomes and 2 are sex chromosomes.

50. Females have sex chromosomes XX — both chromosomes are X.

51. Males have sex chromosomes XY — one X and one Y chromosome.

52. When a female (XX) forms eggs during meiosis, ALL eggs carry exactly ONE X chromosome. (No Y chromosomes are available for the female to pass on.)

53. When a male (XY) forms sperm during meiosis, 50% of sperms carry an X chromosome and 50% carry a Y chromosome.

54. If an X-bearing sperm fertilises the egg → XX → FEMALE baby (daughter)

55. If a Y-bearing sperm fertilises the egg → XY → MALE baby (son)

Therefore: The sex of the child is entirely determined by WHICH TYPE OF SPERM (X or Y) fertilises the egg. The mother ALWAYS contributes an X chromosome. The father determines whether the child will be XX (daughter) or XY (son).

 **Note:** Social significance: Blaming women for the sex of their child is not only scientifically wrong but also reflects gender discrimination. The sex-determining chromosome (Y) is present only in males. A woman has NO Y chromosome to pass on — she can only give an X. It is the sperm (from the father) that carries either X or Y and therefore determines the sex of the child. This has been established scientific fact since the early 20th century.

Q20. How many eggs are released by a human ovary in a month? How many eggs would have been released if the mother gave birth to identical twins? Would your answer change if the twins born were fraternal?

Answer:

Part 1: Normal release per month

In a normal menstrual cycle, ONE egg (secondary oocyte) is released by ONE ovary per month during ovulation. The two ovaries alternate in releasing eggs (usually). So: 1 egg per month per cycle.

Part 2: Identical (Monozygotic) Twins

56. Identical twins arise from a SINGLE egg fertilised by a SINGLE sperm → forming ONE zygote.

57. At an early stage of development (typically at 2-cell or blastocyst stage), this ONE zygote splits into two separate embryos.

58. Since identical twins come from one egg, only ONE egg was released by the ovary.

59. Both twins are genetically identical (same DNA) and always the same sex.

Answer: 1 egg was released.

Part 3: Fraternal (Dizygotic) Twins — Does the answer change?

60. YES, the answer changes for fraternal twins.

61. Fraternal (non-identical) twins arise from TWO separate eggs released in the same cycle (super-ovulation), each fertilised by a DIFFERENT sperm → forming TWO separate zygotes.

62. Both embryos develop simultaneously in the uterus but are genetically different (just like normal siblings — same parents, different genetic combination).

63. Fraternal twins can be of same or different sexes.

Answer: 2 eggs were released (one from each ovary, or both from the same ovary in that cycle).

 **Note:** Memory shortcut: Identical (monozygotic) = 1 egg + 1 sperm → 1 zygote splits. Fraternal (dizygotic) = 2 eggs + 2 sperms → 2 separate zygotes. Identical twins are ALWAYS genetically identical and same sex; fraternal twins are genetically as similar as any two siblings.

Q21. How many eggs do you think were released by the ovary of a female dog which gave birth to 6 puppies?

Answer:

A female dog gave birth to 6 puppies — all 6 developed simultaneously in the same uterus. This means 6 separate embryos developed, which requires 6 separate fertilisation events.

Reasoning:

- Each puppy (offspring) arises from one fertilised egg (one zygote).
- To produce 6 separate embryos, 6 separate eggs must have been fertilised by 6 separate sperms.
- This means the dog's ovaries underwent superovulation — releasing multiple eggs in the same ovulation event.
- Dogs are polytocous animals — they regularly ovulate and release multiple eggs per cycle, allowing for large litters.

Answer: 6 eggs were released by the ovary (or ovaries) of the female dog.

 **Note:** Contrast with humans: Humans are monotocous — usually 1 egg per cycle, resulting in single births (or rarely twins/triplets). Dogs, cats, pigs, rabbits — polytocous animals — regularly release multiple eggs per cycle, resulting in litters of multiple offspring. The rule is: number of eggs released = number of offspring (when all fertilised eggs survive), assuming no identical twinning.

Chapter 3: Reproductive Health

Q1. What do you think is the significance of reproductive health in a society?

Answer:

Reproductive health refers to total well-being in ALL aspects of reproduction — physical, emotional, behavioural, and social (WHO definition). Its significance for society is wide-ranging:

A. Individual-level significance:

- **Physical well-being:** Ensures that reproductive organs function normally, free from diseases or disorders. Prevents STIs, reproductive cancers, hormonal imbalances, and infertility.
- **Emotional well-being:** Mentally healthy individuals have accurate knowledge about their reproductive roles, reducing anxiety, shame, or guilt associated with sexuality.
- **Safe practices:** Awareness about safe and hygienic sexual behaviour reduces the spread of STIs, including HIV/AIDS.

B. Family-level significance:

- **Planned families:** Couples can make informed decisions about family size using contraception, enabling better economic planning and child care.
- **Maternal and child health:** Proper antenatal and post-natal care reduces maternal mortality rate (MMR) and infant mortality rate (IMR).
- **Prevention of genetic disorders:** Techniques like amniocentesis help detect foetal abnormalities early.

C. Societal-level significance:

- **Population control:** Reproductive health education and contraceptive use help control population explosion — a major threat to resources.
- **Gender equality:** Reproductive health programmes promote equal opportunities for boys and girls and discourage female foeticide.
- **Reduced social evils:** Awareness helps combat sex abuse, sex-related crimes, and exploitation.
- **Economic development:** Healthier families contribute more productively to the economy.

 **Note:** India was the FIRST country in the world to launch national-level Family Planning Programmes in 1951, recognising reproductive health as a social goal. These evolved into the Reproductive and Child Health (RCH) programmes that continue today.

Q2. Suggest the aspects of reproductive health which need to be given special attention in the present scenario.

Answer:

In today's world, the following aspects of reproductive health need urgent attention:

1. **Sex education and awareness:** Despite progress, myths and misconceptions about sex, puberty, and reproduction still persist — especially in rural areas. Comprehensive, age-appropriate sex education in schools is critical.
2. **Adolescent reproductive health:** The 15–24 age group is most vulnerable to STIs, unplanned pregnancies, and sexual abuse. Targeted education about safe sexual practices, consent, and reproductive rights is essential.
3. **Control of STIs including HIV/AIDS:** STIs remain a major public health threat. Early detection, destigmatisation, and promotion of condom use must be prioritised.
4. **Population stabilisation:** Though India's population growth rate has declined, it remains significant. Better contraceptive awareness, especially in rural and semi-urban areas, is needed.

5. Prevention of female foeticide: Illegal use of amniocentesis and other prenatal tests for sex determination and subsequent abortion of female fetuses is a grave problem. Strict enforcement of the PCPNDT Act is necessary.
6. Maternal and infant health: Reducing MMR and IMR through medically assisted deliveries, post-natal care, and immunisation programmes remains vital — especially in rural areas with limited healthcare access.
7. Infertility management: Access to ART (Assisted Reproductive Technologies) is limited to urban areas. More widespread, affordable infertility clinics are needed.
8. Mental and emotional well-being: Social stigma around reproductive health issues, sexual abuse, and infertility causes psychological distress. Counselling services need to be integrated into reproductive healthcare.
9. MTP awareness and access: Illegal and unsafe abortions remain a leading cause of maternal mortality. Awareness about legal, safe MTP services must be increased.

 **Note:** The present scenario is characterised by rapid urbanisation, widespread use of social media (often spreading misinformation), increasing teenage sexual activity, and persisting gender inequality — all of which make reproductive health education more critical than ever.

Q3. Is sex education necessary in schools? Why?

Answer:

YES, sex education is absolutely necessary in schools. Here is a detailed justification:

Arguments in FAVOUR of sex education in schools:

10. Replaces myths with facts: Children and adolescents often obtain sexual information from unreliable sources — peers, internet, pornography — which are rife with inaccuracies. School-based sex education provides scientifically accurate, age-appropriate information.
11. Puberty and adolescent changes: Young people undergo significant physical and emotional changes during puberty. Understanding these changes — menstruation, voice changes, development of secondary sexual characters — reduces confusion, anxiety, and embarrassment.
12. Prevention of STIs and HIV/AIDS: Informed adolescents are more likely to adopt safe sexual practices and use condoms, significantly reducing the spread of STIs including HIV. India has one of the highest rates of new HIV infections globally, particularly among 15–24 year olds.
13. Prevention of teenage pregnancy: Knowledge about contraception and responsible sexual behaviour helps reduce unwanted teenage pregnancies, which carry serious health and social consequences.
14. Protection against abuse: Children who understand concepts of personal boundaries, consent, and inappropriate touch are better equipped to recognise and report sexual abuse.
15. Promotes gender equality: Sex education promotes respect for the opposite gender, debunks patriarchal myths, and teaches that both sexes have equal rights in reproductive decisions.
16. Supports population control: Awareness about family planning from a young age contributes to long-term population stabilisation goals.

 **Note:** Sex education should be: (1) age-appropriate, (2) factual and scientifically accurate, (3) inclusive and sensitive, (4) taught by trained educators. It is NOT promotion of sexual activity — research globally shows sex education DELAYS sexual initiation and INCREASES safe behaviour.

Q4. Do you think that reproductive health in our country has improved in the past 50 years? If yes, mention some such areas of improvement.

Answer:

YES. India has made remarkable progress in reproductive health over the past 50 years, though challenges remain.

Area of Improvement	Evidence / Details
Decline in Maternal Mortality Rate (MMR)	MMR has dropped significantly — from over 600 per lakh live births in the 1970s to around 97 per lakh live births (2018–20). This is due to better antenatal care, skilled birth attendants, and institutional deliveries.
Decline in Infant Mortality Rate (IMR)	IMR fell from ~165 per 1000 live births at independence to around 28 per 1000 (2020). Better nutrition, immunisation, and post-natal care are key reasons.
Improved birth control awareness	Contraceptive prevalence has increased. Family planning programmes have led to a reduction in the total fertility rate (TFR) from ~6 in 1950s to ~2 today, near replacement level.
STI detection and cure	Better diagnosis, treatment centres, and awareness have improved early detection and treatment of curable STIs. Free antiretroviral therapy (ART) for HIV-positive patients has been a major advance.
Amniocentesis and prenatal diagnosis	Though misused for sex determination (hence banned), amniocentesis is now used legitimately for early detection of genetic disorders like Down syndrome, haemophilia, and sickle-cell anaemia.
Development of indigenous contraceptives	India developed 'Saheli' — a non-steroidal once-a-week oral contraceptive at CDRI, Lucknow — showing capability in reproductive research.
Legal framework	MTP Act (1971, amended 2017), PCPNDT Act (banning sex determination), and Protection of Children from Sexual Offences (POCSO) Act strengthen reproductive rights.
Assisted Reproductive Technologies (ART)	IVF, ICSI, GIFT and other ART methods are now available in India, helping infertile couples have children.

 **Note:** Despite improvements, challenges remain — high teenage pregnancy rates in rural areas, maternal mortality in remote regions, sex-selective abortions, and limited ART accessibility. The journey is ongoing.

Q5. What are the suggested reasons for population explosion?

Answer:

The world population grew from about 2 billion in 1900 to 7.2 billion by 2011. India's population crossed 1.2 billion in 2011. The following factors are responsible for this rapid population growth:

Primary causes:

17. **Rapid decline in Death Rate:** Medical advancements, better nutrition, improved sanitation, and vaccination programmes dramatically reduced the death rate. People are living longer. However, birth rates did NOT fall proportionally — this gap drove population growth.
18. **Decline in Maternal Mortality Rate (MMR):** Better obstetric care means fewer women die during childbirth, preserving the reproductive population.

19. Decline in Infant Mortality Rate (IMR): More children surviving to adulthood means more people entering the reproductive age group in the next generation, accelerating growth.
20. Increase in reproductive age population: A large proportion of the population falling in the 15–49 age group (reproductive years) means a high birth rate even if the fertility rate per woman is declining.

Contributing social factors:

- Low literacy and lack of family planning awareness: In many rural areas, awareness about contraception is limited. Cultural or religious beliefs may also discourage family planning.
- Early marriage: Though the legal age has been raised (18 for females, 21 for males), child marriages still occur in some communities, extending reproductive years.
- Son preference: Desire for a male child leads to continued childbearing, inflating family sizes.
- Poverty: In poor families, children are seen as economic assets (extra earning hands), leading to larger families.

 **Key Point:** The population growth rate (as of 2011 census) was less than 2%, i.e., 20 per 1000 per year. While this sounds small, applied to a base of 1.2 billion people, it means millions are added every year — hence 'population explosion'. Doubling time at 2% growth = ~35 years.

Q6. Is the use of contraceptives justified? Give reasons.

Answer:

YES, the use of contraceptives is justified. Although they are used against a natural reproductive event (conception), they serve vital personal, social, and public health purposes.

Justifications FOR contraceptive use:

21. Population control: Uncontrolled population growth leads to scarcity of food, shelter, water, and employment. Contraceptives are a key tool for population stabilisation — a national necessity for a country like India.
22. Maternal health: Repeated pregnancies at short intervals deplete a woman's nutritional reserves and increase risk of maternal mortality. Spacing pregnancies using contraceptives protects maternal health.
23. Child health: Closely spaced pregnancies mean each child gets less care and nutrition. Contraceptive use allows proper time between pregnancies for the child to be adequately nurtured.
24. Prevention of unwanted pregnancy: Contraceptives prevent unintended pregnancies resulting from consensual or non-consensual intercourse, reducing the need for MTPs (abortions).
25. STI prevention (condoms): Barrier methods like condoms serve a dual purpose — they prevent both pregnancy AND the transmission of STIs including HIV/AIDS. This is a major public health benefit.
26. Personal autonomy: Contraceptives empower individuals — especially women — to control their own reproductive choices and plan their families according to their economic and personal circumstances.
27. Emergency situations: Emergency contraceptives used within 72 hours after rape or contraceptive failure are medically and ethically justified.

Important caution:

Contraceptives should be used under medical guidance. Possible side effects (nausea, irregular bleeding, hormonal imbalances, rarely breast cancer) should not be ignored. They should not be used as a substitute for regular healthcare.

 **Note:** An ideal contraceptive: user-friendly, easily available, effective, reversible, minimal side effects, does not interfere with sexual drive or the act. No single contraceptive meets ALL criteria — choice should be individualised after medical consultation.

Q7. Removal of gonads cannot be considered as a contraceptive option. Why?

Answer:

Gonads are the primary reproductive organs — testes in males and ovaries in females.

Why gonadectomy (removal of gonads) is NOT a contraceptive option:

28. Irreversibility: Contraceptives, by definition, must be REVERSIBLE methods (or at least terminal without causing other health damage). Removal of gonads is a permanent, irreversible procedure. Once removed, they cannot be restored.
29. Loss of gamete production only prevents conception in a limited sense — it causes PERMANENT sterility, not contraception: Contraception implies the temporary prevention of conception. Gonad removal causes permanent sterility — a far more drastic outcome.
30. Loss of hormone production: This is the most critical reason. Gonads are not just gamete factories — they are also major endocrine (hormone-secreting) glands:
 - Testes produce testosterone → essential for male secondary sexual characteristics (voice, muscle mass, facial hair, libido, bone density, mood)
 - Ovaries produce estrogen and progesterone → essential for female secondary sexual characteristics, menstrual cycle, bone density, cardiovascular health, and mood
 Removal causes hypogonadism — a serious medical condition with wide-ranging health consequences including osteoporosis, cardiovascular disease, sexual dysfunction, and severe psychological effects.
31. Hormonal collapse: Surgical removal of ovaries in pre-menopausal women (oophorectomy) leads to surgical menopause — with severe hot flashes, night sweats, vaginal dryness, depression, and accelerated bone loss. Similarly, castration (orchidectomy) in males leads to severe hormonal deficiency.
32. Ethical and medical principle: Acceptable contraceptive methods must be health-preserving, not health-damaging. Removing healthy organs violates the principle of medical ethics (primum non nocere — first, do no harm).

 **Note:** Contrast with sterilisation (vasectomy/tubectomy): These ARE accepted contraceptive methods because they ONLY block gamete transport through ducts, WITHOUT removing the gonads. Hormone production continues normally after vasectomy or tubectomy. This is why they are acceptable; gonad removal is not.

Q8. Amniocentesis for sex determination is banned in our country. Is this ban necessary? Comment.

Answer:

YES, the ban is absolutely necessary and well-justified.

What is amniocentesis?

Amniocentesis is a prenatal diagnostic technique in which a small amount of amniotic fluid (surrounding the foetus in the uterus) is extracted using a needle and analysed. The foetal cells and dissolved substances in this fluid can reveal:

- Chromosomal abnormalities (Down syndrome, Turner syndrome, Klinefelter syndrome)
- Genetic disorders (haemophilia, sickle-cell anaemia, Tay-Sachs disease, cystic fibrosis)
- Metabolic disorders
- The sex of the foetus (XX = female, XY = male)

Why the ban on sex determination is necessary:

33. Female foeticide epidemic: India has a deeply entrenched cultural preference for male children (economic reasons, dowry system, social status). When amniocentesis reveals a female foetus, it has frequently been followed by termination of pregnancy — female foeticide. This practice is widespread, illegal, and devastating.
34. Skewed sex ratio: The consequences are visible — India's sex ratio is severely skewed in many states (e.g., Haryana: 879 females per 1000 males; Punjab: 893 per 1000 — 2011 census). This creates a demographic catastrophe.
35. Social consequences: Fewer women leads to increased violence against women, trafficking, forced marriages, and social instability.
36. Discrimination and rights violation: Sex-selective abortion denies the female foetus the right to life. It is a form of gender-based discrimination at its most extreme.

Legal framework:

India enacted the Pre-conception and Pre-natal Diagnostic Techniques (PCPNDT) Act, 1994 (amended 2003), which strictly prohibits using any prenatal diagnostic technique for sex determination. Violators face imprisonment up to 3 years and fines.

Amniocentesis for legitimate medical purposes remains ALLOWED:

- Detecting chromosomal and genetic abnormalities (where sex is not the purpose)
- Assessing foetal lung maturity
- When the foetus is at high genetic risk (family history of genetic disorder)

 **Note:** The ban is a targeted restriction on a specific MISUSE of the technology — not a ban on the technology itself. This balance between allowing legitimate medical use while preventing misuse reflects sound public policy. The ban also challenges the deep-rooted social attitudes that devalue female children.

Q9. Suggest some methods to assist infertile couples to have children.

Answer:

Infertility is defined as the inability to conceive after 2 years of regular unprotected sexual cohabitation. It can result from problems in either partner. The following Assisted Reproductive Technologies (ART) are available:

Technique	Full Form / Description	Suitable For
IVF + ET	In Vitro Fertilisation + Embryo Transfer ('Test Tube Baby' programme). Ova from wife/donor and sperm from husband/donor are collected and fertilisation is induced in the lab. The resulting embryo is then transferred back to the female.	When normal fertilisation inside the body is not possible. Most widely used ART.
ZIFT	Zygote Intra Fallopian Transfer. A zygote or early embryo (up to 8 blastomeres) formed by IVF is transferred into the fallopian tube (not uterus).	When uterus cannot support implantation but fallopian tube is functional.
IUT	Intra Uterine Transfer. Embryos with more than 8 blastomeres (formed by IVF) are transferred directly into the uterus.	When fallopian tube is blocked or damaged.

GIFT	Gamete Intra Fallopian Transfer. A donor ovum is collected and transferred into the fallopian tube of a woman who cannot produce eggs but has a functional reproductive tract.	Women who cannot produce eggs but can carry a pregnancy.
ICSI	Intra Cytoplasmic Sperm Injection. A single sperm is directly injected into the ovum under microscope in the laboratory.	Severe male infertility — very low sperm count or poor motility. Most advanced ART.
AI / IUI	Artificial Insemination / Intra-Uterine Insemination. Collected semen (from husband or healthy donor) is introduced artificially into the vagina or uterus.	When male partner cannot inseminate the female naturally, or has very low sperm count.
Surrogacy	A surrogate mother carries the embryo (formed from the couple's gametes via IVF) in her uterus and delivers the baby.	When the female partner cannot carry a pregnancy due to uterine problems.
Adoption	Legal adoption of a child. India's laws permit it and it remains one of the most humane solutions.	Any infertile couple; provides a home for orphaned children.

 **Note:** All ART methods require specialised professionals and expensive equipment, so they are currently available only in select urban centres. Emotional, religious, and social factors also influence couples' choices. Legal adoption remains one of the most accessible and socially valuable options.

Q10. What are the measures one has to take to prevent from contracting STDs?

Answer:

Sexually Transmitted Infections (STIs) — also called Venereal Diseases (VD) or Reproductive Tract Infections (RTI) — include gonorrhoea, syphilis, genital herpes, chlamydia, genital warts, trichomoniasis, hepatitis-B, and HIV/AIDS. Prevention is the best strategy.

Preventive measures:

37. Avoid sex with unknown/multiple partners: The risk of contracting STIs is directly proportional to the number of sexual partners. Monogamous relationships with a tested, uninfected partner greatly reduce risk.
38. Consistent and correct use of condoms: Condoms (both male and female types) are highly effective barriers against most STIs when used correctly and consistently during every act of coitus. They are the ONLY contraceptive method that also protects against STIs.
39. Early detection and complete treatment: If any symptoms appear (itching, unusual discharge, sores, pain in genital area), consult a qualified doctor IMMEDIATELY. Early treatment is highly effective for most STIs (except hepatitis-B, genital herpes, and HIV, which are not completely curable). Never self-medicate or ignore symptoms.
40. Avoid sharing injection needles and syringes: HIV and hepatitis-B can be transmitted through contaminated needles. Always use sterile, single-use needles for injections.
41. Safe blood transfusion: Ensure blood transfusions only from screened, certified blood banks. Both HIV and hepatitis-B can be transmitted through infected blood.
42. Vaccination: Hepatitis-B can be prevented by vaccination. HPV (Human Papilloma Virus — which causes genital warts and cervical cancer) vaccines are now available and recommended for adolescents.

43. Awareness and education: Understanding what STIs are, how they spread, and how to prevent them is foundational. Social stigma must be reduced so people seek timely help without shame.
44. Prevent mother-to-child transmission: HIV-positive pregnant women should receive antiretroviral therapy (ART) to prevent transmission to the foetus. Medical supervision during delivery and guidance on breastfeeding are essential.

 **Key Point:** STIs are most prevalent in the 15–24 age group. Most STIs have mild early symptoms (or none at all, especially in females), making them easy to miss. Untreated STIs can lead to pelvic inflammatory disease (PID), infertility, ectopic pregnancy, still births, and even reproductive cancers. Early detection is CRITICAL.

Q11. State True/False with explanation for each statement.

Answer:

Statement	T / F	Explanation
(a) Abortions could happen spontaneously too.	TRUE	YES — spontaneous abortion (miscarriage) occurs naturally when a pregnancy fails due to chromosomal abnormalities, hormonal problems, infections, uterine issues, or maternal health conditions. It is NOT always deliberately induced. MTP (Medical Termination of Pregnancy) refers to induced/voluntary abortion, but abortion as a phenomenon includes spontaneous events.
(b) Infertility is defined as the inability to produce a viable offspring and is always due to abnormalities/defects in the female partner.	FALSE	PARTIAL CORRECTION: While the definition of infertility is broadly correct (inability to conceive after 2 years of regular unprotected cohabitation), it is NOT always due to female abnormalities. Infertility can result from problems in the MALE partner (low sperm count, poor motility, erectile dysfunction), the FEMALE partner, or BOTH. In India, despite the social tendency to blame women, problems often lie with the male partner. Causes include physical, congenital, disease-related, drug-related, immunological, or psychological factors in either partner.
(c) Complete lactation could help as a natural method of contraception.	TRUE	YES — this is the Lactational Amenorrhea Method (LAM). During intense, complete breastfeeding after childbirth, prolactin levels remain elevated, which suppresses GnRH release → FSH and LH are suppressed → ovulation does NOT occur → no menstrual cycle → no chance of conception. HOWEVER, this method is effective ONLY up to a maximum of 6 months after parturition, AND only if the mother is

		fully (exclusively) breastfeeding. It is not reliable after 6 months or if breastfeeding is partial.
(d) Creating awareness about sex related aspects is an effective method to improve reproductive health of the people.	TRUE	YES — awareness is the FOUNDATION of reproductive health improvement. Knowing about reproductive organs, safe practices, contraception, STIs, adolescent changes, and legal rights empowers people to make informed decisions. Awareness reduces: unwanted pregnancies, STI transmission, maternal mortality, female foeticide, and sex-related crimes. It is the primary and most cost-effective tool for societal reproductive health improvement, as stated by WHO and India's RCH programme.

Q12. Correct the following statements:

Answer:

Incorrect Statement	Corrected Statement
(a) Surgical methods of contraception prevent gamete formation.	CORRECTED: Surgical methods of contraception (vasectomy in males; tubectomy in females) prevent GAMETE TRANSPORT, not gamete formation. Explanation: In vasectomy, the vas deferens is cut and tied — sperm continue to be produced in the testes but cannot reach the outside. In tubectomy, the fallopian tubes are cut and tied — ova continue to be produced by the ovaries but cannot travel to the uterus. The gonads are intact and continue to function normally. Only the transport pathway is blocked.
(b) All sexually transmitted diseases are completely curable.	CORRECTED: Not all sexually transmitted infections are completely curable. Most bacterial STIs (gonorrhoea, syphilis, chlamydiasis, trichomoniasis) ARE curable with antibiotics if detected early. However, viral STIs — HIV/AIDS, genital herpes (Herpes Simplex Virus), and Hepatitis-B — are NOT completely curable. These can be managed and controlled with antiviral drugs, but the virus remains in the body and cannot be fully eliminated with current medical technology.
(c) Oral pills are very popular contraceptives among the rural women.	CORRECTED: Oral contraceptive pills are more popular among educated, urban women. In rural areas, IUDs (Intra Uterine Devices like Copper-T) and sterilisation (tubectomy) are the more widely accepted and used contraceptive methods. Rural women often have less access to medical facilities for follow-up, less literacy to follow a daily pill regimen, and less awareness about oral pills. IUDs offer long-term protection without daily compliance and are thus preferred in rural settings.

(d) In E.T. techniques, embryos are always transferred into the uterus.

CORRECTED: In Embryo Transfer (ET) techniques, embryos are NOT always transferred into the uterus. The destination depends on the embryo's stage of development: • Early embryos (up to 8 blastomeres): Transferred into the FALLOPIAN TUBE — this is called ZIFT (Zygote Intra Fallopian Transfer). • Embryos with MORE than 8 blastomeres: Transferred into the UTERUS — this is called IUT (Intra Uterine Transfer). In GIFT (Gamete Intra Fallopian Transfer), a donor ovum (not an embryo) is transferred into the fallopian tube, where it is fertilised in vivo.

 **Note:** Q12 is very commonly tested in board exams. Remember the four key corrections: (a) surgical methods block transport, not formation; (b) viral STIs are incurable; (c) rural women prefer IUDs and sterilisation over pills; (d) ZIFT goes to fallopian tube, IUT goes to uterus — depends on number of blastomeres.

— End of Solutions — Chapter 3: Reproductive Health —

NCERT Biology Class XII | All 12 Exercises Solved with Explanatory Notes

Chapter 4: Principles of Inheritance and Variation

Q1. Mention the advantages of selecting pea plant for experiment by Mendel.

Gregor Mendel chose the garden pea plant (*Pisum sativum*) for his experiments for several practical and biological reasons that made it ideal for studying inheritance:

Advantage	Explanation
Short life cycle	Pea plants complete their life cycle in one season, allowing many generations to be studied in a short time.
Easy to cultivate	They grow well in garden conditions and are easy to maintain in large numbers.
Clear contrasting traits	Pea plants have 7 pairs of sharply contrasting characters (tall/dwarf, round/wrinkled, etc.) with no intermediate forms, making analysis straightforward.
Self-pollination possible	Pea flowers are bisexual and naturally self-pollinate, allowing true-breeding lines to be maintained easily.
Cross-pollination possible	Mendel could also perform artificial cross-pollination by removing anthers (emasculation) and transferring pollen from another plant.
Large number of offspring	Each cross produces a large number of seeds/plants, providing statistically significant data.
True-breeding lines available	Varieties that bred true for specific traits over many generations were available, providing pure parental lines.

7 Traits of Mendel

Mendel worked with 7 pairs of contrasting traits: (1) Stem height – Tall/Dwarf, (2) Flower colour – Violet/White, (3) Flower position – Axial/Terminal, (4) Pod shape – Inflated/Constricted, (5) Pod colour –

Green/Yellow, (6) Seed shape – Round/Wrinkled, (7) Seed colour – Yellow/Green. His experiments ran from 1856–1863.

Q2. Differentiate between the following: (a) Dominance and Recessive (b) Homozygous and Heterozygous (c) Monohybrid and Dihybrid

(a) Dominance and Recessive:

Feature	Dominant Trait	Recessive Trait
Definition	The trait that expresses itself in both homozygous and heterozygous condition	The trait that expresses itself only in homozygous condition
Expression in F1	Always expressed in F1 hybrid	Not expressed in F1 (masked by dominant)
Notation	Represented by capital letter (e.g., T)	Represented by small letter (e.g., t)
Example	Tallness (T) in pea plant	Dwarfness (t) in pea plant
Molecular basis	Usually codes for functional enzyme or protein	Usually codes for non-functional or no enzyme

(b) Homozygous and Heterozygous:

Feature	Homozygous	Heterozygous
Definition	Both alleles for a gene are identical	Two different alleles for a gene are present
Example	TT (tall) or tt (dwarf)	Tt (tall, but carries dwarf allele)
Gametes produced	Only one type of gamete	Two different types of gametes
True breeding?	Yes – breeds true generation after generation	No – offspring show variation in F2
Also called	Pure-breeding or true-breeding	Hybrid

(c) Monohybrid and Dihybrid:

Feature	Monohybrid	Dihybrid
Definition	A cross between parents differing in ONE pair of contrasting characters	A cross between parents differing in TWO pairs of contrasting characters
Parental genotype	TT × tt	RRYY × rryy
F1 genotype	Tt	RrYy
F2 phenotype ratio	3:1 (dominant : recessive)	9:3:3:1
F2 genotype ratio	1:2:1 (AA:Aa:aa)	1:2:1:2:4:2:1:2:1
Law demonstrated	Law of Dominance & Law of Segregation	Law of Independent Assortment

Key Point

Memory trick: Mono = one trait, Di = two traits. The F2 phenotype ratio for monohybrid is 3:1, for dihybrid is 9:3:3:1 (= 3:1 × 3:1).

