BITSAT Biology Sample Paper – 16

Duration: 60 Minutes **Maximum Marks: 120**

Instructions

- This paper contains **40** Multiple Choice Questions (Single Correct Answer).
- Each correct answer carries **+3 marks**. Each incorrect answer carries **−1** mark. Unattempted questions carry **0** marks.
- Only **one** option is correct. Choose carefully.
- Use of mobile phones, calculators, or electronic gadgets is strictly prohibited.

Q1. From S phase until anaphase, sister chromatids of each duplicated chromosome are held together by:

(A) The cohesin complex — a ring-shaped structure (SMC1, SMC3, RAD21, SA proteins) that topologically traps the two sister DNA duplexes; cleaved at anaphase by separase (after APC/C destroys securin, the separase inhibitor), allowing chromatid separation

(B) Centrosomes

(C) Microtubules of the spindle

(D) Histone H1 alone

Q2. Cytoplasmic continuity between adjacent plant cells is maintained by:

(A) Plasmodesmata — microscopic channels through the cell wall, lined by plasma membrane, with a central thread of ER (the desmotubule); allow direct passage of water, ions, small molecules, and signalling molecules (and viruses!) between neighbouring cells; size-gated by callose deposition

(B) Tight junctions (these are in animal epithelia)

(C) Gap junctions (animal cells)

(D) Desmosomes (animal cells)

Q3. The animal-cell equivalent of plasmodesmata — channels allowing direct cytoplasmic communication between adjacent cells, important especially in cardiac myocytes and smooth muscle — are:

(A) Tight junctions

(B) Gap junctions — formed by alignment of two connexons (each made of 6 connexin subunits); the central pore allows ions, sugars, amino acids, cyclic nucleotides (under ~ 1 kDa) to pass directly; essential for cardiac muscle electrical coupling and propagation of contraction

(C) Desmosomes

(D) Adherens junctions

Q4. The cytoskeletal element of intermediate diameter ($\sim 10\,\text{nm}$) made of rope-like proteins varying with tissue (keratin in epithelia, vimentin in mesenchyme, neurofilaments in axons, lamins in nucleus) is the:

(A) Microtubule (made of tubulin)

(B) Microfilament (made of actin)

(C) Intermediate filament — provides mechanical strength to cells; resists tensile stress; lamins specifically line the inner nuclear envelope and shape the nucleus; defects cause many "laminopathies" including progeria and muscular dystrophies

(D) Tonoplast filament

Q5. Selective degradation of intracellular proteins (misfolded proteins, regulatory proteins like cyclins, transcription factors) in eukaryotic cells occurs via:

(A) Random hydrolysis in the cytosol

(B) Lysosomal acid hydrolases (this handles bulk autophagy and extracellular material)

(C) Diffusion out of the cell

(D) The ubiquitin-proteasome system: proteins tagged with chains of ubiquitin (76 aa) by E1-E2-E3 enzyme cascade; tagged proteins recognised and threaded into the 26S proteasome, a barrel-shaped multisubunit protease (~ 2.5 MDa); product is short peptides plus recycled ubiquitin. Awarded 2004 Chemistry Nobel

Q6. The cellular process of self-digestion — engulfing damaged organelles, protein aggregates, or invading pathogens within a double-membrane vesicle that then fuses with a lysosome — is:

(A) Autophagy (Greek *auto* = self, *phagein* = to eat); the autophagosome forms by lipidation of LC3-PE on a phagophore; ATG genes drive the process. Critical for cellular housekeeping, response to starvation, and immunity. Yoshinori Ohsumi awarded 2016 Nobel Prize for elucidating the molecular machinery

(B) Endocytosis

(C) Apoptosis

(D) Necrosis

Q7. Among endocytic pathways, the engulfment of solid particles ($> 0.5\,\mu$m, e.g. bacteria) by professional cells is termed phagocytosis. The uptake of extracellular fluid and dissolved solutes by vesicle formation is called:

(A) Receptor-mediated endocytosis (this is highly selective uptake of specific ligands via coated pits)

(B) Pinocytosis — "cell drinking"; bulk-fluid uptake via small vesicles; non-selective; constitutive in most cells

(C) Exocytosis

(D) Trans-endocytosis

Q8. In the mitochondrial electron transport chain, Complex III (cytochrome bc_1 complex) pumps protons across the inner membrane via:

(A) Direct proton extrusion

(B) ATP hydrolysis

(C) Substrate-level phosphorylation

(D) The Q (ubiquinone) cycle: ubiquinol (QH_2) is oxidised at the Qo site (releasing $2\,H^+$ to intermembrane space) in a bifurcated electron flow; one electron travels along the high-potential chain to cytochrome c, the other reduces a second Q at the Qi site; two turns of the cycle deliver $4\,H^+$ to the intermembrane space per $2\,e^-$ transferred to cytochrome c

Q9. When acidic chyme enters the duodenum from the stomach, two key intestinal hormones are released to coordinate digestion:

(A) Cholecystokinin (CCK, from I cells, in response to fats/proteins) stimulates gallbladder contraction and pancreatic enzyme secretion; secretin (from S cells, in response to acid) stimulates pancreatic bicarbonate secretion to neutralise duodenal acid

(B) Insulin and glucagon

(C) ACTH and TSH

(D) Renin and aldosterone

Q10. The sigmoidal shape of the oxygen-haemoglobin dissociation curve reflects:

(A) Random oxygen binding to each haem independently

(B) Cooperative binding of O_2 across the four haem groups: binding of the first O_2 triggers a T (tense, low-affinity) $\rightarrow$ R (relaxed, high-affinity) conformational shift that increases the affinity at the remaining sites; produces sigmoidal cooperativity; Hill coefficient ~ 2.7

(C) Inhibition of O_2 binding at low pH

(D) Lack of any cooperativity (curve would be hyperbolic)

Q11. The Rh (Rhesus) blood group system, named after experiments on rhesus macaques, is clinically important because:

(A) Rh-positive blood lacks all surface antigens

(B) Anti-D antibodies are present in everyone from birth

(C) The D antigen is highly immunogenic; an Rh-negative mother carrying an Rh-positive foetus may, after exposure to fetal blood at delivery, develop anti-D IgG; subsequent Rh-positive pregnancies face haemolytic disease of the newborn (HDN, erythroblastosis foetalis); prevented by anti-D Ig (RhoGAM) prophylaxis at 28 weeks and after delivery

(D) Rh-negative individuals cannot give birth to Rh-positive children

Q12. Micturition (the act of urination) is coordinated by:

(A) Pure voluntary control with no reflex component

(B) Sympathetic stimulation only

(C) Renal contractions

(D) A coordinated spino-bulbar reflex: bladder stretch activates afferents to spinal cord and pontine micturition centre; parasympathetic (S2–S4) outflow contracts the detrusor muscle; somatic (pudendal) inhibition relaxes the external (voluntary) urethral sphincter; cerebral cortex provides voluntary timing and inhibition

Q13. The autonomic nervous system has two branches with generally opposing actions on visceral organs. The branch that dominates during "rest and digest" (lowering heart rate, increasing GI motility, constricting pupil) is:

(A) Parasympathetic — with long preganglionic and short postganglionic fibres; arises from cranial nerves III, VII, IX, X and sacral S2–S4; uses ACh at both pre- and postganglionic synapses; postganglionic ACh acts on muscarinic receptors at the effector

(B) Sympathetic ($\rightarrow$ "fight or flight")

(C) Somatic motor

(D) Enteric only

Q14. Melatonin, secreted by the pineal gland with a strong circadian rhythm (high at night, low in daytime), is the hormone of:

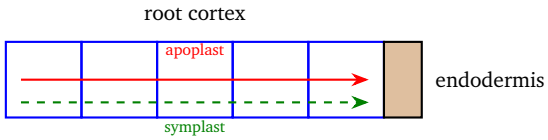
(A) Calcium regulation

(B) The biological clock — entrains the suprachiasmatic-nucleus driven circadian rhythm; promotes sleep onset; regulates seasonal reproductive cycles in many mammals; clinically used for jet-lag and sleep disorders; its synthesis is suppressed by light reaching the retina (especially blue light)

(C) Growth and bone elongation

(D) Blood pressure regulation

Q15. Water and ions absorbed by plant roots travel radially across the cortex by two parallel routes, shown below. The pathway through the continuous cytoplasm via plasmodesmata is the:



(A) Apoplast (water flows through cell walls and intercellular spaces; halted at the suberised Casparian strip of the endodermis)

(B) Transpiration stream within the xylem

(C) Symplast (cytoplasm-to-cytoplasm pathway via plasmodesmata; allows selective control by plant cells); continues through the endodermis (which blocks the apoplastic route)

(D) Vacuolar pathway

Q16. Photorespiration is the wasteful oxygenation reaction catalysed by RuBisCO that:

(A) Increases net photosynthesis

(B) Does not occur in any plant

(C) Occurs only in C_4 plants

(D) Consumes O_2 + RuBP $\rightarrow$ phosphoglycolate (a 2C compound) and 3-PGA; phosphoglycolate is salvaged via the photorespiratory pathway (chloroplast $\rightarrow$ peroxisome $\rightarrow$ mitochondrion) with loss of CO_2 and NH_3; reduces net photosynthetic efficiency by up to 25% in C_3 plants on hot dry days. C_4 and CAM plants minimise photorespiration by concentrating CO_2 around RuBisCO

Q17. In medical genetics, a family tree (pedigree) showing the inheritance of a trait reveals its mode of inheritance. An autosomal dominant trait shows:

(A) Affected individuals in every generation; both sexes equally affected; an affected parent has $\sim 50\%$ chance of having an affected child; the trait does not skip generations; examples include Huntington's disease, Marfan syndrome, achondroplasia

(B) Trait only in males, inherited from the mother (X-linked recessive)

(C) Trait skipping generations through unaffected female carriers (X-linked recessive)

(D) Affected children only when both parents are carriers (autosomal recessive)

Q18. Insertion or deletion of one or two nucleotides in a protein-coding region of DNA results in:

(A) Substitution of a single amino acid (this is a missense mutation; one base substitution)

(B) A frameshift mutation — shifts the reading frame of all codons downstream of the insertion/deletion site; usually produces an entirely different and often truncated protein due to a premature stop codon. Insertion of 3 (or multiples of 3) nucleotides causes only an in-frame addition — not a frameshift

(C) Reversal of the entire gene

(D) No change to the protein

Q19. The genetic code is read in triplet codons, ungapped, starting from an AUG initiation codon. A given mRNA sequence has theoretically:

(A) Only one reading frame

(B) Two reading frames

(C) Three possible reading frames in each direction (six total, including the complementary strand) — but only one is used in any given mRNA; the start codon defines it

(D) Six reading frames per strand

Q20. The naturalist who independently arrived at the theory of evolution by natural selection (after fieldwork in the Malay Archipelago, 1854–1862), and whose letter to Darwin in 1858 prompted the joint announcement of natural selection at the Linnean Society, was:

(A) Thomas Henry Huxley

(B) Alfred Lord Tennyson

(C) Joseph Hooker

(D) Alfred Russel Wallace — also famous for the "Wallace line" separating the Asian and Australian biotas at Lombok Strait, and for his early work in biogeography

Q21. The peppered moth (*Biston betularia*) population shift from light to dark forms during the British Industrial Revolution (and reversal after Clean Air Act), is the classic textbook example of:

(A) Natural selection (industrial melanism): pre-industrial light moths were camouflaged on pale lichen-covered tree bark; soot-blackened tree bark in industrial areas favoured dark (melanic, *carbonaria*) variants; after pollution controls, lichens returned and light forms

returned to dominance. Kettlewell's mark-recapture experiments (1950s) documented selective bird predation

(B) Genetic drift

(C) Founder effect

(D) Bottleneck effect

Q22. Transposable elements (transposons, "jumping genes") discovered by Barbara McClintock (1948 in maize; Nobel 1983) are:

(A) Stable centromeric sequences

(B) DNA sequences that can change position within a genome — by "cut-and-paste" (DNA transposons, encode transposase) or "copy-and-paste" (retrotransposons, via RNA intermediate and reverse transcriptase); abundant in eukaryotic genomes ($\sim 45\%$ of human genome consists of transposon-derived sequences, mostly LINEs and SINEs); responsible for some genetic diseases (haemophilia from insertion mutations) but also for genome evolution and immune diversity (V(D)J recombination)

(C) Only found in viruses

(D) Components of the ribosome

Q23. In mammalian (including human) early embryos, cleavage divisions are:

(A) Meroblastic (incomplete, due to yolk-rich egg; characteristic of fish, reptiles, birds)

(B) Discoidal (a special pattern of meroblastic cleavage)

(C) Holoblastic — complete cleavage of the entire zygote into smaller blastomeres; characteristic of eggs with little or modest yolk (mammals, amphibians, echinoderms). In mammals, cleavage is also slow (~ 24 h per division initially) and asynchronous

(D) Superficial

Q24. Amniotic fluid surrounding the developing foetus serves multiple functions, including:

(A) Providing nutrients for the foetus (this is the role of placenta, not amniotic fluid)

(B) Carrying oxygen via placenta to foetus (placenta does this)

(C) Stem-cell reservoir only

(D) Cushioning the foetus from mechanical shock; maintaining constant temperature; allowing free movement (essential for musculoskeletal development); preventing adhesions; permitting the foetus to "practice" breathing movements; lubricating the birth canal at delivery; can be sampled diagnostically (amniocentesis ~ 16 weeks) for genetic studies and lung maturity assessment

Q25. Monozygotic (identical) twins arise from:

(A) Two separate ova fertilised by two separate sperm (this is dizygotic / fraternal twins; the more common type; runs in some families)

(B) A single zygote that splits into two embryos during early development; genetically identical (apart from rare post-zygotic mutations); always the same sex and same blood type; share the same DNA fingerprint. Splitting at different stages gives different chorion/amnion sharing patterns

(C) Separate ova from different cycles

(D) Failure of fertilisation

Q26. In Vitro Fertilisation (IVF), pioneered by Steptoe and Edwards (first baby Louise Brown, 1978; Nobel 2010 to Edwards), involves:

(A) Natural conception only

(B) Donor uterus surgery

(C) Ovarian hyperstimulation $\rightarrow$ retrieval of multiple oocytes by transvaginal aspiration $\rightarrow$ fertilisation in lab (with sperm; or by ICSI, intracytoplasmic sperm injection in male-factor infertility) $\rightarrow$ embryo cul-

ture for 3–5 days → transfer of 1–2 best embryos to uterus; surplus embryos can be cryopreserved

(D) Implantation of partial cells from the donor

Q27. In angiosperms, the triploid endosperm of the seed forms by:

(A) Mitosis of the egg without fertilisation

(B) Direct development from the integuments

(C) Polyembryony from nucellar cells

(D) Triple fusion ("vegetative fertilisation"): one of the two sperm nuclei from the pollen tube fuses with the two polar nuclei (or with the already-formed $2n$ secondary nucleus) at the centre of the embryo sac, producing a $3n$ primary endosperm nucleus, which then divides to form the endosperm tissue. This double fertilisation (one sperm → egg → embryo; one sperm → central cell → endosperm) is UNIQUE to angiosperms

Q28. The collective term for the calyx (sepals) and corolla (petals) of a flower — the non-reproductive accessory floral organs — is:

(A) Perianth (or perigone) — when sepals and petals are indistinguishable (e.g. tulip, lily, magnolia), the term *tepals* is used for the perianth segments

(B) Androecium (the male whorl, stamens)

(C) Gynoecium (the female whorl, carpels/pistils)

(D) Pedicel (the flower stalk)

Q29. In a barley grain, the aleurone layer (single cell layer surrounding the endosperm) is induced by which hormone to secrete α-amylase that mobilises the stored starch for the germinating embryo?