Q3. A diploid organism is heterozygous for 4 loci, how many types of gametes can be produced?

Formula: If an organism is heterozygous for 'n' loci, the number of types of gametes = 2^n

Given: $n = 4$ loci (4 gene pairs, each heterozygous, e.g., AaBbCcDd)

Number of gamete types = $2^4 = 2 \times 2 \times 2 \times 2 = 16$ types

Explanation: Each heterozygous locus (e.g., Aa) contributes 2 options (A or a) to each gamete. Since segregation at different loci is independent (Law of Independent Assortment), we multiply the possibilities:

- Locus 1 (Aa): gametes can have A or a → 2 options
- Locus 2 (Bb): gametes can have B or b → 2 options
- Locus 3 (Cc): gametes can have C or c → 2 options
- Locus 4 (Dd): gametes can have D or d → 2 options

Total gamete types = $2 \times 2 \times 2 \times 2 = 16$

The 16 Gamete Types

The 16 gamete types would be: ABCD, ABCd, ABcD, ABcd, AbCD, AbCd, AbcD, Abcd, aBCD, aBCd, aBcD, aBcd, abCD, abCd, abcd. Each is produced with equal frequency of 1/16.

Q4. Explain the Law of Dominance using a monohybrid cross.

Law of Dominance states:

- Characters are controlled by discrete units called factors (genes).
- Factors occur in pairs (alleles).
- In a dissimilar pair of factors, one member of the pair dominates (dominant) the other (recessive).

Monohybrid Cross Example – Tall × Dwarf pea plants:

Generation	Details
Parents (P)	Tall (TT) × Dwarf (tt) TT produces gametes: all T tt produces gametes: all t
F1 Generation	All F1 offspring: Tt (Tall) Though the genotype is Tt, the phenotype is TALL. This shows T (Tall) DOMINATES over t (dwarf). Result: 100% Tall plants
F1 Self-pollination	Tt × Tt Gametes: T and t (each 50%) F2 genotypes: TT : Tt : tt = 1 : 2 : 1
F2 Generation	Phenotype ratio = 3 Tall : 1 Dwarf TT (Tall) + Tt (Tall) + tt (Dwarf) Both T and t alleles are preserved but T dominates in Tt

How Law of Dominance is demonstrated:

- In F1, ALL plants are Tall (Tt) even though both T and t alleles are present → Dominance of T over t
- The dwarf trait (t) is not destroyed, merely 'hidden' → Both alleles preserved, no blending
- In F2, dwarf reappears ($1/4 = tt$) → Proves t was present all along, just recessive

Key Point

Dominance occurs at the molecular level: T allele codes for a functional enzyme making a pigment/protein; t allele produces no/non-functional enzyme. One functional copy (T) is sufficient for expression, so Tt looks like TT.

Q5. Define and design a test-cross.

Definition of Test Cross:

A test cross is a cross between an organism showing a dominant phenotype (whose genotype is unknown – could be TT or Tt) with the homozygous recessive parent (tt) to determine the genotype of the organism showing dominant phenotype.

Purpose: Since TT and Tt both look identical (both tall), we cannot distinguish them by appearance alone. A test cross reveals the hidden genotype.

Design of a Test Cross:

Case 1: Unknown plant is TT (Homozygous dominant)	Case 2: Unknown plant is Tt (Heterozygous)
Cross: TT × tt	Cross: Tt × tt
Gametes: T only × t only	Gametes: T or t × t only
Offspring: All Tt (Tall)	Offspring: Tt (Tall) and tt (Dwarf) in 1:1 ratio
Result: ALL offspring are TALL → Unknown was TT	Result: 50% Tall : 50% Dwarf → Unknown was Tt

Inference:

- If ALL offspring show dominant phenotype → organism is homozygous dominant (TT)
- If offspring show 1:1 ratio (dominant : recessive) → organism is heterozygous (Tt)

Why Recessive Parent?

Test cross is always done with HOMOZYGOUS RECESSIVE (tt) parent, NOT with another dominant plant. The recessive parent contributes only 't' gametes, so any dominant trait appearing in offspring must come from the test organism.

Q6. Using a Punnett Square, workout the distribution of phenotypic features in the first filial generation after a cross between a homozygous female and a heterozygous male for a single locus.

Given: Homozygous female × Heterozygous male

Since we are not told which trait, we use the example of seed colour: Yellow (Y) dominant over green (y)

Case 1 – If the female is homozygous dominant (YY) and male is heterozygous (Yy):

Female (YY) ↓ Male (Yy) →	Y (from male)	y (from male)
Y (from female)	YY (Yellow)	Yy (Yellow)
Y (from female)	YY (Yellow)	Yy (Yellow)

Result (Case 1): Genotypic ratio: 2YY : 2Yy (= 1:1). Phenotypic ratio: 4 Yellow : 0 Green = ALL Yellow (100%)

Case 2 – If the female is homozygous recessive (yy) and male is heterozygous (Yy):

Gametes: Female produces only 'y' gametes. Male produces 'Y' and 'y' gametes.

Offspring: Yy (Yellow) and yy (green) in 1:1 ratio

Phenotypic ratio: 50% Yellow : 50% green

Important Note

The question says 'homozygous female' but doesn't specify dominant or recessive. Most likely it means homozygous dominant (since that creates an interesting F1). In that case: ALL F1 offspring are phenotypically DOMINANT (100% Yellow or 100% Tall). Genotypically they are in 1:1 ratio (homozygous dominant : heterozygous).

Q7. When a cross is made between tall plant with yellow seeds (TtYy) and tall plant with green seed (Tt yy), what proportions of phenotype in the offspring could be expected to be (a) tall and green, (b) dwarf and green.

Parents: TtYy (tall, yellow) × Tt yy (tall, green)

Step 1: Analyse each gene separately (since they assort independently):

Gene 1 – Height (T gene): Tt × Tt

Offspring: TT : Tt : tt = 1 : 2 : 1 → Phenotype: 3 Tall : 1 Dwarf

Gene 2 – Seed colour (Y gene): Yy × yy

Offspring: Yy : yy = 1 : 1 → Phenotype: 1 Yellow : 1 Green (or 50% Yellow : 50% Green)

Step 2: Combine (multiply probabilities):

Phenotype	Probability Calculation	Expected Proportion
Tall and Yellow	$3/4$ (tall) × $1/2$ (yellow)	$3/8$
Tall and Green	$3/4$ (tall) × $1/2$ (green)	$3/8$
Dwarf and Yellow	$1/4$ (dwarf) × $1/2$ (yellow)	$1/8$
Dwarf and Green	$1/4$ (dwarf) × $1/2$ (green)	$1/8$

Answers:

(a) Tall and Green = $3/8$ of the offspring

(b) Dwarf and Green = $1/8$ of the offspring

Verification

Quick check: $3/8 + 3/8 + 1/8 + 1/8 = 8/8 = 1$ (all possibilities accounted for). The overall ratio is 3:3:1:1.

Q8. Two heterozygous parents are crossed. If the two loci are linked what would be the distribution of phenotypic features in F1 generation for a dihybrid cross?

Setup: Two heterozygous parents (e.g., AaBb × AaBb) are crossed. The two loci A and B are LINKED (located on the same chromosome).

Normal Expectation (Independent Assortment): If genes were on different chromosomes (unlinked), F1 would show 9:3:3:1 ratio.

What happens when genes are LINKED:

When two genes are on the same chromosome, they tend to be inherited TOGETHER (not independently). This means:

- Parental combinations (AB together, ab together) appear MORE frequently than expected
- Non-parental (recombinant) combinations (Ab, aB) appear LESS frequently than expected

Result of Linkage:

Phenotype	Expected ratio (Unlinked)	Actual ratio (Linked)
A_B_ (dominant for both)	9/16	More than 9/16 (parental)
A_bb (dominant A, recessive b)	3/16	Less than 3/16 (recombinant)
aaB_ (recessive a, dominant B)	3/16	Less than 3/16 (recombinant)
aabb (recessive for both)	1/16	More than 1/16 (parental)

The deviation from 9:3:3:1 depends on the STRENGTH of linkage:

- Tight linkage (genes very close): mostly parental types, very few recombinants → ratio close to 3:1 (only two phenotypes)
- Loose linkage (genes far apart): more recombinants → ratio approaches 9:3:3:1

Key Point

Morgan's *Drosophila* experiments proved this. White-eyed and yellow-body genes (tightly linked on X chromosome) showed only 1.3% recombination. White and miniature wing showed 37.2% recombination (loosely linked). This deviation from 9:3:3:1 is the evidence for linkage.

Q9. Briefly mention the contribution of T.H. Morgan in genetics.

Thomas Hunt Morgan (1866–1945) made some of the most fundamental contributions to modern genetics. He worked primarily with the fruit fly *Drosophila melanogaster* and received the Nobel Prize in Physiology or Medicine in 1933.

Contribution	Details
Experimental Verification of Chromosomal Theory	Morgan used <i>Drosophila</i> to experimentally confirm that genes are located on chromosomes, validating Sutton and Boveri's hypothesis.
Discovery of Linkage	Showed that genes on the same chromosome tend to be inherited together (do not assort independently). Coined the term 'linkage' for physical association of genes on a chromosome.
Discovery of Recombination	Coined the term 'recombination' for non-parental gene combinations arising due to crossing over. Showed some linked genes show more recombination than others.
Sex-linked Inheritance	Discovered sex-linked traits (e.g., white eye in <i>Drosophila</i>) and demonstrated that sex-linked genes are carried on sex chromosomes.
Chromosome Mapping (via student Sturtevant)	His student Alfred Sturtevant used recombination frequency as a measure of distance between genes and created the first genetic (linkage) maps.
<i>Drosophila</i> as Model Organism	Established <i>Drosophila melanogaster</i> as the premier model organism for genetic studies – advantages include short life cycle, large progeny, easy sex determination, and visible hereditary variations.

Morgan's Famous Crosses

Morgan worked with four genes in *Drosophila* that were sex-linked: yellow body (y), white eye (w), miniature wing (m), and rudimentary wing. His Cross A (y and w) showed 1.3% recombination (tightly linked); Cross B (w and m) showed 37.2% recombination (loosely linked). These crosses proved that recombination frequency = distance between genes on chromosome.

Q10. What is pedigree analysis? Suggest how such an analysis, can be useful.

Definition: Pedigree analysis is the study of the inheritance pattern of a particular trait, abnormality, or disease through several generations of a family, represented in a diagrammatic family tree form (pedigree chart).

How a Pedigree is constructed:

- Squares (■/□) represent males; Circles (●/○) represent females
- Filled/shaded symbols represent affected individuals
- Horizontal lines represent mating; vertical lines represent descent
- Roman numerals denote generations (I, II, III...); Arabic numerals denote individuals within a generation

How Pedigree Analysis is Useful:

Use	Explanation
Determines mode of inheritance	Can tell if a trait is dominant or recessive, autosomal or sex-linked, based on the pattern of affected individuals across generations.
Identifies carriers	Heterozygous carriers (who appear normal but carry a disease allele) can be identified, especially important for recessive disorders like haemophilia.
Genetic counselling	Helps doctors predict the probability of a genetic disorder appearing in future offspring and counsel families accordingly.
Study in absence of controlled crosses	Since controlled crosses cannot be performed in humans (unlike pea plants), pedigree analysis provides the next best way to study human inheritance.
Prenatal diagnosis guidance	Helps identify at-risk pregnancies where prenatal testing (amniocentesis, CVS) may be warranted.
Tracing genetic disorders through history	Example: Queen Victoria's pedigree showed she was a carrier of haemophilia, which was transmitted to several European royal families.

Key Point

Rules for reading a pedigree: If a disorder appears in EVERY generation → likely dominant. If it skips generations → likely recessive. If mostly males are affected → likely X-linked recessive. If both parents are unaffected but child is affected → autosomal recessive.

Q11. How is sex determined in human beings?

Sex determination in humans is of the XY type (male heterogamety type).

Chromosomal Basis:

- Humans have 46 chromosomes (23 pairs): 22 pairs of autosomes + 1 pair of sex chromosomes
- Females: 44 autosomes + XX (homogametic – produce only one type of egg carrying X)
- Males: 44 autosomes + XY (heterogametic – produce two types of sperm: X-bearing and Y-bearing)

Mechanism of Sex Determination:

Sperm Type	Outcome
X-bearing sperm (50%) + Egg (X)	XX zygote → Female offspring

Sperm Type	Outcome
Y-bearing sperm (50%) + Egg (X)	XY zygote → Male offspring

Key Points:

- It is the SPERM (father's contribution), not the egg, that determines the sex of the child.
- In each pregnancy, there is always a 50% probability of a male or female child.
- Females are homogametic (XX) → produce only X-carrying eggs.
- Males are heterogametic (XY) → produce 50% X-carrying and 50% Y-carrying sperms.
- The Y chromosome carries the SRY gene (Sex-determining Region on Y) which triggers male development.

Important Social Note

It is scientifically incorrect and socially wrong to blame women for the sex of a child. Since females produce only X-carrying eggs and males produce both X and Y-carrying sperms, the sex of the child is ALWAYS determined by the FATHER's sperm. This is also why female foeticide is a grave misunderstanding – the father determines whether a child is a girl or boy.

Q12. A child has blood group O. If the father has blood group A and mother blood group B, work out the genotypes of the parents and the possible genotypes of the other offsprings.

This question is based on the ABO blood group system, which involves multiple alleles (I^A , I^B , i) and co-dominance.

Step 1: Determine the genotypes from blood groups:

- Child has blood group O → genotype must be ii (only genotype for group O)
- Since the child got one ' i ' from father and one ' i ' from mother, BOTH parents must carry an ' i ' allele.

Step 2: Determine parental genotypes:

- Father has blood group A: can be $I^A I^A$ or $I^A i$. Since he passed ' i ' to the child → Father's genotype = $I^A i$
- Mother has blood group B: can be $I^B I^B$ or $I^B i$. Since she passed ' i ' to the child → Mother's genotype = $I^B i$

Step 3: Cross – $I^A i \times I^B i$:

↓ Father / Mother →	I^B	i
I^A	$I^A I^B$ → Blood Group AB	$I^A i$ → Blood Group A
i	$I^B i$ → Blood Group B	ii → Blood Group O

Summary:

- Father's genotype: $I^A i$ (Blood Group A)
- Mother's genotype: $I^B i$ (Blood Group B)
- Child (already born): ii (Blood Group O)
- Possible genotypes of other offspring: $I^A I^B$ (AB), $I^A i$ (A), $I^B i$ (B), ii (O)
- Phenotypic ratio: 1 AB : 1 A : 1 B : 1 O (equal probability of all four blood groups)

Key Point

This is a remarkable example of multiple alleles and co-dominance. Notice that from an A father and B mother, a child can have any of the 4 blood groups (A, B, AB, or O). This is the basis of forensic blood group matching.

Q13. Explain the following terms with example: (a) Co-dominance (b) Incomplete dominance

(a) Co-dominance:

Definition: When both alleles in a heterozygote are independently expressed simultaneously, resulting in an F1 that resembles BOTH parents at the same time. Neither allele is dominant or recessive.

Example: ABO Blood Groups in Humans

The gene I has three alleles: I^A , I^B , and i .

- When both I^A and I^B are present (genotype $I^A I^B$), BOTH produce their own type of sugar on the red blood cell surface.
- Result: Blood Group AB – the person has BOTH A and B antigens.
- Neither I^A dominates I^B nor vice versa – they are co-dominant.
- Both alleles are fully and independently expressed in the heterozygote.

(b) Incomplete Dominance:

Definition: When neither allele in a heterozygote is completely dominant over the other, the heterozygote shows an INTERMEDIATE phenotype – a blend of the two parental traits.

Example: Flower colour in Snapdragon (*Antirrhinum* sp. / dog flower)

Generation	Cross	Genotype	Phenotype
P (Parents)	Red × White	$RR \times rr$	Red × White
F1	–	All Rr	All PINK (intermediate – not red or white!)
F2 (F1 selfed)	$Rr \times Rr$	$1RR : 2Rr : 1rr$	1 Red : 2 Pink : 1 White

Explanation: R allele codes for red pigment enzyme. r allele produces no functional enzyme. In Rr heterozygotes, only ONE copy of R is present → only HALF the normal amount of pigment is made → pink colour (incomplete/intermediate).

Feature	Co-dominance	Incomplete Dominance
F1 appearance	Resembles BOTH parents simultaneously	Intermediate – resembles neither parent fully
Example	AB blood group (both A and B sugars present)	Pink snapdragon (intermediate between red and white)
F2 phenotype ratio	1:2:1 (same as genotype ratio)	1:2:1 (same as genotype ratio)
F2 genotype ratio	1:2:1	1:2:1
Nature of expression	Both alleles fully expressed	Each allele partially expressed

Q14. What is point mutation? Give one example.

Definition: Point mutation is a change in a single base pair (nucleotide) in the DNA sequence of a gene. It is the simplest type of mutation at the molecular level.

Types of Point Mutations:

- Substitution: One nucleotide is replaced by another (most common in point mutations)
- Transition: Purine replaced by purine, or pyrimidine by pyrimidine ($A \leftrightarrow G$, $C \leftrightarrow T$)
- Transversion: Purine replaced by pyrimidine or vice versa ($A \leftrightarrow C$, $A \leftrightarrow T$, $G \leftrightarrow C$, $G \leftrightarrow T$)

Example: Sickle-cell Anaemia

Level	Normal Haemoglobin (HbA)	Sickle-cell Haemoglobin (HbS)
DNA (template strand)	...CTC... at codon 6	...CAC... at codon 6 ($A \rightarrow T$ substitution)
mRNA codon	GAG (Glutamic acid)	GUG (Valine)
Amino acid at position 6	Glutamic acid (Glu) – charged, hydrophilic	Valine (Val) – non-polar, hydrophobic
Effect	Normal biconcave RBC, normal blood flow	RBC becomes sickle-shaped under low oxygen; causes anaemia, pain, organ damage

This single base substitution ($A \rightarrow T$ on template strand, $GAG \rightarrow GUG$ on mRNA) completely changes the function of haemoglobin and causes a serious disease – demonstrating the power of even a single base change.

Other Examples

Other examples of point mutations: (1) β -Thalassemia – single base mutations in the HBB gene reduce β -globin production. (2) Phenylketonuria – mutation in gene coding for phenylalanine hydroxylase enzyme. (3) Colour blindness – mutations in genes for red or green cone pigments on X chromosome.

Q15. Who had proposed the chromosomal theory of the inheritance?

The Chromosomal Theory of Inheritance was proposed by Walter Sutton and Theodore Boveri in 1902.

Scientist	Contribution
Walter Sutton (American)	Was studying grasshopper chromosomes and noticed the parallel behaviour of chromosomes during meiosis and Mendel's factors (genes). He proposed that chromosomes carry Mendel's hereditary factors (genes).
Theodore Boveri (German)	Independently arrived at the same conclusions while studying sea urchin development. He showed that each chromosome carries different information and that a complete set is needed for normal development.

Observations that led to the theory:

- Chromosomes occur in pairs $\rightarrow$ just like Mendel's 'factors' (alleles) occur in pairs
- Chromosomes segregate during meiosis $\rightarrow$ mirrors Mendel's Law of Segregation
- Different pairs of chromosomes assort independently $\rightarrow$ mirrors Law of Independent Assortment
- Only one chromosome from each pair passes to each gamete $\rightarrow$ same as one allele per gamete

Later Confirmation: Thomas Hunt Morgan's experiments with *Drosophila* (1910 onwards) provided experimental proof that genes are indeed physically located on chromosomes, further validating Sutton-Boveri's theory.

Historical Note

The Chromosomal Theory of Inheritance is sometimes called the Sutton-Boveri Theory. Mendel's work (1865) had no physical basis until chromosomes were discovered and their meiotic behaviour studied. By 1902, Sutton and Boveri united genetics and cytology.

Q16. Mention any two autosomal genetic disorders with their symptoms.

Autosomal genetic disorders are caused by mutations/abnormalities in autosomes (non-sex chromosomes). Here are two important examples:

1. Sickle-cell Anaemia (Autosomal Recessive)

Aspect	Details
Type	Autosomal recessive – requires two copies of defective allele (HbS HbS) to show disease
Cause	Point mutation in beta-globin gene (GAG→GUG) → Glutamic acid replaced by Valine at position 6 of β -chain
Symptoms	Anaemia (chronic), jaundice, severe pain crises (especially in bones and joints), swollen hands/feet, fatigue, frequent infections, delayed growth, possible organ damage
RBC changes	Red blood cells become elongated sickle/crescent shaped under low oxygen → block small blood vessels → pain and tissue damage
Carrier	HbA HbS individuals are carriers (sickle-cell trait) – appear normal but can pass HbS to offspring

2. Phenylketonuria (PKU) (Autosomal Recessive)

Aspect	Details
Type	Autosomal recessive – inborn error of metabolism
Cause	Mutation in gene coding for enzyme phenylalanine hydroxylase → cannot convert phenylalanine to tyrosine
Metabolic effect	Phenylalanine accumulates → converted to phenylpyruvic acid and other toxic derivatives → accumulate in brain
Symptoms	Intellectual disability (mental retardation), reduced hair and skin pigmentation (since tyrosine is needed for melanin production), musty odor of urine and sweat (phenylpyruvic acid excreted), seizures, behavioral problems, eczema
Treatment	Detected by Guthrie test in newborns; managed by low-phenylalanine diet. If untreated, leads to severe intellectual disability.

Mendelian vs. Chromosomal Disorders

Chromosomal disorders (like Down's syndrome, Turner's syndrome, Klinefelter's syndrome) are DIFFERENT from autosomal genetic disorders. Chromosomal disorders arise due to errors in chromosome number (trisomy, monosomy), while Mendelian/autosomal disorders are caused by mutations in individual genes.

Additional Autosomal Disorders

Other autosomal disorders you should know: (1) Thalassemia – autosomal recessive; reduced/abnormal globin chain production; anaemia. Alpha-thalassemia (chromosome 16) and Beta-thalassemia (chromosome 11). (2) Cystic Fibrosis – autosomal recessive; affects lung and digestive system due to defective chloride channel protein. (3) Huntington's disease – autosomal DOMINANT; progressive neurodegeneration.

End of Chapter 4 Solutions — Principles of Inheritance and Variation

NCERT Biology Class XII | All 16 Questions Answered

Chapter 5: Molecular Basis of Inheritance

Q1. Group the following as nitrogenous bases and nucleosides: Adenine, Cytidine, Thymine, Guanosine, Uracil and Cytosine.

A nitrogenous base is just the base molecule alone. A nucleoside = nitrogenous base + pentose sugar (but no phosphate group).

Nitrogenous Bases	Nucleosides
Adenine (purine base — A)	Cytidine (Cytosine + Ribose sugar)
Thymine (pyrimidine base — T, found in DNA)	Guanosine (Guanine + Ribose sugar)
Uracil (pyrimidine base — U, found in RNA)	
Cytosine (pyrimidine base — C)	

Easy Identification

Memory trick: Nucleosides end in '-sine' or '-dine' — these are Adenosine, Guanosine, Cytidine, Uridine, Thymidine. When a phosphate is added to a nucleoside, it becomes a nucleotide (e.g., Adenosine monophosphate = AMP). Pure bases (Adenine, Guanine, Cytosine, Thymine, Uracil) are just the ring molecules without any sugar.

Q2. If a double stranded DNA has 20 per cent of cytosine, calculate the per cent of adenine in the DNA.

Using Chargaff's Rules for double-stranded DNA:

- %C = %G (Cytosine always pairs with Guanine)
- %A = %T (Adenine always pairs with Thymine)
- %A + %T + %G + %C = 100%

Given: %C = 20%

Step 1: Since %C = %G → %G = 20%

Step 2: %C + %G = 20 + 20 = 40%

Step 3: %A + %T = 100 – 40 = 60%

Step 4: Since %A = %T → %A = %T = 60/2 = 30%

Answer: Adenine = 30%

Chargaff's Rule Calculation

Quick summary: C=20% → G=20% → C+G=40% → A+T=60% → A=T=30%. This is a standard Chargaff's rule calculation. If given A%, find T% (equal), then $G = C = (100 - A - T)/2$.

Q3. If the sequence of one strand of DNA is: 5'-ATGCATGCATGCATGCATGCATGC-3', write down the sequence of complementary strand in 5'→3' direction.

Rule: The complementary strand is antiparallel and follows base pairing rules:

A pairs with T | T pairs with A | G pairs with C | C pairs with G

Given strand (5'→3'): 5'-ATGCATGCATGCATGCATGCATGC-3'

Complementary strand (3'→5') written below the given strand:

3'-TACGTACGTACGTACGTACGTACG-5'

Now reverse this to write in 5'→3' direction:

Answer: 5'-GCATGCATGCATGCATGCATGCAT-3'

Two-step Method

Two-step approach: (1) Write the complementary bases opposite each base in the given strand (maintaining 3'→5' direction). (2) Reverse the sequence to get 5'→3' direction. The complementary strand is ALWAYS written antiparallel to the template. Note: The pattern ATGC repeats, so the complement TACG also repeats, but shifted by one position when reversed.

Q4. If the sequence of the coding strand in a transcription unit is: 5'-ATGCATGCATGCATGCATGCATGC-3', write down the sequence of mRNA.

Key concept: The mRNA sequence is the SAME as the coding strand EXCEPT that Thymine (T) is replaced by Uracil (U).

Reason: The mRNA is transcribed from the TEMPLATE strand (which is complementary/antiparallel to the coding strand). RNA polymerase reads the template strand 3'→5' and synthesises mRNA in 5'→3' direction. The resulting mRNA sequence mirrors the coding strand, but with U instead of T.

Coding strand: 5'-ATGCATGCATGCATGCATGCATGC-3'

Answer: mRNA: 5'-AUGCAUGCAUGCAUGCAUGCAUGC-3'

Coding vs Template Strand

Remember: Coding strand = Non-template strand = Same sequence as mRNA (with T→U). Template strand = Antisense strand = Complement of mRNA. The coding strand 'codes' in the sense that its sequence corresponds directly to the mRNA (and hence the protein), even though it is NOT what's being copied during transcription.

Q5. Which property of DNA double helix led Watson and Crick to hypothesise semi-conservative mode of DNA replication? Explain.

The property of COMPLEMENTARITY OF THE TWO DNA STRANDS (i.e., base pairing between complementary bases through hydrogen bonds) led Watson and Crick to propose semi-conservative DNA replication.

Watson and Crick observed in their famous statement:

"It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material." (Watson and Crick, 1953)

How Complementarity Led to the Semiconservative Model:

- (1) Each strand serves as a template: Because A always pairs with T and G always pairs with C, each strand can act as a blueprint for synthesising a new complementary strand.
- (2) Each strand contains complete information: Since the sequence of one strand predicts the other, no information is lost when strands separate.
- (3) After replication: Each daughter DNA molecule would have ONE parental strand (old) and ONE newly synthesised strand — this is semiconservative.

Meselson-Stahl Proof

Semiconservative replication was PROVEN experimentally by Meselson and Stahl (1958) using heavy nitrogen (^{15}N) labelling in *E. coli*. After one generation: all DNA was hybrid (^{15}N - ^{14}N). After two generations: 50% hybrid + 50% light (^{14}N - ^{14}N). This perfectly matched the semiconservative model predictions.

Q6. Depending upon the chemical nature of the template (DNA or RNA) and the nature of nucleic acids synthesised from it, list the types of nucleic acid polymerases.

Polymerase Type	Template	Product	Where/Example
DNA-dependent DNA polymerase	DNA	DNA	All organisms during replication (Replication)
DNA-dependent RNA polymerase	DNA	RNA	All organisms during transcription (Transcription)
RNA-dependent RNA polymerase (RdRp / Replicase)	RNA	RNA	RNA viruses (e.g., TMV, influenza) for genome copying
RNA-dependent DNA polymerase (Reverse Transcriptase)	RNA	DNA	Retroviruses (e.g., HIV) — reverse transcription

Key Historical Facts

The Central Dogma (DNA→RNA→Protein) was proposed by Francis Crick. Reverse Transcriptase was discovered independently by Howard Temin and David Baltimore in 1970 (Nobel Prize 1975). This enzyme allows HIV to insert its RNA genome into the host cell's DNA as a DNA copy (provirus). The RNA-dependent RNA polymerase in SARS-CoV-2 is the target of the antiviral drug Remdesivir.

Q7. How did Hershey and Chase differentiate between DNA and protein in their experiment while proving that DNA is the genetic material?