(A) Auxin

(B) Gibberellin (GA_3) — diffuses from the embryo to the aleurone layer; activates transcription of α-amylase genes; this α-amylase, plus other

hydrolases, mobilises the endosperm reserves to fuel growth until photosynthesis takes over. The basis of commercial malting in beer brewing

(C) Cytokinin

(D) ABA (inhibits the process)

Q30. Plant roots growing toward a source of water in soil, even against gravity (sometimes), illustrate:

(A) Gravitropism (downward growth response to gravity)

(B) Thigmotropism (response to touch)

(C) Hydrotropism — directional growth toward water; mediated by MIZ1 gene products in root cap; can override gravitropism in dry soil. Mechanistically distinct from gravitropism (involves a different set of signalling components, with weaker auxin redistribution)

(D) Phototropism (response to light)

Q31. Viroids — the smallest known infectious agents, discovered by Theodor Diener (1971, in potatoes) — consist of:

(A) Protein capsid + DNA genome

(B) RNA genome + protein capsid

(C) DNA only, no protein

(D) Naked, single-stranded circular RNA ($\sim$ 200–400 nt), without any protein coat or capsid; cause several plant diseases (potato spindle tuber viroid PSTV, citrus exocortis, coconut cadang-cadang); the RNA forms a highly base-paired rod-like secondary structure; some are ribozymes (self-cleaving). PSTV was the first viroid identified

Q32. Fungi placed in the artificial group "Deuteromycetes" (Fungi Imperfecti) are characterised by:

(A) Production of distinct ascospores

(B) Production of distinct basidiospores

(C) Absence of a known sexual reproductive stage — only the asexual (anamorphic) stage is observed; reproduce by conidia. Examples: *Aspergillus* (some species; now mostly placed in Ascomycota when sexual stage is found), *Penicillium*, *Candida albicans*, *Alternaria*, *Cercospora*, *Trichoderma*. With molecular phylogenetics, most have been re-classified into Ascomycota or Basidiomycota

(D) Zygospore formation

Q33. Class Mammalia is diagnosed by which combination of unique features?

(A) Feathers, beak, wings

(B) Scales, gills, lateral line

(C) Naked seeds and ovules

(D) Hair/fur (keratin-based); mammary glands (modified sweat glands; lactation feeds young); diaphragm (separating thoracic and abdominal cavities, enables negative-pressure breathing); three middle-ear ossicles (malleus, incus, stapes); a single bone in the lower jaw (dentary); heterodont dentition; endothermy; viviparity (in most; monotremes lay eggs)

Q34. The common intestinal roundworm of humans, *Ascaris lumbricoides*, belongs to:

(A) Phylum Nematoda (round worms): pseudocoelomate; cylindrical, tapering at both ends; complete digestive tract; cuticle moulted four times during development; separate sexes (female larger); transmitted by faecal-oral contamination with eggs from soil. Globally over a billion infections, particularly in children in developing countries

(B) Phylum Annelida

(C) Phylum Platyhelminthes

(D) Phylum Arthropoda

Q35. Allergic asthma is an inflammatory disease of the airways characterised by:

(A) Acute viral infection of the alveoli only

(B) Type-I IgE-mediated hypersensitivity to inhaled allergens (dust mites, pollen, animal dander, cockroach, mould): allergen crosslinks IgE on mast cells $\rightarrow$ mediator release (histamine, leukotrienes, prostaglandins) $\rightarrow$ bronchoconstriction, airway oedema, mucus hypersecretion. Late-phase inflammation involves eosinophils, Th2 cytokines (IL-4, IL-5, IL-13). Treated with β_2 agonists (salbutamol), inhaled corticosteroids, leukotriene antagonists, anti-IgE (omalizumab)

(C) Bacterial infection of the bronchi

(D) Cancer of pulmonary epithelium

Q36. Long-term cigarette smoking causes:

(A) Improved lung function

(B) Only mild reversible bronchitis

(C) Chronic obstructive pulmonary disease (COPD) — combination of chronic bronchitis and emphysema; lung cancer (the leading cause of cancer death globally); cardiovascular disease (atherosclerosis, stroke, MI); peripheral artery disease; many other cancers (mouth, larynx, oesophagus, pancreas, bladder); reduced fertility; lower birth weight in babies of smoking mothers; addiction via nicotine acting on nicotinic ACh receptors in brain reward circuits

(D) No documented health effects

Q37. Alien (invasive) species — non-native species introduced (deliberately or accidentally) into new ecosystems where they spread aggressively — threaten biodiversity by:

(A) Outcompeting native species, predating on naive native fauna (which lack co-evolved defences), spreading novel pathogens, disrupting

food webs and ecosystem function. Examples: *Lantana camara* (smothering native vegetation in Indian forests), water hyacinth *Eichhornia crassipes* (choking water bodies), African catfish (*Clarias gariepinus* introduced in Indian aquaculture), Nile perch in Lake Victoria (caused massive cichlid extinction)

(B) Always benefit native ecosystems by adding species

(C) Have no effect on native biodiversity

(D) Improve genetic variation of native species

Q38. In conservation biology, the two complementary strategies are *in-situ* (on-site) and *ex-situ* (off-site) conservation. Examples of *in-situ*:

(A) Botanical gardens and zoos

(B) National parks, wildlife sanctuaries, biosphere reserves, sacred groves — protecting species in their natural habitats with full ecological integrity (food web, mating, dispersal). India has 106 national parks, ~ 565 wildlife sanctuaries, and 18 biosphere reserves

(C) Seed banks for crop genetic resources

(D) Cryopreservation of gametes

Q39. Among the developmental potency classes of stem cells, the ones that can give rise to a complete organism including extra-embryonic tissues (placenta) are:

(A) Pluripotent stem cells (can form all three germ layers + germ line, but NOT extra-embryonic tissues; e.g. embryonic stem cells from inner cell mass)

(B) Multipotent stem cells (limited to one lineage; e.g. haematopoietic stem cells)

(C) Totipotent stem cells — can produce all cell types of the embryo PLUS all extra-embryonic tissues; the only natural totipotent cells in mammals are the zygote and (briefly) blastomeres of the first few cleavage divisions

(D) Unipotent stem cells (can only generate one cell type)

Q40. Secondary dengue infection (with a different serotype than the primary infection) often causes more severe disease (dengue haemorrhagic fever) because of:

(A) Direct neutralisation by primary-infection antibodies

(B) Complete cross-immunity to all four serotypes

(C) Reduced viral entry into cells

(D) Antibody-dependent enhancement (ADE): sub-neutralising antibodies from the primary infection (waning IgG, or cross-reactive antibodies against a different serotype) bind the new virion but do not neutralise; the antibody-virus complex is taken up via Fc receptors on monocytes/macrophages, enhancing entry; viral load and inflammation rise; cytokine storm and plasma leakage cause severe dengue. A major obstacle to vaccine design

Detailed Solutions

Q1.

Solution

Concept — Cohesin — the sister chromatid glue: A ring-shaped multi-subunit complex that physically links the two newly replicated sister chromatids.

Step 1 — Composition:

- SMC1 and SMC3: "Structural Maintenance of Chromosomes" ATPase subunits; form a long V-shaped coiled-coil.
- RAD21 (kleisin): closes the ring by bridging SMC1 and SMC3 heads.
- SA1/SA2 accessory proteins.

Step 2 — Function:

- Loaded onto chromosomes in late G_1/early S; topologically traps the two sister DNA duplexes as they emerge from the replication fork.
- Holds sisters together through G_2 and into mitosis.
- At metaphase, sister kinetochores are pulled in opposite directions by spindle microtubules; cohesin resists this pull until anaphase.

Step 3 — Anaphase release:

- The anaphase-promoting complex (APC/C) ubiquitinates securin $\rightarrow$ securin destroyed.
- Free separase (a cysteine protease) cleaves RAD21.
- Cohesin rings open; sister chromatids separate; the spindle pulls them to opposite poles.

Step 4 — Clinical relevance:

- Cornelia de Lange syndrome (cohesin-loading factor NIPBL mutations).
- Aneuploidy from cohesin defects (chromosome missegregation).
- Cohesin is essential during meiosis too — maintains sister-chromatid cohesion until anaphase II; defects contribute to age-related increase in trisomy.

Final Answer: Cohesin complex $\Rightarrow$ $\boxed{\text{A}}$

Answer: (A) Go Back to Q1

Q2.

Solution

Concept — Plasmodesmata — the plant cell-cell channels: The plant counterpart of animal gap junctions; create cytoplasmic continuity (the symplast) across the entire plant body.

Step 1 — Structure:

- Cylindrical pores through the cell wall, ~ 40–50 nm diameter.
- Lined by plasma membrane continuous between adjacent cells.
- Central thread of compressed endoplasmic reticulum = the desmotubule.
- Cytoplasmic sleeve between desmotubule and plasma membrane is the conducting pathway.

Step 2 — Function:

- Direct symplastic transport of water, ions, sugars, amino acids, hormones, small RNAs, transcription factors.
- Coordinates development and signalling across cell boundaries.
- Size-exclusion limit: usually ~ 1 kDa, but plant viruses encode movement proteins that enlarge the size limit to allow passage.
- Closure: callose (β-$1,3$-glucan) deposited around plasmodesma neck transiently closes the channel.

Step 3 — Symplast vs apoplast: The cellular interior connected by plasmodesmata = symplast; the cell wall and intercellular spaces = apoplast. The two pathways operate in parallel for radial transport across roots, ending at the endodermis where the Casparian strip blocks the apoplastic route.

Final Answer: Plasmodesmata $\Rightarrow$ $\boxed{\text{A}}$

Answer: (A) Go Back to Q2

Q3.

Solution

Concept — Gap junctions — animal cell-cell channels: Discovered by Werner Loewenstein and Yoshinori Kanno (1964). The functional analogue of plant plasmodesmata in animal tissues.

Step 1 — Structure:

- Each cell contributes a hemichannel called a **connexon**, made of 6 connexin

protein subunits arranged hexagonally around a central pore.
- Two aligned connexons from adjacent cells form the complete intercellular channel (~ 2 nm pore diameter).
- Hundreds of channels cluster into a gap junction plaque.

Step 2 — What passes: Small molecules under ~ 1 kDa: ions, sugars, amino acids, nucleotides, cyclic AMP, IP_3, Ca^{2+}. Proteins and nucleic acids are excluded.

Step 3 — Functions:

- Cardiac muscle: gap junctions at intercalated discs propagate action potentials between cardiomyocytes $\rightarrow$ synchronous heart contraction.
- Smooth muscle: coordinated contraction (uterus, intestine, ureter).
- Neurons: electrical synapses (very fast, no synaptic delay).
- Bone (osteocytes): metabolic coupling.
- Epithelia: spread of signalling molecules.
- Embryonic development: morphogen gradient communication.

Step 4 — Regulation: Gap junction channels can close in response to Ca^{2+}, low pH, or high voltage — isolating damaged cells from the syncytium (a protective response).

Step 5 — Clinical relevance:

- Connexin 26 (GJB2) mutations: most common cause of autosomal recessive non-syndromic hearing loss.
- Connexin 32 (GJB1): X-linked Charcot-Marie-Tooth disease.
- Cardiac connexin defects: arrhythmias.

Final Answer: Gap junctions (two connexons of 6 connexins each) $\Rightarrow$ $\boxed{\text{B}}$

Answer: (B) Go Back to Q3

Q4.

Solution

Concept — The three cytoskeletal element types: The eukaryotic cytoskeleton has three distinct components with characteristic diameter, monomer protein, and function.

Step 1 — The three types:

- **Microfilaments** (~ 7 nm): polymers of G-actin into F-actin double helix;

dynamic (treadmilling); involved in cell shape, motility, contraction, cytokinesis (contractile ring), and (with myosin) muscle contraction.
- **Intermediate filaments** ($\sim$ 10 nm): tissue-specific proteins (see below); rope-like; very stable; provide mechanical strength.
- **Microtubules** ($\sim$ 25 nm): polymers of $\alpha\beta$-tubulin heterodimers; dynamic (dynamic instability); intracellular highways (kinesin/dynein motors carry cargo); mitotic spindle; cilia/flagella ($9 + 2$ axoneme).

Step 2 — Intermediate filament proteins by cell type:

- Keratins (over 50 types): epithelial cells, hair, nails.
- Vimentin: mesenchymal cells (fibroblasts, endothelium).
- Desmin: muscle.
- GFAP (glial fibrillary acidic protein): astrocytes.
- Neurofilaments (NF-L, NF-M, NF-H): neurons.
- **Nuclear lamins** (A, B, C): line the inner nuclear envelope; only intermediate filaments in the nucleus.
- Peripherin: peripheral nerves.

Step 3 — Structure of an IF: Monomer (central α-helical rod + N- and C-terminal domains) $\rightarrow$ parallel dimer $\rightarrow$ antiparallel staggered tetramer $\rightarrow$ 8 tetramers assemble into a $\sim$ 10 nm rope-like filament. Lateral packing gives high tensile strength.

Step 4 — Function:

- Mechanical strength: resists tensile (pulling) stress; for stretchy tissues like skin, blood vessels, muscle.
- Maintain cell and nuclear shape.
- Anchored at desmosomes (cell-cell) and hemidesmosomes (cell-matrix).

Step 5 — Diseases ("laminopathies" and IF-pathies):

- Epidermolysis bullosa simplex: keratin 5/14 mutations; skin blisters from minor friction.
- Emery-Dreifuss muscular dystrophy: emerin or lamin A/C defects.
- Hutchinson-Gilford progeria: lamin A mutation $\rightarrow$ accelerated ageing.
- Familial partial lipodystrophy, dilated cardiomyopathy: also lamin A/C mutations.

Final Answer: Intermediate filaments $\Rightarrow$ C

Answer: (C) Go Back to Q4

Q5.

Solution

Concept — The ubiquitin-proteasome system (UPS): The major pathway for selective intracellular protein degradation in eukaryotes. Discovered by Aaron Ciechanover, Avram Hershko, and Irwin Rose — 2004 Chemistry Nobel.