Hershey and Chase (1952) used the differential chemistry of DNA and protein along with radioactive isotopes to distinguish between the two:

Feature	DNA	Protein
Contains Phosphorus (P)?	YES — backbone of DNA has phosphate groups	NO — proteins do not contain phosphorus
Contains Sulfur (S)?	NO — DNA has no sulfur	YES — amino acids like Methionine and Cysteine contain sulfur
Isotope used for labelling	Radioactive ^{32}P (phosphorus-32)	Radioactive ^{35}S (sulfur-35)

Experimental Steps and Logic:

1. Two batches of T2 bacteriophage were grown: one in ^{32}P medium (labelling DNA) and one in ^{35}S medium (labelling protein coat).
2. Both labelled phages were allowed to infect *E. coli* bacteria, then separated from bacteria by blending + centrifugation.
3. Result with ^{32}P -labelled phage: Radioactivity (^{32}P) found INSIDE bacteria (not in supernatant) → DNA entered bacteria.
4. Result with ^{35}S -labelled phage: Radioactivity (^{35}S) found in SUPERNATANT (not inside bacteria) → Protein did NOT enter bacteria.

Conclusion: Only DNA was injected into the bacterium; the protein coat stayed outside. Since new phages were produced using only the injected material, DNA alone carried all the genetic information. DNA is the genetic material.

Key Point

The brilliance of the experiment lay in using the chemical difference between DNA (phosphorus) and protein (sulfur). The radioactive labels acted as molecular 'name tags' — wherever ^{32}P went, DNA went; wherever ^{35}S went, protein went.

Q8. Differentiate between: (a) Repetitive DNA and Satellite DNA (b) mRNA and tRNA (c) Template strand and Coding strand

(a) Repetitive DNA and Satellite DNA:

Feature	Repetitive DNA	Satellite DNA
Definition	DNA sequences that are repeated many times in the genome (general term)	A subset of repetitive DNA that can be separated from bulk DNA by density gradient centrifugation as distinct 'satellite' bands
Position in genome	Scattered throughout genome, near centromeres and telomeres	Primarily located near centromeres and heterochromatin regions
Detection	By DNA sequencing and hybridisation	By CsCl density gradient centrifugation — appears as separate satellite peaks
Types	Satellite DNA, Mini-satellites (VNTRs), Micro-satellites (STRs)	Sub-category of repetitive DNA: mini-satellites, micro-satellites
Coding function	Generally non-coding	Non-coding; but forms basis of DNA fingerprinting due to high polymorphism

(b) mRNA and tRNA:

Feature	mRNA (Messenger RNA)	tRNA (Transfer RNA)
Full name	Messenger RNA	Transfer RNA (also called sRNA — soluble RNA)
Function	Carries genetic information from DNA to ribosome; provides template for protein synthesis	Adapter molecule — reads mRNA codons (via anticodon) and brings specific amino acids to ribosome
Structure	Linear single-stranded molecule with 5' cap and 3' poly-A tail in eukaryotes; contains codons	Clover-leaf secondary structure (L-shaped in 3D); has anticodon loop and amino acid acceptor end (3'-OH)

Feature	mRNA (Messenger RNA)	tRNA (Transfer RNA)
Size	Variable (hundreds to thousands of nucleotides)	Small — ~73-93 nucleotides
Diversity	One mRNA per gene/operon	At least 61 types (one for each sense codon); multiple tRNAs per amino acid

(c) Template Strand and Coding Strand:

Feature	Template Strand	Coding Strand
Also known as	Antisense strand, Non-coding strand, (-) strand	Sense strand, Non-template strand, (+) strand
Polarity	3'→5' direction (read by RNA polymerase 3'→5')	5'→3' direction
Role in transcription	USED as template by RNA polymerase to synthesise mRNA	NOT used as template — it is displaced during transcription
Relationship to mRNA	Complementary to mRNA (opposite sequence)	SAME sequence as mRNA (except T instead of U)
Naming paradox	Actually directly involved in making RNA (so more 'active')	Called 'coding' because its sequence matches the protein code, even though it doesn't directly act as template

Q9. List two essential roles of ribosome during translation.

The ribosome plays two essential roles during translation:

Role 1 — Structural Platform for mRNA-tRNA Interaction:

The ribosome has a small subunit and a large subunit. The small subunit binds to mRNA and facilitates the reading of codons. The large subunit has two binding sites (A site — aminoacyl site, and P site — peptidyl site) that hold two adjacent charged tRNAs in the correct position so their anticodons align with consecutive mRNA codons. This ensures accurate codon-anticodon recognition.

Role 2 — Catalysis of Peptide Bond Formation (Ribozyme Activity):

The ribosome acts as a ribozyme (RNA-based enzyme). The 23S rRNA of the large subunit (in bacteria) catalyses the formation of the peptide bond between the amino acid on the A-site tRNA and the growing polypeptide chain on the P-site tRNA. This is an example of RNA acting as an enzyme (ribozyme), suggesting that life began with RNA.

Additional Ribosome Functions

Additional roles: The ribosome also moves (translocates) along the mRNA in the 5'→3' direction after each amino acid addition, exposing the next codon. It also recognises the stop codon (via release factor, NOT a tRNA) and releases the completed polypeptide. In bacteria, multiple ribosomes can translate a single mRNA simultaneously (polysome = polyribosome).

Q10. In the medium where *E. coli* was growing, lactose was added, which induced the lac operon. Then, why does lac operon shut down some time after addition of lactose in the medium?

This question tests understanding of the lac operon regulation mechanism. The answer lies in what happens to lactose over time:

Step-by-step explanation:

1. Lactose added → enters cells via permease → some lactose is converted to allolactose (a metabolite of lactose by beta-galactosidase at basal levels).
2. Allolactose acts as inducer → binds to lac repressor → repressor changes shape → can no longer bind to operator.
3. RNA polymerase accesses promoter → lac operon is transcribed → z, y, a genes expressed → beta-galactosidase, permease, transacetylase are produced.
4. Beta-galactosidase actively metabolises lactose → breaks lactose into galactose + glucose.
5. Over time, ALL the lactose in the medium is consumed/metabolised by E. coli.
6. With no lactose left: No more allolactose (inducer) is produced.
7. Without inducer: The repressor (constitutively synthesised from i gene) is now free and ACTIVE.
8. Active repressor binds back to operator → blocks RNA polymerase → lac operon shuts down.

Elegant Self-Regulation

In simple terms: Lactose is both the INDUCER (via allolactose) and the SUBSTRATE (broken down by beta-galactosidase). When bacteria finish eating all the lactose, there is no more inducer, so the repressor reasserts control and turns off the operon — an elegant example of resource-saving gene regulation. The operon only stays ON as long as there is lactose present and preferred carbon sources (like glucose) are absent.

Q11. Explain (in one or two lines) the function of the followings: (a) Promoter (b) tRNA (c) Exons

(a) Promoter:

The promoter is a specific DNA sequence located upstream (5'-end/before the start) of a structural gene in a transcription unit. It provides the binding site for RNA polymerase, thus determining where transcription begins and which strand of DNA will be used as the template. It essentially 'switches on' gene transcription.

(b) tRNA (Transfer RNA):

tRNA acts as an ADAPTER molecule during translation. It has two functional ends: the anticodon loop (which base-pairs with the complementary mRNA codon to 'read' the genetic code) and the amino acid acceptor end (3'-OH, which binds to the specific amino acid corresponding to that codon). It physically bridges the gap between the nucleotide language of mRNA and the amino acid language of proteins.

(c) Exons:

Exons are the coding sequences (expressed sequences) in eukaryotic genes that appear in the mature, processed mRNA. In eukaryotes, genes are 'split' — exons are interrupted by non-coding introns. After transcription, introns are removed by splicing and exons are joined together to form functional mRNA that codes for proteins. The word 'exon' = expressed sequence.

Memory Aids

Easy memory: Exons = EXpressed sequences (kept in final mRNA). Introns = INTRvening sequences (removed/spliced out). Promoter = the 'on switch' for transcription. tRNA = the 'translator' that converts codon language to amino acid language.

Q12. Why is the Human Genome project called a mega project?

The Human Genome Project (HGP) is called a mega project because of its enormous scale, cost, technical complexity, duration, and impact. Here are the reasons:

Aspect	Why it was 'MEGA'
Scale of data	Human genome has $\sim 3 \times 10^9$ bp (3 billion base pairs). If stored in books (1000 letters/page, 1000 pages/book), it would require 3300 books!
Cost	Estimated cost was $\sim \$3$ per base pair $\times$ 3 billion bp = approximately 9 billion US dollars total
Duration	13-year project (1990–2003); chromosome 1 sequence completed only in May 2006
International collaboration	Coordinated by US Dept. of Energy + NIH; major partners: UK (Wellcome Trust), Japan, France, Germany, China
Technical challenge	Required development of BAC and YAC vectors, automated DNA sequencers (Sanger method), and entirely new computer programs for sequence alignment
Bioinformatics impact	Generated so much data that it necessitated creation of an entirely new scientific field — Bioinformatics — for data storage, retrieval, and analysis
Goals	Identify 20,000-25,000 genes; sequence 3 billion base pairs; address ethical/legal/social issues (ELSI); transfer technologies to industry
Impact	Changed all of biological research — from studying individual genes to whole-genome approaches; enabled personalised medicine, new diagnostics, genomics of other organisms

Key Point

HGP salient findings: 3164.7 million bp total; $\sim 30,000$ genes (far fewer than estimated); $>50\%$ gene functions unknown; $<2\%$ genome codes for protein; repeated sequences form very large portion; Chromosome 1 has most genes (2968); Y chromosome has fewest (231); ~ 1.4 million SNP locations identified.

Q13. What is DNA fingerprinting? Mention its application.

Definition of DNA Fingerprinting:

DNA fingerprinting (also called DNA profiling or DNA typing) is a forensic technique used to identify individuals by their unique DNA patterns. It is based on the fact that every individual (except identical/monozygotic twins) has unique repetitive DNA sequences called Variable Number of Tandem Repeats (VNTRs) or mini-satellites.

Principle: About 99.9% of human DNA sequences are identical in all humans, but the 0.1% that differs — particularly in repetitive sequences — shows high polymorphism. The pattern of bands produced by VNTRs is unique to each individual.

Steps in DNA Fingerprinting (originally developed by Alec Jeffreys):

- (i) Isolation of DNA from sample (blood, saliva, hair follicle, skin, bone, sperm, etc.)
- (ii) Digestion of DNA with restriction endonucleases
- (iii) Separation of DNA fragments by gel electrophoresis
- (iv) Blotting of fragments to nylon/nitrocellulose membrane (Southern blotting)
- (v) Hybridisation with radiolabelled VNTR probe

(vi) Autoradiography — bands appear as 'fingerprint' pattern

Applications:

Application	Details
Forensic Science	Identifying criminals/suspects from crime scene samples (blood, semen, hair, skin cells). DNA from crime scene compared with suspects.
Paternity/Maternity Testing	Resolving disputes about biological parentage — child's DNA bands should match 50% from each parent (VNTR polymorphisms are inherited)
Immigration Disputes	Verifying biological family relationships for immigration claims
Identifying Victims	Identifying bodies in mass disasters (wars, accidents, natural disasters) — match DNA with known family members
Population Genetics	Studying genetic diversity within and between populations; tracing human migration and evolutionary history
Wildlife Conservation	Determining parentage, poaching detection, species identification, breeding programs
Medical Research	Genetic disease mapping, identifying disease-associated genes, genome mapping

Modern Development

Modern DNA fingerprinting uses PCR-based methods — even a single cell is sufficient for analysis! This dramatically increased sensitivity. The technique now often uses STRs (Short Tandem Repeats / microsatellites) instead of the original VNTR probe method, as STR analysis is faster and more reliable.

Q14. Briefly describe the following: (a) Transcription (b) Polymorphism (c) Translation (d) Bioinformatics

(a) Transcription:

Transcription is the process of copying genetic information from ONE strand of DNA (template strand) into a complementary RNA molecule, catalysed by RNA polymerase.

Stage	Details
Initiation	RNA polymerase binds to promoter (with sigma factor in bacteria). Template strand is identified. Transcription bubble opens.
Elongation	RNA polymerase moves along template strand 3'→5', synthesises complementary RNA in 5'→3' direction using NTPs. A pairs with U (not T) in RNA.
Termination	Polymerase reaches terminator sequence; rho (ρ) factor assists termination in bacteria; nascent RNA and polymerase are released.

In eukaryotes: Additional processing of hnRNA — capping (5'-methyl guanosine triphosphate added), tailing (poly-A tail of 200-300 adenylates added at 3'-end), and splicing (introns removed, exons joined) → mature mRNA transported to cytoplasm.

(b) Polymorphism:

Polymorphism refers to the existence of two or more variants (alleles) at a genetic locus in a population at a frequency greater than 0.01 (1%). It arises due to mutations — when a heritable mutation occurs in germ cells and spreads through sexual reproduction to affect more than 1% of the population, it is called DNA polymorphism.

Types: Single Nucleotide Polymorphisms (SNPs), VNTRs (Variable Number Tandem Repeats), STRs (Short Tandem Repeats). Polymorphism in non-coding regions accumulates faster since it has no direct effect on fitness.

Significance: (i) Basis of DNA fingerprinting, (ii) Used in genetic mapping of human genome, (iii) Associated with susceptibility to certain diseases, (iv) Basis of evolutionary biology and population genetics.

(c) Translation:

Translation is the process of decoding the genetic information in mRNA to synthesise a specific polypeptide (protein). It occurs at ribosomes.

Stage	Details
Activation	Amino acids are activated in presence of ATP and attached to their cognate tRNA (aminoacylation/charging of tRNA).
Initiation	Ribosome assembles at AUG (start codon) on mRNA; initiator tRNA (Met-tRNA) recognises AUG.
Elongation	Charged tRNAs sequentially bind to A-site; peptide bond forms between amino acids (catalysed by 23S rRNA = ribozyme); ribosome translocates along mRNA codon by codon.
Termination	Stop codon (UAA, UAG, or UGA) reached; release factor binds; polypeptide released from ribosome.

(d) Bioinformatics:

Bioinformatics is an interdisciplinary field that uses computer science, mathematics, and statistics to store, retrieve, analyse, and interpret biological data — particularly large-scale genomic and proteomic data. It emerged as a necessity during the Human Genome Project due to the enormous amount of sequence data generated.

Key tools and applications: Sequence databases (GenBank, EMBL, DDBJ), sequence alignment algorithms (BLAST, CLUSTAL), genome annotation software, protein structure prediction, phylogenetic analysis, drug target identification, SNP analysis, and systems biology. Bioinformatics has revolutionised biology from a small-scale to a data-intensive, hypothesis-generating science.



How They Connect

These four terms are interconnected: Transcription produces RNA from DNA → Translation produces protein from RNA (together = gene expression). Polymorphism in DNA is the basis of genetic variation and DNA fingerprinting. Bioinformatics helps analyse the enormous amounts of data generated in studying all of the above at genome-wide scale.

Chapter 6: Evolution

Section 1: Key Concepts at a Glance

This section provides a concise summary of all important topics covered in Chapter 6, serving as a quick reference for revision.

1.1 Origin of Life

- Universe is ~13.8 billion years old; Earth formed ~4.5 billion years ago.
- Big Bang theory explains origin of universe: singular explosion → expansion → cooling → formation of H and He → galaxies.
- Early Earth had no free oxygen; atmosphere contained CH₄, NH₃, H₂O vapour, H₂.
- Life appeared ~4 billion years ago (500 million years after Earth's formation).
- Theories on origin of life:
 - Panspermia: Life (spores) came from outer space — favoured by some astronomers.
 - Spontaneous Generation: Life from non-living matter (straw, mud) — disproved by Louis Pasteur.
 - Chemical Evolution (Oparin-Haldane): Life arose from non-living organic molecules formed under early Earth conditions.
- Miller-Urey Experiment (1953): S.L. Miller simulated early Earth conditions (CH₄, H₂, NH₃, H₂O vapour, electric discharge at 800° C) → amino acids formed. This supported chemical evolution.
- First non-cellular life forms: ~3 billion years ago (giant RNA/Protein molecules).
- First cellular life: ~2000 million years ago (single cells, in water).

1.2 Evolution of Life Forms — Darwin's Theory

- Special Creation Theory (pre-Darwin): All species created as they are; Earth ~4000 years old. Strongly challenged in the 19th century.
- Charles Darwin — observations from H.M.S. Beagle voyage → Theory of Natural Selection.
- Key conclusions: Life forms share common ancestors; extinctions occurred; gradual evolution took place.
- Fitness = Reproductive fitness (ability to leave more progeny in a given environment).
- Natural Selection: Those better adapted survive and reproduce more; nature selects for fitness.
- Alfred Wallace independently reached similar conclusions around the same time.
- Two key concepts of Darwinian Theory: Branching Descent and Natural Selection.

1.3 Evidences for Evolution

- Paleontological (Fossil) Evidence: Fossils in rock sediments; different ages → different life forms; study of geological time-spans.
- Embryological Evidence: Ernst Haeckel proposed embryos of all vertebrates show gill slits (vestigial). Karl Ernst von Baer refuted this — embryos never pass through adult stages of other animals.
- Comparative Anatomy and Morphology:
 - Homologous Organs: Same structure, different functions (e.g., forelimbs of whales, bats, cheetah, humans — all have humerus, radius, ulna, carpals). Result of Divergent Evolution.

- Analogous Organs: Different structure, same function (e.g., wings of butterfly and bird, eye of octopus and mammals). Result of Convergent Evolution.
- Industrial Melanism (England): Before industrialisation — white moths dominant; after industrialisation — dark moths dominant (tree trunks darkened). Shows natural selection in action.
- Biochemical Evidence: Similar proteins/genes across organisms indicate common ancestry.
- Artificial Selection: Man-made breeds (e.g., dogs) within hundreds of years support the idea that nature can do the same over millions.

1.4 Adaptive Radiation

- Process of evolution of different species from a single ancestral form in a geographical area, radiating to various habitats.
- Example 1 — Darwin's Finches (Galapagos Islands): Seed-eating ancestor → multiple species with varied beaks (insectivorous, vegetarian, etc.).
- Example 2 — Australian Marsupials: From one ancestral stock evolved many marsupials (kangaroo, koala, wombat, Tasmanian wolf, etc.).
- When multiple adaptive radiations occur in isolated areas producing similar forms: called Convergent Evolution (e.g., Placental wolf vs. Tasmanian wolf).

1.5 Biological Evolution

- Natural selection acts on heritable genetic variation.
- Fitness has a genetic basis — adaptive ability is inherited.
- Lamarck's Theory (prior to Darwin): Evolution by use and disuse of organs (e.g., giraffes stretching necks) — inheritance of acquired characters. No longer accepted.
- Hugo de Vries: Mutations (large sudden changes) cause evolution — called Saltation. Opposed to Darwin's gradual, directional variations.
- Branching descent + Natural selection = Core of Darwinism.

1.6 Hardy-Weinberg Principle

- Allele frequencies in a population remain constant from generation to generation (genetic equilibrium), if no evolutionary force acts.
- For two alleles A (freq p) and a (freq q): $p + q = 1$; genotype frequencies: p^2 (AA) + $2pq$ (Aa) + q^2 (aa) = 1.
- Five factors disturb Hardy-Weinberg equilibrium (causes evolution):
 - Gene Migration / Gene Flow
 - Genetic Drift (random change in allele frequency)
 - Mutation
 - Genetic Recombination
 - Natural Selection
- Founder Effect: When drifted population establishes a new colony with different gene frequencies.
- Natural selection types: Stabilisation, Directional change, Disruption (Figure 6.8 in textbook).

1.7 A Brief Account of Evolution (Timeline)

Time (mya)	Key Event
~2000 mya	First cellular life forms appeared (single cells in water)
~500 mya	Invertebrates formed and active

~350 mya	Jawless fish evolved; fish with fins could move on land (lobefins)
~320 mya	Sea weeds and early plants on land
~200 mya	Some land reptiles returned to water (Ichthyosaurs)
~65 mya	Dinosaurs disappeared; mammals and birds diversified
~15 mya	Primates Dryopithecus and Ramapithecus existing
~3-4 mya	Man-like primates (hominids) walked upright in East Africa
~2 mya	Australopithecines in East Africa; Homo habilis (brain: 650-800cc)
~1.5 mya	Homo erectus in Java (brain: ~900cc)
1,00,000–40,000 ya	Neanderthal man (brain: 1400cc); used hides, buried dead
~75,000–10,000 ya	Modern Homo sapiens (ice age)
~18,000 ya	Pre-historic cave art (e.g., Bhimbetka, Madhya Pradesh)
~10,000 ya	Agriculture began; human settlements started

1.8 Human Evolution (Section 6.9)

- ~15 mya: Dryopithecus (ape-like) and Ramapithecus (more man-like); hairy, walked like gorillas.
- ~3-4 mya: Hominids, ~4 feet tall, upright walking, fossils found in Ethiopia & Tanzania.
- ~2 mya: Australopithecines — hunted with stone weapons, ate fruit mainly.
- Homo habilis — first true hominid; brain: 650–800cc; did not eat meat.
- Homo erectus (~1.5 mya, Java fossils) — brain ~900cc; probably ate meat.
- Neanderthal man — brain 1400cc; lived 1,00,000–40,000 ya; used hides, buried dead.
- Homo sapiens — arose in Africa; spread across continents; modern form during ice age (75,000–10,000 ya).
- Cave art ~18,000 ya; Agriculture ~10,000 ya.

Section 2: Exercise Solutions

Detailed answers to all textbook exercises (Chapter 6, NCERT Biology Class 12).

Q1. Explain antibiotic resistance observed in bacteria in light of Darwinian selection theory.

Answer:

Bacteria, like all organisms, show natural variation in their genetic makeup. In any large bacterial population, a few individuals may carry random mutations that make them less susceptible — or resistant — to a particular antibiotic. When antibiotics are administered, they act as a selection pressure:

- Susceptible bacteria (the majority) are killed by the antibiotic.
- Resistant bacteria (those with beneficial mutations) survive and reproduce rapidly.
- Since bacteria reproduce in very short time cycles (minutes to hours), within a few generations the entire population can be dominated by the resistant strain.

This is exactly what Darwin's Natural Selection predicts: heritable variations that enhance survival are 'selected' by the environment (here, the antibiotic). The resistant organisms have higher reproductive fitness in the antibiotic-containing environment. Over multiple generations, the resistant type becomes the new 'normal' population.

This is also an example of evolution by anthropogenic action — human use of antibiotics drives the selection process. It also demonstrates that evolution is not directed; it is stochastic — the resistance mutation pre-existed in the population and was simply selected for, not created by the antibiotic.

Q2. Find out from newspapers and popular science articles any new fossil discoveries or controversies about evolution.

Answer:

(This is an activity-based question. Below are well-known examples students can refer to or expand upon with current research:)

- Discovery of *Homo naledi* (2015, South Africa): A new species of archaic human found in the Rising Star Cave system. It had both primitive and advanced features, challenging the linear view of human evolution.
- *Homo luzonensis* (2019, Philippines): Fossils discovered showing a previously unknown ancient human species that lived ~67,000 years ago, suggesting multiple hominin lineages coexisted in Southeast Asia.
- *Ardipithecus ramidus* ('Ardi'): A 4.4-million-year-old hominid fossil from Ethiopia that pushed back the evidence for upright walking.
- Feathered dinosaur fossils (China): Discoveries of *Anchiornis* and *Microraptor* confirmed the dinosaur-bird evolutionary link, supporting the view that birds are living dinosaurs.
- Controversy — Piltdown Man: A famous scientific fraud (1912–1953) where a skull was fabricated to 'fill a gap' in human evolution. Eventually exposed using fluorine dating.
- *Tiktaalik roseae* (2004): A transitional fossil ('fishapod') between fish and four-limbed vertebrates, showing the fish-to-land transition in evolution.

Q3. Attempt giving a clear definition of the term 'species'.

Answer:

A species is a group of organisms that share common morphological, physiological, and genetic characteristics and are capable of interbreeding among themselves to produce fertile offspring, but are reproductively isolated from members of other such groups.

Key aspects of this definition:

- Morphological similarity: Members look broadly alike.
- Genetic compatibility: They share a common gene pool.
- Reproductive isolation: They do not normally interbreed with other species; even if they do, offspring are infertile (e.g., mule from horse × donkey).

Note: This is the Biological Species Concept (Ernst Mayr). However, it has limitations — it cannot apply to asexually reproducing organisms (bacteria, some plants) or to fossils. Hence, other concepts like Morphological Species Concept and Phylogenetic Species Concept are also used.

Q4. Try to trace the various components of human evolution (hint: brain size and function, skeletal structure, dietary preference, etc.)

Answer:

Human evolution can be traced through several interrelated components:

a) Brain Size

Hominin	Brain Capacity (cc)	Approximate Time
<i>Homo habilis</i>	650–800 cc	~2 mya
<i>Homo erectus</i>	~900 cc	~1.5 mya

Neanderthal	~1400 cc	1,00,000–40,000 ya
Modern Homo sapiens	~1350–1450 cc	~75,000 ya – present

b) Skeletal Structure

- Early hominids (Dryopithecus, Ramapithecus, ~15 mya): walked on all fours, like gorillas.
- ~3-4 mya hominids: upright bipedal walking (~4 feet tall); S-shaped spine developed.
- Skull shape changed: smaller jaws, larger brain case, reduced brow ridges over time (as seen in Figure 6.11: baby chimp skull resembles adult human skull more than adult chimp skull).
- Modern Homo sapiens: fully upright posture, reduced body hair, dexterous hands with opposable thumbs.

c) Dietary Preference

- Early hominids and Australopithecines: primarily frugivorous (fruit-eating); used stone tools for hunting.
- Homo habilis: probably did not eat meat.
- Homo erectus: likely ate meat (associated with use of fire for cooking).
- Neanderthal and Homo sapiens: omnivorous; evidence of hunting large animals and gathering.
- ~10,000 ya: Agriculture developed → shift to cultivated grains and domesticated animals.

d) Tool Making and Cultural Evolution

- Stone Age tools: crude stone weapons (Australopithecines) → refined hand axes (Homo erectus) → sophisticated tools (Homo sapiens).
- Use of fire: Homo erectus onwards.
- Language development: Likely in Homo sapiens with brain complexity; enabled social cooperation.
- Cave art: ~18,000 ya (e.g., Bhimbetka, Madhya Pradesh) shows symbolic thinking.

Q5. Find out through internet and popular science articles whether animals other than man have self-consciousness.

Answer:

Self-consciousness refers to the ability to recognise oneself as an individual distinct from the environment and other individuals. The Mirror Self-Recognition (MSR) test is the most common benchmark used to test self-awareness in animals.

Animals that have passed the MSR test:

- Great Apes: Chimpanzees, bonobos, orangutans, and gorillas (some individuals) have shown self-recognition.
- Bottlenose Dolphins: Can recognise themselves in mirrors.
- Asian Elephants: Certain individuals recognise their own reflection and show self-directed behaviour.
- Eurasian Magpies: The only known non-mammal to pass the MSR test.
- Orcas (Killer Whales): Some evidence of self-recognition.

These findings suggest that self-consciousness is not unique to humans, but exists in varying degrees across cognitively advanced species. However, the extent and nature of self-awareness likely differ significantly from human self-consciousness, which includes complex introspection, language, and abstract thought.

Q6. List 10 modern-day animals and link them to a corresponding ancient fossil. Name both.

Answer:

Modern Animal	Ancient Fossil Ancestor
Horse (<i>Equus caballus</i>)	Eohippus (<i>Hyracotherium</i>) — 55 mya, dog-sized
Elephant (<i>Elephas maximus</i>)	Moeritherium — ~37 mya, pig-sized, semi-aquatic
Whale (<i>Balaenoptera musculus</i>)	Pakicetus — ~53 mya, land-dwelling mammal
Bird (<i>Columba livia</i> — pigeon)	Archaeopteryx — ~150 mya, transitional dinosaur-bird
Crocodile (<i>Crocodylus niloticus</i>)	Protosuchus — ~195 mya, early crocodilian
Human (<i>Homo sapiens</i>)	<i>Homo erectus</i> — ~1.5 mya
Dog (<i>Canis lupus familiaris</i>)	Hesperocyon — ~40 mya, ancestral canid
Frog (<i>Rana tigrina</i>)	Triadobatrachus — ~250 mya, early frog-like amphibian
Shark (<i>Carcharodon carcharias</i>)	<i>Carcharodon megalodon</i> — ~23 mya, giant extinct shark
Ginkgo tree (<i>Ginkgo biloba</i>)	Ginkgoites — ~270 mya fossil relative

Q7. Practise drawing various animals and plants.

Answer:

(This is a practical/activity exercise. Students are encouraged to draw the following key organisms mentioned in the chapter:)

- Darwin's Finches — four beak types (seed-eater, insectivore, cactus-feeder, etc.)
- Homologous forelimbs — human arm, whale flipper, bat wing, cheetah forelimb
- Australian marsupials — kangaroo, koala, wombat, Tasmanian wolf
- Moth variants — white-winged and dark-winged (melanised) pepper moths
- Dinosaurs — *Tyrannosaurus rex*, *Stegosaurus*, *Triceratops*, *Brachiosaurus*
- Early plants — Rhynia-type, Psilophyton, Ferns, Cycads, Angiosperms
- Human skull comparison — modern *Homo sapiens*, Neanderthal, *Homo erectus*

Q8. Describe one example of adaptive radiation.

Answer:

Adaptive Radiation of Darwin's Finches in the Galapagos Islands

During his voyage, Darwin observed several species of small black birds (later called Darwin's Finches) on the Galapagos Islands. He concluded that all these species had evolved from a single ancestral seed-eating finch that originally colonised the islands.

Over time, due to different food sources available in different habitats on the islands, variations in beak shape were naturally selected:

- Thick, crushing beak — for seed-eating.
- Slender, pointed beak — for catching insects (insectivorous finches).
- Long, probing beak — for feeding on cactus flowers and nectar.
- Woodpecker-like beak — for extracting insects from tree bark.

Each beak type was suited to a particular food source and ecological niche. This is the classic example of adaptive radiation — a single ancestral species giving rise to multiple descendant species, each adapted to a different environment or food source, radiating out from a common geographic origin.

This process is driven by: natural selection acting on heritable variation, ecological opportunity (multiple niches available), and geographic isolation enabling divergence.

Q9. Can we call human evolution as adaptive radiation?

Answer:

Human evolution shows some features of adaptive radiation, but it is not a textbook case of adaptive radiation. Let us examine both sides:

Similarities with Adaptive Radiation:

- Humans (*Homo sapiens*) originated from a single ancestral stock in Africa and spread across all continents — a geographic radiation from a common origin.
- Different human populations adapted to different environments (cold, tropical, high altitude) — showing some degree of ecological divergence.
- The hominin lineage shows branching descent from common ancestors (*Dryopithecus* → *Australopithecus* → *Homo habilis* → *Homo erectus* → *Homo sapiens*).

Differences from Classic Adaptive Radiation:

- In adaptive radiation (e.g., Darwin's finches), multiple distinct species arise and occupy different ecological niches. In human evolution, there is ultimately only one surviving species — *Homo sapiens*.
- Adaptive radiation typically involves diversification of form and function (beaks, limbs). Human evolution is more about increasing brain size, cognitive ability, tool use, and language — not a dramatic diversification of body form.
- Human populations, while diverse, remain a single interbreeding species — not reproductively isolated groups.

Conclusion: Human evolution cannot be strictly called adaptive radiation, but rather a linear (with some branching) evolution driven by increasing brain capacity, intelligence, and cultural adaptation — not morphological diversification into multiple ecologically distinct species.

Q10. Trace the evolutionary stages of any one animal — the Horse (*Equus caballus*).

Answer:

Evolution of the Horse — A Classic Case Study

The evolution of the horse is one of the best-documented cases in paleontology, showing gradual changes in size, limb structure, dental structure, and toe reduction over ~55 million years.

Ancestor	Time (mya)	Size / Toes	Key Feature
Eohippus (Hyracotherium)	~55 mya	Dog-sized / 4 toes (front)	Forest browser; low-crowned teeth
Mesohippus	~40 mya	Sheep-sized / 3 toes	Longer legs; adapted to open woodland
Merychippus	~20 mya	Larger / 3 toes (side toes small)	High-crowned teeth; grazed on grass
Pliohippus	~10 mya	Horse-sized / 1 toe (functional)	First one-toed horse; strong hooves
Equus (modern horse)	~4 mya–present	Large / 1 toe (hoof)	Fully adapted for running on open plains

Evolutionary Trends in Horse Evolution:

- Increase in body size (from dog-sized to horse-sized).

- Reduction in number of toes: 4 → 3 → 1 (the single hoof = a modified third toe).
- Elongation of limbs for speed — adaptation from forest to open grassland.
- Changes in teeth: low-crowned → high-crowned (from browsing leaves to grazing tough grass).
- Increase in brain size and sensory capabilities.

Horse evolution is driven by changing environments — as forests gave way to grasslands, horses that could run faster on hard ground and digest tough grass had higher fitness. This is directional natural selection over millions of years.

Section 3: Important Terms & Definitions

Quick reference glossary for Chapter 6 — Evolution:

Evolution: Change in the heritable characteristics of biological populations over successive generations.

Natural Selection: Process by which organisms with heritable traits better suited to the environment survive and reproduce more successfully.

Fitness: Reproductive fitness — the ability to survive and leave more progeny in a given environment.

Adaptive Radiation: Evolution of different species from a single ancestor, radiating to occupy various ecological niches in a geographical area.

Homologous Organs: Organs with same basic structure/embryonic origin but performing different functions; indicate common ancestry (divergent evolution).

Analogous Organs: Organs with different structures but performing similar functions; result of convergent evolution.

Divergent Evolution: Evolution from a common ancestor into different forms due to different environmental pressures.

Convergent Evolution: Independent evolution of similar traits in unrelated lineages due to similar environmental pressures.

Hardy-Weinberg Principle: Allele frequencies in a population remain constant across generations in the absence of evolutionary forces.

Genetic Drift: Random change in allele frequencies in a small population due to chance events.

Founder Effect: Loss of genetic variation when a new population is established by a small number of individuals from a larger population.

Gene Flow: Transfer of alleles between populations through migration.

Mutation: Random change in the DNA sequence; provides raw material for evolution.

Saltation: Single-step large mutation causing speciation (proposed by Hugo de Vries).

Panspermia: Hypothesis that life exists throughout the universe and was carried to Earth by meteors or comets.

Chemical Evolution: Formation of complex organic molecules from simple inorganic molecules, preceding the origin of life (Oparin-Haldane hypothesis).

Fossil: Preserved remains or traces of ancient organisms found in rock sediments.

Industrial Melanism: Increase in the proportion of dark-coloured (melanised) moths in polluted industrial areas — a classic example of natural selection.

Speciation: Process by which new species arise from existing species.

Biogenesis: The principle that life arises only from pre-existing life.

Chapter 7: Human Health and Disease

Section 1: Key Concepts at a Glance

A concise summary of all major topics in Chapter 7 for quick revision.

1.1 Definition of Health

- Health is NOT merely absence of disease or physical fitness.
- WHO defines health as a state of complete physical, mental and social well-being.
- Health is affected by: (i) Genetic disorders, (ii) Infections, (iii) Lifestyle (diet, exercise, habits).
- Balanced diet, personal hygiene, regular exercise, and Yoga are essential for good health.

1.2 Common Diseases in Humans

Disease-causing organisms are called pathogens (bacteria, viruses, fungi, protozoans, helminths).

Disease	Pathogen / Causative Agent	Mode of Transmission	Key Symptoms
Typhoid	Salmonella typhi (Bacterium)	Contaminated food/water	High fever (39–40° C), headache, stomach pain, constipation
Pneumonia	Streptococcus pneumoniae / Haemophilus influenzae	Inhaled droplets, shared utensils	Fever, chills, cough; lips may turn bluish in severe cases
Common Cold	Rhino viruses	Inhaled droplets, contaminated objects	Nasal congestion, sore throat, cough (3–7 days)
Malaria	Plasmodium (P. vivax, P. malaria, P. falciparum)	Bite of female Anopheles mosquito	High fever (chill) every 3–4 days, due to haemozoin release
Amoebiasis	Entamoeba histolytica (Protozoan)	Contaminated food/water; houseflies	Constipation, abdominal cramps, bloody mucous stools
Ascariasis	Ascaris (roundworm, helminth)	Contaminated water/vegetables	Internal bleeding, muscular pain, fever, anaemia, intestinal blockage
Filariasis / Elephantiasis	Wuchereria bancrofti / W. malayi	Bite of female mosquito vectors	Chronic inflammation of lymphatic vessels, gross limb deformity
Ringworm	Microsporum, Trichophyton, Epidermophyton (Fungi)	Soil, towels, combs of infected persons	Dry scaly lesions on skin, nails, scalp; intense itching

Life Cycle of Plasmodium (Malaria)

- Sporozoites enter human via bite of infected female Anopheles mosquito.
- Parasites multiply in liver cells → attack RBCs → RBCs rupture.

- Rupture releases haemozoin (toxic) → fever and chills every 3–4 days.
- When mosquito bites infected person → takes up gametocytes → forms sporozoites in salivary glands → cycle continues.
- Two hosts: Human (definitive/intermediate) and female *Anopheles* (vector).
- Most dangerous: *Plasmodium falciparum* causes malignant malaria — can be fatal.
- Diagnostic test for typhoid: Widal test.

1.3 Immunity

Innate Immunity (Non-specific, present at birth) — 4 Barriers:

- Physical barriers: Skin; mucus lining of respiratory, GI, and urogenital tracts.
- Physiological barriers: Acid in stomach, saliva (mouth), tears (eyes) — prevent microbial growth.
- Cellular barriers: PMNL-neutrophils, monocytes, natural killer lymphocytes (blood); macrophages (tissues) — phagocytose and destroy microbes.
- Cytokine barriers: Virus-infected cells secrete interferons → protect non-infected cells from viral infection.

Acquired Immunity (Pathogen-specific, has memory):

- Primary response: Low intensity on first encounter.
- Secondary (Anamnestic) response: Highly intensified on re-exposure — basis of vaccination.
- Two types of lymphocytes involved: B-lymphocytes and T-lymphocytes.
- B-lymphocytes → produce antibodies (proteins) → Humoral Immune Response (HIR).
- T-lymphocytes → Cell-Mediated Immunity (CMI) — responsible for graft rejection.
- Antibody structure: 4 peptide chains — 2 light (L) + 2 heavy (H) = H_2L_2 ; Y-shaped. Types: IgA, IgM, IgE, IgG.

Active vs. Passive Immunity:

Feature	Active Immunity	Passive Immunity
How produced	Body produces own antibodies	Ready-made antibodies given from outside
Speed	Slow; takes time to respond	Immediate protection
Duration	Long-lasting (memory)	Short-lived (no memory)
Examples	Natural infection; vaccination	Colostrum (IgA); antibodies via placenta; antitoxin injection, anti-snake venom

Vaccination and Immunisation:

- Based on immunological memory — weakened/inactivated pathogen (antigen) introduced → body produces antibodies + memory B and T cells.
- On actual infection, memory cells produce rapid, massive antibody response.
- Passive immunisation: Direct injection of preformed antibodies/antitoxin (e.g., tetanus antitoxin, anti-snake venom).
- Recombinant DNA vaccines: Antigenic polypeptides produced in bacteria/yeast (e.g., Hepatitis B vaccine from yeast).

Allergies:

- Exaggerated immune response to certain environmental antigens (allergens).

- Allergens: dust mites, pollens, animal dander.
- Antibodies involved: IgE type.
- Mediators: Histamine and serotonin (from mast cells) → sneezing, watery eyes, running nose, breathing difficulty.
- Treatment: Anti-histamine, adrenalin, steroids.

Auto-immunity:

- Body attacks its own cells (self-cells) → auto-immune disease.
- Example: Rheumatoid arthritis.

Lymphoid Organs:

- Primary lymphoid organs: Bone marrow (all blood cells + B-lymphocytes) and Thymus (T-lymphocytes mature). Both provide microenvironment for lymphocyte maturation.
- Secondary lymphoid organs: Spleen, lymph nodes, tonsils, Peyer's patches (small intestine), appendix.
- MALT (Mucosa-Associated Lymphoid Tissue): Lines respiratory, digestive, urogenital tracts; constitutes ~50% of lymphoid tissue.
- Thymus: Large at birth, shrinks with age; very small by puberty.
- Spleen: Bean-shaped; contains lymphocytes and phagocytes; filters blood-borne microorganisms; reservoir of erythrocytes.

1.4 AIDS

- AIDS = Acquired Immuno Deficiency Syndrome. First reported in 1981.
- Caused by HIV (Human Immunodeficiency Virus) — a retrovirus with RNA genome.
- Transmission: (a) Sexual contact with infected person, (b) Contaminated blood transfusion, (c) Sharing infected needles (IV drug abusers), (d) Infected mother to child via placenta.
- HIV does NOT spread by touch or casual physical contact.
- Incubation period: Few months to many years (usually 5–10 years).
- Mechanism: HIV → enters macrophages → RNA → viral DNA (reverse transcriptase) → integrated into host genome → produces new viruses → attacks helper T-lymphocytes (TH cells) → progressive decline in TH count → immune deficiency → opportunistic infections (Mycobacterium, Toxoplasma, fungi).
- Diagnostic test: ELISA (Enzyme Linked Immuno-Sorbent Assay).
- Treatment: Anti-retroviral drugs — only partially effective; prolong life but death is inevitable.
- Prevention: Safe sex, disposable needles, blood screening, condom distribution, NACO programmes.

1.5 Cancer

- Caused by loss of contact inhibition → uncontrolled cell division → tumours.
- Benign tumour: Localised, does not spread, less dangerous.
- Malignant tumour: Spreads rapidly (metastasis) — most feared property; invades surrounding tissues; carried via blood.
- Causes (Carcinogens): Physical (ionising radiation: X-rays, gamma rays; non-ionising: UV), Chemical (tobacco smoke), Biological (oncogenic viruses with viral oncogenes; proto-oncogenes/c-onc in normal cells).
- Detection: Biopsy + histopathology; blood/bone marrow tests; Radiography, CT, MRI; ELISA with cancer-specific antigens.
- Treatment: Surgery, radiotherapy, chemotherapy (combination), immunotherapy (α -interferon — biological response modifier).

1.6 Drugs and Alcohol Abuse

Drug Category	Examples	Source Plant	Effect / Mode of Action
Opioids	Heroin (smack/diacetylmorphine)	Papaver somniferum (opium poppy)	Depressant; slows body functions; binds opioid receptors in CNS and GI tract
Cannabinoids	Marijuana, hashish, charas, ganja	Cannabis sativa (inflorescences)	Acts on cannabinoid receptors in brain; effects on cardiovascular system
Coca alkaloids	Cocaine (coke/crack)	Erythroxylum coca	Inhibits dopamine transport; CNS stimulant; euphoria, energy, hallucinations
Hallucinogens	Atropa belladonna, Datura	Various plant sources	Alter perception; hallucinogenic effects
Tobacco (Nicotine)	Cigarettes, chewing tobacco	Nicotiana tabacum	Stimulates adrenaline; raises BP and heart rate; lung/oral cancers; CO poisoning

- Addiction: Psychological attachment to euphoric effects of drugs/alcohol; tolerance develops → higher doses needed.
- Dependence: Body shows withdrawal syndrome (anxiety, shakiness, nausea) when drug is abruptly stopped.
- Effects of abuse: Reckless behaviour, violence, coma/death (respiratory/heart failure), AIDS and Hepatitis B (intravenous drug use), liver cirrhosis, stunted growth (adolescents), anabolic steroid side effects.
- Prevention: Avoid peer pressure, counselling, education, parental involvement, professional help, de-addiction programmes.

Section 2: Exercise Solutions

Detailed answers to all 17 textbook exercises (Chapter 7, NCERT Biology Class 12).

Q1. What are the various public health measures, which you would suggest as safeguard against infectious diseases?

Answer:

Public health measures against infectious diseases can be grouped by the mode of transmission:

For food- and water-borne diseases (typhoid, amoebiasis, ascariasis):

- Proper disposal of waste and sewage to prevent contamination of water sources.
- Periodic cleaning and disinfection of water reservoirs, tanks, and cesspools.
- Ensuring safe drinking water through boiling, chlorination, or filtration.
- Maintaining hygiene in public food catering — periodic health checks of food handlers.
- Washing fruits and vegetables before consumption.

For air-borne diseases (pneumonia, common cold):

- Avoid close contact with infected persons; wear masks.
- Infected individuals should cover mouth and nose while coughing/sneezing.

- Ventilation of public spaces.

For vector-borne diseases (malaria, filariasis, dengue):

- Prevent stagnation of water in and around residential areas.
- Regular cleaning of household coolers, flower pots, etc.
- Use of mosquito nets and wire mesh on doors/windows.
- Introducing larvivorous fish like *Gambusia* in ponds.
- Spraying insecticides in ditches, drainage areas, and swamps.

General measures:

- Vaccination and immunisation against infectious diseases (polio, diphtheria, tetanus, smallpox, etc.).
- Use of antibiotics and drugs as per medical prescription.
- Awareness programmes and public health education.

Q2. In which way has the study of biology helped us to control infectious diseases?

Answer:

Biology has made transformative contributions to controlling infectious diseases in several ways:

- Understanding pathogens: Identification of bacteria, viruses, fungi, protozoans, and helminths as disease-causing agents has enabled targeted therapies.
- Vaccines and immunisation: Knowledge of immune memory led to vaccines for smallpox (eradicated), polio, diphtheria, tetanus, pneumonia, hepatitis B, etc.
- Antibiotics and drugs: Discovery of antibiotics (penicillin, streptomycin) through biological research has enabled treatment of bacterial infections.
- Recombinant DNA technology: Allows mass production of safer vaccines (e.g., hepatitis B vaccine from yeast) and diagnostic proteins.
- Vector biology: Understanding the life cycle of vectors (e.g., *Anopheles* mosquito for malaria) enables targeted vector control.
- Diagnostics: Biological techniques like ELISA, PCR, biopsy, and Widal test enable rapid and accurate disease detection.
- Epidemiology: Study of disease spread patterns helps in quarantine, contact tracing, and outbreak control.
- Interferons: Knowledge of cytokines led to use of interferons as antiviral treatments.

Q3. How does the transmission of each of the following diseases take place? (a) Amoebiasis (b) Malaria (c) Ascariasis (d) Pneumonia

Answer:

(a) Amoebiasis (Amoebic Dysentery):

- Caused by: *Entamoeba histolytica* (protozoan parasite in large intestine).
- Transmission: Through contaminated food and water (contaminated with faecal matter of infected persons).
- Vector: Houseflies act as mechanical carriers — transmit the parasite from faeces of infected persons to food and water.

(b) Malaria:

- Caused by: *Plasmodium* species (*P. vivax*, *P. malaria*, *P. falciparum*).
- Transmission: Through the bite of an infected female *Anopheles* mosquito (vector).
- Sporozoites from mosquito salivary glands are injected into human bloodstream during the bite.

(c) Ascariasis:

- Caused by: *Ascaris* (roundworm helminth).
- Transmission: Through contaminated food, water, vegetables, or fruits that contain the eggs of the parasite (eggs shed in faeces of infected persons contaminate soil, water, and food).

(d) Pneumonia:

- Caused by: *Streptococcus pneumoniae* and *Haemophilus influenzae*.
- Transmission: (i) Inhalation of droplets/aerosols released by an infected person during coughing or sneezing. (ii) Sharing glasses and utensils with an infected person.

Q4. What measure would you take to prevent water-borne diseases?

Answer:

- Boiling drinking water before consumption to kill pathogens.
- Using water purifiers with filtration and UV/chlorine treatment.
- Proper disposal of sewage and waste to prevent contamination of water sources.
- Regular cleaning and disinfection of water storage tanks, reservoirs, and cesspools.
- Avoiding open defecation near water sources.
- Washing hands thoroughly with soap before eating and after using the toilet.
- Washing fruits and vegetables with clean water before eating.
- Avoiding consumption of food/water from unhygienic public places.
- Vaccination where available (e.g., typhoid vaccine).
- Maintaining hygiene in public food catering and checking for infected food handlers.

Q5. Discuss with your teacher what does 'a suitable gene' means, in the context of DNA vaccines.

Answer:

In the context of DNA vaccines, 'a suitable gene' refers to the gene that codes for an antigenic protein (or a part of it) specific to the pathogen — a protein that can trigger an immune response in the host without causing disease.

Key characteristics of a 'suitable gene':

- It must encode a surface protein, coat protein, or other immunogenic protein of the pathogen that is recognised by the host's immune system.
- The protein encoded must be antigenic — capable of stimulating production of specific antibodies and/or T-cell response.
- It should NOT encode any toxic or virulent factor of the pathogen.
- The gene should be stable, easily expressed in host cells, and capable of being incorporated into a plasmid vector.

Mechanism: The DNA vaccine (plasmid containing the suitable gene) is introduced into host cells. The host cells express the protein encoded by the gene. The expressed protein acts as an antigen, stimulating the immune system to produce antibodies and memory cells — providing protection against future infection. Example: Hepatitis B surface antigen (HBsAg) gene expressed in yeast for Hepatitis B vaccine.

Q6. Name the primary and secondary lymphoid organs.

Answer:

Primary Lymphoid Organs:

- Bone Marrow — site of production and maturation of B-lymphocytes; all blood cells are produced here.
- Thymus — site of maturation of T-lymphocytes; lobed organ near heart; large at birth, shrinks with age.

Secondary Lymphoid Organs:

- Spleen — bean-shaped; contains lymphocytes and phagocytes; filters blood.
- Lymph nodes — trap antigens from lymph and tissue fluid.
- Tonsils — present at throat entry.
- Peyer's patches — in the wall of small intestine.
- Appendix — vestigial but contains lymphoid tissue.
- MALT (Mucosa-Associated Lymphoid Tissue) — lines respiratory, digestive, and urogenital tracts; ~50% of lymphoid tissue.

Q7. Expand the following abbreviations used in this chapter: (a) MALT (b) CMI (c) AIDS (d) NACO (e) HIV

Answer:

- MALT — Mucosa-Associated Lymphoid Tissue
- CMI — Cell-Mediated Immunity
- AIDS — Acquired Immuno Deficiency Syndrome
- NACO — National AIDS Control Organisation
- HIV — Human Immunodeficiency Virus

Q8. Differentiate the following and give examples of each: (a) Innate and acquired immunity (b) Active and passive immunity

Answer:

(a) Innate Immunity vs. Acquired Immunity:

Feature	Innate Immunity	Acquired Immunity
Nature	Non-specific	Pathogen-specific
Present at birth?	Yes — present since birth	No — develops after exposure
Memory	No immunological memory	Has memory (secondary response)
Types of barriers	Physical, physiological, cellular, cytokine	Humoral (antibodies) and cell-mediated
Response speed	Immediate	Slow (primary); rapid (secondary)
Examples	Skin, mucus, interferons, phagocytes, stomach acid	Antibodies from B-cells; CMI by T-cells; vaccine-induced immunity

(b) Active Immunity vs. Passive Immunity:

Feature	Active Immunity	Passive Immunity
Mechanism	Host produces own antibodies after antigen exposure	Ready-made antibodies provided from external source
Time for response	Slow; takes days to weeks	Immediate protection
Duration	Long-lasting (memory cells formed)	Short-lived (no memory)
Memory	Yes	No
Examples	Natural infection; vaccination (polio, smallpox)	Colostrum (IgA to newborn), maternal antibodies via placenta, antitoxin injection (tetanus), anti-snake venom

Q9. Draw a well-labelled diagram of an antibody molecule.

Answer:

(Please draw the Y-shaped antibody structure. Below is a written description of its components for labelling:)

- Overall shape: Y-shaped (symmetric).
- Two Heavy chains (H) — longer; form the base and arms of the Y.
- Two Light chains (L) — shorter; attached to the upper portion of each heavy chain arm.
- Antibody represented as: H_2L_2 .
- Antigen binding sites (2 per antibody molecule) — at the tips of the two arms (N-terminus, variable region).
- Constant region (Fc region) — the base of the Y; interacts with immune cells and complement.
- Variable region — upper portions of both H and L chains; forms antigen-binding site.
- Disulfide bonds — hold the chains together.
- Types of antibodies: IgA, IgM, IgE, IgG (differ in heavy chain constant regions).

Q10. What are the various routes by which transmission of human immunodeficiency virus takes place?

Answer:

- Sexual contact with an HIV-infected person (unprotected sexual intercourse).
- Transfusion of contaminated blood and blood products (unscreened blood banks).
- Sharing of infected needles and syringes (common among intravenous drug abusers).
- From an HIV-infected mother to her child through the placenta during pregnancy.

Important: HIV is NOT spread by casual physical contact, shaking hands, hugging, sharing food, or insect bites. It spreads only through body fluids (blood, semen, vaginal secretions, breast milk).

Q11. What is the mechanism by which the AIDS virus causes deficiency of immune system of the infected person?

Answer:

The mechanism by which HIV causes immune deficiency involves the following sequential steps:

- Entry: HIV enters the body and infects macrophages first.
- Replication in macrophages: The RNA genome of HIV is reverse-transcribed to viral DNA by the enzyme reverse transcriptase. This viral DNA integrates into the host cell genome. The infected macrophages become a 'HIV factory' — continuously producing new virus particles.
- Attack on Helper T-lymphocytes (TH cells): HIV then enters helper T-lymphocytes (CD4+ T cells), replicates inside them, and new progeny viruses are released into the blood.
- Progressive destruction of TH cells: The released viruses attack more and more helper T-lymphocytes. This leads to a progressive and dramatic decrease in the number of TH cells in the body.
- Loss of immune control: Helper T-cells are critical for coordinating both humoral (B-cell antibody) and cell-mediated (cytotoxic T-cell) immune responses. Their loss effectively cripples the entire immune system.
- Opportunistic infections: The severely immunocompromised patient becomes susceptible to infections that a healthy immune system would easily overcome — such as *Mycobacterium tuberculosis*, *Toxoplasma*, fungi, and other viruses. These opportunistic infections eventually cause death.
- Symptoms: Bouts of fever, diarrhoea, and weight loss during progression.

Q12. How is a cancerous cell different from a normal cell?

Answer:

Feature	Normal Cell	Cancerous Cell
Contact inhibition	Present — stops dividing when in contact with other cells	Lost — continues to divide uncontrollably
Cell division	Controlled and regulated	Uncontrolled; rapid and unlimited
Growth pattern	Follows normal differentiation	Dedifferentiated; reverts to more primitive state
Spread	Stays in its original location	Can spread to other parts (metastasis)
Nutrient use	Normal metabolic needs	Competes aggressively for nutrients, starving normal cells
Response to growth signals	Responds to growth-regulating signals	Ignores regulatory signals; contains activated oncogenes
Tumour formation	Does not form tumours	Forms tumours (benign or malignant)

Q13. Explain what is meant by metastasis.Answer:

Metastasis is the process by which cancerous cells from a primary (original) malignant tumour break away and travel to distant sites in the body via the bloodstream or lymphatic system, where they establish new secondary tumours.

Key steps in metastasis:

- Cancerous cells from the malignant tumour detach from the primary tumour mass.
- These cells enter the bloodstream or lymphatic vessels.
- They travel through circulation to distant organs and tissues.
- At the new site, they lodge in the capillaries or tissues and start multiplying to form a new secondary tumour.

Metastasis is considered the most feared property of malignant tumours because it makes cancer extremely difficult to treat surgically (removing one tumour does not eliminate all cancerous cells) and leads to multi-organ failure. Benign tumours, by contrast, do NOT metastasize.

Q14. List the harmful effects caused by alcohol/drug abuse.Answer:**Immediate/Short-term Effects:**

- Reckless behaviour, vandalism, and violence.
- Loss of coordination and impaired judgment.
- Excessive doses may lead to coma or death (respiratory failure, heart failure, cerebral haemorrhage).
- Combining drugs with alcohol leads to overdosing and death.

Long-term Physical Effects:

- Damage to nervous system.
- Liver damage — cirrhosis (from chronic alcohol use).
- Lung, oral, bladder cancers (smoking/tobacco chewing).
- Increased heart rate, high blood pressure (nicotine).
- Oxygen deficiency due to increased CO in blood (smoking).
- HIV and Hepatitis B infection (from shared infected needles in IV drug use).
- Adverse effects on foetus if used during pregnancy.

Side Effects of Anabolic Steroid Abuse (in Sports):

- In females: Masculinisation, mood swings, abnormal menstrual cycles, facial hair growth, deepening of voice, clitoris enlargement.
- In males: Acne, reduced testicular size, decreased sperm production, breast enlargement, premature baldness, prostate enlargement.
- In adolescents: Stunted growth (premature closure of bone growth centres), severe acne.

Psychological and Social Effects:

- Addiction and dependence.
- Withdrawal syndrome (anxiety, nausea, shakiness, sweating).
- Drop in academic performance; absenteeism.
- Deteriorating relationships with family and friends.
- Financial distress; may turn to theft/crime to fund habit.
- Depression, aggression, isolation.

Q15. Do you think that friends can influence one to take alcohol/drugs? If yes, how may one protect himself/herself from such an influence?

Answer:

Yes, peer influence (friend pressure) is one of the most significant factors in initiating drug and alcohol abuse, especially among adolescents. The desire to 'fit in', social acceptance, curiosity, and the perception that it is 'cool' or 'progressive' to drink or use drugs are powerful motivators among youth.

Ways to protect oneself from peer influence:

- Develop self-confidence and a strong sense of personal identity — know your own values and stick to them.
- Learn to say NO firmly and without feeling guilty — refusal skills are key.
- Choose friends wisely — surround yourself with positive, supportive peers who share healthy values.
- Seek guidance from trusted adults — parents, teachers, counsellors — when feeling pressured.
- Stay engaged in constructive activities — sports, music, arts, yoga, extracurricular activities — that provide fulfilment and leave no space for negative influences.
- Understand the consequences — educating oneself about the real, serious dangers of drugs and alcohol reduces susceptibility to peer pressure.
- Recognise manipulation — if 'friends' pressure you to use substances, they may not have your best interests at heart.

Q16. Why is it that once a person starts taking alcohol or drugs, it is difficult to get rid of this habit?

Answer:

This difficulty is explained by the biological and psychological mechanisms of addiction and dependence:

Addiction (Psychological):

- Drugs and alcohol produce pleasurable effects — euphoria, temporary stress relief, a sense of well-being.
- The brain associates these substances with pleasure (involving dopamine pathways in the brain's reward system).
- This creates a psychological craving — the desire to experience these effects again and again.

Tolerance:

- With repeated use, the receptors in the body become desensitised to the drug.

- Higher and higher doses are needed to achieve the same effect — this drives greater and greater intake.

Dependence (Physical):

- The body adapts to the presence of the drug — it begins to require it to function 'normally'.
- When the drug is abruptly stopped, withdrawal syndrome occurs — anxiety, shakiness, nausea, sweating.
- In severe cases, withdrawal can be life-threatening, requiring medical supervision.

Vicious cycle:

- The combination of addiction, tolerance, and dependence creates a vicious cycle — the person cannot stop without experiencing severe discomfort, and continuing makes the problem worse.

This is why professional medical and psychological help (de-addiction programmes, rehabilitation centres) is essential to break the habit. Willpower alone is often insufficient.

Q17. In your view what motivates youngsters to take to alcohol or drugs and how can this be avoided?

Answer:

Motivating Factors:

- Peer pressure: The strong desire to fit in with a peer group that uses drugs/alcohol.
- Curiosity and experimentation: Adolescents naturally want to explore new experiences.
- Stress and academic pressure: Pressure to excel in studies, sports, or competitions can push youngsters to seek escape.
- Perception of being 'cool': Media (TV, movies, social media) often glamourises smoking, drinking, and drug use.
- Family environment: Unstable, unsupportive, or abusive family structures increase risk.
- Easy availability: Ready access to alcohol and drugs lowers the barrier to use.
- Escapism: Using substances to cope with emotional problems, loneliness, depression, or failure.