Step 1 — Ubiquitin tagging — the E1-E2-E3 cascade:

(a) E1 (ubiquitin-activating enzyme): activates ubiquitin with ATP, attaches it via thioester bond.
(b) E2 (ubiquitin-conjugating enzyme): accepts activated ubiquitin from E1.
(c) E3 (ubiquitin ligase): substrate-specific; transfers ubiquitin from E2 to a lysine residue on the target protein. The E3 family has hundreds of members — substrate selectivity arises here.
(d) Multiple ubiquitins added in a chain (K48-linked polyubiquitin is the standard "destroy me" tag); ≥ 4 ubiquitins needed for efficient targeting.

Step 2 — The 26S proteasome — the degradation machine:

- ~ 2.5 MDa multi-subunit complex.
- 20S core: a barrel of four stacked rings ($\alpha\beta\beta\alpha$); active proteolytic sites (caspase-, trypsin-, chymotrypsin-like) sequestered inside the barrel.
- 19S regulatory caps: at each end of the 20S barrel; recognise ubiquitinated substrates; unfold them; remove ubiquitin (recycled); thread the substrate through the barrel.
- Output: short peptides ($\sim$ 8–10 aa), which are further degraded or, for MHC class I, exported and presented at the cell surface.

Step 3 — Substrates (selectively destroyed):

- Misfolded or damaged proteins.
- Regulatory proteins with short half-lives: cyclins, transcription factors (p53, c-Myc), IκB (inhibitor of NF-κB), HIF-1α.
- Viral proteins.
- Cell-cycle checkpoint regulators.

Step 4 — Specific examples:

- Mitotic cyclin B degraded at anaphase by APC/C ubiquitin ligase $\rightarrow$ mitotic exit.
- p53 degraded by MDM2 E3 ligase under normal conditions; stabilised on DNA damage by phosphorylation that blocks MDM2 binding.

- HIF-1α in normoxia: hydroxylated by PHD enzymes, recognised by VHL E3 ligase, ubiquitinated, degraded. In hypoxia: not hydroxylated, stable, activates hypoxia response genes (EPO, VEGF).
- ER-associated degradation (ERAD): misfolded ER proteins retrotranslocated to cytosol and degraded by UPS.

Step 5 — Therapeutic targeting:

- Bortezomib (Velcade): proteasome inhibitor; multiple myeloma, mantle cell lymphoma.
- Carfilzomib, ixazomib: second-generation proteasome inhibitors.
- Thalidomide and lenalidomide: act through cereblon (a substrate adapter of an E3 ligase) to ubiquitinate IKZF1/3 transcription factors $\rightarrow$ used in myeloma.
- PROTAC drugs (proteolysis-targeting chimeras): heterobifunctional molecules that recruit an E3 ligase to a disease-causing protein, triggering its degradation. A revolutionary new modality.

Final Answer: Ubiquitin-proteasome system $\Rightarrow$ D

Answer: (D) Go Back to Q5

Q6.

Solution

Concept — Autophagy — the cellular self-eating pathway: The major route for bulk turnover of cytoplasmic contents (organelles, protein aggregates). Yoshinori Ohsumi's screens in yeast identified ATG (AuTophaGy-related) genes; awarded the 2016 Medicine Nobel.

Step 1 — Three types of autophagy:

- **Macroautophagy** (the main type): formation of a double-membrane autophagosome around a portion of cytoplasm.
- **Microautophagy:** lysosomal membrane invaginates and engulfs cytoplasm directly.
- **Chaperone-mediated autophagy:** specific proteins (with KFERQ motif) recognised by Hsc70 and translocated into lysosomes via LAMP-2A.

Step 2 — Macroautophagy steps:

(a) Initiation: ULK1 kinase complex activated when mTORC1 is inhibited (e.g. during starvation).

(b) Nucleation: PI3KC3 complex (Beclin1/VPS34) on an isolation membrane (phagophore).
(c) Elongation: two ubiquitin-like conjugation systems — ATG5-ATG12-ATG16L1 and LC3-PE (LC3 lipidation with phosphatidylethanolamine).
(d) Closure: phagophore curves around cargo, sealing into a double-membrane autophagosome.
(e) Maturation and fusion: autophagosome fuses with lysosome $\rightarrow$ autolysosome; contents degraded by lysosomal hydrolases; macromolecule precursors (amino acids, fatty acids, nucleotides) returned to cytosol.

Step 3 — Selective autophagy: Cargo-specific autophagy is directed by autophagy receptors that recognise both the cargo and LC3:

- Mitophagy: degradation of damaged mitochondria (PINK1/Parkin pathway). Defects $\rightarrow$ Parkinson's disease.
- Xenophagy: digestion of intracellular pathogens (bacteria, viruses).
- Aggrephagy: removal of protein aggregates (relevant in neurodegeneration: Huntington's, ALS, Alzheimer's).
- ER-phagy, ribophagy, pexophagy: clearance of damaged organelles.

Step 4 — Regulation:

- mTORC1 is the master suppressor: when nutrient supply is good, mTORC1 is active and autophagy is off. Nutrient depletion, hypoxia, oxidative stress inactivate mTORC1 $\rightarrow$ autophagy on.
- AMPK (low-energy sensor) activates autophagy.
- Drugs/conditions that induce autophagy: caloric restriction, fasting, exercise, rapamycin (mTOR inhibitor), spermidine, resveratrol.

Step 5 — Health and disease:

- Cancer: paradoxical role; in early stages tumour-suppressing (Beclin1 haploinsufficiency $\rightarrow$ cancer); in advanced cancer, supports tumour metabolism under stress.
- Neurodegeneration: defective autophagy contributes to Parkinson's, Huntington's, Alzheimer's via accumulating aggregates.
- Aging: autophagy declines with age; boosting autophagy extends lifespan in many organisms.
- Infection: xenophagy clears intracellular bacteria (M. tuberculosis, Salmonella) and viruses.

Final Answer: Autophagy $\Rightarrow$ $\boxed{\text{A}}$

Answer: (A) Go Back to Q6

Q7.

Solution

Concept — Endocytic uptake pathways: Several distinct mechanisms by which cells take up material from their surroundings.

Step 1 — Phagocytosis ("cell eating"):

- Large particles ($> 0.5\,\mu\text{m}$): bacteria, dead cells, debris.
- Actin-dependent pseudopod extension and engulfment.
- Professional phagocytes: macrophages, neutrophils, dendritic cells.
- Phagosome fuses with lysosome $\rightarrow$ phagolysosome $\rightarrow$ degradation.
- Receptors involved: FcγR (opsonised pathogen), CR3 (complement), Dectin-1 (β-glucan), etc.

Step 2 — Pinocytosis ("cell drinking"):

- Bulk-fluid uptake plus dissolved solutes.
- Non-selective; sampling extracellular fluid.
- Vesicles small ($\sim 100\,\text{nm}$).
- Constitutive in most cells.
- Subtypes: macropinocytosis (actin-driven ruffling; nutrient uptake in cancer cells), clathrin-independent pinocytosis.

Step 3 — Receptor-mediated endocytosis:

- Highly selective; concentrates specific ligands > 1000-fold.
- Clathrin-coated pits: cargo receptors cluster, coated vesicle pinches off (dynamin-mediated), clathrin coat disassembled in cytosol.
- Classic examples: LDL-receptor (cholesterol uptake), transferrin receptor (iron uptake), insulin receptor.
- Defects: familial hypercholesterolaemia (Goldstein & Brown, Nobel 1985): LDL receptor mutations $\rightarrow$ high blood LDL $\rightarrow$ premature atherosclerosis.

Step 4 — Caveolae: Flask-shaped invaginations rich in caveolin protein; cholesterol- and sphingolipid-rich membrane regions; involved in some pathogen entry, transcytosis across endothelium.

Final Answer: Pinocytosis $\Rightarrow$ B

Answer: (B) Go Back to Q7

Q8.

Solution

Concept — The Q (ubiquinone) cycle: Discovered by Peter Mitchell (1976) as the proton-pumping mechanism of Complex III. Mitchell's broader chemiosmotic theory won the 1978 Chemistry Nobel.

Step 1 — Complex III (cytochrome bc_1):

- A dimer of ~ 240 kDa per monomer; located in the inner mitochondrial membrane.
- Contains: cytochromes b_L, b_H, c_1; Rieske iron-sulfur cluster (FeS).
- Substrate: reduced ubiquinone (ubiquinol, QH_2).
- Product: oxidised cytochrome c + transmembrane H^+ gradient.

Step 2 — Q-cycle mechanism:

- **Qo (outer) site:** ubiquinol oxidised; releases $2\,H^+$ into the intermembrane space. Electrons bifurcate:
  - First electron $\rightarrow$ Rieske FeS $\rightarrow$ cytochrome c_1 $\rightarrow$ cytochrome c (the high-potential chain).
  - Second electron $\rightarrow$ cytochrome b_L $\rightarrow$ cytochrome b_H $\rightarrow$ a Q at the Qi site (the low-potential chain).
- **Qi (inner) site:** a Q is reduced in two successive cycles to QH_2, taking up $2\,H^+$ from the matrix.
- Net: $2\,QH_2$ oxidised + $1\,Q$ reduced at Qi $\rightarrow$ $4\,H^+$ to intermembrane space and $2\,e^-$ delivered to cytochrome c, with $2\,H^+$ taken from matrix.

Step 3 — Stoichiometry: For each pair of electrons through Complex III, $4\,H^+$ pumped to the intermembrane space, contributing to the proton gradient that drives ATP synthase. Total ETC proton-pumping stoichiometry: Complex I ($4\,H^+$), Complex III ($4\,H^+$), Complex IV ($2\,H^+$) per pair of electrons from NADH.

Step 4 — ATP yield: ATP synthase synthesises ~ 1 ATP per 3–4 H^+ returning to matrix. From one NADH: ~ 2.5 ATP (newer figure; older textbooks say 3). From one $FADH_2$ (entering at Complex II, bypassing Complex I): ~ 1.5 ATP. Total per glucose: $\sim$ 30–32 ATP.

Step 5 — Pharmacological inhibitors of Complex III:

- Antimycin A: blocks Qi site; classical research tool.
- Stigmatellin: blocks Qo site.
- Atovaquone: anti-malarial; selectively inhibits parasite Complex III.

Step 6 — Reactive oxygen species (ROS): When Q-cycle electron flow is impeded, electrons can leak from cytochrome b_L to O_2 $\rightarrow$ superoxide. Complex I and III are the major mitochondrial ROS sources; relevant to aging, neurodegeneration, ischaemia-reperfusion injury.

Final Answer: Q (ubiquinone) cycle $\Rightarrow$ $\boxed{\text{D}}$

Answer: (D) Go Back to Q8

Q9.

Solution

Concept — Duodenal hormones — CCK and secretin: The first hormones ever discovered: secretin by Bayliss and Starling (1902; Starling coined the term "hormone"). CCK by Ivy and Oldberg (1928).

Step 1 — Cholecystokinin (CCK):

- Source: I cells of duodenal and jejunal mucosa.
- Stimulus: fatty acids and partially digested proteins (peptides, amino acids) in the duodenum.
- Actions:
  - Stimulates gallbladder contraction $\rightarrow$ bile release into duodenum.
  - Relaxes sphincter of Oddi to allow bile/pancreatic juice flow.
  - Stimulates pancreatic acinar cells to release digestive enzymes (amylase, lipase, trypsinogen, chymotrypsinogen, etc.).
  - Slows gastric emptying.
  - Suppresses appetite (acts on vagal afferents and CCK receptors in brain).

Step 2 — Secretin:

- Source: S cells of duodenal mucosa.
- Stimulus: H^+ (acidic chyme from stomach) and fatty acids.
- Actions:
  - Stimulates pancreatic ductal cells to secrete bicarbonate-rich fluid $\rightarrow$ neutralises acidic chyme; this enables pancreatic enzymes to function (optimal pH $\sim$ 7–8).

- Stimulates bile flow from liver.
- Inhibits gastric acid secretion and gastric emptying.

Step 3 — GIP (gastric inhibitory peptide / glucose-dependent insulinotropic peptide): From K cells of duodenum/jejunum; released in response to glucose, fatty acids; stimulates insulin secretion (the incretin effect: oral glucose causes more insulin release than equivalent IV glucose).

Step 4 — GLP-1 (glucagon-like peptide-1): From L cells of distal small intestine; another incretin; stimulates insulin, suppresses glucagon, slows gastric emptying, promotes satiety. GLP-1 analogues (semaglutide, liraglutide) are landmark drugs for type 2 diabetes and obesity.

Step 5 — Other GI hormones:

- Gastrin (G cells, antrum): stimulates parietal cell acid secretion.
- Motilin: triggers Migrating Motor Complex (housekeeping movements between meals); macrolide antibiotics agonise motilin receptor, giving them prokinetic side effects.
- Somatostatin (D cells): inhibits multiple GI hormones (the universal "off" signal).
- Ghrelin (stomach): hunger hormone.

Final Answer: CCK + secretin $\Rightarrow$ A

Answer: (A) Go Back to Q9

Q10.

Solution

Concept — The sigmoidal O_2-Hb dissociation curve: The hallmark of cooperative ligand binding to a multi-subunit protein. Without cooperativity, the curve would be hyperbolic (like myoglobin's).

Step 1 — Haemoglobin structure:

- Tetramer: $\alpha_2\beta_2$ (adult HbA).
- Each subunit has a haem group with a central Fe^{2+} that binds O_2.
- Total of 4 O_2 binding sites per haemoglobin molecule.

Step 2 — Two quaternary conformations:

- **T (tense) state:** low O_2 affinity; subunits constrained by salt bridges; dominant when O_2 is low (deoxy form).

- **R (relaxed) state:** high O_2 affinity; salt bridges broken; dominant when O_2 is high (oxy form).

The transition is concerted (MWC model) or sequential (KNF model); reality is somewhere between.

Step 3 — Cooperativity:

- First O_2 binds with relatively low affinity (T state).
- Binding triggers conformational shift, lowering the energy barrier for the remaining sites $\rightarrow$ they bind O_2 more readily.
- Successive O_2 molecules bind with progressively higher affinity.
- Hill coefficient $n_H \sim 2.7$ (would be 1 for no cooperativity, 4 for perfect).
- Result: sigmoidal curve.

Step 4 — Functional advantage:

- In lungs (high pO_2, ~ 100 mmHg): Hb $\sim 98\%$ saturated.
- In tissues (low pO_2, ~ 25–40 mmHg): Hb releases a large fraction of bound O_2 for delivery.
- Steep middle portion of curve maximises O_2 release at physiologically relevant pO_2.
- Compare myoglobin (single subunit, no cooperativity): hyperbolic curve, holds tightly until very low pO_2 — suitable for muscle O_2 storage.

Step 5 — Allosteric modulators of Hb:

- Bohr effect: low pH (high CO_2, lactic acid in active tissue) RIGHT-shifts the curve (lower affinity) $\rightarrow$ more O_2 release in tissues.
- CO_2 binding to N-terminal amines $\rightarrow$ carbamino-Hb (low affinity).
- BPG (2,3-bisphosphoglycerate): RBC-specific allosteric inhibitor; RIGHT-shifts curve. Adapts to altitude (BPG rises) and chronic anaemia.
- Foetal Hb (HbF, $\alpha_2\gamma_2$): low BPG affinity $\rightarrow$ LEFT-shifted curve $\rightarrow$ extracts O_2 from maternal blood across placenta.
- Temperature: heat RIGHT-shifts.

Step 6 — Pathological:

- Sickle haemoglobin (HbS): point mutation Glu6Val on β-chain; deoxy form polymerises $\rightarrow$ sickled RBCs $\rightarrow$ vaso-occlusion.
- Methaemoglobin: Fe^{3+} instead of Fe^{2+}; cannot bind O_2.

- CO binding: $200\times$ higher affinity than O_2; carboxyhaemoglobinaemia.

Final Answer: Cooperative binding (T $\rightarrow$ R conformational shift) $\Rightarrow$ B

Answer: (B) Go Back to Q10

Q11.

Solution

Concept — The Rh blood group system and HDN: After ABO, the most important human blood group system clinically. Karl Landsteiner (who also discovered ABO) and Wiener (1937) discovered Rh while studying rhesus macaque blood.

Step 1 — Rh antigens:

- The Rh gene cluster encodes several membrane proteins, of which the D antigen is the most immunogenic.
- Rh-positive ($\sim 85\%$ of population, varies by ethnicity): expresses D antigen.
- Rh-negative ($\sim 15\%$): D antigen absent.
- Unlike ABO, Rh-negative people do NOT have pre-formed anti-D antibodies; they make them only AFTER exposure to D-positive blood.

Step 2 — Sensitisation:

- Rh-negative person receives Rh-positive blood transfusion $\rightarrow$ develops anti-D antibodies (delayed reaction).
- More commonly: Rh-negative mother carrying Rh-positive foetus (inherited from father). At delivery (or amniocentesis, miscarriage, abdominal trauma), fetal RBCs cross placenta into maternal circulation; mother makes anti-D IgG (memory generated).
- First Rh-positive pregnancy: usually no problem (sensitisation at the end, baby already born).
- SECOND Rh-positive pregnancy: maternal anti-D IgG crosses placenta (IgG is the only class transported) $\rightarrow$ binds and destroys fetal RBCs $\rightarrow$ **haemolytic disease of the newborn (HDN)** = erythroblastosis foetalis.

Step 3 — HDN clinical features:

- Anaemia (haemolysis).
- Hyperbilirubinaemia (from haem breakdown) $\rightarrow$ jaundice $\rightarrow$ if severe, bilirubin crosses immature blood-brain barrier $\rightarrow$ kernicterus (bilirubin encephalopathy with permanent neurological damage).

- Hydrops fetalis (severe foetal anaemia, heart failure, oedema; often fatal).

Step 4 — Prevention — RhoGAM (anti-D Rh immunoglobulin):

- Pooled IgG preparation containing anti-D antibodies.
- Given to Rh-negative mothers at 28 weeks gestation, within 72 hours after delivery of an Rh-positive baby, and after any event with potential fetal-maternal blood mixing (miscarriage, amniocentesis, ectopic pregnancy, abdominal trauma).
- Mechanism: passive anti-D coats and clears fetal Rh-positive RBCs from maternal circulation before the maternal immune system can produce its own active memory.
- One of the great success stories of preventive medicine; HDN incidence has fallen dramatically since the 1970s.

Step 5 — Treatment if HDN develops:

- Intrauterine transfusion for severely affected foetuses.
- Postnatal phototherapy (breaks down bilirubin).
- Exchange transfusion in severe cases.

Final Answer: D-antigen incompatibility causes HDN; prevented by anti-D Ig $\Rightarrow$ C

Answer: (C) Go Back to Q11

Q12.

Solution

Concept — Micturition (urination) reflex: A coordinated spino-bulbar reflex modulated by voluntary cortical control.

Step 1 — Bladder anatomy:

- Detrusor muscle: smooth muscle wall of the bladder body and dome.
- Internal urethral sphincter: smooth muscle at bladder neck; involuntary.
- External urethral sphincter: skeletal muscle; voluntary control via pudendal nerve.
- Trigone: triangular region with three openings (two ureters, urethra).

Step 2 — Storage (filling) phase:

- Bladder relaxed (detrusor inhibited by sympathetic via β_3 receptors).

- Internal sphincter contracted (sympathetic, α_1).
- External sphincter contracted (somatic via pudendal).
- Bladder fills (capacity $\sim$ 400–500 mL).

Step 3 — Voiding (micturition) phase:

- Bladder stretch receptors (in detrusor) activate afferent fibres at $\sim$ 250–400 mL volume.
- Signal ascends to pontine micturition centre (PMC) and cerebral cortex.
- If timing is acceptable, PMC sends descending excitation:
  - Parasympathetic (S2–S4, pelvic nerve) $\rightarrow$ detrusor contraction (M_3 muscarinic receptors).
  - Inhibition of sympathetic tone $\rightarrow$ internal sphincter opens.
  - Voluntary relaxation of external sphincter (cortical, via pudendal).
- Urine flows out through urethra.

Step 4 — Higher-centre control:

- Pontine micturition centre coordinates the reflex.
- Cerebral cortex provides social timing: inhibits PMC until appropriate.
- Cord lesions above sacral level $\rightarrow$ initial atonic bladder, then spastic (automatic) bladder with reflex micturition without voluntary control.
- Cord lesions at/below sacral $\rightarrow$ flaccid bladder; overflow incontinence.
- Cauda equina syndrome: loss of bladder/bowel control; surgical emergency.

Step 5 — Pathophysiology and pharmacology:

- Overactive bladder (urgency, frequency): anticholinergics (oxybutynin, tolterodine) or β_3 agonists (mirabegron).
- Benign prostatic hyperplasia (BPH, men): bladder outlet obstruction $\rightarrow$ α_1-blockers (tamsulosin) relax internal sphincter; 5α-reductase inhibitors (finasteride) shrink prostate.
- Stress incontinence (especially in postmenopausal women): pelvic floor exercises, surgery.
- Diabetic autonomic neuropathy: bladder atony.

Final Answer: Coordinated spino-bulbar reflex with parasympathetic + voluntary control $\Rightarrow$ $\boxed{\text{D}}$

Answer: (D) Go Back to Q12

Q13.

Solution

Concept — Autonomic nervous system — two opposing branches: The visceral motor system regulates smooth muscle, cardiac muscle, glands, and metabolism. Two anatomically and functionally distinct branches.

Step 1 — Parasympathetic (PNS) — "rest and digest":

- Origin: cranio-sacral (CN III, VII, IX, X + sacral S2–S4). Vagus (CN X) supplies most thoracic and abdominal viscera.
- Long preganglionic, short postganglionic fibres (ganglia near or in target organ).
- Neurotransmitters: ACh at both pre- and postganglionic synapses.
- Postganglionic ACh acts on muscarinic receptors at the effector.
- Effects: slows heart rate (M_2), increases GI motility/secretion (M_3), constricts pupil (M_3), bronchoconstriction (M_3), bladder emptying, sexual arousal.

Step 2 — Sympathetic (SNS) — "fight or flight":

- Origin: thoraco-lumbar (T1–L2).
- Short preganglionic, long postganglionic fibres; ganglia close to spinal cord (paravertebral sympathetic chain).
- Preganglionic: ACh on nicotinic receptors at ganglia.
- Postganglionic: noradrenaline (NA) on α- and β-adrenergic receptors (with one exception: sweat glands, where postganglionic is ACh on muscarinic receptors).
- Adrenal medulla: a modified sympathetic ganglion; releases adrenaline and noradrenaline directly into the bloodstream.
- Effects: increases heart rate (β_1), bronchodilation (β_2), vasoconstriction (α_1) in skin and gut, vasodilation (β_2) in skeletal muscle, pupillary dilation (α_1), glycogenolysis/lipolysis, decreased GI motility, ejaculation.

Step 3 — Antagonistic balance: Most organs are dually innervated; the balance between SNS and PNS tone is constantly adjusted. Some organs are predominantly one or the other (e.g. blood vessels are mostly sympathetic).

Step 4 — Receptors and pharmacology:

- α_1: vasoconstriction. Phenylephrine (agonist), prazosin (antagonist).
- β_1: heart rate, contractility. Dobutamine (agonist), metoprolol (antagonist).
- β_2: bronchodilation. Salbutamol (agonist).

- M_1: gastric acid. M_2: heart. M_3: smooth muscle, glands. Atropine: non-selective muscarinic blocker.
- Nicotinic: at autonomic ganglia and NMJ. Curare-like drugs at NMJ.

Step 5 — Enteric nervous system (ENS): The "second brain" of the gut: ~ 500 million neurons in myenteric (Auerbach's) and submucosal (Meissner's) plexuses. Largely autonomous; modulated by vagus and sympathetic input. Coordinates peristalsis, secretion, blood flow.

Final Answer: Parasympathetic $\Rightarrow$ A

Answer: (A) Go Back to Q13

Q14.

Solution

Concept — Melatonin and the pineal gland: N-acetyl-5-methoxytryptamine; the principal hormone of the circadian clock.

Step 1 — Source: The pineal gland — a small pinecone-shaped organ in the epithalamus (Descartes once called it the "seat of the soul"); contains pinealocytes. Also produced in retina, gut, and other sites.

Step 2 — Synthesis: From dietary tryptophan:

$$\text{Tryptophan} \rightarrow \text{5-HTP} \rightarrow \text{Serotonin} \rightarrow \text{N-acetylserotonin} \rightarrow \text{Melatonin}$$

The key regulated enzyme is N-acetyltransferase (AANAT), whose activity rises at night.

Step 3 — Circadian rhythm:

- Light reaches retina $\rightarrow$ intrinsically photosensitive retinal ganglion cells (containing melanopsin) $\rightarrow$ retinohypothalamic tract $\rightarrow$ suprachiasmatic nucleus (SCN), the master clock $\rightarrow$ SCN inhibits pineal melatonin output via the superior cervical ganglion.
- In darkness: pineal melatonin output rises sharply; peaks around 3 am.
- Blue light (computer/phone screens at night) maximally suppresses melatonin.

Step 4 — Actions:

- Promotes sleep onset (binds MT1 and MT2 G-protein-coupled receptors in the hypothalamus and elsewhere).

- Reinforces the circadian rhythm.
- Lowers core body temperature.
- In seasonal breeders (sheep, deer, horses), melatonin signal duration (longer in winter) controls reproductive cycle.
- Has antioxidant activity (free-radical scavenger).
- May have immunomodulatory effects.

Step 5 — Clinical use:

- Jet lag.
- Shift-work sleep disorder.
- Delayed sleep phase syndrome.
- Primary insomnia (sleep-onset).
- Ramelteon, agomelatine: melatonin receptor agonists; FDA-approved for insomnia/depression.

Step 6 — Circadian biology: Won the 2017 Medicine Nobel (Hall, Rosbash, Young) for discovery of the molecular clock (period, timeless, clock genes; transcription-translation feedback loops).

Final Answer: Melatonin (biological-clock hormone) $\Rightarrow$ B

Answer: (B) Go Back to Q14

Q15.

Solution

Concept — Radial transport across plant roots: symplast vs apoplast: Water and dissolved minerals absorbed by root hairs must travel radially across the cortex to reach the xylem in the stele.

Step 1 — The two parallel pathways:

- **Apoplast pathway:** water + solutes flow through cell walls and intercellular spaces, without entering any cell membrane.
  - Fast, passive, bulk flow.
  - No cellular selectivity.
  - Blocked at the endodermis (see below).
- **Symplast pathway:** water + solutes pass through the cytoplasm via plasmodesmata, from one cell to the next.
  - Slower (must cross cell membranes initially).
  - Plant cells can regulate what enters the symplast.

  - Continues uninterrupted through the endodermis.
- **Transmembrane (vacuolar) pathway:** alternative; water repeatedly crosses cell membranes and vacuoles.

Step 2 — The endodermis and Casparian strip: The endodermis is the innermost cortex layer surrounding the stele. Its cells deposit suberin and lignin in a ring (the Casparian strip) on the radial and transverse walls → a hydrophobic barrier to apoplastic flow.

- Apoplast must give way to symplast at the endodermis.
- Plant gains **selectivity**: only solutes that have entered the symplast (passed through a plasma membrane) reach the xylem.
- Critical for excluding toxins and concentrating nutrients.

Step 3 — Onward to xylem: After crossing the endodermis, solutes are pumped out of the pericycle/parenchyma cells into the apoplast of the xylem vessels by membrane transporters. From the xylem, water and solutes ascend to shoots driven by transpiration pull (cohesion-tension theory) plus root pressure.

Step 4 — Driving forces:

- Transpiration (water loss from leaves) generates negative pressure (tension) in xylem, pulling water up.
- Root pressure (osmotic; from active ion accumulation in stele) pushes water from below; visible as guttation in early morning.
- Capillary action: minor contribution.

Final Answer: Symplast ⇒ $\boxed{\text{C}}$

Answer: (C) Go Back to Q15

Q16.

Solution

Concept — Photorespiration — the cost of RuBisCO's dual chemistry: RuBisCO (Ribulose-$1,5$-Bisphosphate Carboxylase/Oxygenase) — the most abundant protein on Earth — catalyses two competing reactions, only one of which is productive.

Step 1 — The two RuBisCO reactions:

- **Carboxylation (productive):** RuBP (5C) + $CO_2 \rightarrow 2 \times 3$-phosphoglycerate (PGA, 3C); enters Calvin cycle $\rightarrow$ G3P $\rightarrow$ sugars.
- **Oxygenation (wasteful):** RuBP + $O_2 \rightarrow 1$ PGA (3C) + 1 phosphoglycolate (2C). Phosphoglycolate is not useful and must be salvaged.

Step 2 — The photorespiratory salvage pathway (three organelles):

(a) Chloroplast: phosphoglycolate $\rightarrow$ glycolate (released to peroxisome).
(b) Peroxisome: glycolate $\rightarrow$ glyoxylate $\rightarrow$ glycine (released to mitochondrion).
(c) Mitochondrion: 2 glycines $\rightarrow 1$ serine + CO_2 + NH_3.
(d) Back to peroxisome and chloroplast: serine $\rightarrow$ 3-PGA (re-enters Calvin cycle).

Net: $1/4$ of the carbon in oxygenated RuBP is lost as CO_2; the energy spent is substantial.

Step 3 — Why does RuBisCO have this oxygenase activity?

- RuBisCO evolved ~ 3 billion years ago, when atmospheric O_2 was very low. Discrimination between CO_2 and O_2 was not selected for.
- Now, with O_2 at 21% and CO_2 at 0.04% of atmosphere, the oxygenase reaction occurs frequently — ~ 1 oxygenation per 2–4 carboxylations in C_3 plants.
- Hot, dry days are worst: stomata close to conserve water $\rightarrow$ internal CO_2 falls, O_2 rises (from photosynthesis) $\rightarrow$ photorespiration spikes.