How to Avoid/Prevent:

- Education: Age-appropriate education about the real harms of drugs and alcohol — in schools and at home.
- Counselling: Professional and peer counselling to develop coping mechanisms for stress and failure.
- Parental involvement: Warm, supportive parenting with consistent discipline — high nurturance + clear boundaries.
- Healthy activities: Channelling energy into sports, arts, yoga, music, and community service.
- Avoiding peer pressure: Teaching refusal skills and confidence to say no.
- Media literacy: Teaching young people to critically evaluate the glorification of substance use in media.
- Strong school programmes: Anti-drug awareness programmes, teacher involvement, and prompt identification of at-risk students.
- Seeking help early: Any sign of substance use should be addressed immediately with professional guidance.

Section 3: Important Terms & Definitions

Health: State of complete physical, mental and social well-being (WHO definition).

Pathogen: Disease-causing microorganism (bacteria, virus, fungus, protozoan, helminth).

Immunity: Overall ability of the host to fight disease-causing organisms, conferred by the immune system.

Innate Immunity: Non-specific, inborn defence present at birth; includes physical, physiological, cellular and cytokine barriers.

Acquired Immunity: Pathogen-specific immunity developed after exposure; characterised by immunological memory.

Antibody: Protein (H_2L_2) produced by B-lymphocytes in response to antigens; neutralises pathogens.

Antigen: Foreign substance (usually protein) that triggers an immune response.

Humoral Immunity: Antibody-mediated immune response by B-lymphocytes.

Cell-Mediated Immunity (CMI): T-lymphocyte-mediated immune response; responsible for graft rejection.

Active Immunity: Immunity developed when the host produces its own antibodies after antigen exposure (slow but long-lasting).

Passive Immunity: Immunity provided by ready-made antibodies from an external source (immediate but short-lived). E.g., colostrum, antitoxin.

Vaccine: Preparation of inactivated/weakened pathogen or its antigenic proteins; stimulates immune memory.

Allergen: Substance (e.g., dust mites, pollen) that causes an exaggerated immune response (allergy).

Allergy: Exaggerated immune response to certain environmental antigens; mediated by IgE antibodies.

Auto-immune Disease: Condition where the body's immune system attacks its own cells (e.g., rheumatoid arthritis).

Haemozoin: Toxic substance released when Plasmodium ruptures RBCs; responsible for the characteristic cycles of fever and chills in malaria.

MALT: Mucosa-Associated Lymphoid Tissue; lymphoid tissue lining major body tracts; ~50% of total lymphoid tissue.

Retrovirus: Virus with RNA genome that uses reverse transcriptase to make DNA; HIV is a retrovirus.

Reverse Transcriptase: Enzyme used by retroviruses (like HIV) to convert viral RNA into DNA in the host cell.

ELISA: Enzyme Linked Immuno-Sorbent Assay; widely used diagnostic test for detecting HIV/AIDS.

Contact Inhibition: Property of normal cells to stop dividing when in contact with other cells; lost in cancer cells.

Metastasis: Spread of cancer cells from a primary tumour to distant sites via blood/lymph, forming secondary tumours.

Carcinogen: Agent (physical, chemical, biological) that causes cancer.

Oncogene: Gene that when activated, leads to cancerous transformation. Viral oncogenes and cellular oncogenes (proto-oncogenes) exist.

Benign Tumour: Localised tumour that does not spread; less dangerous.

Malignant Tumour: Tumour that invades surrounding tissues and metastasises; cancerous.

Interferon: Protein secreted by virus-infected cells that protects non-infected cells; also used as α -interferon in cancer therapy.

Addiction: Psychological craving and compulsive use of a substance despite harmful consequences.

Dependence: Physical state where the body needs the substance to function normally; withdrawal symptoms occur without it.

Withdrawal Syndrome: Unpleasant physical symptoms (anxiety, shakiness, nausea, sweating) when an addicted person abruptly stops a drug.

Colostrum: Yellowish fluid secreted by mother in the initial days of lactation; rich in IgA antibodies — provides passive immunity to newborn.

Widal Test: Blood test used to diagnose typhoid fever; detects antibodies against Salmonella typhi.

Vector: Organism (e.g., mosquito) that transmits a pathogen from one host to another.

Chapter 8: Microbes in Human Welfare

Section 1: Key Concepts at a Glance

A complete summary of all major topics in Chapter 8, organised by section.

1.1 Microbes in Household Products

Product / Food	Microbe Involved	Process / Notes
Curd (Dahi)	Lactobacillus and other Lactic Acid Bacteria (LAB)	LAB grow in milk → produce acids → coagulate milk proteins; increases vitamin B ₁₂ ; inoculum (starter) added to fresh milk
Idli & Dosa dough	Bacteria (from air/environment)	Fermentation produces CO ₂ → puffed-up appearance; anaerobic fermentation pathway
Bread	Baker's yeast (Saccharomyces cerevisiae)	Fermentation produces CO ₂ → bread rises
Toddy (Palm wine)	Microbes (fermentation)	Fermented sap from palm trees; traditional drink of South India
Swiss Cheese	Propionibacterium sharmanii (bacterium)	Produces large amounts of CO ₂ → forms the characteristic large holes
Roquefort Cheese	Specific fungi	Fungi ripened on cheese → gives characteristic flavour
Fermented fish, soyabean, bamboo shoots	Various microbes	Traditional fermented foods; microbes impart texture and flavour

LAB also play a beneficial role in the stomach by checking the growth of disease-causing microbes.

1.2 Microbes in Industrial Products

Fermented Beverages:

- Yeast used: *Saccharomyces cerevisiae* (brewer's yeast) — same as baker's yeast.
- Substrate: Malted cereals and fruit juices → ethanol (via anaerobic fermentation).
- Without distillation: Wine and beer.
- With distillation of fermented broth: Whisky, brandy, rum.
- Industrial production in large vessels called fermentors.

Antibiotics:

- Definition: Chemical substances produced by microbes that can kill or retard growth of other (disease-causing) microbes.

- Penicillin: First antibiotic discovered — chance discovery by Alexander Fleming (1928) while working on Staphylococci. Observed mould (*Penicillium notatum*) inhibiting bacterial growth. Full potential established by Ernest Chain and Howard Florey. Used in World War II. Nobel Prize 1945 awarded to Fleming, Chain and Florey.
- Antibiotics treat: Plague, whooping cough (Kali Khansi), diphtheria (Gal Ghotu), leprosy (Kusht Rog), typhoid, pneumonia, etc.

Chemicals, Enzymes and Bioactive Molecules — Quick Reference Table:

Product	Microbe	Type	Application
Citric acid	<i>Aspergillus niger</i>	Fungus	Food industry, pharmaceuticals
Acetic acid	<i>Acetobacter aceti</i>	Bacterium	Vinegar production
Butyric acid	<i>Clostridium butylicum</i>	Bacterium	Industrial chemical
Lactic acid	<i>Lactobacillus</i>	Bacterium	Food preservation, cosmetics
Ethanol	<i>Saccharomyces cerevisiae</i>	Yeast	Beverages, biofuel
Lipases	Various microbes	Enzyme	Detergent formulations — remove oily stains
Pectinases & Proteases	Various microbes	Enzyme	Clarify bottled fruit juices
Streptokinase	<i>Streptococcus</i> (+ genetic engineering)	Enzyme	'Clot buster' — removes blood clots in heart attack patients (myocardial infarction)
Cyclosporin A	<i>Trichoderma polysporum</i> (fungus)	Bioactive molecule	Immunosuppressive agent in organ transplant patients
Statins	<i>Monascus purpureus</i> (yeast)	Bioactive molecule	Blood-cholesterol lowering agents; competitive inhibitor of cholesterol-synthesising enzyme

1.3 Microbes in Sewage Treatment

- Sewage = Municipal waste water containing human excreta, large amounts of organic matter, and pathogenic microbes.
- Cannot be discharged directly into rivers/streams — would cause massive water pollution and spread water-borne diseases.
- Treated in Sewage Treatment Plants (STPs) by naturally present heterotrophic microbes.

Two Stages of Sewage Treatment:

Stage	Type	Process	Key Terms
Primary Treatment	Physical	1. Filtration: remove floating debris 2. Sedimentation: remove grit (soil, pebbles) Solids settle → primary sludge; liquid on top = effluent	Primary sludge, Effluent
Secondary Treatment	Biological	Primary effluent → aeration tanks (air pumped in, mechanically agitated) → aerobic microbes form flocs → consume organic matter → BOD reduced → settling tank → flocs settle as activated sludge → small part recycled as	Flocs, BOD, Activated sludge, Anaerobic sludge digesters, Biogas

		inoculum → rest goes to anaerobic sludge digesters → bacteria digest sludge anaerobically → produce biogas ($\text{CH}_4 + \text{H}_2\text{S} + \text{CO}_2$)	
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- BOD (Biochemical Oxygen Demand): Amount of oxygen that would be consumed if all organic matter in 1 litre of water were oxidised by bacteria. Higher BOD = more polluted water.
- Effluent from secondary treatment is released into rivers/streams.
- Ganga Action Plan and Yamuna Action Plan: Govt. initiatives to build more STPs to prevent river pollution.

1.4 Microbes in Production of Biogas

- Biogas: Mixture of gases (predominantly methane) produced by microbial activity; used as fuel (flammable).
- Methanogens: Bacteria that grow anaerobically on cellulosic material, producing $\text{CH}_4 + \text{CO}_2 + \text{H}_2$. Example: Methanobacterium.
- Found in: Anaerobic sludge (sewage treatment) and rumen of cattle (help digest cellulose).
- Cattle dung (gobar) is rich in methanogens → used to produce gober gas.
- Biogas Plant structure: Concrete tank (10–15 feet deep); slurry of dung + biowastes fed in; floating cover rises as gas is produced; gas outlet → supply to houses; spent slurry removed → used as fertiliser.
- Technology developed in India by: IARI (Indian Agricultural Research Institute) and KVIC (Khadi and Village Industries Commission).
- Use: Cooking and lighting in rural areas.

1.5 Microbes as Biocontrol Agents

- Biocontrol: Use of biological methods (living organisms) to control plant diseases and pests, instead of toxic chemical pesticides.
- Organic farming philosophy: Biodiversity promotes health; pests kept at manageable levels by natural checks, not eradicated.

Biocontrol Agent	Type	Target Pest / Disease	Mechanism / Notes
Ladybird (beetle)	Insect (predator)	Aphids	Ladybird feeds on aphids
Dragonflies	Insect (predator)	Mosquitoes	Dragonflies feed on mosquitoes
Bacillus thuringiensis (Bt)	Bacterium	Butterfly caterpillars (on brassicas, fruit trees)	Dried spores sprayed on plants → eaten by larvae → toxin released in gut → larvae killed; does not harm other insects. Bt-toxin genes introduced into plants (Bt-cotton) for pest resistance.
Trichoderma species	Free-living fungus	Several plant pathogens (root diseases)	Common in root ecosystems; effective biocontrol agent
Baculoviruses (Nucleopolyhedrovirus)	Virus	Insects and arthropods	Species-specific, narrow spectrum; no negative impact on plants, mammals, birds, fish, or non-target insects; ideal for IPM programmes

1.6 Microbes as Biofertilisers

- Biofertilisers: Organisms that enrich the nutrient quality of the soil. Main sources: bacteria, fungi, cyanobacteria.

Biofertiliser	Organism(s)	Mechanism	Benefit to Soil/Plant
Rhizobium (symbiotic)	Rhizobium bacteria	Symbiotic association with roots of leguminous plants; forms root nodules; fixes atmospheric N ₂ into organic forms	Provides fixed nitrogen as plant nutrient; enriches soil nitrogen
Free-living nitrogen fixers	Azospirillum, Azotobacter	Free-living bacteria in soil; fix atmospheric nitrogen independently	Enrich nitrogen content of soil
Mycorrhiza (symbiotic fungi)	Glomus (genus)	Fungal symbiont absorbs phosphorus from soil and transfers to plant	Phosphorus nutrition; also provides resistance to root-borne pathogens, drought and salinity tolerance; overall plant growth promotion
Cyanobacteria (Blue-green algae)	Anabaena, Nostoc, Oscillatoria	Autotrophic; fix atmospheric nitrogen; add organic matter to soil	Important biofertiliser in paddy fields; increases soil fertility

Section 2: Exercise Solutions

Complete answers to all 15 textbook questions from Chapter 8.

Q1. Bacteria cannot be seen with the naked eyes, but these can be seen with the help of a microscope. If you have to carry a sample from your home to your biology laboratory to demonstrate the presence of microbes with the help of a microscope, which sample would you carry and why?

Answer:

The best sample to carry from home would be curd (dahi) — and here is why:

- Curd is made by the action of Lactic Acid Bacteria (LAB) such as *Lactobacillus*. It contains millions of live bacteria per millilitre.
- A thin smear of curd on a glass slide, when stained (e.g., with methylene blue or crystal violet) and viewed under a compound microscope at 400×–1000× magnification, clearly shows rod-shaped and coccoid bacterial cells.
- Curd is easily available at home, safe to handle, and does not require any special equipment for transport.
- No risk of contamination or biohazard during transport.

Other equally valid samples from home: Bread showing mould growth (shows fungal filaments and spores under microscope), water from a flower vase or still pond (shows protozoa and algae), or dental plaque (shows bacteria).

Curd is recommended most because it reliably and safely demonstrates large numbers of bacteria that are easy to observe and identify.

Q2. Give examples to prove that microbes release gases during metabolism.

Answer:

- Curd formation: LAB ferment milk and produce lactic acid. During this, CO₂ is also released as a metabolic by-product.
- Dough fermentation (Idli, Dosa, Bread): Bacteria and yeast (*Saccharomyces cerevisiae*) ferment carbohydrates anaerobically and produce CO₂. This CO₂ makes the dough rise and gives a puffed-up appearance.
- Alcoholic fermentation: Yeast (*S. cerevisiae*) ferments sugars to produce ethanol and CO₂. The bubbling/frothing seen in fermenting beer/wine is due to CO₂ release.
- Swiss cheese production: *Propionibacterium sharmanii* produces large amounts of CO₂ during metabolism, forming the characteristic holes in Swiss cheese.
- Biogas production: Methanogens (e.g., *Methanobacterium*) growing anaerobically on cellulosic material produce methane (CH₄), CO₂, and hydrogen gas (H₂). Biogas plants make use of this.
- Anaerobic sludge digestion (in sewage treatment): Anaerobic bacteria break down organic sludge and produce a mixture of CH₄, H₂S and CO₂.

Q3. In which food would you find lactic acid bacteria? Mention some of their useful applications.

Answer:

Foods containing Lactic Acid Bacteria (LAB):

- Curd (Dahi) — primary example; LAB (*Lactobacillus* and related bacteria) convert milk to curd.
- Butter milk, yoghurt, cheese — other dairy products where LAB are involved.
- Idli and Dosa batter — fermented by bacteria including LAB.
- Fermented pickles and sauerkraut.
- Fermented fish and soyabean products.

Useful Applications of LAB:

- Curd formation: LAB grow in milk → produce lactic acid → coagulate milk proteins → curd formed; improves nutritional quality by increasing vitamin B₁₂.
- Gut health: LAB in the stomach play a beneficial role in checking the growth of disease-causing microbes — a probiotic effect.
- Food preservation: Lactic acid produced lowers pH → prevents growth of spoilage and pathogenic organisms.
- Industrial production of lactic acid: *Lactobacillus* is used for commercial production of lactic acid used in food, textile and pharmaceutical industries.
- Cheese ripening: LAB contribute to flavour development in various cheeses.
- Starter cultures: Small amounts of curd containing LAB are used as inoculum/starter to make fresh batches of curd.

Q4. Name some traditional Indian foods made of wheat, rice and Bengal gram (or their products) which involve use of microbes.

Answer:

Made from Rice:

- Idli — made from fermented rice and urad dal batter; bacteria ferment the batter, releasing CO₂ → fluffy idli.
- Dosa — made from the same fermented rice-urad dal batter; thin, crispy.
- Appam — South Indian rice-based fermented pancake.
- Toddy — traditional fermented drink made from palm sap (fermentation by microbes).

Made from Wheat:

- Bread — wheat flour dough fermented by *Saccharomyces cerevisiae* (baker's yeast); CO₂ makes bread rise.
- Bhatoora — deep-fried bread made from fermented maida (refined wheat flour) using yeast.
- Jalebi — batter of maida fermented by yeast before frying.

Made from Bengal Gram (Chickpeas/Chana):

- Dhokla — made from fermented batter of Bengal gram flour (besan) and rice; bacteria ferment batter → CO₂ → fluffy texture.
- Papad — traditionally made from fermented urad dal or Bengal gram; microbes may be involved in processing.
- Idada / Handvo (Gujarat) — fermented lentil and rice preparations.

Q5. In which way have microbes played a major role in controlling diseases caused by harmful bacteria?

Answer:

Microbes have played their most important role in controlling bacterial diseases through the production of antibiotics:

- Antibiotics are chemical substances produced by certain microbes that can kill or retard the growth of other (disease-causing) microbes.
- Penicillin (from *Penicillium notatum*) was the first antibiotic discovered and has saved millions of lives from bacterial infections.
- Other microbially produced antibiotics include: Streptomycin (from *Streptomyces griseus*), Tetracycline (from *Streptomyces*), Erythromycin (from *Streptomyces*), Chloramphenicol, etc.
- Antibiotics have greatly improved our ability to treat deadly bacterial diseases such as plague, whooping cough (diphtheria), leprosy, typhoid, pneumonia, and tuberculosis, which used to kill millions across the globe.
- Streptokinase (from *Streptococcus*, modified by genetic engineering) acts as a 'clot buster' — removes blood clots from vessels of heart attack patients.

In summary, by producing antimicrobial compounds (antibiotics and enzymes), microbes have become our most powerful allies in fighting bacterial diseases.

Q6. Name any two species of fungus, which are used in the production of antibiotics.

Answer:

- *Penicillium notatum* — produces Penicillin (the first antibiotic, discovered by Alexander Fleming).
- *Penicillium chrysogenum* — high-yielding strain now used in commercial production of Penicillin.
- *Cephalosporium* (*Acremonium*) — produces Cephalosporin antibiotics (broad-spectrum antibiotics).

Note: Most other famous antibiotics (streptomycin, tetracycline, erythromycin) are produced by bacteria (*Streptomyces* species), not fungi. The most exam-relevant fungal antibiotic producers are from the genus *Penicillium*.

Q7. What is sewage? In which way can sewage be harmful to us?

Answer:

What is sewage?

Sewage is the municipal waste water generated in cities and towns. It consists primarily of human excreta (faeces, urine) along with domestic and industrial waste water. It contains large amounts of organic matter, suspended solids, and a variety of microbes, many of which are pathogenic.

How can sewage be harmful?

- Contains pathogenic microbes: Bacteria (*Salmonella typhi* — typhoid, *Vibrio cholerae* — cholera), viruses, protozoa (*Entamoeba histolytica* — amoebiasis), and helminths (*Ascaris* eggs).
- Water-borne diseases: If discharged untreated into rivers or water bodies, sewage contaminates drinking water sources and causes widespread outbreaks of typhoid, cholera, dysentery, amoebiasis, and hepatitis.
- Oxygen depletion: High organic content in sewage creates very high BOD; microbes consuming this organic matter deplete dissolved oxygen → kills fish and aquatic life (eutrophication/dead zones).
- Soil and groundwater pollution: Untreated sewage seeping into soil contaminates groundwater, posing serious health risks to communities dependent on bore wells.
- Odour and aesthetic pollution: Decomposing organic matter produces foul-smelling gases (H_2S , ammonia) that make the environment unpleasant.
- Algal blooms: Excess nutrients (nitrogen, phosphorus) in sewage entering water bodies trigger algal blooms, which further deplete oxygen and poison water.

Q8. What is the key difference between primary and secondary sewage treatment?

Answer:

Feature	Primary Treatment	Secondary Treatment
Type of process	Physical process	Biological process
What is removed	Solid particles — floating debris, grit (soil, pebbles)	Dissolved organic matter and remaining microbes
Methods used	Sequential filtration and sedimentation	Aeration tanks with aerobic microbes forming flocs; then anaerobic sludge digesters
Microbes involved	No specific microbial action	Aerobic microbes (in aeration tanks); anaerobic bacteria (in sludge digesters)
Key products	Primary sludge + effluent	Activated sludge + biogas (CH_4 , H_2S , CO_2) + treated effluent
BOD reduction	Minimal BOD reduction	Significantly reduces BOD of effluent
Effluent destination	Effluent sent to secondary treatment	Treated effluent released into rivers/streams

Key point: Primary treatment is a physical/mechanical process that removes suspended solids. Secondary treatment is a biological process that removes dissolved organic matter using microbial action. Secondary treatment is the more important step for reducing polluting potential (BOD).

Q9. Do you think microbes can also be used as source of energy? If yes, how?

Answer:

Yes, microbes can definitely be used as a source of energy. The most important example is biogas production:

- Biogas production: Methanogens (e.g., *Methanobacterium*) grow anaerobically on cellulosic material and organic waste (cattle dung/gobar), producing biogas — a mixture of predominantly methane (CH_4), along with CO_2 and H_2 .

- Biogas is highly flammable and is used directly as fuel for cooking and lighting in rural areas (gobar gas plants).
- Technology developed in India by IARI and KVIC; widely deployed in rural areas.
- Biogas from sewage treatment: During anaerobic digestion of sludge in sewage treatment plants, bacteria produce biogas that can be harnessed as energy.
- Bioethanol: Yeast (*Saccharomyces cerevisiae*) ferments sugars from plant material (sugarcane, corn starch, cellulose) to produce ethanol, which can be used as biofuel to power vehicles (mixed with petrol as E10, E20, etc.).
- Hydrogen gas: Some bacteria and algae can produce hydrogen gas (H_2) through biological processes — hydrogen is a clean fuel with great future potential.
- Microbial Fuel Cells (MFCs): Research-stage technology where microbes break down organic matter and directly generate electricity through electrochemical reactions.

The use of microbes as energy sources is sustainable, renewable, and environment-friendly compared to fossil fuels.

Q10. Microbes can be used to decrease the use of chemical fertilisers and pesticides. Explain how this can be accomplished.

Answer:

Reducing Chemical Fertilisers — through Biofertilisers:

- Nitrogen fixation by Rhizobium: These bacteria form symbiotic associations (root nodules) with leguminous plants and fix atmospheric nitrogen into organic forms → reduces need for chemical nitrogen fertilisers.
- Free-living nitrogen fixers (*Azospirillum*, *Azotobacter*): Fix atmospheric nitrogen in soil while living freely → enrich soil nitrogen naturally.
- Mycorrhizal fungi (*Glomus*): Form symbiotic associations with plant roots → absorb soil phosphorus and transfer to plants → reduces need for phosphatic fertilisers. Also improve drought tolerance and resistance to root pathogens.
- Cyanobacteria (*Anabaena*, *Nostoc*, *Oscillatoria*): Fix atmospheric nitrogen and add organic matter to soil → especially important biofertilisers in paddy fields.

Reducing Chemical Pesticides — through Biocontrol Agents:

- *Bacillus thuringiensis* (Bt): Bacterial spores sprayed on crops kill butterfly caterpillars and other larvae specifically without harming other organisms. Bt toxin genes introduced into crop plants (Bt-cotton) make plants resistant to pests.
- *Trichoderma* (fungus): Free-living fungus in root ecosystems used as biocontrol agent against several plant pathogens → reduces need for fungicides.
- Baculoviruses (Nucleopolyhedrovirus): Species-specific, narrow-spectrum insecticidal viruses that attack only targeted insects and arthropods; have no negative impact on plants, mammals, or beneficial insects.
- Natural predators: Ladybirds control aphids; dragonflies control mosquito populations — maintaining ecological balance.

By using biofertilisers and biocontrol agents together, organic farming becomes viable — reducing chemical pollution of soil and groundwater, protecting human health, and maintaining soil fertility sustainably.

Q11. Three water samples — river water, untreated sewage water and secondary effluent — were labelled A (BOD = 20 mg/L), B (BOD = 8 mg/L), and C (BOD = 400 mg/L). Which sample is most polluted? Assign correct labels.

Answer:

Concept: BOD (Biochemical Oxygen Demand) measures the amount of oxygen that would be consumed to oxidise all organic matter in 1 litre of water. Higher BOD = more organic matter = more polluted water.

Identifying the most polluted sample:

- Sample C (BOD = 400 mg/L) is the MOST POLLUTED — it has the highest organic matter content.

Assigning correct labels:

Sample	BOD Value	Correct Water Type	Reasoning
Sample C	400 mg/L	Untreated sewage water	Highest BOD — raw sewage contains massive amounts of organic matter (human excreta, food waste, etc.) not yet broken down
Sample A	20 mg/L	River water (relatively clean)	Moderate BOD — river water contains some naturally occurring organic matter but is relatively clean
Sample B	8 mg/L	Secondary effluent from STP	Lowest BOD — secondary treatment significantly reduces organic matter; treated water has very low BOD before release into rivers

Note: In practice, secondary effluent (Sample B, 8 mg/L) may have a lower BOD than even the river water in some cases, which is why it can be safely released into rivers after treatment.

Q12. Find out the name of the microbes from which Cyclosporin A and Statins are obtained.

Answer:

- Cyclosporin A (immunosuppressive drug used in organ transplant patients): Produced by the fungus *Trichoderma polysporum*.
- Statins (blood cholesterol lowering agents): Produced by the yeast *Monascus purpureus*. Statins act by competitively inhibiting the enzyme responsible for cholesterol synthesis.

Q13. Find out the role of microbes in (a) Single Cell Protein (SCP) and (b) Soil.

Answer:

(a) Single Cell Protein (SCP):

Single Cell Protein refers to the protein-rich biomass or dried cells of microorganisms grown on cheap substrates, used as protein-rich food or animal feed.

- Microbes used: *Spirulina* (cyanobacterium), *Chlorella* (green alga), *Saccharomyces cerevisiae* (yeast), *Methylophilus methylotrophus* (bacterium).
- Substrates: Agricultural wastes, cellulose, starch, industrial effluents, methanol, or hydrocarbons — cheap and otherwise unused materials.
- Significance: SCP can address protein deficiency (malnutrition) at a global scale. Microbes grow extremely rapidly on cheap substrates and can produce large amounts of protein biomass in a small space.
- *Spirulina*: High protein content (~70%), rich in vitamins, minerals and fatty acids; produced commercially in many countries; used as food supplement.
- SCP reduces pressure on conventional protein sources (land-intensive crops, livestock) and can utilise waste materials sustainably.

(b) Role of Microbes in Soil:

Microbes are essential for soil health and fertility. Without them, soil would be dead and unable to support plant life.

- Decomposition and nutrient cycling: Bacteria and fungi break down dead organic matter (leaves, animal remains) into simpler inorganic compounds — humus formation enriches soil.
- Nitrogen fixation: Rhizobium (symbiotic), Azotobacter and Azospirillum (free-living) fix atmospheric N_2 into ammonium/organic forms usable by plants.
- Nitrification: Bacteria (Nitrosomonas, Nitrobacter) convert ammonium → nitrites → nitrates (plant-available form).
- Denitrification: Bacteria return some nitrogen back to atmosphere — maintains nitrogen balance.
- Phosphorus solubilisation: Certain bacteria and fungi solubilise insoluble phosphorus compounds into plant-available forms.
- Mycorrhizal associations: Fungi form associations with roots and improve nutrient (especially phosphorus) and water absorption.
- Soil structure: Microbial activity and organic matter produced by microbes help maintain soil aggregation and water retention properties.
- Biocontrol: Trichoderma and other soil microbes protect plant roots from pathogenic organisms.

Q14. Arrange the following in decreasing order of importance for human welfare, with reasons: Biogas, Citric acid, Penicillin and Curd.

Answer:

Decreasing order of importance: Penicillin > Curd > Biogas > Citric acid

1st — Penicillin (Most Important):

- Penicillin is considered one of the greatest discoveries of the 20th century. It was the first antibiotic and has saved hundreds of millions of human lives globally by treating deadly bacterial infections (plague, diphtheria, pneumonia, wound infections in World War II).
- Without antibiotics, routine infections, surgeries, and childbirth would have mortality rates comparable to the pre-antibiotic era. The impact on human longevity and quality of life is incalculable.

2nd — Curd:

- Curd is a universally consumed, nutritious food item made daily by millions of people. LAB improve the nutritional value of milk (increases vitamin B_{12}), aid digestion, and promote gut health by suppressing pathogens.
- It represents the most ancient and widespread use of microbes in food — practically every household in India uses it daily. Also forms the basis for yoghurt, buttermilk, and cheese industries worldwide.

3rd — Biogas:

- Biogas provides clean, renewable cooking fuel for millions of rural households in developing countries, reducing dependence on wood/coal, reducing indoor air pollution, and providing energy security. Also a sustainable waste management solution.
- Important but impacts a specific (mainly rural) population segment.

4th — Citric acid (Least Important in this list):

- While citric acid has many commercial uses (food flavouring, preservative, pharmaceuticals, cleaning agents), its direct impact on human welfare is far less critical than antibiotics (which save lives), curd (which nourishes billions daily), or biogas (which provides energy).
- It is a useful industrial commodity but not a life-saving or welfare-critical product.

Q15. How do biofertilisers enrich the fertility of the soil?