Step 4 — C_4 and CAM adaptations:

- C_4 **plants** (maize, sugarcane, sorghum, many tropical grasses):
  - Spatial separation: PEP carboxylase (no O_2 activity, very high affinity for CO_2) in mesophyll cells fixes CO_2 into oxaloacetate $\rightarrow$ malate $\rightarrow$ pumped to bundle-sheath cells.

  - In bundle sheath: malate releases CO_2 around RuBisCO at high concentration $\rightarrow$ RuBisCO operates as a pure carboxylase.
  - Kranz anatomy: ring of bundle-sheath cells around vascular bundle.
- **CAM plants** (cacti, succulents, pineapple):
  - Temporal separation: stomata open at night (cooler, less water loss); CO_2 fixed by PEP carboxylase into malate, stored in vacuole.
  - During day, stomata closed; malate releases CO_2 around RuBisCO.
  - Excellent water economy at the cost of slower growth.

Step 5 — Engineering "better" RuBisCO: A major goal in agricultural biotechnology. Approaches: introduce C_4 biology into C_3 crops (rice C4 Project), engineer better RuBisCO variants, install cyanobacterial CO_2-concentrating mechanisms. Could boost crop yields 20–50%.

Final Answer: O_2 + RuBP $\rightarrow$ phosphoglycolate; salvaged at energy cost; CO_2 loss $\Rightarrow$ $\boxed{\text{D}}$

Answer: (D) Go Back to Q16

Q17.

Solution

Concept — Pedigree analysis and inheritance patterns: A pedigree is a family tree showing how a trait/disease is passed across generations. Standard symbols: squares = males, circles = females, filled = affected, half-filled = carrier (where known), horizontal line = marriage, vertical line down to offspring.

Step 1 — Autosomal dominant (AD):

- Trait appears in every generation (no skipping).
- Both sexes equally affected.
- Affected parent has 50% chance of passing trait to each child (heterozygous parent).
- Unaffected individuals do NOT transmit the trait (no carriers).
- Vertical pattern of inheritance.
- Examples: Huntington's disease, Marfan syndrome, achondroplasia, neurofibromatosis type 1, Familial hypercholesterolaemia.
- Note: late-onset AD (Huntington's) may seem to skip generations if affected individuals died before symptom onset.

Step 2 — Autosomal recessive (AR):

- Trait often skips generations.

- Both sexes equally affected.
- Both parents are usually unaffected carriers (heterozygous).
- Affected child has 25% probability when both parents are carriers; carrier siblings 50%.
- Consanguinity (cousin marriages) increases risk.
- Examples: cystic fibrosis, sickle cell disease, β-thalassaemia, Tay-Sachs, PKU.

Step 3 — X-linked recessive:

- Predominantly affects males (males have only one X, so any X-recessive allele is expressed).
- Inherited from carrier mother; affected son receives X from mother.
- Females rarely affected (would need to be homozygous, or have skewed X-inactivation).
- Affected man's daughters are all carriers; sons all unaffected.
- Examples: haemophilia A and B, Duchenne muscular dystrophy, red-green colour blindness, G6PD deficiency.

Step 4 — X-linked dominant:

- Both sexes affected, but with twice as many affected females as males.
- Affected father transmits to ALL daughters and NO sons.
- Affected mother transmits to half her children regardless of sex.
- Often lethal in males if hemizygous (only affected females observed in some).
- Examples: hypophosphataemic rickets, Rett syndrome, incontinentia pigmenti.

Step 5 — Mitochondrial inheritance:

- Strictly maternal (sperm mitochondria are destroyed after fertilisation).
- Affected mother $\rightarrow$ all children affected (variable severity due to heteroplasmy).
- Affected father $\rightarrow$ no children affected.
- Examples: LHON, MELAS, MERRF.

Final Answer: Autosomal dominant: every generation, both sexes, 50% recurrence $\Rightarrow$ $\boxed{\text{A}}$

Answer: (A) Go Back to Q17

Q18.

Solution

Concept — Types of mutations: Genetic mutations are classified by their effect on DNA sequence and protein product.

Step 1 — Substitutions (point mutations):

- **Silent:** different codon, same amino acid (third-base wobble). No phenotype.
- **Missense:** codon now specifies a different amino acid. Effect varies: from benign (conservative substitution) to severe (sickle cell anaemia: Glu6Val on β-globin).
- **Nonsense:** codon becomes a stop codon $\rightarrow$ truncated protein. Usually severe loss of function.

Step 2 — Insertions and deletions (indels):

- **In-frame indel** ($3n$ bases inserted/deleted): adds or removes n amino acids, but reading frame preserved downstream. Effect depends on which residues.
- **Frameshift mutation** (insertion/deletion of 1, 2, or any non-multiple of 3): shifts the reading frame from that point on $\rightarrow$ all subsequent codons mistranslated $\rightarrow$ usually a premature stop codon within a few dozen codons $\rightarrow$ severely truncated, dysfunctional protein.

Step 3 — Why frameshift is usually catastrophic:

- Stop codons occur statistically every ~ 21 codons in a random reading frame ($3/64$).
- Truncated proteins lack C-terminal domains; mRNAs are often degraded by nonsense-mediated decay (NMD).
- Loss-of-function nature.

Step 4 — Example: cystic fibrosis CFTR mutations:

- ΔF508 (most common): in-frame deletion of CTT codon $\rightarrow$ loss of phenylalanine 508; doesn't shift frame but causes misfolding.
- Other CF mutations include frameshift, missense, nonsense.

Step 5 — Trinucleotide repeat expansion diseases: A class of in-frame "insertions" where a repeat unit (CAG, CGG, etc.) expands across generations:

- Huntington's disease (CAG in HTT, > 40 repeats pathogenic).

- Fragile X syndrome (CGG in FMR1).
- Myotonic dystrophy (CTG in DMPK 3′UTR).
- Anticipation: severity increases in successive generations.

Step 6 — Frameshift-suppressor tRNAs: Engineered tRNAs that read 4-base codons can suppress some frameshift mutations — both a research tool and a potential therapeutic approach.

Final Answer: Frameshift mutation $\Rightarrow$ B

Answer: (B) Go Back to Q18

Q19.

Solution

Concept — Reading frames and genetic code: The triplet, ungapped, non-overlapping nature of the genetic code was established by Crick, Brenner et al. (1961) using bacteriophage T4 frameshift mutations.

Step 1 — Three frames per strand: A given nucleotide sequence can be read in three different ways starting from positions 1, 2, or 3:

$$5'\text{-ATG CAT GGA-}3' \quad \text{(frame 1)}$$

$$5'\text{-A TGC ATG GA} - 3' \quad \text{(frame 2)}$$

$$5'\text{-AT GCA TGG A} - 3' \quad \text{(frame 3)}$$

Step 2 — Six frames per dsDNA: DNA is double-stranded, so the complementary strand also has its own three reading frames $\rightarrow$ six frames total. When analysing an unknown DNA region for protein-coding potential, all six are scanned for open reading frames (ORFs).

Step 3 — Choosing the actual frame: Translation begins at the first AUG (Kozak context in eukaryotes; Shine-Dalgarno-led in bacteria), and the frame is fixed from there until a stop codon. Only one frame is used per mRNA.

Step 4 — Overlapping genes: Some compact genomes (viruses, bacteriophages, mitochondrial) have overlapping genes that use different reading frames of the same DNA stretch:

- Bacteriophage ϕX174: multiple genes overlap; landmark Sanger sequencing target.
- HIV: *tat*, *rev* overlap with *env*.

- Hepatitis B virus: extensive overlapping.
- Mitochondrial *ATP6/ATP8*: overlap by 46 nucleotides.

Step 5 — Reading-frame shifts as regulation: Some viruses (HIV) and bacteria use programmed ribosomal frameshifting to produce two different proteins from one mRNA — usually a -1 shift at a slippery sequence.

Final Answer: Three reading frames per strand, six total per dsDNA $\Rightarrow$ C

Answer: (C) Go Back to Q19

Q20.

Solution

Concept — Alfred Russel Wallace (1823–1913) — co-discoverer of natural selection: A self-taught British naturalist whose independent insight into natural selection forced Darwin to publish.

Step 1 — The 1858 event — the Linnean Society reading:

- Darwin had been working on his theory of natural selection since 1838 but had not published, fearing the controversy.
- In June 1858, Wallace sent Darwin a manuscript ("On the Tendency of Varieties to Depart Indefinitely from the Original Type"), written while ill with fever in Ternate (Indonesia), outlining a theory remarkably similar to Darwin's.
- Darwin's friends Charles Lyell and Joseph Hooker arranged a joint reading of papers by Darwin and Wallace at the Linnean Society on 1 July 1858.
- The next year (1859), Darwin rushed to finish *On the Origin of Species*.

Step 2 — Wallace's other contributions:

- **Biogeography:** Wallace is often called the father of biogeography. His extensive fieldwork in the Amazon (1848–1852) and Malay Archipelago (1854–1862) mapped the geographic distribution of species.
- **The Wallace Line:** the biogeographic boundary between the Asian (Bali, Sumatra, Borneo) and Australian (Lombok, Sulawesi, New Guinea) faunal regions, crossing through Lombok Strait. Asian side: tigers, rhinos, monkeys. Australian side: marsupials, cockatoos. The line marks the deep ocean trench from the Ice-Age limits of land bridge connections.
- Founded zoogeography as a discipline.
- Co-developed the theory of mimicry and warning coloration (Wallace's effect).

- Studied protective coloration in animals.

Step 3 — Differences from Darwin:

- Wallace was more cautious about applying natural selection to human mental faculties; he leaned toward spiritualism in later life.
- Darwin extended selection to sexual selection; Wallace was more sceptical.
- Wallace defended natural selection rigorously when others (e.g. Lord Kelvin) attacked Darwin.

Step 4 — Legacy: Wallace was less remembered for many decades — "Darwin's moon". Recent scholarship has restored his stature. Numerous awards and honours, including the Order of Merit (1908). The 2013 centenary of his death prompted reassessment.

Step 5 — Other figures in the question:

- Thomas Huxley: "Darwin's bulldog"; vigorous public advocate of evolution; debated Bishop Wilberforce (1860).
- Joseph Hooker: botanist and close friend of Darwin; helped arrange the joint reading.
- Alfred Lord Tennyson: poet, not a scientist.

Final Answer: Alfred Russel Wallace $\Rightarrow$ $\boxed{\text{D}}$

Answer: (D) Go Back to Q20

Q21.

Solution

Concept — Industrial melanism in the peppered moth (*Biston betularia*): The textbook example of natural selection in action, documented in real time within a few human generations.

Step 1 — Pre-industrial baseline: Before the Industrial Revolution in Britain (early 1800s), peppered moths existed almost entirely in the typical light-grey ("typica") form. Their speckled wings provided camouflage against the lichen-covered, pale-coloured tree bark of unpolluted woodlands. Bird predators (mostly small insectivorous birds) found them hard to spot.

Step 2 — Industrial Revolution effect:

- Coal-burning factories belched soot.

- Acidic pollution killed lichens; tree bark became darkened.
- A dark-coloured (melanic, "carbonaria") form of the moth, previously a rare variant (caused by a dominant allele), became conspicuously well-camouflaged on the now-darker bark.
- Light moths were spotted and eaten more easily on dark bark; melanic moths were spotted and eaten more easily on pale bark.
- Selection pressure was reversed in industrial vs rural areas.

Step 3 — Numerical change:

- Pre-1850: melanic form $< 1\%$ in most populations.
- By 1900: melanic form $> 95\%$ in heavily industrialised regions (Manchester, Birmingham).
- In rural southwest England: melanic form remained rare throughout.

Step 4 — Kettlewell's experiments (1953–1955): H. B. D. Kettlewell at Oxford did mark-recapture experiments:

- Released marked moths of both forms in polluted (Birmingham) and unpolluted (Dorset) woodlands.
- Recaptured significantly more typica in clean areas, more carbonaria in polluted areas.
- Direct observation: birds (with hidden cameras) selectively preyed on the less-camouflaged form.
- Established the bird-predation selection hypothesis.

Step 5 — Reversal — the Clean Air Act (1956 in Britain):

- Air pollution dropped; lichens recovered; bark lightened.
- Melanic moth frequency plummeted; typica returned.
- By 2000, carbonaria nearly extinct in most regions.

Step 6 — Genetic basis: The carbonaria allele is a transposable-element insertion in the cortex gene (Saccheri et al., 2016). The insertion arose around 1819, consistent with the timing of industrial melanism. Beautiful case study integrating ecology, genetics, history.

Step 7 — Recent re-examinations: Some critics questioned Kettlewell's methods. Subsequent careful experiments (Cook, Majerus and Saccheri, 2012) confirmed selective bird predation drives the change. Settled.

Final Answer: Natural selection (industrial melanism) $\Rightarrow$ $\boxed{\text{A}}$

Answer: (A) Go Back to Q21

Q22.

Solution

Concept — Transposable elements — "jumping genes": DNA segments that can move from one site to another within a genome. Discovered by Barbara McClintock in maize (1948); long ignored, finally rewarded with the Nobel Prize in Medicine (1983).

Step 1 — McClintock's discovery:

- Studied genetics of maize kernel pigmentation; saw unusual mosaic patterns.
- Identified two genetic elements: Ds (Dissociation) and Ac (Activator).
- Ds could move and cause chromosome breakage; Ac controlled Ds movement.
- Concluded that genes can move within and between chromosomes — revolutionary at the time, when the genome was thought to be stable.

Step 2 — Two major classes of transposons:

- **Class I (retrotransposons, "copy-and-paste"):**
  - Transposition via RNA intermediate.
  - RNA copy transcribed, reverse-transcribed by encoded reverse transcriptase, integrated into new genomic site.
  - Original copy stays put; copy number can grow rapidly.
  - Two subclasses: LTR retrotransposons (have long terminal repeats, like retroviruses) and non-LTR (LINEs and SINEs in mammals).
- **Class II (DNA transposons, "cut-and-paste"):**
  - Transposition without RNA intermediate.
  - Encode their own transposase; excise the element from one site and insert at another.
  - Some leave behind a footprint (small insertion) at the original site.
  - Examples: Ac/Ds (maize), P element (*Drosophila*), Tn5, Tn10 (bacteria), *Sleeping Beauty* (resurrected, used as a gene-delivery tool), *piggyBac*.

Step 3 — Abundance:

- Human genome: $\sim 45\%$ derived from transposable elements (mostly LINE-1, SINE/Alu, LTR retrotransposons).
- Maize: $\sim 85\%$ of genome.

- Most transposon copies are decayed and non-functional "fossils".