Answer:

Biofertilisers are organisms (bacteria, fungi, cyanobacteria) that enrich the nutrient quality of the soil through biological processes. They improve soil fertility in the following ways:

1. Nitrogen fixation:

- Rhizobium (symbiotic with leguminous plants): Forms root nodules; converts atmospheric N_2 into ammonia and organic nitrogen → plant uses it directly as nutrient; dead nodules enrich soil with nitrogen.
- Azospirillum and Azotobacter (free-living): Fix atmospheric N_2 independently in the soil, directly enriching soil nitrogen content.
- Cyanobacteria (Anabaena, Nostoc, Oscillatoria): Autotrophic nitrogen-fixers; important in paddy/waterlogged fields; fix nitrogen and add organic matter to soil.

2. Phosphorus solubilisation and mobilisation (Mycorrhizal fungi):

- Glomus and other mycorrhizal fungi form symbiotic associations (mycorrhiza) with plant roots.
- The fungal hyphae extend into soil far beyond the root zone and absorb phosphorus (often from insoluble forms) and transfer it to the plant.
- Result: Plants access more phosphorus without additional phosphatic chemical fertilisers.

3. Organic matter addition:

- Cyanobacteria (blue-green algae) and decomposing microbial biomass add organic matter (humus) to the soil, improving soil structure, water-holding capacity, and fertility.

4. Additional plant growth benefits:

- Plants with mycorrhizal associations show increased resistance to root-borne pathogens, better tolerance to drought and salinity, and overall improved growth and development.
- LAB and other soil bacteria produce plant-growth promoting substances (vitamins, hormones) that benefit crop growth.

Overall impact: Biofertilisers replenish soil nutrients naturally and sustainably, reduce dependence on expensive and environmentally damaging chemical fertilisers, and maintain long-term soil health — making them a cornerstone of sustainable and organic agriculture.

Section 3: Key Terms and Definitions

Microbes / Microorganisms: Microscopic organisms including bacteria, viruses, fungi, protozoa, algae, viroids, and prions.

Prions: Proteinaceous infectious agents — no nucleic acid; cause diseases like BSE (mad cow disease).

Viroids: Infectious RNA molecules without a protein coat; cause plant diseases.

Fermentation: Metabolic process by which microorganisms convert organic substrates (sugars) into acids, gases, or alcohol in the absence of oxygen.

Lactic Acid Bacteria (LAB): Bacteria (e.g., Lactobacillus) that produce lactic acid by fermenting sugars; convert milk to curd.

Fermentor: Large industrial vessel used for growing microbes on a commercial scale for production of antibiotics, beverages, enzymes, etc.

Antibiotic: Chemical substance produced by a microorganism that kills or inhibits the growth of other microorganisms (disease-causing ones).

Sewage: Municipal waste water containing human excreta, organic matter, and pathogenic microbes.

BOD (Biochemical Oxygen Demand): Amount of oxygen that would be consumed if all organic matter in 1 litre of water were oxidised by bacteria. Measure of water pollution.

Flocs: Masses of bacteria associated with fungal filaments forming mesh-like structures in aeration tanks during sewage treatment.

Activated Sludge: Sediment formed in the settling tank after secondary sewage treatment; contains microbial flocs. Small portion recycled as inoculum.

Anaerobic Sludge Digesters: Large tanks in STPs where anaerobic bacteria digest the activated sludge, producing biogas.

Biogas: Mixture of gases (predominantly methane) produced by microbial (methanogen) activity on organic matter; used as fuel (gobar gas).

Methanogens: Anaerobic bacteria (e.g., *Methanobacterium*) that produce methane from cellulosic material; found in cattle rumen and anaerobic sludge.

Biocontrol: Use of biological organisms (microbes, insects) to control plant diseases and pests, as an alternative to chemical pesticides.

***Bacillus thuringiensis* (Bt):** Bacterium used as biocontrol agent against caterpillars; produces toxin that kills larvae upon ingestion. Bt-cotton uses its toxin gene.

Baculoviruses: Viruses (genus *Nucleopolyhedrovirus*) used as biological control agents against insects; species-specific and harmless to non-target organisms.

Biofertiliser: Living organism (bacteria, fungi, cyanobacteria) that enriches soil fertility through nitrogen fixation, phosphorus solubilisation, or organic matter addition.

Mycorrhiza: Symbiotic association between plant roots and fungi (e.g., *Glomus*); fungus absorbs and transfers phosphorus to plant.

Rhizobium: Nitrogen-fixing symbiotic bacteria in root nodules of leguminous plants.

Cyclosporin A: Immunosuppressive drug produced by the fungus *Trichoderma polysporum*; used in organ transplant patients.

Statins: Cholesterol-lowering drugs produced by the yeast *Monascus purpureus*; competitively inhibit cholesterol synthesis enzyme.

Streptokinase: Enzyme from *Streptococcus* (genetically engineered) used as 'clot buster' in heart attack patients.

Single Cell Protein (SCP): Protein-rich microbial biomass (e.g., *Spirulina*, yeast) grown on cheap substrates; used as food supplement or animal feed.

IPM (Integrated Pest Management): A holistic approach to pest control combining biocontrol, cultural practices and minimal chemical use to manage pests sustainably.

IARI: Indian Agricultural Research Institute; played key role in developing biogas production technology in India.

KVIC: Khadi and Village Industries Commission; co-developed biogas technology for rural India with IARI.

Chapter 9: Biotechnology: Principles and Processes

Q1. Can you list 10 recombinant proteins used in medical practice?

The following are 10 recombinant proteins widely used in therapeutics:

1. Recombinant Human Insulin (Humulin) - Treatment of diabetes mellitus. Produced in *E. coli* or yeast; was the first recombinant therapeutic approved (Eli Lilly, 1982).
2. Recombinant Human Growth Hormone (Somatropin) - Treatment of growth hormone deficiency and short stature in children.
3. Recombinant Erythropoietin (EPO) - Treatment of anaemia in chronic kidney disease and chemotherapy patients. Stimulates red blood cell production.
4. Recombinant Hepatitis B Vaccine (HBsAg) - Prevention of Hepatitis B infection. Contains recombinant hepatitis B surface antigen produced in yeast.
5. Recombinant Tissue Plasminogen Activator (tPA / Alteplase) - Thrombolytic agent to dissolve blood clots in heart attacks and strokes.
6. Recombinant Factor VIII (Advate) - Treatment of Haemophilia A (deficiency of clotting factor VIII).
7. Recombinant Factor IX - Treatment of Haemophilia B (Christmas disease). Avoids the risk of blood-borne infections from plasma-derived products.
8. Recombinant Interferon-alpha (IFN-alpha / Intron A) - Treatment of viral infections (Hepatitis B, C) and certain cancers (hairy cell leukaemia).
9. Recombinant Interleukin-2 (IL-2 / Aldesleukin) - Immunotherapy for metastatic renal cell carcinoma and melanoma.
10. Recombinant Streptokinase - Thrombolytic enzyme used to dissolve blood clots in myocardial infarction. Produced in bacteria.

Q2. Make a chart showing a restriction enzyme, its substrate DNA, cut site, and product.

The table below summarises three commonly used restriction endonucleases:

Restriction Enzyme	Source Organism	Recognition Sequence (Cut Site)	Type of End Produced
EcoRI	<i>Escherichia coli</i> RY13	5'-G AATTC-3' / 3'-CTTAA G-5'	5' Sticky ends (4-nt overhang: AATT)
HindIII	<i>Haemophilus influenzae</i> Rd	5'-A AGCTT-3' / 3'-TTCGA A-5'	5' Sticky ends (4-nt overhang: AGCT)
BamHI	<i>Bacillus amyloliquefaciens</i> H	5'-G GATCC-3' / 3'-CCTAG G-5'	5' Sticky ends (4-nt overhang: GATC)
SmaI	<i>Serratia marcescens</i> Sb	5'-CCC GGG-3' / 3'-GGG CCC-5'	Blunt ends (no overhang)
PstI	<i>Providencia stuartii</i> 164	5'-CTGCA G-3' / 3'-G ACGTC-5'	3' Sticky ends (4-nt overhang: ACGT)

Note: The symbol | shows the cut point. EcoRI is the most commonly used restriction enzyme in recombinant DNA technology experiments.

Q3. Are enzymes bigger or is DNA bigger in molecular size?

Answer: DNA molecules are vastly larger than enzyme molecules in molecular size.

- Enzymes are proteins. Their molecular weight ranges from about 10,000 to a few hundred thousand Daltons (10 kDa to ~500 kDa). For example, EcoRI has a molecular weight of about 31,000 Da per subunit.
- DNA, especially genomic DNA, is an enormously long polymer. The human haploid genome contains about 3×10^9 base pairs. A single DNA molecule of a human chromosome can be 250 million base pairs long, with a molecular weight in the hundreds of billions of Daltons.
- Even a small plasmid (e.g., pBR322 with 4361 bp) has a molecular weight of about 2.9 million Daltons - already far exceeding that of most enzymes.
- Textbook clue: Restriction enzymes recognise sequences of only 4-8 base pairs on the much larger DNA molecule, and a single enzyme molecule can act on many DNA molecules. This clearly shows DNA is the larger substrate.

Conclusion: DNA is orders of magnitude larger than enzymes in molecular mass and physical dimensions.

Q4. What would be the molar concentration of human DNA in a human cell?

This can be estimated using known biological values:

- A diploid human cell contains approximately 6 picograms (6×10^{-12} g) of DNA.
- The human diploid genome has $\sim 6 \times 10^9$ base pairs. Average molecular weight of one base pair = 660 g/mol.
- Total molecular weight of human diploid DNA = $6 \times 10^9 \times 660 = 3.96 \times 10^{12}$ g/mol.

Calculation:

$$\begin{aligned} \text{Moles of DNA per cell} &= \text{mass} / \text{molecular weight} \\ &= (6 \times 10^{-12} \text{ g}) / (3.96 \times 10^{12} \text{ g/mol}) \\ &= \text{approximately } 1.5 \times 10^{-24} \text{ mol} \end{aligned}$$

$$\text{Volume of human cell} = \text{approximately } 2\text{-}3 \text{ picolitres} = 2 \times 10^{-12} \text{ litres}$$

$$\text{Molar concentration} = \text{moles} / \text{volume} = (1.5 \times 10^{-24}) / (2 \times 10^{-12}) = \sim 7.5 \times 10^{-13} \text{ M}$$

Result: The molar concentration of total human DNA in a cell is approximately 10^{-12} M (about 1 picomolar). This extremely low value reflects the enormous molecular size of DNA - the molecule is so large that even though there are 2 copies per cell, their molar concentration is vanishingly small.

Q5. Do eukaryotic cells have restriction endonucleases? Justify your answer.

Answer: No. Eukaryotic cells do not have restriction endonucleases.

Justification:

- Restriction endonucleases are found exclusively in prokaryotes (bacteria and archaea). They evolved as part of the bacterial Restriction-Modification (R-M) system - a primitive immune defence against invading bacteriophage DNA.
- In bacteria, the host's own DNA is protected by methylation at the same recognition sequences by a companion methyltransferase. Foreign (unmethylated) DNA from viruses is recognised as 'non-self' and destroyed by the restriction enzyme.
- Eukaryotes have entirely different and far more sophisticated immune defence systems (innate and adaptive immunity involving cells and antibodies). They do not need restriction enzymes to fight viral DNA.
- Critically, if eukaryotic cells possessed restriction endonucleases, these enzymes would indiscriminately cut the cell's own genomic DNA at every recognition sequence, causing lethal fragmentation of the chromosomes. The absence of restriction enzymes in eukaryotes is therefore essential for genome integrity.

- Eukaryotic nucleases exist (DNases, RNases) but these degrade DNA non-specifically and are not sequence-specific restriction enzymes.

Conclusion: Restriction endonucleases are a prokaryote-specific adaptation and are entirely absent from eukaryotic cells.

Q6. What other advantages do stirred-tank bioreactors have over shake flasks?

Apart from better aeration and mixing, stirred-tank bioreactors offer the following additional advantages:

- Large-scale production: Bioreactors hold 100-1000 litres of culture, enabling industrial-scale production. Shake flasks are limited to typically less than 1 litre.
- Precise environmental control: Dedicated sensors and automated feedback systems maintain optimal and constant temperature, pH, dissolved oxygen (DO), CO₂ levels, and nutrient concentrations throughout the culture. Shake flasks rely only on incubator temperature control.
- Foam control: A mechanical foam breaker (impeller at the surface) and antifoam agents prevent excessive foam build-up that would reduce gas exchange and contaminate the system - impossible in shake flasks.
- Continuous culture mode (chemostat): Fresh medium can be continuously added while spent medium is withdrawn, keeping the culture in exponential growth phase for prolonged maximum productivity.
- Sampling ports: Aseptic sampling ports allow withdrawal of small volumes for periodic analysis (pH, cell density, product levels) without contaminating the main culture.
- Better sterility assurance: Designed for rigorous steam-in-place (SIP) sterilisation and continuous sterile operation at large scale - far superior to the cotton-plugged flask approach.
- Higher biomass and product yield: The combination of all the above results in significantly higher cell densities and greater yields of recombinant protein per litre of culture.

Q7. Collect 5 examples of palindromic DNA sequences.

A palindromic DNA sequence is one that reads the same on both strands in the 5' to 3' direction. Below are five examples with the recognising restriction enzyme:

Restriction Enzyme	5' to 3' (Top strand)	3' to 5' (Bottom strand)	Palindrome confirmed?
EcoRI	5'-G A A T T C-3'	3'-C T T A A G-5' (= 5'-GAATTC-3')	Yes
HindIII	5'-A A G C T T-3'	3'-T T C G A A-5' (= 5'-AAGCTT-3')	Yes
BamHI	5'-G G A T C C-3'	3'-C C T A G G-5' (= 5'-GGATCC-3')	Yes
SmaI	5'-C C C G G G-3'	3'-G G G C C C-5' (= 5'-CCCGGG-3')	Yes
PstI	5'-C T G C A G-3'	3'-G A C G T C-5' (= 5'-CTGCAG-3')	Yes

Key concept: In each case, reading the complementary strand in the 5' to 3' direction gives the identical sequence as the top strand - confirming the palindromic nature. These sequences are the recognition sites for restriction endonucleases.

Q8. At what stage of meiosis is recombinant DNA made?

In the context of natural genetic recombination during meiosis, recombinant DNA is made during Prophase I of Meiosis I, specifically during the Pachytene sub-stage.

Sequence of events:

- Leptotene: Chromosomes begin to condense and become visible.
- Zygotene: Homologous chromosomes begin to pair (synapsis) along their lengths with help of the synaptonemal complex.
- Pachytene (key stage): Synapsis is complete. Non-sister chromatids of homologous chromosomes exchange segments at points called chiasmata - this physical exchange of DNA creates recombinant chromatids. This process is called crossing over.
- Diplotene: The synaptonemal complex dissolves and homologues begin to separate, but remain connected at chiasmata (now visible as X-shaped structures).
- Diakinesis: Further condensation; chiasmata move to chromosome ends (terminalisation).

Result: The crossing over during pachytene creates new combinations of alleles (recombinant chromosomes) in the gametes produced at the end of Meiosis II. This is the biological basis of genetic variation.

Important note: In recombinant DNA technology (genetic engineering), recombinant DNA is created artificially in vitro using restriction enzymes and DNA ligase - this is entirely independent of meiosis.

Q9. How can a reporter enzyme be used to monitor transformation?

A reporter enzyme is used in a technique called insertional inactivation to identify which bacterial colonies have taken up a recombinant plasmid (with foreign DNA insert) as opposed to a non-recombinant plasmid (without insert).

Principle - Insertional Inactivation:

The reporter enzyme gene (e.g., lacZ encoding beta-galactosidase) is located within the Multiple Cloning Site (MCS) of the vector. When a foreign DNA insert is ligated into the MCS, it disrupts and inactivates the lacZ gene.

Blue-White Screening (most classic example):

- The vector (e.g., pUC19) contains the lacZ gene in its MCS. The host bacteria are lacZ-deficient.
- Transformed bacteria are plated on agar containing: (a) Ampicillin - selects only transformed cells (those that took up the plasmid), and (b) X-gal (5-bromo-4-chloro-3-indolyl-beta-D-galactopyranoside) + IPTG (inducer).
- Non-recombinant colonies (plasmid with no insert, intact lacZ): Produce functional beta-galactosidase which cleaves X-gal to release a blue indigo dye. Colonies appear BLUE.
- Recombinant colonies (plasmid with insert disrupting lacZ): No functional beta-galactosidase is made. X-gal is not cleaved. Colonies appear WHITE.

Result: White colonies are the recombinants of interest. Blue colonies are non-recombinants. This provides a rapid, visual, one-step screening method requiring no additional replica-plating or biochemical assays.

Advantage: The reporter enzyme system distinguishes not just transformed vs. non-transformed cells (which ampicillin resistance already does), but also specifically identifies which transformants carry the insert - the crucial extra step in recombinant DNA work.

Q10. Describe briefly: (a) Origin of Replication, (b) Bioreactors, (c) Downstream Processing

(a) Origin of Replication (ori):

The origin of replication (ori) is a specific DNA sequence in a plasmid or chromosome where DNA replication begins. It is recognised and bound by the host cell's DNA replication initiation proteins, which recruit the replisome complex to start copying the DNA.

In the context of cloning vectors, the ori is an essential element because: (1) Any foreign DNA ligated into the vector must be linked to an ori so that it can replicate autonomously inside the host cell. (2) The ori determines the copy number of the plasmid - high-copy ori sequences (e.g., ColE1 ori) produce 100+ copies per cell, while low-copy ori sequences produce fewer copies. High copy number maximises the yield of cloned gene and its expressed protein.

(b) Bioreactors:

Bioreactors are large, specially designed vessels used for the large-scale cultivation of genetically modified microorganisms, plant cells, or animal cells to produce recombinant proteins or other biotechnological products. They typically hold 100 to 1000 litres of culture medium.

Key features of a stirred-tank bioreactor: (1) Impeller/stirrer - provides mixing and homogeneous distribution of nutrients and oxygen; (2) Sparger - bubbles sterile air/oxygen through the culture; (3) Baffles - prevent vortex formation; (4) Temperature and pH control systems; (5) Foam breaker; (6) Sampling ports for monitoring; (7) Inlet/outlet for continuous culture operation. Bioreactors provide the optimal environment for maximum biomass and product yield.

(c) Downstream Processing:

Downstream processing refers to all the steps performed after a bioreactor run to isolate, purify, and formulate the recombinant product before it can be used as a final therapeutic or commercial product.

Steps include: (1) Separation - centrifugation or filtration to separate cells from culture broth; (2) Cell disruption (if product is intracellular) - by sonication, mechanical lysis, or enzymatic treatment; (3) Clarification - removal of cell debris by centrifugation or filtration; (4) Purification - using chromatographic techniques (affinity, ion-exchange, size exclusion, HPLC) to obtain highly pure product; (5) Formulation - adding stabilisers, excipients, and buffers; (6) Quality control testing for purity, potency, sterility; (7) Clinical trials and regulatory approval for pharmaceuticals. The specific steps vary for each product.

Q11. Explain briefly: (a) PCR, (b) Restriction Enzymes and DNA, (c) Chitinase

(a) PCR (Polymerase Chain Reaction):

PCR is an in vitro enzymatic technique developed by Kary Mullis (Nobel Prize 1993) used to amplify a specific target DNA sequence from a complex mixture, producing billions of identical copies within a few hours.

Components required: Template DNA, two specific oligonucleotide primers (complementary to the two ends of the target sequence), thermostable Taq DNA polymerase (from *Thermus aquaticus*), dNTPs (deoxyribonucleotides), and buffer with Mg²⁺.

Each PCR cycle (repeated 30-40 times) has 3 steps:

- Denaturation (~94 degrees C): The double-stranded template DNA is heat-denatured into two single strands.
- Annealing (~55 degrees C): The two primers anneal (bind) to their complementary sequences on the opposite strands of the template.
- Extension (~72 degrees C): Taq polymerase extends each primer in the 5' to 3' direction, synthesising new complementary strands.

After 30 cycles, the target sequence is amplified approximately 10⁹-fold. PCR is used in diagnostics (detecting pathogens), forensics (DNA fingerprinting), cloning (preparing DNA inserts), and research.

(b) Restriction Enzymes and DNA:

Restriction endonucleases (restriction enzymes) are bacterial enzymes that act as 'molecular scissors' - they recognise specific short palindromic sequences (4-8 bp called recognition sequences) in double-stranded DNA and cut both strands at defined positions within or near the recognition site.

Mechanism: The enzyme binds to its recognition sequence and cleaves the phosphodiester bonds of both DNA strands. The cuts produce either: (1) Sticky ends (staggered cuts leaving short single-stranded overhangs, e.g., EcoRI produces 5'-AATT overhangs); or (2) Blunt ends (cuts in the middle of the recognition sequence, e.g., SmaI).

Significance in biotechnology: Two different DNA molecules (e.g., vector and foreign insert) cut with the same restriction enzyme have compatible sticky ends. These can be joined by DNA ligase to form recombinant DNA. Over 900 restriction enzymes are known from more than 230 bacterial strains. Named by convention: first letter of genus + two letters of species + strain designation + isolation order (e.g., EcoRI = *Escherichia coli*, strain RY13, first enzyme).

(c) Chitinase:

Chitinase is a hydrolytic enzyme that degrades chitin - a structural polysaccharide made of N-acetylglucosamine units linked by beta-1,4-glycosidic bonds. Chitin is the main structural component of fungal cell walls (and arthropod exoskeletons).

In biotechnology: Chitinase is used during the DNA isolation protocol from fungal cells. It breaks down the fungal cell wall by hydrolysing the chitin polymer, releasing the cell contents (including genomic DNA) into the solution for subsequent extraction and purification.

Analogy: Chitinase does for fungi what lysozyme does for bacteria (breaks down peptidoglycan) and what cellulase does for plants (breaks down cellulose). Each cell wall type requires its specific degrading enzyme.

Q12. Distinguish between: (a) Plasmid DNA vs Chromosomal DNA, (b) RNA vs DNA, (c) Exonuclease vs Endonuclease

(a) Plasmid DNA vs. Chromosomal DNA

Feature	Plasmid DNA	Chromosomal DNA
Location	Cytoplasm (extrachromosomal)	Nucleus (or nucleoid in prokaryotes)
Size	Small: 1 to 200 kb	Very large: millions to billions of bp
Shape	Circular, double-stranded	Linear in eukaryotes; circular in prokaryotes
Replication	Autonomous - independently of chromosome	Coordinated with cell division cycle
Genes encoded	Non-essential (e.g., antibiotic resistance, toxins)	Essential genes for survival and development
Copy number	Multiple copies per cell (1 to 100+)	Usually 1 to 2 copies per cell
Histone association	Not associated with histones in bacteria	Associated with histones in eukaryotes
Role in biotech	Used as cloning vectors for recombinant DNA work	Source of genes to be cloned

(b) RNA vs. DNA

Feature	RNA (Ribonucleic Acid)	DNA (Deoxyribonucleic Acid)
Sugar	Ribose (has -OH group at 2' carbon)	Deoxyribose (has -H at 2' carbon)
Strands	Usually single-stranded	Double-stranded (double helix)

Feature	RNA (Ribonucleic Acid)	DNA (Deoxyribonucleic Acid)
Bases	A, U, G, C (Uracil replaces Thymine)	A, T, G, C (Thymine replaces Uracil)
Stability	Less stable; -OH at 2' makes it susceptible to hydrolysis	More stable; suited for long-term genetic storage
Location	Cytoplasm, nucleus, ribosomes	Mainly nucleus; also mitochondria and chloroplasts
Function	Protein synthesis (mRNA, tRNA, rRNA); gene regulation (miRNA, siRNA)	Stores and transmits genetic information across generations
Types	mRNA, tRNA, rRNA, miRNA, siRNA, snRNA	Genomic DNA, plasmid DNA, mitochondrial DNA

(c) Exonuclease vs. Endonuclease

Feature	Exonuclease	Endonuclease
Site of cleavage	Cleaves from the ends (5' or 3' terminus) of the DNA/RNA strand	Cleaves within the interior of the DNA/RNA strand
Direction	Progressively removes nucleotides one at a time from ends	Makes cuts at specific internal positions
Sequence specificity	Generally non-specific	Restriction endonucleases are highly sequence-specific (palindromes)
Product	Releases individual mononucleotides from the ends	Produces defined DNA fragments of various sizes with sticky or blunt ends
Examples	Exonuclease I (3' to 5'), Snake venom phosphodiesterase, Lambda exonuclease	EcoRI, HindIII, BamHI (restriction endonucleases); DNase I
Role in biotech	Used in DNA sequencing, end-polishing, and single-strand removal	Central tool in recombinant DNA technology for cutting DNA at specific sites

Chapter 10: Biotechnology and Its Applications

Q1. Which part of the plant is best suited for making virus-free plants and why?

Answer: The meristem (apical and axillary meristems) is best suited for making virus-free plants.

Reason: Even when a plant is systemically infected by a virus, the meristematic tissue remains virus-free. This is because viruses spread through the vascular system and plasmodesmata, but the meristematic cells divide so rapidly that the virus cannot keep pace with cell division. Additionally, the apical meristem lacks a fully developed vascular system, which restricts viral entry.

The meristem can be excised and grown in vitro under sterile conditions to produce virus-free plantlets. This technique has been successfully used for banana, sugarcane, and potato, which are commonly affected by viral diseases.

Q2. What is the major advantage of producing plants by micropropagation?

Micropropagation is the technique of producing thousands of genetically identical plants (somaclones) from a small piece of plant tissue (explant) in a very short period of time, using in vitro tissue culture.

The major advantages are:

- **Rapid clonal multiplication:** Thousands of disease-free, genetically identical plants can be produced from a single plant in a very short duration — something impossible through conventional vegetative propagation.
- **Production of somaclones:** All plants produced are genetically identical to the parent, ensuring preservation of desirable traits.
- **Disease-free plants:** Explants from meristematic tissue produce virus-free, pathogen-free healthy plants.
- **Year-round production:** Not dependent on seasons — plants can be propagated throughout the year under controlled conditions.
- **Conservation of rare and endangered species:** Plants that are difficult to propagate conventionally can be multiplied and conserved.
- **Commercial applications:** Important food plants like tomato, banana, apple, orchids, and ornamentals are commercially produced this way.

Q3. What are the various components of the medium used for propagation of an explant in vitro?

The nutrient medium used for in vitro propagation of explants (tissue culture medium) typically contains the following components:

- **Carbon source:** Sucrose (usually 2–3%) — provides energy and acts as an osmoticum for growth.
- **Inorganic salts (macro- and micronutrients):** Major mineral elements (nitrogen as NH_4^+ and NO_3^- , phosphorus, potassium, calcium, magnesium, sulphur) and trace elements (iron, manganese, zinc, copper, boron, molybdenum, cobalt, iodine). Murashige and Skoog (MS) medium is the most commonly used.
- **Vitamins:** Thiamine (B1), nicotinic acid, pyridoxine (B6), and inositol — essential for cell metabolism and growth.
- **Amino acids:** Glycine and glutamine are sometimes added as nitrogen sources to promote growth.
- **Plant growth regulators (phytohormones):** Auxins (e.g., IAA, NAA, 2,4-D) — promote cell elongation and root initiation; Cytokinins (e.g., BAP, kinetin) — promote cell division and shoot formation. The ratio of auxin to cytokinin determines the type of growth (high auxin/cytokinin = root formation; high cytokinin/auxin = shoot formation; equal ratio = callus formation).

- Gelling agent: Agar (0.6–1.0%) — solidifies the medium for solid culture. Liquid media is used for suspension cultures.
- Water: High-purity distilled or deionised water.
- pH: The medium is typically adjusted to pH 5.6–5.8 before autoclaving.

The medium is sterilised by autoclaving (121° C, 15 psi, 15–20 minutes) to ensure aseptic (contamination-free) conditions.

Q4. Crystals of Bt toxin produced by some bacteria do not kill the bacteria themselves because –

The correct answer is: (c) toxin is inactive (protoxin form).

Explanation: *Bacillus thuringiensis* produces the Bt toxin protein as an inactive precursor called a protoxin, which is stored in crystalline form (protein crystals) in the bacterial spore. The inactive protoxin does not harm the bacterium itself because:

- The toxin is produced and stored in an inactive crystalline form (as protoxin) — it has no toxic activity in this state.
- The activation of the protoxin requires the alkaline pH (pH ~9–11) of the insect midgut. In insects, the alkaline environment solubilises the crystals and proteolytic enzymes cleave the protoxin into its active toxic form.
- Bacteria do not have this alkaline gut environment, so the toxin remains inactive and harmless inside or around the bacterial cell.
- Once activated in the insect gut, the toxin binds to specific receptors on midgut epithelial cells, forms pores, causes cell swelling and lysis, and ultimately kills the insect.

Option (a) is incorrect — bacteria are not 'resistant'; the toxin simply never gets activated in them.

Options (b) and (d) are incorrect descriptions.

Q5. What are transgenic bacteria? Illustrate using any one example.

Transgenic bacteria: Transgenic bacteria are bacteria whose genome has been altered by the introduction of a foreign gene (from another organism) using recombinant DNA technology. These bacteria can then express the foreign gene and produce a protein of interest.

Example: Production of Human Insulin using *E. coli*

Human insulin is a protein hormone consisting of two polypeptide chains — chain A (21 amino acids) and chain B (30 amino acids) — linked by disulphide bridges.

Steps in producing transgenic insulin-producing *E. coli*:

1. The human insulin gene was chemically synthesised — two separate DNA sequences were prepared, one corresponding to chain A and one to chain B.
2. Each DNA sequence was separately cloned into a plasmid vector (at the restriction site within the plasmid) using restriction enzymes and DNA ligase.
3. The recombinant plasmids were transformed into separate *E. coli* cells (made competent using CaCl₂ treatment).
4. The transformed *E. coli* cells expressed the insulin gene and produced insulin chains A and B separately.
5. The two chains were extracted, purified, and combined in vitro by forming disulphide bonds to produce functional human insulin (commercially called Humulin).

This was accomplished by Eli Lilly, an American company, in 1983. These *E. coli* bacteria, carrying and expressing the human insulin gene, are examples of transgenic bacteria.

Q6. Compare and contrast the advantages and disadvantages of production of genetically modified crops.

Advantages	Disadvantages / Concerns
Crops more tolerant to abiotic stresses (drought, cold, salt, heat) — extends cultivation to marginal lands.	Potential for unintended ecological effects — transgenes may spread to wild relatives causing 'genetic pollution'.
Reduced reliance on chemical pesticides (e.g., Bt crops), lowering environmental pollution and farmer costs.	Loss of biodiversity — widespread adoption of a few GM varieties may displace traditional varieties.
Reduced post-harvest losses through longer shelf life.	Possible development of 'superweeds' or 'superpests' — pests may evolve resistance to Bt toxin.
Enhanced nutritional value (e.g., Golden Rice with Vitamin A precursor) — helps combat malnutrition.	Concerns about unknown long-term health effects of consuming GM foods.
Increased efficiency of mineral usage — prevents early soil exhaustion.	Ethical and religious concerns about 'playing God' with life forms.
Higher crop yields — helps feed a growing global population.	Socioeconomic issues — patenting of GM crops by corporations may exploit farmers, especially in developing nations (biopiracy).
Can be tailored to produce industrial raw materials (starches, fuels, pharmaceuticals).	Regulatory and monitoring burden — requires stringent oversight (e.g., GEAC in India).

Conclusion: Genetically modified crops offer significant potential in addressing food security and environmental challenges, but they must be developed and deployed responsibly, with strict regulatory oversight (e.g., GEAC in India), long-term safety testing, and equitable policies to protect biodiversity and farmers' rights.

Q7. What are Cry proteins? Name the organism that produces them. How has man exploited this protein to his benefit?

Cry proteins (Crystal proteins): Cry proteins (also called delta-endotoxins or Bt toxins) are insecticidal proteins produced by the bacterium *Bacillus thuringiensis* (Bt) during sporulation in the form of protein crystals. The genes encoding these proteins are called cry genes (e.g., cryIAc, cryIAb, cryIAb). Different cry genes encode proteins that are toxic to specific groups of insects.

Organism: *Bacillus thuringiensis* (a Gram-positive soil bacterium).

How man has exploited Cry proteins:

- The cry genes were isolated from *Bacillus thuringiensis* and cloned into crop plant genomes using recombinant DNA technology (via *Agrobacterium tumefaciens* as a vector) to create transgenic (Bt) crops.
- **Bt Cotton:** The cryIAc and cryIAb genes were incorporated into cotton plants — these proteins are toxic to lepidopterans such as the cotton bollworm (*Helicoverpa armigera*), significantly reducing crop damage and pesticide use.
- **Bt Corn:** The cryIAb gene product controls the corn borer (*Ostrinia nubilalis*).
- Other Bt crops include rice, tomato, potato, soyabean, and brinjal.
- **Mechanism of action:** When an insect ingests the plant tissue, the alkaline pH of its midgut converts the inactive protoxin into the active toxin, which binds to epithelial receptors in the

midgut, creates pores, causes cell lysis, and kills the insect — with no harm to birds, mammals, or humans (as they lack the alkaline gut environment and the specific receptors).

- **Benefit:** Reduction in the amount of chemical insecticides used, lowering environmental pollution, reducing production costs for farmers, and producing safer food.

Q8. What is gene therapy? Illustrate using the example of ADA deficiency.

Gene therapy: Gene therapy is a collection of methods that allows the correction of a gene defect diagnosed in a child or embryo. It involves the insertion of a functional (normal) gene into a person's cells or tissues to replace or compensate for a defective or absent gene, thus treating the disease at its genetic root.

Illustration: Adenosine Deaminase (ADA) Deficiency

Disease: ADA deficiency is a genetic disorder caused by deletion of the gene encoding the enzyme adenosine deaminase, which is essential for the immune system to function (catalyses the deamination of adenosine). Its deficiency results in severe combined immunodeficiency (SCID) — the patient lacks functional T and B lymphocytes and is highly vulnerable to infections.

Gene therapy steps (first clinical trial, 1990, 4-year-old girl):

6. Lymphocytes were isolated from the patient's blood and grown in culture outside the body (ex vivo).
7. A functional ADA cDNA was cloned into a retroviral vector (retroviruses can integrate their RNA/DNA into the host cell genome).
8. The retroviral vector carrying the functional ADA gene was introduced into the patient's lymphocytes in culture (transduction).
9. The genetically engineered lymphocytes (now expressing functional ADA) were returned (infused) into the patient's blood.
10. These lymphocytes restored some immune function in the patient.

Limitation: Since lymphocytes are not immortal cells, the treatment is not permanent — periodic infusions of engineered lymphocytes are required.

Potential permanent cure: If the ADA gene is introduced into bone marrow stem cells at an early embryonic stage, the correction would be heritable in all immune cells derived from those stem cells, providing a permanent cure.

Q9. Diagrammatically represent the experimental steps in cloning and expressing a human gene (e.g., growth hormone gene) into *E. coli*.

The following steps outline the cloning and expression of the human growth hormone (hGH) gene in *E. coli*:

Step 1: Isolation of hGH Gene

The human growth hormone gene is identified in human genomic DNA or obtained as cDNA (synthesised from mRNA using reverse transcriptase). The mRNA for hGH is isolated from pituitary gland cells.

Step 2: Cutting with Restriction Enzyme

Both the hGH gene/cDNA and the cloning vector (e.g., plasmid pBR322) are cut with the same restriction enzyme (e.g., EcoRI) to produce compatible sticky ends.

Step 3: Ligation into Vector

The hGH gene is ligated into the linearised vector using DNA ligase, producing a recombinant plasmid (rDNA) carrying the hGH gene.

Step 4: Transformation into *E. coli*

The recombinant plasmid is introduced into competent *E. coli* cells (treated with CaCl_2 and heat shock at 42°C). Transformed cells are selected on ampicillin plates (using the antibiotic resistance selectable marker).

Step 5: Screening of Recombinants

Recombinant colonies (carrying the hGH insert) are identified using colony hybridisation with a labelled hGH probe, or by insertional inactivation (blue-white screening).

Step 6: Expression of the Gene

The recombinant *E. coli* cells are grown in bioreactors. The hGH gene is expressed under the control of a suitable promoter — the bacteria produce the hGH protein (recombinant human growth hormone, rhGH).

Step 7: Downstream Processing

The recombinant hGH protein is extracted from the bacterial cells, purified by chromatography, formulated, and subjected to quality control before use as a therapeutic product.

Diagrammatic flow: Isolation of mRNA from pituitary → Reverse transcription → hGH cDNA → Cut with EcoRI → Insert into plasmid vector → Ligation → Recombinant plasmid → Transform into *E. coli* → Select transformants → Express hGH → Purify recombinant protein.

Q10. Can you suggest a method to remove oil (hydrocarbon) from seeds based on rDNA technology and chemistry of oil?

Seed oils are primarily triglycerides (triacylglycerols) — esters of glycerol and three fatty acids. The biosynthesis of these fatty acids in seeds involves key enzymes such as fatty acid synthase, acetyl-CoA carboxylase, and desaturases, encoded by specific genes.

Method using rDNA Technology (Gene Silencing / RNA Interference):

- Identify the genes encoding key enzymes in the fatty acid biosynthesis pathway of the plant (e.g., fatty acid desaturase gene in soyabean or cotton).
- Use RNAi (RNA interference) technology: Design a construct that produces a dsRNA complementary to the mRNA of these fatty acid biosynthesis genes.
- Introduce this construct into the plant via *Agrobacterium*-mediated transformation.
- In the transgenic plants, the dsRNA triggers RNAi — the specific mRNA for fatty acid biosynthesis enzymes is degraded (silenced), resulting in seeds with greatly reduced oil content.

Alternatively:

- The genes encoding specific desaturases or elongases (that convert saturated to unsaturated fatty acids) can be knocked out or over-expressed to modify the fatty acid composition rather than eliminate all oil — useful for creating low-fat or modified-fat crops.
- Antisense technology: Introduce an antisense version of the fatty acid synthase gene — the antisense RNA binds to and blocks translation of the enzyme's mRNA, reducing oil synthesis in seeds.

Practical application: This approach has already been used to create low-erucic-acid rapeseed (canola) and high-oleic soyabeans. In principle, it could be extended to produce essentially oil-free seeds.

Q11. Find out from the internet what is Golden Rice.

Golden Rice: Golden Rice is a variety of rice (*Oryza sativa*) that has been genetically engineered to produce beta-carotene (a precursor of Vitamin A) in the endosperm (the edible part of the grain). Ordinary rice does not produce beta-carotene in its endosperm.

Development:

- Golden Rice was developed by Ingo Potrykus (ETH Zurich) and Peter Beyer (University of Freiburg) in the late 1990s and first published in 2000.
- Two genes were introduced into the rice genome: *psy* (phytoene synthase gene from daffodil/maize) and *crtI* (phytoene desaturase gene from the bacterium *Erwinia uredovora*). These two enzymes catalyse the biosynthesis of beta-carotene in the rice endosperm.
- The beta-carotene gives the rice a characteristic golden-yellow colour, hence the name 'Golden Rice.'

Significance:

- Vitamin A deficiency affects ~190 million children and ~19 million pregnant women globally (WHO data), causing blindness (xerophthalmia) and increased mortality.
- Golden Rice is designed to supplement dietary Vitamin A intake in populations that depend heavily on rice as their staple food, particularly in South and Southeast Asia.
- Golden Rice 2, a more recent version using a maize *psy* gene, produces 23 times more beta-carotene than the original Golden Rice — enough to provide a significant portion of the daily Vitamin A requirement from a typical serving.

Current status: Golden Rice has been approved for consumption in the Philippines (2021) and is under review in other countries. It remains controversial due to debates around biosafety, socioeconomic impact, and food sovereignty.

Q12. Does our blood have proteases and nucleases?

Answer: No, human blood does not normally contain active proteases and nucleases in significant amounts under healthy conditions — and this is of critical importance for understanding why protein and nucleic acid therapeutics (like recombinant insulin or gene therapy DNA) cannot be administered orally.

Detailed explanation:

- Blood plasma does contain some proteolytic activity in the form of the complement system, the coagulation cascade (e.g., thrombin, plasmin), and the fibrinolytic system — but these are highly specific clotting/immune proteins, not general-purpose proteases that would degrade all proteins indiscriminately.
- Blood serum does not contain DNases (deoxyribonucleases) or RNases (ribonucleases) in significant active concentrations, which is why DNA molecules injected intravenously (as in gene therapy) can circulate briefly before being degraded.
- The digestive tract (not blood) is where active proteases (pepsin, trypsin, chymotrypsin) and nucleases (pancreatic DNase, RNase) are present in high concentrations.

Relevance: This is why recombinant protein drugs like insulin cannot be given orally — the proteases in the stomach and intestine would digest the protein before it reaches the bloodstream. They must be given by injection (subcutaneous or intravenous). The digestive nucleases would similarly degrade nucleic acid-based drugs. This represents a major challenge in developing oral drug delivery systems for biological therapeutics.

Q13. How to make orally active protein pharmaceutical. What is the major problem?

Challenge: The major problem with oral administration of protein pharmaceuticals (like insulin, erythropoietin, growth hormone) is their degradation in the gastrointestinal (GI) tract.

Problems encountered:

- Enzymatic degradation: Proteases in the stomach (pepsin at pH 1.5–2) and the small intestine (trypsin, chymotrypsin, elastase from pancreas) rapidly hydrolyse proteins into amino acids, destroying their therapeutic activity.
- Acidic environment: The highly acidic gastric pH (1.5–3.5) denatures most proteins, unfolding them and rendering them inactive and more susceptible to protease attack.
- Poor mucosal absorption: Intact large protein molecules (high molecular weight) cannot cross the intestinal epithelial barrier (tight junctions) — they have very low bioavailability.
- First-pass metabolism: Even if a protein survives the gut, liver enzymes may degrade it before it reaches systemic circulation.

Approaches to make orally active protein pharmaceuticals:

- Microencapsulation / Nanoparticle formulations: Encasing the protein in biodegradable polymers (e.g., PLGA, chitosan) or lipid nanoparticles that protect it from gastric acid and proteases, releasing it at the desired site (e.g., small intestine).
- Enteric coatings: Coating tablets/capsules with acid-resistant polymers (e.g., Eudragit) that dissolve only at the higher pH of the small intestine, bypassing stomach degradation.
- Protease inhibitors co-administration: Including specific protease inhibitors in the formulation to protect the protein in the gut — though this has safety concerns for long-term use.
- Chemical modification: PEGylation (attaching polyethylene glycol) or other chemical modifications can protect the protein from enzymatic attack and improve its stability.
- Oral gene therapy approach: Instead of administering the protein directly, gene constructs can be delivered to intestinal cells to produce the protein in situ.
- Cell-penetrating peptides / Permeation enhancers: Chemical agents (e.g., bile salts, fatty acids, EDTA) can transiently open tight junctions to allow protein absorption.

Example of progress: Oral insulin formulations (e.g., ORMD-0801) using enteric capsules with protease inhibitors are currently in Phase III clinical trials (2024), representing a major advance. However, no orally active protein drug has yet achieved bioavailability comparable to injectable forms.

Chapter 11: Organisms and Populations

Q1. List the attributes that populations possess but not individuals.

Populations have emergent properties that individual organisms do not possess:

- **Birth rate (Natality):** The per capita rate at which new individuals are added to the population through reproduction. An individual can give birth, but only a population has a birth rate. Example: 8 new lotus plants in a pond of 20 = birth rate of 0.4 per lotus per year.
- **Death rate (Mortality):** The per capita rate of deaths in the population per unit time. Example: 4 deaths in a fruitfly population of 40 = death rate of 0.1 per fruitfly per week.
- **Sex ratio:** The proportion of males and females in the population. An individual is either male or female; only a population has a sex ratio (e.g., 60% females : 40% males).
- **Age distribution / Age pyramid:** The proportion of individuals of different age groups (pre-reproductive, reproductive, post-reproductive) in the population. An individual has an age; a population has an age distribution, represented as an age pyramid.
- **Population density (N):** The number (or biomass/per cent cover) of individuals per unit area or volume at a given time. Meaningful only at the population level.
- **Growth rate (r):** The intrinsic rate of natural increase — the net per capita rate of change in population size. Calculated as $r = b - d$ (birth rate minus death rate).

Q2. If a population growing exponentially doubles in size in 3 years, what is the intrinsic rate of increase (r)?

For exponential (geometric) growth, the integral form of the growth equation is:

$$N_t = N_0 \times e^{(rt)}$$

Given: The population doubles in 3 years, so $N_t = 2N_0$ and $t = 3$ years.

Substituting:

$$2N_0 = N_0 \times e^{(r \times 3)}$$

$$2 = e^{(3r)}$$

Taking natural logarithm on both sides:

$$\ln(2) = 3r$$

$$r = \ln(2) / 3$$

$$r = 0.6931 / 3$$

$$r \approx 0.231 \text{ per year}$$

Therefore, the intrinsic rate of natural increase (r) of the population is approximately 0.231 per individual per year (or 0.231 year^{-1}).

Q3. Name important defence mechanisms in plants against herbivory.

Plants cannot move away from herbivores, so they have evolved diverse morphological (physical) and chemical defences:

A. Morphological Defences:

- **Thorns and spines:** Hard, sharp structures that deter browsing. Examples: Acacia (thorns), Cactus (spines), Rose (prickles).
- **Trichomes (hair-like structures):** Surface hairs that make leaves unpalatable or trap insects. Example: Stinging nettle (*Urtica*) has trichomes that inject formic acid.
- **Waxy or tough cuticle:** Makes leaves difficult to chew or digest. Example: Holly leaves.

- Silica bodies (phytoliths): Grass leaves contain silica crystals that wear down the teeth and mouthparts of grazers.

B. Chemical Defences:

- Alkaloids: Nicotine (tobacco), caffeine (coffee/tea), quinine (cinchona), strychnine (Strychnos), morphine (opium poppy) — toxic or deterrent to herbivores.
- Cardiac glycosides: Calotropis produces toxic glycosides, which is why cattle and goats avoid it.
- Tannins: Polyphenolic compounds that bind to digestive enzymes and proteins, reducing nutritional value and making leaves bitter. Example: Oak leaves.
- Terpenoids and resins: Pine resins deter insect herbivores.
- Protease inhibitors: Released upon wounding, these inhibit the digestive enzymes of insects. Example: Tomato and potato plants produce these in response to caterpillar attack.
- Latex and gums: Sticky, toxic secretions that trap and deter insects. Example: Euphorbia latex.

Q4. An orchid plant is growing on the branch of a mango tree. How do you describe this interaction?

Type of interaction: This interaction is Commensalism (+/0).

The orchid growing as an epiphyte on the mango branch is an example of commensalism, where:

- The orchid (Species A) benefits: It uses the mango tree merely as a physical support (substrate) to grow at a height, getting better access to sunlight and air for photosynthesis. It is not parasitic — it does not derive nutrition from the mango tree.
- The mango tree (Species B) is neither harmed nor benefited: The orchid causes no significant damage to the mango tree, nor does it provide any benefit. The interaction is neutral for the mango.

Summary: Orchid (+), Mango (0) → Commensalism.

Other examples of commensalism: barnacles on whales, cattle egret with grazing cattle, clownfish with sea anemone.

Q5. What is the ecological principle behind biological control of pest insects?

Ecological principle: Biological control is based on the principle of predator-prey interactions in natural ecosystems — specifically, the ability of predators (or parasitoids/pathogens) to regulate and keep pest prey populations under control.

Key aspects of the principle:

- In natural ecosystems, every prey (pest) species has its natural enemies — predators, parasites, parasitoids, or pathogens — that regulate its population density and prevent it from reaching outbreak levels.
- When a pest species is introduced into a new region (or its natural enemies are removed), it grows exponentially without control, becoming invasive and causing enormous damage.
- Biological control introduces or augments the natural enemy of the pest to bring the pest population back within tolerable levels, without using chemical pesticides.
- The predator does not eradicate the pest entirely — it maintains a dynamic equilibrium at low pest densities. A prudent predator keeps the prey at a manageable level, because complete elimination of prey would cause the predator's own extinction.

Classic example: The prickly pear cactus (*Opuntia*) introduced into Australia in the 1920s spread uncontrollably over millions of hectares. It was brought under control only by introducing its natural predator — the cactus moth (*Cactoblastis cactorum*) from its native South America. The moth larvae feed on the cactus and kept its population in check.

Another example: Ladybirds (*Coccinella*) are used to control aphid pests in agriculture.

Q6. Define population and community.

Population:

A population is a group of individuals of the same species living in a well-defined geographical area, sharing or competing for similar resources, and capable of interbreeding (or potentially so). They constitute a reproductive unit and share a common gene pool.

Examples: All the lotus plants in a pond, all the tigers in Ranthambore National Park, all the fruitflies in a laboratory culture.

Community (Biotic Community):

A community is the assemblage of populations of all the different species (plants, animals, microbes) that live together and interact in a defined geographical area at a given time.

A community includes all interspecific interactions — predation, competition, mutualism, parasitism, commensalism — and is characterised by its species composition, diversity, and the relationships between its component populations.

Example: All the organisms (trees, shrubs, herbs, deer, tigers, insects, bacteria, fungi, etc.) living together in a tropical forest constitute a community. A coral reef ecosystem's community includes corals, fish, sea anemones, algae, and countless other species.

Key difference: A population consists of one species; a community consists of all species in a habitat. A community is at a higher level of biological organisation than a population.

Q7. Define the following terms and give one example for each:

(a) Commensalism (+/0):

Commensalism is an interspecific interaction in which one species (the commensal) benefits while the other species (the host) is neither harmed nor benefited. It is a one-sided benefit with no effect on the host.

Example 1: Orchid (epiphyte) growing on a mango tree — the orchid gets support and sunlight; the mango is unaffected.

Example 2: Cattle egret and grazing cattle — egrets follow cattle and catch insects stirred up by the cattle's movement; the cattle are unaffected.

Example 3: Clown fish living among the stinging tentacles of a sea anemone — the fish gets protection from predators; the anemone is unaffected.

(b) Parasitism (+/-):

Parasitism is an interspecific interaction in which one species (the parasite) benefits by deriving nutrition and shelter from the other species (the host), while the host is harmed. The parasite lives in or on the host and does not usually kill it outright, as this would eliminate its food source.

Example 1: Plasmodium (malarial parasite) in human red blood cells — Plasmodium benefits; the human host suffers from malaria.

Example 2: Cuscuta (dodder) — a parasitic plant that grows on hedge plants, absorbing nutrients from the host, while the host is weakened.

Example 3 (Brood parasitism): Koel (Eudynamys scolopaceus) lays its eggs in a crow's nest; the crow incubates and raises the koel chick.

(c) Camouflage (Cryptic colouration):

Camouflage is a type of adaptation (morphological defence) in which an organism's colouration, shape, or texture blends with its background environment, making it difficult for predators (or prey) to detect it. It is an evolved predator-avoidance mechanism.

Example 1: Stick insect (Phasmid) — resembles a twig or branch so closely that predators overlook it.

Example 2: Some species of frogs are cryptically coloured to match the green leaves or bark they sit on.

Example 3: The Dead-leaf mantis (*Deroplatys desiccata*) looks exactly like a dead brown leaf, remaining undetected by its predators.

(d) Mutualism (+/+):

Mutualism is an interspecific interaction in which both the interacting species benefit. It is an obligate or facultative association that is beneficial to both partners. Many mutualistic relationships involve co-evolution.

Example 1: Lichens — an intimate mutualistic association between a fungus and photosynthesising algae/cyanobacteria. The fungus provides shelter and absorbs water and minerals; the alga provides organic food through photosynthesis.

Example 2: Mycorrhizae — association of fungi with roots of higher plants. Fungi help in absorption of phosphorus and minerals; the plant supplies carbohydrates to the fungi.

Example 3 (Fig-wasp): The female wasp pollinates the fig inflorescence while laying eggs in the fig fruit; the fig provides food for the wasp larvae in the form of developing seeds.

(e) Interspecific Competition (-/-):

Interspecific competition is an interaction in which both species suffer a reduction in their fitness (reproductive success/growth rate) as a result of competing for the same limited resources (food, space, light, mates, etc.). The competitively inferior species may eventually be eliminated (Competitive Exclusion Principle by Gause).

Example 1: In shallow South American lakes, flamingoes (visiting) and resident fish both compete for zooplankton — the common food source.

Example 2: *Balanus* (larger barnacle) competitively excludes the smaller barnacle *Chthamalus* from the intertidal zone on rocky Scottish coasts (Connell's experiments).

Example 3: When goats were introduced on Galapagos Islands, the Abingdon tortoise became extinct within a decade due to competition for the same plant food — the goats were more efficient browsers.

Q8. With the help of a suitable diagram, describe the logistic population growth curve.

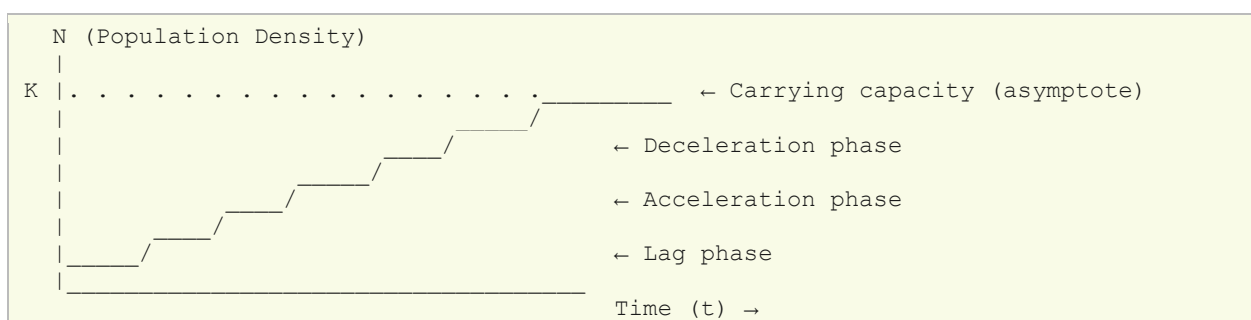
In nature, resources (food, space) are finite and become limiting over time. Hence, no population can grow exponentially indefinitely. The more realistic model of population growth under limited resources is the Verhulst-Pearl Logistic Growth model.

Equation:

$$\frac{dN}{dt} = rN \left[\frac{K - N}{K} \right]$$

Where: N = population density at time t ; r = intrinsic rate of natural increase; K = carrying capacity of the environment (maximum population size the habitat can sustain).

Diagram (Logistic / S-shaped / Sigmoid Growth Curve):



Description of the phases:

- Lag phase: Initial slow growth when the population is small and adapting to the new environment. Birth rates are low and the population size is far below K.
- Acceleration phase (log/exponential phase): Rapid population growth as individuals reproduce. Resources are still not severely limiting.
- Deceleration phase: Growth rate slows as population size approaches K. The term $(K-N)/K$ decreases — it acts as a 'brake' on growth. When N is close to K, $(K-N)/K$ approaches zero, so $dN/dt \rightarrow 0$.
- Asymptote (carrying capacity K): Population growth stops when $N = K$. The population stabilises at K, giving the characteristic S-shaped (sigmoid) curve.

Key feature — Carrying Capacity (K):

K is determined by the available food, space, and other resources in the habitat. The logistic model is considered more realistic than the exponential model because resources in nature are always finite and become limiting.

Comparison: The exponential (J-shaped) curve ($dN/dt = rN$) has no upper limit; the logistic (S-shaped) curve is bounded by K.

Q9. Select the statement which best explains parasitism.

Correct answer: (d) One organism is benefited, other is affected.

Explanation: In parasitism, the parasite (Species A: +) derives benefit (food, shelter) from the host (Species B: -) while the host is harmed. The harm to the host may include reduced survival, growth, reproduction, or population density.

Why the other options are incorrect:

- (a) 'One organism is benefited' — incomplete; does not specify the effect on the second organism. This could also describe commensalism (+/0).
- (b) 'Both organisms are benefited' — this describes mutualism (+/+), not parasitism.
- (c) 'One organism is benefited, other is not affected' — this describes commensalism (+/0), not parasitism.
- (d) 'One organism is benefited, other is affected (harmed)' — this correctly and completely describes parasitism (+/-).

Q10. List any three important characteristics of a population and explain.

Three key characteristics (attributes) of a population are:

Characteristic	Definition	Significance / Explanation
1. Population Density (N)	The number of individuals (or biomass / % cover) of a species per unit area or volume at a given time.	Indicates the status of the population in the habitat. Changes in N reflect ecological processes like predation, disease, or food availability. Can be measured as total number, biomass, or per cent cover depending on species. Examples: tigers (pug marks), bacteria (turbidity or colony count), fish (catch per trap).
2. Birth Rate (Natality) & Death Rate (Mortality)	Birth rate = per capita number of new individuals added to the population per unit time. Death	Natality increases population density; mortality decreases it. The difference ($b - d = r$, the intrinsic rate of natural increase)

Characteristic	Definition	Significance / Explanation
	rate = per capita number of individuals dying per unit time.	determines whether the population is growing, stable, or declining. Example: 8 new lotus plants in a pond of 20 → birth rate = 0.4/year.
3. Age Distribution / Age Pyramid	The proportion of individuals belonging to different age groups (pre-reproductive, reproductive, post-reproductive) in the population, depicted graphically as an age pyramid.	The shape of the age pyramid reveals the growth status of the population: Expanding population = broad base (many young), triangular shape; Stable population = roughly equal proportions at each age, bell-shaped; Declining population = narrow base (few young), urn-shaped. This is particularly used for human population analysis.

Additional characteristics not listed above include: Sex ratio (proportion of males to females), population growth rate, and spatial distribution (uniform, random, or clumped).

Chapter 12: Ecosystem

Q1. Fill in the blanks.

- (a) Plants are called as Producers (autotrophs) because they fix carbon dioxide (perform photosynthesis to produce organic matter from CO₂ using solar energy).
- (b) In an ecosystem dominated by trees, the pyramid of numbers is Inverted type. A single large tree supports a very large number of insects (herbivores), which in turn support smaller numbers of birds (carnivores). So the numbers at the producer level (1 tree) are less than at the herbivore level — giving an inverted pyramid.
- (c) In aquatic ecosystems, the limiting factor for the productivity is Light (solar radiation). In aquatic ecosystems, light penetrates only the upper layers (photic zone). Below the photic zone, light is absent, restricting photosynthesis and hence primary productivity. Nutrient availability (especially nitrogen and phosphorus) can also be limiting.
- (d) Common detritivores in our ecosystem are Earthworms, millipedes, woodlice (pill bugs), soil mites, termites, and certain beetles. Earthworms are the most familiar — they fragment detritus and mix it into the soil.
- (e) The major reservoir of carbon on earth is Rocks and sediments (geological reservoir) — particularly fossil fuels (coal, oil, natural gas) and limestone (CaCO₃). Among active reservoirs, the oceans hold the largest amount of dissolved inorganic carbon (as bicarbonates). The atmosphere (CO₂) is a smaller but highly dynamic reservoir.

Q2. Which one of the following has the largest population in a food chain?

Correct Answer: (d) Decomposers

Although this might seem counterintuitive, decomposers (fungi and bacteria) have the largest population (numbers) in any ecosystem. They are present at every level of the food chain — decomposing dead matter from producers, primary consumers, secondary consumers, and top carnivores alike.

While producers (option a) have the highest biomass and energy at the first trophic level, decomposers as a group are ubiquitous (present everywhere in the soil, water, and all detritus) and their total numbers vastly exceed those of any consumer group.