Step 4 — Biological consequences:

- **Genome evolution:** transposons reshuffle DNA, create new gene regulatory elements, contribute to species diversity.
- **Disease-causing insertions:** occasional new insertions into a gene disrupt function. Examples:
  - Haemophilia A (Factor VIII gene): some cases from LINE-1 insertion.
  - Some Duchenne muscular dystrophy cases.
  - Neurofibromatosis, breast cancer, etc.
- **V(D)J recombination** of immunoglobulin and T-cell receptor genes is mediated by RAG1/2, derived from an ancient transposon — giving rise to adaptive immunity.
- **Beneficial domestication:** syncytin (placenta development) is derived from an endogenous retrovirus env gene; centromere function in some species involves transposon-derived sequences.
- Transposons used in research: P-element in fly transgenesis; *Sleeping Beauty*, *piggyBac*, and CRISPR/Cas systems for genome engineering.

Step 5 — Host defences: Eukaryotes have evolved mechanisms to control transposon activity: DNA methylation, repressive histone marks, small RNAs (piRNAs in germline, siRNAs).

Final Answer: DNA sequences that change position in the genome $\Rightarrow$ $\boxed{\text{B}}$

Answer: (B) Go Back to Q22

Q23.

Solution

Concept — Cleavage patterns in different animals: Cleavage = rapid mitotic divisions of the zygote without intervening growth. The pattern is determined largely by the amount and distribution of yolk in the egg.

Step 1 — Three main types based on completeness:

- **Holoblastic (complete):** the entire zygote divides into smaller blastomeres. Found in eggs with little/modest yolk: mammals, amphibians (*Xenopus*), echinoderms, lancelets (*Amphioxus*). Subtypes:
  - Equal holoblastic: blastomeres are similar in size (mammals, echinoderms).

  - Unequal holoblastic: vegetal blastomeres larger (yolk-rich) than animal (amphibians).
- **Meroblastic (incomplete):** cleavage limited to the yolk-free region; only part of the zygote divides into cells, the rest remains an undivided yolky mass. Found in eggs with abundant yolk: fish, reptiles, birds.
  - Discoidal meroblastic: cleavage confined to a disc on top of the yolk (birds, reptiles, most fish).
- **Superficial:** nuclear divisions without cytokinesis form a syncytial blastoderm at the periphery; later cellularises. Insects (*Drosophila*).

Step 2 — Mammalian cleavage:

- Holoblastic and roughly equal.
- Slow (~ 24 h per division initially).
- Asynchronous (blastomeres divide at slightly different times after the second division).
- Rotational cleavage at the second division: first cell divides along one axis, second cell along a perpendicular axis.
- Compaction at 8-cell stage: E-cadherin maximises cell-cell contacts.
- Inner cell mass forms inside, trophoblast outside.

Step 3 — Cleavage patterns by symmetry:

- Radial holoblastic (deuterostomes: echinoderms, chordates).
- Spiral holoblastic (protostomes: molluscs, annelids, flatworms).
- Bilateral (tunicates).
- Rotational (mammals).

Step 4 — Maternal vs zygotic control: Early cleavage divisions use maternal RNAs and proteins deposited in the egg; the zygotic genome turns on (mid-blastula transition) at varying timing across species (in mammals, this happens early — at 2-cell stage in mice, 4-8 cell in humans).

Step 5 — Twinning: Holoblastic cleavage allows monozygotic twinning: if the embryo separates into two parts at 2-cell, morula, or blastocyst stages, each can develop into a viable twin (with different membrane-sharing patterns).

Final Answer: Mammalian cleavage is holoblastic $\Rightarrow$ $\boxed{\text{C}}$

Answer: (C) Go Back to Q23

Q24.

Solution

Concept — Amniotic fluid — the foetal environment: The fluid filling the amniotic sac that surrounds the developing foetus throughout pregnancy.

Step 1 — Composition and origin:

- Early pregnancy: mostly transudate from amniotic membrane.
- From $\sim$ week 16 onward: predominantly foetal urine.
- Late pregnancy: fetal urine ($\sim$ 800 mL/day at term) plus fluid from foetal lung and oral/nasal secretions.
- Amniotic fluid is swallowed by the foetus and re-absorbed in the gut, then re-excreted as urine.
- Volume: rises to peak $\sim$ 800–1000 mL at $\sim$ 34–36 weeks; declines slightly toward term.

Step 2 — Functions:

- **Mechanical cushion:** protects foetus from mechanical trauma to the maternal abdomen.
- **Temperature regulation:** buffers the foetus against thermal fluctuations.
- **Free movement:** allows musculoskeletal development through movement (essential; movement is required for joint development, lung development).
- **Prevents adhesions:** between the foetus and the amniotic sac.
- **Lung development:** foetus practises "breathing" movements; AF inhaled and exhaled stimulates lung maturation.
- **Antibacterial properties:** contains lysozyme, transferrin, defensins.
- **Lubrication:** at delivery, the rupture of membranes (waters breaking) lubricates the birth canal.

Step 3 — Diagnostic uses:

- **Amniocentesis** ($\sim$ 16 weeks): needle-aspiration of amniotic fluid for prenatal diagnosis.
  - Foetal cells $\rightarrow$ karyotyping (trisomy 21, etc.), molecular genetic testing.
  - AFP (alpha-fetoprotein): elevated in neural tube defects.
  - Lecithin/Sphingomyelin (L/S) ratio: > 2 indicates lung maturity.
  - Bilirubin levels (delta OD450): Rh disease severity.
- Amniotic stem cells: a source of pluripotent-like stem cells for research and therapy.

Step 4 — Pathology:

- Oligohydramnios (too little AF): renal agenesis (Potter sequence), urinary obstruction, premature membrane rupture, placental insufficiency. Associated with limb deformities, pulmonary hypoplasia (lungs need AF to develop properly).
- Polyhydramnios (too much AF): maternal diabetes, fetal swallowing defects (oesophageal atresia, anencephaly), multiple gestation.
- Premature rupture of membranes (PROM): risk of chorioamnionitis, preterm labour.

Final Answer: Cushion, temperature, movement, lung development, lubrication $\Rightarrow \boxed{\text{D}}$

Answer: (D) Go Back to Q24

Q25.

Solution

Concept — Twinning: Multiple pregnancies arise by two main mechanisms.

Step 1 — Monozygotic (identical) twins:

- A single fertilised egg (zygote) splits into two embryos.
- Genetically identical (apart from rare post-zygotic mutations).
- Always same sex; same blood type; same DNA fingerprint.
- Frequency $\sim$ 3–4 per 1000 pregnancies; doesn't run in families (no genetic basis).
- Membrane sharing depends on when the split occurs:
  - Split at 1–3 days (before blastocyst): dichorionic-diamniotic (separate chorion + amnion). $\sim 25\%$.
  - Split at 4–8 days: monochorionic-diamniotic (shared chorion, separate amnion). $\sim 70\%$. Most common.
  - Split at 8–12 days: monochorionic-monoamniotic (shared chorion AND amnion). Rare, higher risk of cord entanglement.
  - Split at 13+ days: conjoined twins. Very rare.

Step 2 — Dizygotic (fraternal) twins:

- Two separate ova ovulated in the same cycle, each fertilised by a different sperm.
- Genetically as related as ordinary siblings (sharing $\sim 50\%$ of variable alleles).

- Can be same or different sex; may be different blood types.
- Always dichorionic-diamniotic (each with own placenta and membranes).
- Frequency varies widely by population ($\sim 8/1000$ in Europeans; higher in Africa, lower in Asia).
- Tends to run in families; due to maternal genetics (FSH levels, ovulatory pattern). Maternal age and assisted reproductive techniques (IVF) raise frequency.

Step 3 — Higher-order multiples: Triplets, quadruplets, etc.: can be all monozygotic, all dizygotic, or a mix.

Step 4 — Clinical implications:

- Twin pregnancies are at higher risk of:
  - Preterm delivery (mean 36 weeks vs 40).
  - Pre-eclampsia, gestational diabetes.
  - Twin-to-twin transfusion syndrome (TTTS): in monochorionic twins, vascular anastomoses across shared placenta create imbalanced blood flow; one twin becomes anaemic (donor), the other polycythaemic (recipient). Treated by fetoscopic laser ablation of anastomoses.
- Twin studies are foundational in behavioural genetics: comparing MZ vs DZ concordance estimates heritability of traits and disorders.

Step 5 — Identification: DNA fingerprinting (microsatellite analysis) can distinguish MZ from DZ when membrane pattern alone is ambiguous (e.g. dichorionic could be MZ if split happened early, or DZ).

Final Answer: Single zygote that splits into two embryos $\Rightarrow$ $\boxed{\text{B}}$

Answer: (B) Go Back to Q25

Q26.

Solution

Concept — In Vitro Fertilisation (IVF): Pioneered by gynaecologist Patrick Steptoe and physiologist Robert Edwards; first IVF baby Louise Brown born 25 July 1978 in Oldham, England. Robert Edwards awarded the 2010 Medicine Nobel (Steptoe had died in 1988).

Step 1 — The clinical IVF cycle:

(a) **Ovarian hyperstimulation:** daily injections of FSH (and LH or hCG) to stimulate multiple follicles to mature simultaneously (instead of the usual one).
(b) Monitoring: serial ultrasound and serum estradiol to track follicle growth.
(c) **Trigger:** once follicles are mature, a single dose of hCG (or GnRH agonist) triggers final oocyte maturation, mimicking the LH surge.
(d) **Oocyte retrieval:** ~ 36 h post-trigger, transvaginal ultrasound-guided needle aspiration of multiple follicles under sedation.
(e) **Fertilisation:**
- Conventional IVF: oocytes incubated with motile sperm.
- ICSI (intracytoplasmic sperm injection): a single sperm injected directly into the oocyte; for male-factor infertility (low count, motility, morphology). Now used in $> 50\%$ of IVF cycles.

(f) **Embryo culture:** fertilised eggs cultured in vitro for 3–5 days, until cleavage stage (8-cell, day 3) or blastocyst stage (day 5).
(g) **Pre-implantation genetic testing (PGT, optional):** blastocyst biopsy to screen embryos for chromosomal aneuploidy (PGT-A) or specific genetic disorders (PGT-M); selected normal embryo transferred.
(h) **Embryo transfer:** 1–2 best embryos transferred to uterus via a thin catheter (no anaesthesia needed). Single-embryo transfer increasingly preferred to avoid multiple pregnancies.
(i) **Cryopreservation:** surplus embryos frozen in liquid nitrogen for later cycles.
(j) Pregnancy test ~ 2 weeks post-transfer.

Step 2 — Success rates: Varies with age (the biggest factor):

- < 35: ~ 40–50% live birth per cycle.
- 35–37: ~ 30–40%.
- 40–42: ~ 10–15%.
- Multiple cycles often needed.

Step 3 — Variants and add-ons:

- Donor oocytes (for women with premature ovarian insufficiency, advanced age).
- Donor sperm (for severe male infertility, single mothers by choice, same-sex couples).
- Gestational surrogacy.
- Mitochondrial replacement (UK-approved): for mothers with mitochondrial DNA mutations.

Step 4 — Risks:

- Ovarian hyperstimulation syndrome (OHSS): rare but potentially serious; managed by GnRH-agonist triggering and cycle cancellation in risky cases.
- Multiple pregnancy (higher with multiple embryo transfer): pre-term birth, etc.
- Ectopic pregnancy slightly elevated.
- Slight increase in birth defects (uncertain whether intrinsic to IVF or to the underlying infertility).

Step 5 — Cumulative impact: Over 10 million IVF babies born worldwide as of the 2020s. Has profoundly changed reproductive medicine and family-building options.

Final Answer: Hyperstimulation $\rightarrow$ retrieval $\rightarrow$ in vitro fertilisation/ICSI $\rightarrow$ embryo transfer $\Rightarrow$ $\boxed{\text{C}}$

Answer: (C) Go Back to Q26

Q27.

Solution

Concept — Double fertilisation and triple fusion: A unique feature of angiosperms (flowering plants), where the pollen tube delivers two sperm cells, both of which take part in fertilisation events.

Step 1 — Pollen tube delivery:

- Pollen germinates on a compatible stigma.
- Pollen tube grows through the style toward the ovary, guided by chemoattractants from synergid cells in the embryo sac.
- Tube enters the ovule through the micropyle.
- Tube ruptures and releases two sperm cells into the embryo sac.

Step 2 — The two fusion events:

- **Syngamy (egg fertilisation):** one sperm (n) fuses with the egg cell (n) $\rightarrow$ diploid zygote ($2n$) $\rightarrow$ develops into embryo.
- **Triple fusion (central cell fertilisation):** the other sperm (n) fuses with the two polar nuclei (each n; together n+n = $2n$, or already fused as a $2n$ secondary nucleus) at the centre of the embryo sac $\rightarrow$ triploid ($3n$) primary endosperm nucleus $\rightarrow$ develops into endosperm.

Step 3 — Why endosperm is $3n$: The $3n$ endosperm is unique to angiosperms (gymnosperms have $1n$ female gametophyte tissue as the seed storage tissue; angiosperms have $3n$ endosperm). The triploid status:

- Maximises nutrient storage (extra paternal investment).
- Imprinted genes regulate endosperm growth (maternally and paternally expressed differ).
- Endosperm size is a major determinant of seed size.

Step 4 — Endosperm types:

- Nuclear (free nuclear division initially, then cellularises): most common.
- Cellular (cell wall formed after each division from the start): some basal angiosperms.
- Helobial (intermediate): in many monocots.

Step 5 — Endosperm fate:

- Persistent endosperm: remains in the mature seed and feeds the embryo on germination. Examples: cereals (wheat, rice, maize — white rice is endosperm), coconut (coconut water is liquid endosperm; coconut meat is solid endosperm).
- Consumed during seed development: endosperm absorbed by the developing embryo; mature seed stores food in the cotyledons (dicots like beans, peas).

Step 6 — Economic importance: Endosperm is the major source of human caloric intake (cereal endosperm, particularly rice, wheat, maize). Engineering endosperm composition is a major goal of plant biotechnology (Golden Rice provitamin A in endosperm; high-lysine maize; etc.).

Final Answer: Triple fusion (1 sperm + 2 polar nuclei $\rightarrow 3n$) $\Rightarrow$ $\boxed{\text{D}}$

Answer: (D) Go Back to Q27

Q28.

Solution

Concept — Floral whorls: A typical flower has four whorls of modified leaves, arranged concentrically.

Step 1 — The four whorls (outer to inner):

- **Calyx** (sepals): outermost; typically green; protective of the bud; collectively = calyx.
- **Corolla** (petals): often coloured, scented; attract pollinators; collectively = corolla.
- **Androecium** (stamens): male whorl; each stamen = filament + anther (where pollen is produced).
- **Gynoecium** (carpels / pistils): female whorl; each carpel = stigma + style + ovary (with ovules).

Step 2 — Perianth: The collective term for the calyx + corolla (the non-reproductive accessory whorls). When sepals and petals are clearly distinct (most dicots) we name them separately. When they look identical (many monocots: lily, tulip, daffodil), we call the units **tepals** and the whole is the perianth (or perigone).

Step 3 — Flower classification by perianth:

- Complete flower: all four whorls present (e.g. hibiscus, mustard).
- Incomplete flower: missing one or more whorls.
- Apetalous: lacks petals (some wind-pollinated flowers like grasses).
- Apopetalous (polypetalous): petals separate (rose).
- Sympetalous (gamopetalous): petals fused into a tube (morning glory, petunia).
- Aposepalous, synsepalous: same but for sepals.

Step 4 — Reproductive arrangement:

- Bisexual (hermaphrodite, perfect): both stamens and carpels in the same flower. Most flowers.
- Unisexual: only stamens (staminate) or only carpels (carpellate / pistillate).
- Monoecious: separate male and female flowers on the same plant (maize, cucumber).
- Dioecious: male and female flowers on separate plants (papaya, date palm, willow, mulberry).

Step 5 — ABC model of floral organ identity: Coen and Meyerowitz: three (now four) homeotic gene classes specify identity of each whorl:

- A alone: sepals.
- A + B: petals.
- B + C: stamens.
- C alone: carpels.
- E genes: required throughout.

Mutations cause homeotic conversion (one whorl identity replaced by another); a beautiful illustration of developmental genetics.

Final Answer: Perianth = calyx + corolla $\Rightarrow$ $\boxed{\text{A}}$

Answer: (A) Go Back to Q28

Q29.

Solution

Concept — GA-induced α-amylase in cereal aleurone: The textbook example of hormone-induced gene expression in plant biology. Foundation of beer-brewing biochemistry.

Step 1 — Barley seed structure:

- Embryo: at one end of the seed; future seedling.
- Starchy endosperm: bulk of the seed; stored starch in amyloplasts; surrounded by –
- Aleurone layer: 2-3 cell-thick living tissue around the endosperm; produces hydrolytic enzymes on germination.
- Pericarp + seed coat: protective outer layers.

Step 2 — Events on imbibition (water uptake):

(a) Water enters the seed; embryo hydrates.
(b) Embryo synthesises and releases **gibberellin (GA_3)**.
(c) GA diffuses through the endosperm to the aleurone layer.
(d) GA activates expression of α-amylase genes in aleurone cells.
(e) Aleurone cells secrete α-amylase (plus β-amylase, proteases, nucleases) into the starchy endosperm.
(f) α-Amylase hydrolyses starch $\rightarrow$ maltose $\rightarrow$ glucose; embryo absorbs the sugars and grows.

Step 3 — Signal transduction:

- GA binds GID1 receptor.
- DELLA proteins (transcriptional repressors) are then targeted for ubiquitination via the SCF^{SLY1} complex and degraded by the proteasome.
- Removing DELLA repressors allows GAMYB and other transcription factors to activate α-amylase gene transcription.

Step 4 — ABA antagonism: ABA opposes GA action — maintains dormancy. The GA:ABA ratio is the key determinant of whether the seed germinates. Stress conditions raise ABA; favourable conditions raise GA.

Step 5 — The malting process in beer brewing:

- Barley grains are induced to germinate (steeping, then aeration) so α-amylase and other enzymes are produced.
- Germination halted by drying (kilning) once enzymes are maximal but starch is mostly intact.
- The dried product (malt) is later crushed and mashed: hot water reactivates the enzymes, which digest starch to fermentable sugars.
- Yeast then ferments the sugar to alcohol and CO_2.
- Commercial malting industry: GA_3 application accelerates the process.

Step 6 — Industrial α-amylase: The same enzyme is produced commercially from *Bacillus* for use in laundry detergents, food production, and textile manufacturing.

Final Answer: Gibberellin (GA_3) $\Rightarrow$ $\boxed{\text{B}}$

Answer: (B) Go Back to Q29

Q30.

Solution

Concept — Plant tropisms: Directional growth responses to environmental stimuli. The direction of growth defines whether the tropism is "positive" (toward stimulus) or "negative" (away).

Step 1 — Hydrotropism:

- Directional growth of roots toward moisture (positive hydrotropism).
- Adaptive in soil with patchy water distribution; root architecture is reshaped to find water.
- Can override gravitropism in conditions of severe water deficit.
- Sensed at the root cap.

Step 2 — Mechanism:

- Root cap perceives water gradient; cortical cells in the elongation zone differentially expand.
- **MIZ**1 (MIZU-KUSSEI 1) gene: mutants in *Arabidopsis* show defective hydrotropism but normal gravitropism — demonstrating the mechanisms are genetically separable.
- Cytokinin signalling in elongation zone is required.
- Auxin asymmetry is much weaker than in gravitropism; ABA may play a role.

Step 3 — Other tropisms:

- **Phototropism:** growth toward light (shoots positive, roots usually negative). Mediated by phototropins (blue-light receptors) and auxin redistribution.
- **Gravitropism (geotropism):** shoots negative, roots positive. Mediated by statoliths (dense amyloplasts that sediment); Cholodny-Went hypothesis of auxin redistribution.
- **Thigmotropism:** growth in response to touch. Tendrils coil around supports. Climbing plants (peas, beans, grapevines, passion flower).
- **Chemotropism:** growth toward chemicals. Pollen tubes grow toward synergid-derived signals (LURE peptides).
- **Thermotropism:** growth response to temperature gradients.
- **Heliotropism:** the sunflower's diurnal tracking of the sun (a more complex movement involving the pulvinus and circadian rhythm, not strictly a tropism in the same sense).

Step 4 — Nastic movements (not tropisms): Movements unrelated to direction of stimulus:

- Photonasty (sleep movements): closing of flowers/leaves at night (*Albizia*, beans).
- Thermonasty: temperature-triggered.
- Seismonasty: touch-triggered (mimosa pudica leaflet folding; Venus flytrap closing).
- Hyponasty/epinasty: upward/downward bending.

Step 5 — Agricultural significance: Engineering deeper, more hydrotropic root systems could help crops cope with drought. Genetic targets include MIZ1 and related root-system architecture genes.

Final Answer: Hydrotropism $\Rightarrow$ C

Answer: (C) Go Back to Q30

Q31.

Solution

Concept — Viroids — the smallest infectious agents: Discovered by Theodor Diener (1971) at the USDA. Even smaller and simpler than viruses.

Step 1 — Structure:

- Naked single-stranded circular RNA molecule.
- $\sim$ 200–400 nucleotides long.
- NO protein capsid, NO envelope — just RNA.
- Highly base-paired secondary structure: the circular RNA folds into a rod-like (PSTV-family) or quasi-rod-like structure with extensive intramolecular base pairing.
- No protein-coding capacity (would-be ORFs are too short or absent).

Step 2 — Two families:

- **Pospiviroidae:** replicate in nucleus by host DNA-dependent RNA polymerase II (which the viroid co-opts for RNA-templated synthesis). Rolling-circle replication. Example: **PSTVd** (Potato Spindle Tuber Viroid) — the founding member.
- **Avsunviroidae:** replicate in chloroplasts; have hammerhead ribozyme activity for self-cleavage during rolling-circle replication. Example: Avocado Sunblotch Viroid.

Step 3 — Diseases caused (all in plants):

- PSTV: stunted, spindle-shaped potatoes.
- Citrus exocortis viroid: bark scaling, stunted growth in citrus.
- Coconut cadang-cadang: lethal disease of coconut palms in the Philippines.
- Chrysanthemum stunt viroid: ornamental crops.
- Hop stunt viroid.

Step 4 — Mechanism of disease: The pathogenic mechanism is debated; one model is that viroid-derived small RNAs trigger RNA interference against host plant genes, causing disease symptoms. RNA silencing both helps the host defend against viroids AND can be exploited by viroids to alter host gene expression.

Step 5 — Transmission:

- Mechanical (tool contamination, grafting, vegetative propagation).
- Through seed and pollen (some).

- No animal vectors known.

Step 6 — Evolutionary and conceptual significance:

- Viroids are RNA molecules that replicate and "evolve" — some authors consider them "relics from the RNA world".
- The simplest known replicating biological entities.
- Hepatitis Delta virus (a satellite virus of HBV) has a viroid-like rod structure but encodes one protein.
- Demonstrate that protein-free RNA can be infectious and pathogenic — complementing the discovery of catalytic RNA (ribozymes) by Cech and Altman.

Step 7 — Prions (contrast): The other class of unconventional infectious agents: protein-only (PrP^{Sc}); they cause spongiform encephalopathies (CJD, BSE, scrapie). Discovered by Prusiner (Nobel 1997).

Final Answer: Naked single-stranded circular RNA $\Rightarrow$ $\boxed{\text{D}}$

Answer: (D) Go Back to Q31

Q32.

Solution

Concept — Deuteromycetes (Fungi Imperfecti): A historical, artificial grouping of fungi whose sexual stage has not been observed.

Step 1 — Why "Imperfecti"?

- Traditional fungal taxonomy is based largely on sexual spore type:
  - Zygomycetes: zygospores.
  - Ascomycetes: ascospores in asci.
  - Basidiomycetes: basidiospores on basidia.
- "Deuteromycetes" contained fungi observed to reproduce ONLY asexually (by conidia/spores from conidiophores), with no known sexual stage.
- Reproduction patterns might be: sexual stage absent (truly so), too rare to observe, or restricted to a host or condition not encountered in culture.

Step 2 — Examples:

- *Penicillium* (some species; the source of penicillin): *P. chrysogenum*, *P. notatum*.
- *Aspergillus*: *A. niger*, *A. fumigatus*, *A. flavus* (produces aflatoxin).

- *Candida albicans* (causes thrush).
- *Trichoderma*: used in biocontrol.
- *Alternaria*, *Cercospora*, *Fusarium*: plant pathogens.
- Many dermatophytes (*Trichophyton*, *Microsporum*: ringworm, tinea).

Step 3 — Modern reclassification: With molecular phylogenetics (rRNA gene sequencing especially), almost all "Deuteromycetes" have been placed into Ascomycota or Basidiomycota based on sequence similarities, even without sighting the sexual stage. The current taxonomy uses the term "mitosporic fungi" or simply lists the anamorph (asexual stage). A sexual stage discovered subsequently for a previously imperfect fungus is a teleomorph.

Step 4 — Economic importance:

- Antibiotics: penicillin (*Penicillium chrysogenum*), cephalosporins (*Acremonium*).
- Food: *Penicillium roqueforti*, *P. camemberti* (blue cheese, Camembert).
- Industrial enzymes: *Aspergillus niger* produces citric acid commercially.
- Mycotoxins: *Aspergillus flavus* produces aflatoxin (potent liver carcinogen; major food safety concern).
- Pathogens: of crops (*Fusarium* wilt), humans (*Candida*, dermatophytes), animals.

Step 5 — Biology of asexual reproduction in fungi:

- Conidia (asexual spores) form on specialised conidiophores from the mycelium.
- Released into air (dust), water, or carried by insects.
- Each conidium germinates to form new mycelium.
- Asexual reproduction allows rapid clonal expansion; sexual reproduction (when available) allows genetic recombination.

Final Answer: Lack of known sexual reproductive stage $\Rightarrow$ C

Answer: (C) Go Back to Q32

Q33.

Solution

Concept — Class Mammalia: $\sim 6{,}500$ described living species. The class to which humans belong. Named for the mammary glands.

Step 1 — Synapomorphies (defining features):

- **Hair / fur:** keratin-based; provides insulation, sensation (vibrissae), camouflage, mate signalling. Even cetaceans have a few hairs at some stage.
- **Mammary glands:** modified sweat glands secreting milk to feed young. The defining feature; gives the class its name.
- **Three middle-ear ossicles:** malleus, incus, stapes; transmit sound from eardrum to oval window. (Other vertebrates have only the stapes.) The malleus and incus evolved from ancestral reptilian jaw bones — a beautiful example of evolutionary repurposing.
- **Single bone in the lower jaw** (dentary), articulating directly with the squamosal bone of the skull.
- **Heterodont dentition:** teeth differentiated into incisors, canines, premolars, molars; specialised for diverse diets.
- **Diaphragm:** muscular partition between thoracic and abdominal cavities; enables negative-pressure breathing (most efficient ventilation).
- **Endothermy (warm-bloodedness):** maintain constant high body temperature ($\sim 37\,^{\circ}\mathrm{C}$) by internal heat production. (Independently evolved in birds.)
- **Four-chambered heart:** complete separation of pulmonary and systemic circuits (also in birds).
- **Viviparity** (in most): live birth following intra-uterine development. (Monotremes are exceptions — they lay eggs.)

Step 2 — Three sub-classes:

- **Prototheria (Monotremata):** egg-laying mammals; platypus, echidna; restricted to Australia and New Guinea. Lay leathery-shelled eggs; suckle young with mammary skin patches (no nipples).
- **Metatheria (Marsupialia):** pouched mammals; very short gestation; tiny altricial neonate crawls to pouch where it suckles. Kangaroo, koala, wombat (mostly Australia); opossums (Americas).
- **Eutheria (Placentalia):** placental mammals; longer gestation supported by a chorioallantoic placenta. Most modern diversity: rodents, bats, primates, ungulates, carnivores, cetaceans, etc.

Step 3 — Adaptations to diverse niches:

- Aquatic: cetaceans (whales, dolphins), pinnipeds (seals); streamlined bodies, blubber, modified limbs.
- Aerial: bats (Chiroptera; only mammals capable of true flight; echolocation in microbats).
- Subterranean: moles, mole rats.
- Arboreal: primates, squirrels.
- Cursorial: ungulates, carnivores (running).

Step 4 — Evolutionary origin:

- Mammals evolved from synapsid ("mammal-like reptiles") in the late Triassic, ~ 225 Mya.
- Coexisted with dinosaurs for ~ 160 My (mostly small nocturnal insectivores).
- Diversified rapidly after the K-Pg extinction (66 Mya) eliminated non-avian dinosaurs.

Step 5 — Other interesting features:

- Neocortex (in placental mammals especially): six-layered cerebral cortex; the substrate of complex cognition.
- Sweat glands (eccrine and apocrine): unique to mammals; thermoregulation, scent.
- Sebaceous glands.
- RBCs anucleate in mature form (unusual; nucleated in birds, reptiles, fish).
- Single occipital condyle pair (birds and reptiles have one only).

Final Answer: Hair, mammary glands, three ossicles, diaphragm, single jaw bone $\Rightarrow$ D

Answer: (D) Go Back to Q33

Q34.

Solution

Concept — *Ascaris lumbricoides* — the giant intestinal roundworm: The most common helminth infection of humans worldwide. WHO estimates ~ 800 million infections globally; highest prevalence in low-resource tropical/subtropical settings.

Step 1 — Phylum Nematoda (roundworms):

- Pseudocoelomate (body cavity lined partly by mesoderm).