Note: If the question is interpreted strictly in terms of the grazing food chain only (ignoring decomposers), then the answer would be (a) Producers, because energy decreases by 90% at each trophic level (10% law) and producers must numerically support all consumers.

Q3. The second trophic level in a lake is

Correct Answer: (b) Zooplankton

In a lake (aquatic ecosystem):

- 1st trophic level (Producers): Phytoplankton (microscopic algae and cyanobacteria) — they fix solar energy through photosynthesis.
- 2nd trophic level (Primary consumers / Herbivores): Zooplankton (e.g., Daphnia, Cyclops, copepods) — microscopic animals that feed on phytoplankton.
- 3rd trophic level (Secondary consumers): Small fish and benthos — feed on zooplankton.
- 4th trophic level (Tertiary consumers): Large fish — feed on smaller fish.

Benthos (bottom-dwelling organisms) generally occupy lower trophic levels but are not the primary consumers of phytoplankton. Fishes are at higher trophic levels (3rd and 4th). Therefore, zooplankton occupy the second trophic level.

Q4. Secondary producers are

Correct Answer: (d) None of the above

The term 'secondary producers' is technically not a standard ecological term. However, if used, it sometimes refers to herbivores (primary consumers) because they 'produce' new biomass by assimilating energy from plants.

But none of the options is precisely correct in the conventional sense:

- (a) Herbivores — are primary consumers, not 'producers'. They cannot produce organic matter from inorganic sources.
- (b) Producers — are primary producers (autotrophs) — plants, algae, cyanobacteria.
- (c) Carnivores — are secondary/tertiary consumers.

The textbook definition of secondary productivity is the rate of formation of new organic matter by consumers (i.e., the net energy assimilated by heterotrophs). By this definition, herbivores (primary consumers) would be closest to 'secondary producers', but the question correctly identifies (d) None of the above as the best answer, since herbivores are consumers, not producers.

Q5. What is the percentage of photosynthetically active radiation (PAR) in the incident solar radiation?

Correct Answer: (b) 50%

Of the total incident solar radiation that reaches the Earth's surface:

- Less than 50% is Photosynthetically Active Radiation (PAR) — the wavelength range of 400–700 nm (visible light) that can be used by plants for photosynthesis.
- The remaining >50% consists of infrared radiation (heat), ultraviolet radiation, and other wavelengths that cannot drive photosynthesis.
- Of the PAR that reaches plants, only 2–10% is actually captured (fixed) by plants through photosynthesis to produce organic matter. The rest is reflected, transmitted, or lost as heat.

So: Total solar radiation → ~50% is PAR → Plants use only 2–10% of this PAR for photosynthesis.

Option (d) 2–10% refers to the fraction of PAR captured by plants, not PAR itself.

Q6. Distinguish between the following:

(a) Grazing Food Chain (GFC) vs. Detritus Food Chain (DFC)

Grazing Food Chain (GFC)	Detritus Food Chain (DFC)
Starts with living green plants (producers/autotrophs).	Starts with dead organic matter (detritus) — dead plant and animal remains.
Energy flows from plants → herbivores → carnivores → top carnivores.	Energy flows from detritus → detritivores → decomposers → inorganic nutrients.
Primary producers fix solar energy which drives the chain.	Driven by the chemical energy stored in dead organic matter.
Example: Grass → Grasshopper → Frog → Snake → Eagle.	Example: Leaf litter → Earthworm → Robin → Hawk.
Dominant pathway in aquatic ecosystems.	Dominant pathway in terrestrial ecosystems (larger fraction of energy flows through DFC).
Main decomposers are not part of the chain itself.	Main organisms are decomposers (fungi, bacteria) and detritivores (earthworms).

(b) Production vs. Decomposition

Production (Primary Productivity)	Decomposition
The synthesis of organic matter from inorganic substances using solar energy by autotrophs (photosynthesis).	The breakdown of complex dead organic matter (detritus) into simpler inorganic substances by decomposers.
Carried out by producers (plants, algae, cyanobacteria).	Carried out by decomposers (bacteria, fungi) and detritivores (earthworms).
Results in the build-up of organic matter (biomass) in the ecosystem.	Results in the release of inorganic nutrients (CO ₂ , H ₂ O, minerals) back into the environment.
An anabolic (constructive) process — complex molecules are built.	A catabolic (destructive) process — complex molecules are broken down.
Expressed as GPP and NPP in g m ⁻² yr ⁻¹ or kcal m ⁻² yr ⁻¹ .	Steps include: fragmentation, leaching, catabolism, humification, mineralisation.
Requires solar energy as input.	Requires oxygen (aerobic) and releases energy as heat.

(c) Upright Pyramid vs. Inverted Pyramid

Upright Pyramid	Inverted Pyramid
The base (producers) is the broadest bar; each successive trophic level has a narrower bar.	The base (producers) is narrow; upper trophic levels have progressively wider bars — the pyramid is inverted.
Indicates that the number/biomass/energy at the producer level is greater than at consumer levels.	Indicates that higher trophic levels have more numbers or biomass than the lower ones.
Found in most terrestrial ecosystems for pyramids of number, biomass, and energy.	Seen in specific cases; e.g., pyramid of biomass in aquatic (marine) ecosystems.
Example: Pyramid of numbers in a grassland — millions of grass plants support thousands of herbivores, which support a few carnivores.	Example: Pyramid of biomass in the ocean — a small standing crop of phytoplankton (4 g m ⁻²) supports a larger standing crop of zooplankton (21 g m ⁻²).
Pyramid of energy is always upright — energy always decreases at higher trophic levels (10% law).	Pyramid of energy can never be inverted, as energy is always lost as heat at each trophic transfer.

(d) Food Chain vs. Food Web

Food Chain	Food Web
A linear (single-path) sequence of organisms in which each organism feeds on the one before it and is eaten by the one after it.	A complex network of interconnected food chains in a community; multiple feeding relationships among organisms.
Represents a single, straight-line flow of energy and matter.	Represents the realistic, multidirectional flow of energy and matter in an ecosystem.

Food Chain	Food Web
Example: Grass → Grasshopper → Frog → Snake → Hawk.	Example: Grass eaten by grasshopper AND rabbit; grasshopper eaten by frog AND birds; all connected in a web.
Simple and idealistic; rarely exists in nature in isolation.	Complex and realistic; represents actual feeding relationships in a natural community.
Does not show the true complexity of ecological relationships.	Provides a more accurate picture of energy flow and the role of each organism.
Disruption of one link removes all organisms 'above' it.	More resilient — disruption of one species can be compensated by alternative food sources.

(e) Litter vs. Detritus

Litter	Detritus
Freshly fallen plant material — leaves, bark, twigs, flowers, fruit — that has not yet undergone significant decomposition.	A broader term for all types of dead organic matter including litter, dead animal remains, fecal matter, and partially decomposed organic material.
Refers specifically to the uppermost layer of dead plant material on the soil surface.	Includes litter as well as all stages of decomposing organic matter — from freshly fallen leaves to humified material.
Litter is the initial raw material of decomposition.	Detritus is the total raw material for the detritus food chain and decomposition process.
Example: Dried leaves and twigs on the forest floor.	Example: Dead leaves + dead animal bodies + fecal pellets + partially broken down organic matter in soil.

(f) Primary Productivity vs. Secondary Productivity

Primary Productivity	Secondary Productivity
The rate of biomass production (organic matter) by autotrophs (producers) through photosynthesis per unit area per unit time.	The rate of formation of new organic matter by heterotrophic consumers (animals) by assimilating food energy.
Carried out by producers: green plants, algae, phytoplankton, cyanobacteria.	Carried out by all consumers: herbivores (primary), carnivores (secondary), omnivores.
Divided into: Gross Primary Productivity (GPP) = total photosynthesis; Net Primary Productivity (NPP) = GPP – Respiration.	Not typically subdivided into gross and net in the same way; represents the biomass gain by the consumer population.
NPP is the energy available to heterotrophs (herbivores and decomposers).	Secondary productivity forms the energy available to the next level (carnivores and top predators).
Unit: $\text{g m}^{-2} \text{yr}^{-1}$ or $\text{kcal m}^{-2} \text{yr}^{-1}$.	Unit: same — $\text{g m}^{-2} \text{yr}^{-1}$ or $\text{kcal m}^{-2} \text{yr}^{-1}$.
Annual NPP of whole biosphere $\approx$ 170 billion tonnes.	Always less than primary productivity due to the 10% law of energy transfer.

Q7. Describe the components of an ecosystem.

An ecosystem is a structural and functional unit of nature where living organisms interact among themselves and with their physical environment. It has two main categories of components:

A. Abiotic Components (Non-living Physical Environment):

- Inorganic substances: Carbon dioxide, water, oxygen, nitrogen, phosphorus, sulphur, and other minerals that cycle through the ecosystem.
- Organic compounds: Proteins, carbohydrates, lipids, humus — link abiotic and biotic components.
- Climatic factors: Solar radiation (light), temperature, humidity, wind, precipitation, and photoperiod — regulate all metabolic processes.
- Physical factors: Soil type, pH, salinity, topography, water availability — determine the kind of organisms that can survive.

B. Biotic Components (Living Organisms):

- Producers (Autotrophs): Photosynthetic organisms that fix solar energy to produce organic matter from inorganic substances. In terrestrial ecosystems: green plants, herbs, shrubs, trees. In aquatic ecosystems: phytoplankton, algae, aquatic plants. They form the base of the food chain (first trophic level).
- Consumers (Heterotrophs): Animals that depend on producers (directly or indirectly) for energy. Primary consumers (herbivores): feed on plants (e.g., grasshoppers, cows, zooplankton). Secondary consumers (primary carnivores): feed on herbivores (e.g., frogs, small fish). Tertiary consumers (secondary carnivores): feed on primary carnivores (e.g., snakes, large fish). Top carnivores: apex predators (e.g., lions, eagles).
- Decomposers (Saprotrophs / Detritivores): Heterotrophic microorganisms (mainly bacteria and fungi) that break down dead organic matter (detritus) into simple inorganic substances (CO_2 , H_2O , mineral nutrients), returning them to the abiotic pool for reuse by producers. Examples: *Aspergillus*, *Mucor* (fungi); *Bacillus*, *Pseudomonas* (bacteria); earthworms (detritivores).

Functional aspects:

- Productivity: Rate of biomass production by autotrophs.
- Decomposition: Breakdown of dead organic matter by decomposers.
- Energy flow: Unidirectional transfer of energy through trophic levels, with 90% lost as heat at each level (10% law).
- Nutrient cycling: Cyclical movement of inorganic nutrients between abiotic and biotic components.

Q8. Define ecological pyramids and describe pyramids of number and biomass with examples.

Ecological Pyramids: An ecological pyramid is a graphical representation of the relationship (in terms of number, biomass, or energy) between different trophic levels of a food chain. The base of each pyramid represents the first trophic level (producers) and the apex represents the top consumer. Each successive bar decreases (in most cases) as we go up the trophic levels.

Three types: (i) Pyramid of Numbers, (ii) Pyramid of Biomass, (iii) Pyramid of Energy.

(i) Pyramid of Numbers:

Represents the number of individuals at each trophic level per unit area. Generally upright but can be inverted.

Pyramid of Numbers — Grassland Ecosystem (Upright):

TC (Tertiary Consumer)		3		← Very narrow (few top carnivores)
SC (Secondary Consumer)		354,000		← Narrow

PC (Primary Consumer)	708,000	← Wider
P (Producer)	5,842,000	← Very wide (millions of grass plants)

A single huge tree supports more insects than the tree itself — giving an INVERTED pyramid of numbers in a tree-dominated ecosystem.

Upright example: Grassland — millions of grass plants → hundreds of thousands of grasshoppers → thousands of frogs → few snakes → 1–2 eagles.

Inverted example: A single large tree (1 producer) → thousands of insects (herbivores) → hundreds of birds → few hawks. The single tree at the base gives an inverted pyramid of numbers.

(ii) Pyramid of Biomass:

Represents the total dry weight (biomass) of organisms at each trophic level per unit area (kg m^{-2}). Usually upright in terrestrial ecosystems but inverted in aquatic ecosystems.

Pyramid of Biomass — Terrestrial Ecosystem (Upright, values in kg m^{-2}):

TC	1.5	← Very small biomass at top
SC	11	
PC	37	
P	809	← Largest biomass at base

Pyramid of Biomass — Aquatic/Marine Ecosystem (Inverted):

PC (Zooplankton)	21 g m^{-2}	← Larger biomass
P (Phytoplankton)	4 g m^{-2}	← Smaller biomass

Inverted because phytoplankton reproduce extremely rapidly (high turnover rate) and are consumed almost as fast as they are produced, so their standing crop is small even though they support a larger biomass of zooplankton.

Q9. What is primary productivity? Describe factors that affect it.

Primary Productivity: Primary productivity is defined as the amount of biomass or organic matter produced per unit area per unit time by producers (autotrophs) through photosynthesis. It is expressed in terms of weight (g m^{-2}) or energy (kcal m^{-2}). The rate of biomass production is called productivity, expressed as $\text{g m}^{-2} \text{yr}^{-1}$ or $\text{kcal m}^{-2} \text{yr}^{-1}$.

Types:

- **Gross Primary Productivity (GPP):** The total rate of production of organic matter during photosynthesis, including the portion used by the plant itself in respiration.
- **Net Primary Productivity (NPP):** The biomass remaining after the plant uses some for respiration. $\text{NPP} = \text{GPP} - \text{R}$ (respiration). NPP is the available biomass for consumption by heterotrophs (herbivores and decomposers).

Global NPP: The annual net primary productivity of the whole biosphere is approximately 170 billion tonnes (dry weight). Despite occupying 70% of Earth's surface, oceans contribute only about 55 billion tonnes — due to nutrient and light limitations.

Factors affecting Primary Productivity:

- **Plant species composition:** Different plant species have different photosynthetic efficiencies. C4 plants (maize, sugarcane) are more productive than C3 plants (wheat, rice) under high light and temperature conditions.
- **Solar radiation (PAR):** Light is the primary energy source. Greater PAR availability leads to higher GPP. In aquatic ecosystems, light penetrates only the photic zone — productivity decreases with depth.

- Temperature: Warm temperatures (within optimal range) accelerate enzymatic reactions in photosynthesis. Tropical ecosystems have higher productivity than polar ones.
- Water availability: Water is a raw material for photosynthesis and is essential for plant metabolism. Drought severely limits terrestrial productivity.
- Nutrient availability: Minerals — especially nitrogen (N), phosphorus (P), and potassium (K) — are critical for chlorophyll synthesis, enzyme function, and biomass production. In oceans, nutrient (especially N and P) limitation is a major factor limiting productivity.
- Carbon dioxide concentration: CO₂ is the substrate for photosynthesis. Rising atmospheric CO₂ can enhance productivity ('CO₂ fertilisation effect') under nutrient-replete conditions.
- Photosynthetic capacity of plants: Varies with leaf area index (LAI), chlorophyll content, and stomatal conductance.

Q10. Define decomposition and describe the processes and products.

Decomposition: Decomposition is the process by which decomposers (bacteria and fungi) enzymatically break down complex dead organic matter (detritus) into simpler inorganic substances such as carbon dioxide, water, and inorganic nutrients. It is the reverse of production and is crucial for nutrient cycling.

Raw material: Detritus — dead plant remains (leaves, bark, flowers), dead animal remains, and fecal matter.

Steps / Processes of Decomposition (operate simultaneously):

- 1. Fragmentation: Detritivores (e.g., earthworms, millipedes, woodlice) mechanically break down detritus into smaller particles, increasing the surface area available for microbial action.
- 2. Leaching: Water-soluble inorganic nutrients from detritus move down into the soil horizon (percolation) and get precipitated as unavailable salts in deeper layers.
- 3. Catabolism: Bacterial and fungal enzymes (extracellular — secreted outside the cell) chemically degrade the detritus particles into simpler inorganic substances. This is the primary enzymatic breakdown step.
- 4. Humification: Partially decomposed organic matter is converted into a dark-coloured, amorphous, colloidal substance called humus. Humus is highly resistant to microbial action (decomposes very slowly), serves as a reservoir of nutrients, improves soil water-holding capacity, and is important for soil fertility.
- 5. Mineralisation: Some microbes further degrade humus and release inorganic nutrients (N, P, S, Ca, K, etc.) in forms available for plant uptake. This final step closes the nutrient cycle.

Products of Decomposition:

- Inorganic nutrients: Nitrates, phosphates, sulphates, carbonates, and other mineral ions — released back into the soil/water for reuse by plants.
- Carbon dioxide (CO₂): Released into the atmosphere through microbial respiration.
- Water (H₂O): Released as a product of oxidative breakdown.
- Humus: Intermediate product — a stable, dark colloidal organic matter that improves soil quality.

Factors controlling decomposition rate:

- Chemical composition of detritus: Rich in lignin and chitin → slow decomposition; rich in nitrogen and water-soluble sugars → fast decomposition.
- Temperature: Warm temperature accelerates microbial activity → faster decomposition. Low temperature inhibits decomposers.
- Moisture: Moist conditions favour decomposition. Waterlogged (anaerobic) conditions inhibit it, leading to peat/coal formation over geological time.
- Oxygen availability: Decomposition is primarily aerobic (requires O₂). Anaerobiosis (absence of O₂) greatly slows it.

Q11. Give an account of energy flow in an ecosystem.

Source of Energy:

Except for deep-sea hydrothermal ecosystems, the Sun is the sole source of energy for all ecosystems. Of the total solar radiation reaching the Earth's surface, less than 50% is Photosynthetically Active Radiation (PAR, 400–700 nm). Of this PAR, plants capture only 2–10% through photosynthesis to produce organic matter (GPP). This tiny fraction of solar energy sustains the entire living world.

Key Principles:

- Energy flow is unidirectional — from the Sun → producers → consumers → decomposers. Energy cannot cycle back (unlike nutrients).
- At each trophic transfer, energy is lost as heat (in accordance with the Second Law of Thermodynamics — entropy increases). Ecosystems require a constant external energy input (from the Sun) to maintain their structure and function.

The 10 Per Cent Law (Lindemann, 1942):

Only 10% of the energy at any trophic level is transferred to the next trophic level. The remaining 90% is lost to respiration (metabolic activity, heat), feces, uneaten food, etc. This severely limits the number of trophic levels possible in a food chain (usually 3–5 levels).

Energy flow example (based on Fig 12.4d):

Sunlight available:	1,000,000 J	
P (Producers/Plants):	10,000 J	(1% of sunlight fixed as NPP)
PC (Primary consumers):	1,000 J	(10% of P's energy)
SC (Secondary consumers):	100 J	(10% of PC's energy)
TC (Tertiary consumers):	10 J	(10% of SC's energy)
Each step → ~90% lost as heat to environment		

Two pathways of energy flow:

- Grazing Food Chain (GFC): Starts with living plants. Energy flows through herbivores to carnivores. Dominant in aquatic ecosystems. Sun → Phytoplankton → Zooplankton → Small fish → Large fish.
- Detritus Food Chain (DFC): Starts with dead organic matter (detritus). Energy flows through detritivores and decomposers. Dominant in terrestrial ecosystems. Dead leaves → Earthworms → Bacteria/Fungi → Inorganic nutrients.

The two chains are interconnected — organisms of the DFC can be eaten by GFC organisms (e.g., earthworms eaten by birds). This interconnection forms a food web.

Trophic Levels and Standing Crop:

- Each trophic level has a standing crop — the amount of living biomass at that level at any given time.
- Standing crop is measured as biomass (dry weight) or number per unit area.
- Due to the 10% law, standing crop decreases at higher trophic levels, leading to upright pyramids of energy and biomass in most ecosystems.

Significance of energy flow:

- Explains why food chains are short (usually 3–5 levels) — insufficient energy reaches higher levels to sustain more.
- Explains why vegetarians can support more people per unit area of land than meat-eaters (eating at lower trophic levels is more energy-efficient).
- Explains the importance of producers — they are the foundation of all life in the ecosystem.

Chapter 13: Biodiversity and Conservation

13.1 Biodiversity

Biodiversity — term popularised by sociobiologist Edward Wilson — refers to the combined diversity at ALL levels of biological organisation (from macromolecules to biomes).

13.1.1 Three Levels of Biodiversity

Level	Description & Example
Genetic Diversity	Variation within a species across its range. e.g., <i>Rauwolfia vomitoria</i> varies in reserpine potency across Himalayas; India has >50,000 strains of rice, 1,000 varieties of mango.
Species Diversity	Diversity at species level. e.g., Western Ghats have greater amphibian species diversity than Eastern Ghats.
Ecological Diversity	Diversity at ecosystem level. e.g., India (deserts, rain forests, mangroves, coral reefs, wetlands, alpine meadows) has far greater ecosystem diversity than Norway.

13.1.2 How Many Species? — Global & India

- IUCN (2004): ~1.5 million species described so far.
- Robert May's estimate: ~7 million species globally (conservative).
- Extreme estimates: 20–50 million.
- India: 2.4% of world's land area → 8.1% of global species diversity → one of 12 Mega-Diversity countries.
- India has ~45,000 plant species and ~90,000 animal species recorded.
- Only 22% of total species have been recorded so far (May's estimate).
- India's undiscovered potential: >1,00,000 plant species and >3,00,000 animal species yet to be found.

Key Biodiversity Facts

>70% of all recorded species are animals.

Among animals, insects alone make up >70% (7 out of every 10 animals).

Fungi species > combined total of fish + amphibians + reptiles + mammals.

Prokaryotes are excluded from standard estimates — their diversity could run into millions.

13.1.3 Patterns of Biodiversity

(i) Latitudinal Gradients

Species diversity generally DECREASES from equator towards the poles.

Location (Latitude)	Bird Species
Colombia (~0°)	~1,400

India (tropical)	>1,200
New York (41° N)	105
Greenland (71° N)	56

Why are tropics richer? Three key hypotheses:

- (a) Evolutionary time: Tropics undisturbed for millions of years → long time for speciation.
- (b) Stable environment: Less seasonal, more constant & predictable → promotes niche specialisation → greater diversity.
- (c) More solar energy: Higher solar input → higher productivity → indirectly supports greater diversity.

Amazon Rainforest — greatest biodiversity on earth: >40,000 plant spp, 3,000 fish, 1,300 birds, 427 mammals, 427 amphibians, 378 reptiles, >1,25,000 invertebrates.

(ii) Species–Area Relationship

Equation (log-log scale): $\log S = \log C + Z \log A$

Term	Meaning
S	Species richness
A	Area
Z	Slope (regression coefficient)
C	Y-intercept

- Small to medium areas: $Z = 0.1\text{--}0.2$ (consistent across taxa & regions)
- Very large areas (continents): $Z = 0.6\text{--}1.2$ (steeper slope → species loss is much more severe when large habitats are destroyed)
- Example: frugivorous birds & mammals in tropical forests → $Z = 1.15$

13.1.4 Importance of Species Diversity to Ecosystem

- David Tilman's experiments: plots with MORE species showed LESS year-to-year variation in biomass and HIGHER productivity.
- Stable community = resistant/resilient to disturbances + resistant to alien invasions + consistent productivity.

Rivet Popper Hypothesis (Paul Ehrlich)

Ecosystem = Airplane. Species = Rivets.

Removing a few rivets (losing species) may not affect flight initially...

...but cumulative loss weakens the plane dangerously.

Losing WING rivets (keystone species driving major ecosystem functions) is far more critical than losing seat rivets.

13.1.5 Loss of Biodiversity

- IUCN Red List (2004): 784 species extinct in last 500 years (338 vertebrates, 359 invertebrates, 87 plants).
- Recent extinctions: Dodo (Mauritius), Quagga (Africa), Thylacine (Australia), Steller's Sea Cow (Russia), 3 tiger subspecies (Bali, Javan, Caspian).
- 27 species disappeared in the last 20 years alone.
- Currently threatened: >15,500 species worldwide; 12% birds, 23% mammals, 32% amphibians, 31% gymnosperms.
- 'Sixth Extinction': Current extinction rate is 100–1,000 times faster than pre-human times. Could wipe out nearly half of all species within 100 years.

Consequences of biodiversity loss in a region:

- Decline in plant production.
- Lowered resistance to environmental perturbations (drought, etc.).
- Increased variability in ecosystem processes (plant productivity, water use, pest & disease cycles).

The Evil Quartet — 4 Major Causes of Biodiversity Loss

Cause	Details & Examples
1. Habitat Loss & Fragmentation	MOST IMPORTANT cause. Tropical rain forests: from >14% to <6% of earth's land. Amazon ('lungs of planet') cleared for soya bean cultivation/beef cattle. Large habitat broken into fragments → affects migratory species and large-territory mammals/birds.
2. Over-exploitation	When 'need' turns to 'greed'. Steller's sea cow, passenger pigeon extinct due to overexploitation. Many marine fish populations overharvested today.
3. Alien Species Invasions	Nile perch in Lake Victoria → extinction of >200 cichlid fish species. In India: Parthenium (carrot grass), Lantana, Eichhornia (water hyacinth). African catfish <i>Clarias gariepinus</i> threatens indigenous catfish.
4. Co-extinctions	When one species goes extinct, obligatorily associated species follow. e.g., host fish extinct → its unique parasites also extinct. Plant-pollinator coevolved pairs: extinction of one leads to extinction of other.

13.2 Biodiversity Conservation

13.2.1 Why Conserve Biodiversity? — Three Arguments

Argument	Explanation
Narrowly Utilitarian	Direct economic benefits — food, firewood, fibre, construction, industrial products (tannins, resins, dyes),

	medicines. >25% of drugs sold worldwide derived from plants. 25,000 plant species used in traditional medicine.
Broadly Utilitarian	Ecosystem services — Amazon produces 20% of earth's oxygen; pollination services by bees, birds, bats; pest control; flood control. Intangible aesthetic pleasures of nature.
Ethical	Every species has intrinsic value, irrespective of economic worth. Moral duty to preserve biological legacy for future generations.

13.2.2 How to Conserve Biodiversity

In Situ Conservation (On-site)

Conserve species within their natural habitat — protect the entire ecosystem. 'Save the forest to save the tiger.'

- Biodiversity Hotspots: Regions with very high species richness AND high endemism. Initially 25 identified; now 34 total. Cover <2% of earth's land but extremely species-rich.
- India's 3 hotspots: Western Ghats & Sri Lanka, Indo-Burma, Himalaya.
- Strict protection of hotspots could reduce ongoing extinctions by ~30%.

India's Protected Areas:

Type	Number
Biosphere Reserves	14
National Parks	90
Wildlife Sanctuaries	448

- Sacred Groves: Forest tracts protected by religious/cultural traditions — Khasi & Jaintia Hills (Meghalaya), Aravalli Hills (Rajasthan), Western Ghats (Karnataka, Maharashtra), Sarguja/Chanda/Bastar (MP). In Meghalaya, last refuges for rare & threatened plants.

Ex Situ Conservation (Off-site)

Threatened species removed from natural habitat and protected in special settings.

- Zoological parks, botanical gardens, wildlife safari parks.
- Advanced techniques: Cryopreservation of gametes, in vitro fertilisation, tissue culture propagation, seed banks (genetic strains of commercially important plants).

International Efforts

Convention on Biological Diversity ('Earth Summit') — Rio de Janeiro, 1992: all nations to conserve biodiversity and ensure sustainable utilisation.

World Summit on Sustainable Development — Johannesburg, 2002: 190 countries pledged to significantly reduce biodiversity loss rate by 2010.

Quick Revision: Key Terms & Names

Term / Name	Significance
Edward Wilson	Popularised the term 'Biodiversity'
Robert May	Estimated global species diversity at ~7 million
Alexander von Humboldt	Observed species-area relationship in South American jungles
David Tilman	Long-term experiments showing diversity → stability & productivity
Paul Ehrlich	Rivet Popper Hypothesis (ecosystem = airplane, species = rivets)
IUCN Red List	Documents threatened/extinct species globally
Endemism	Species confined to a particular region, not found elsewhere
In Situ	Conservation in natural habitat
Ex Situ	Conservation outside natural habitat
Bioprospecting	Exploring biodiversity for products of economic importance
The Evil Quartet	4 causes of biodiversity loss: habitat loss, over-exploitation, alien invasions, co-extinctions
Sixth Extinction	Current human-driven mass extinction, 100-1000x faster than pre-human rates

Exercise Answer Pointers

Q1. Three components of biodiversity:

- Genetic diversity
- Species diversity
- Ecological diversity

Q2. How ecologists estimate total species:

Compare temperate vs tropical species richness for exhaustively studied insect groups → extrapolate this ratio to other animal/plant groups → gross estimate. Robert May: ~7 million.

Q3. Three hypotheses for tropical species richness:

- Greater evolutionary time (undisturbed for millions of years)
- Stable, constant, predictable environment → promotes niche specialisation
- More solar energy → higher productivity → indirectly supports more species

Q4. Significance of slope (Z) in species-area relationship:

Z indicates how rapidly species richness increases with area. $Z = 0.1-0.2$ for smaller areas; $Z = 0.6-1.2$ for very large areas (continents). Steeper slope means destruction of a large area causes disproportionately severe species loss.

Q5. Major causes of species losses:

- Habitat loss and fragmentation
- Over-exploitation of natural resources
- Alien/invasive species introductions
- Co-extinctions

Q7. Sacred Groves and their role:

Forest tracts protected under religious/cultural traditions where trees and wildlife are venerated. Found in Meghalaya, Rajasthan, Karnataka, Maharashtra, MP. Serve as refuges for rare and threatened plants — act as natural in situ conservation sites.

Q10. Deliberate extinction — when justified?

Disease-causing organisms (e.g., smallpox virus — already eradicated) may be deliberately targeted for extinction to benefit human health. Justification: the harm caused to humanity outweighs any intrinsic value. However, this remains ethically debated.

—End of Chapter 13 Notes —