- Cylindrical, tapering at both ends; bilateral symmetry.
- Cuticle: tough, non-living covering; moulted four times during development.
- Longitudinal muscles only (no circular) $\rightarrow$ characteristic "thrashing" movement.
- Complete digestive system (mouth to anus).
- Separate sexes (most): females typically larger than males; male tail often coiled or has copulatory bursa.
- No respiratory or circulatory systems (small enough for diffusion).

Step 2 — *Ascaris* morphology:

- Females 20–35 cm long, 3–6 mm thick.
- Males smaller, 15–30 cm.
- Pinkish-yellow, smooth cuticle.
- Females lay up to $200{,}000$ eggs per day — highest fecundity among parasitic helminths.

Step 3 — Life cycle:

(a) Eggs passed in stool of infected human; resistant outer shell.
(b) In moist soil, eggs embryonate over ~ 18 days to become infective.
(c) Ingested via contaminated food/water/hands (faecal-oral).
(d) Eggs hatch in small intestine; larvae penetrate intestinal wall, enter portal circulation $\rightarrow$ liver $\rightarrow$ heart $\rightarrow$ lungs.
(e) In alveoli, larvae moult, mature, and ascend the trachea ("larval migration").
(f) Coughed up and swallowed back to the small intestine.
(g) Mature into adult worms; live 1–2 years; egg laying begins $\sim$ 60–75 days after ingestion.

Step 4 — Clinical features:

- Often asymptomatic with light worm burden.
- Pulmonary phase (during larval migration): cough, wheezing, transient eosinophilic pneumonitis (Löffler's syndrome).
- Intestinal phase: vague abdominal discomfort, malnutrition (with heavy infection in children $\rightarrow$ growth impairment), intestinal obstruction (bolus of worms in pediatric small intestine).
- Worms can migrate into bile duct, pancreatic duct, appendix $\rightarrow$ cholangitis, pancreatitis, appendicitis.

Step 5 — Diagnosis and treatment:

- Diagnosis: microscopy of stool for characteristic eggs.
- Treatment: albendazole or mebendazole (single oral dose) — highly effective.
- Prevention: improved sanitation, hand hygiene, deworming programs (mass drug administration in endemic regions; WHO recommends periodic deworming of school-age children).

Step 6 — Other important nematodes:

- *Enterobius vermicularis* (pinworm): perianal itching in children.
- *Ancylostoma duodenale*, *Necator americanus* (hookworms): blood-feeding; anaemia.
- *Strongyloides stercoralis*: hyperinfection syndrome in immunocompromised.
- *Trichinella spiralis*: trichinosis from undercooked pork.
- *Wuchereria bancrofti*: lymphatic filariasis.
- *Onchocerca volvulus*: river blindness.
- *Loa loa*: African eye worm.
- *Dirofilaria immitis*: dog heartworm.
- *Caenorhabditis elegans*: free-living; major model organism (genetics, development, neurobiology, ageing).

Final Answer: Phylum Nematoda $\Rightarrow$ $\boxed{\text{A}}$

Answer: (A) Go Back to Q34

Q35.

Solution

Concept — Asthma — the chronic inflammatory airway disease: A common condition (affects $\sim$ 300 million people worldwide); leading chronic disease of childhood.

Step 1 — Definition and pathophysiology: Asthma is characterised by:

- Reversible (at least partially) airflow obstruction.
- Bronchial hyperresponsiveness to triggers.
- Chronic airway inflammation.
- Three components of airway narrowing: bronchoconstriction (smooth muscle contraction), airway oedema (mucosal swelling), mucus hypersecretion.

Step 2 — Allergic asthma (the most common phenotype): A type I (IgE-mediated, immediate) hypersensitivity reaction.

(a) Sensitisation: allergen exposure $\rightarrow$ allergen-specific Th2 cells $\rightarrow$ B cells $\rightarrow$ IgE production $\rightarrow$ IgE binds FcϵRI on airway mast cells. No symptoms yet.
(b) Allergen re-exposure: crosslinks IgE on mast cells $\rightarrow$ degranulation within seconds.
(c) Early phase (minutes): histamine, leukotrienes ($LTC_4/D_4/E_4$), prostaglandin D_2 released $\rightarrow$ bronchoconstriction, vasodilation, increased permeability (oedema), mucus.
(d) Late phase (hours): eosinophil recruitment by Th2 cytokines (IL-5, IL-13); chronic inflammation; airway remodelling (smooth muscle hypertrophy, subepithelial fibrosis, basement membrane thickening) with repeated exacerbations.

Step 3 — Common triggers:

- Allergens: dust mites, pet dander, pollen, cockroach, mould.
- Viral upper respiratory infections (most common trigger of exacerbations).
- Exercise (especially cold dry air).
- Cold air.
- Aspirin (NSAID-induced asthma; via leukotriene pathway).
- Occupational exposures (isocyanates, flour, certain chemicals).
- Air pollutants (ozone, NO_2, particulate matter).
- β-blockers can precipitate asthma in susceptible patients.

Step 4 — Clinical features:

- Wheeze (expiratory, high-pitched, polyphonic).
- Dyspnoea, especially nocturnal or early-morning.
- Chest tightness.
- Cough (sometimes the only symptom: cough-variant asthma).
- Variability over time (worse with triggers, better between attacks).
- Spirometry: FEV_1/FVC ratio < 0.7; reversible (improves $> 12\%$ post-bronchodilator).
- Peak expiratory flow (PEF): home monitoring.

Step 5 — Treatment (stepwise):

- **Bronchodilators (relievers):**
  - Short-acting β_2-agonists (SABA): salbutamol/albuterol; first-line acute symptom relief.
  - Long-acting β_2-agonists (LABA): salmeterol, formoterol; never as monotherapy.

- **Anti-inflammatory (controllers):**
  - Inhaled corticosteroids (ICS): budesonide, fluticasone — the most effective long-term controllers.
  - Leukotriene receptor antagonists: montelukast.
  - Mast-cell stabilisers: cromolyn sodium (less used now).
- **Severe / refractory asthma:**
  - Anti-IgE: omalizumab.
  - Anti-IL-5: mepolizumab, reslizumab.
  - Anti-IL-5Rα: benralizumab.
  - Anti-IL-4Rα: dupilumab.
  - Oral corticosteroids: long-term use minimised due to side effects.
- Anticholinergics (ipratropium, tiotropium): in some patients.
- Trigger avoidance, allergen immunotherapy.

Step 6 — Status asthmaticus: Severe, life-threatening asthma not responding to standard treatment; requires aggressive bronchodilators, systemic steroids, and sometimes magnesium sulphate, intubation. Acute management is a medical emergency.

Final Answer: Type-I IgE-mediated hypersensitivity to inhaled allergens $\Rightarrow$ $\boxed{\text{B}}$

Answer: (B) Go Back to Q35

Q36.

Solution

Concept — Health effects of cigarette smoking: The single largest preventable cause of disease and premature death globally. Tobacco kills ~ 8 million people per year.

Step 1 — Components of cigarette smoke:

- $> 4{,}000$ chemicals.
- > 250 are known harmful; > 60 are carcinogenic.
- Key: nicotine (addictive), carbon monoxide (impairs O_2 delivery), tar (particulate matter), free radicals, polycyclic aromatic hydrocarbons (carcinogens), N-nitrosamines, ammonia, formaldehyde, benzene, heavy metals.

Step 2 — Respiratory effects:

- **Chronic obstructive pulmonary disease (COPD):** the combination of chronic bronchitis (mucus hypersecretion, productive cough) and emphy-

sema (destruction of alveolar walls $\rightarrow$ loss of elastic recoil, air trapping). Irreversible airflow obstruction; progressive dyspnoea; eventually respiratory failure. Smoking causes 80–90% of COPD.

- **Lung cancer:** the most strongly causal smoking-related disease. $\sim 85\%$ of lung cancers due to smoking. Squamous cell and small-cell are particularly tobacco-related. Risk falls with cessation but never returns fully to never-smoker baseline.
- Increased susceptibility to respiratory infections (pneumonia, TB).
- Exacerbation of asthma.
- Spontaneous pneumothorax.

Step 3 — Cardiovascular effects:

- Accelerated atherosclerosis.
- Coronary artery disease (myocardial infarction): doubled risk.
- Stroke.
- Peripheral artery disease (gangrene, amputation).
- Aortic aneurysm.
- Hypertension.
- Mechanisms: nicotine $\rightarrow$ catecholamine release $\rightarrow$ HR/BP increase; CO $\rightarrow$ reduced O_2 delivery; endothelial dysfunction; platelet activation; oxidised LDL; inflammation.

Step 4 — Cancer risks (smoking causes $\sim 30\%$ of all cancers):

- Lung (clearest link).
- Mouth, larynx, pharynx, oesophagus (direct exposure).
- Bladder, kidney (carcinogens excreted in urine).
- Stomach, pancreas, liver.
- Cervix.
- Acute myeloid leukaemia.

Step 5 — Other effects:

- Reduced fertility (men and women); erectile dysfunction.
- In pregnancy: low birth weight, premature birth, miscarriage, stillbirth, congenital malformations, sudden infant death syndrome (SIDS).
- Osteoporosis (delayed fracture healing).
- Peptic ulcer.
- Periodontal disease.
- Cataracts, age-related macular degeneration.

- Premature skin ageing.

Step 6 — Nicotine addiction:

- Nicotine activates nicotinic ACh receptors in the brain's reward circuitry (VTA $\rightarrow$ nucleus accumbens dopamine release).
- Tolerance develops; withdrawal causes irritability, anxiety, craving, insomnia, increased appetite.
- Hard to quit; relapse rate is high.

Step 7 — Smoking cessation:

- Counselling + pharmacotherapy is most effective.
- Nicotine replacement (patch, gum, lozenge, inhaler, spray).
- Bupropion: norepinephrine-dopamine reuptake inhibitor.
- Varenicline: partial $\alpha_4\beta_2$ nicotinic agonist (most effective).
- Health benefits begin within hours of quitting and continue for decades.

Step 8 — Public health: Tobacco control measures (taxes, advertising bans, graphic warnings, smoke-free public spaces) have markedly reduced smoking rates in many countries. WHO Framework Convention on Tobacco Control: first global public health treaty.

Final Answer: COPD, lung cancer, CVD, multiple cancers $\Rightarrow$ $\boxed{\text{C}}$

Answer: (C) Go Back to Q36

Q37.

Solution

Concept — Alien (invasive) species: Non-native species that establish populations in new ranges and cause ecological/economic harm. One of the top global drivers of biodiversity loss (alongside habitat destruction, climate change, pollution, over-exploitation).

Step 1 — Why invasive species are harmful:

- Native species often have no co-evolved defences against the newcomer.
- Native predators or pathogens are absent in the new range, releasing the invader from natural population controls (enemy-release hypothesis).
- Invaders may use novel resources or alter habitats.
- Effects: competitive exclusion, predation, hybridisation with native species,

introduction of new diseases, disruption of food webs and nutrient cycles.

Step 2 — Famous examples worldwide:

- *Cane toad* (*Rhinella marina*): introduced to Australia in 1935 to control sugarcane pests; spread rapidly; toxic to native predators (snakes, lizards, marsupials, crocodiles) that try to eat it.
- *Brown tree snake* on Guam: arrived as wartime stowaway; wiped out most native bird species.
- *Burmese python* in Florida Everglades: released pets; decimated native mammal populations.
- *Asian carp* in North American rivers.
- *Zebra mussel* (*Dreissena*) in Great Lakes.
- *Rats* (*Rattus* spp.) on remote islands: devastating to ground-nesting seabirds.
- *Lionfish* in Caribbean: native to Indo-Pacific; introduced via aquarium trade; aggressive predator of reef fish.

Step 3 — Indian examples:

- *Lantana camara*: ornamental plant introduced from Central/South America; now choking native forests across the Western Ghats, central India, and northeast.
- Water hyacinth (*Eichhornia crassipes*): from S America; clogs water bodies, reduces oxygen, eliminates aquatic fauna.
- Prosopis juliflora: introduced to arid regions for fuelwood; now displaces native vegetation, alters hydrology.
- Parthenium hysterophorus (congress grass): allergenic, livestock-toxic, fast-spreading.
- African catfish (*Clarias gariepinus*): introduced into aquaculture; escaped to wild; outcompetes native catfish, disrupts food webs.
- Mile-a-minute weed (*Mikania micrantha*): smothering vegetation in NE India.

Step 4 — Cichlid extinction in Lake Victoria: A landmark conservation tragedy. Nile perch (*Lates niloticus*) introduced into Lake Victoria (Africa) in 1950s for fisheries. Predated on the lake's ~ 500 endemic cichlid species $\rightarrow$ many extinct or critically endangered within decades; one of the largest extinction events of the modern era.

Step 5 — Management:

- Prevention is by far the cheapest and most effective approach (quarantine, biosecurity, regulations on intentional introductions).
- Early detection and rapid response.
- Eradication: feasible for small populations on islands; biological control with introduced natural enemies (risky — some have themselves become invasive).
- Long-term management: containment, biocontrol.
- Aichi Biodiversity Target 9 aims to control or eradicate priority invasive species.

Step 6 — Conservation lesson: Globalisation and increased trade/travel have accelerated species movements. The legal and ethical framework around bringing organisms across borders (ballast water in ships, ornamental plants, exotic pets) is increasingly critical for biodiversity preservation.

Final Answer: Outcompete native species, predation, spread pathogens $\Rightarrow$ $\boxed{\text{A}}$

Answer: (A) Go Back to Q37

Q38.

Solution

Concept — In-situ vs ex-situ conservation: The two complementary strategies for biodiversity conservation, recognised in the Convention on Biological Diversity (1992).

Step 1 — In-situ conservation ("on-site"): Protecting species in their natural habitats. Maintains complete ecological context: food web, pollinators, dispersers, climate, soil, microbiota.

- **National parks:** most strictly protected; no human exploitation; only research and regulated tourism. India: 106 national parks (e.g. Jim Corbett, Kanha, Bandhavgarh, Kaziranga).
- **Wildlife sanctuaries:** protected for one or more species; some human activities permitted (grazing, NTFP collection). India: $\sim$ 565 wildlife sanctuaries.
- **Biosphere reserves:** larger protected areas with zonation (core, buffer, transition); integrate conservation with sustainable use; recognised by UNESCO. India: 18 biosphere reserves (Nilgiri, Nanda Devi, Sundarbans, Manas, Gulf of Mannar, etc.).
- **Reserved/protected forests:** for forest protection and selective use.
- **Sacred groves**: traditionally protected patches of forest associated with deities or ancestors; remarkably intact biodiversity in some regions (Western Ghats, Khasi Hills, etc.).

- **Community-managed reserves** and conservation reserves.

Step 2 — Ex-situ conservation ("off-site"): Conservation outside natural habitats; complements in-situ.

- **Botanical gardens, arboreta:** living plant collections.
- **Zoological gardens (zoos), aquaria:** captive populations of animals; some are involved in breeding endangered species for reintroduction.
- **Seed banks:** cryogenic or low-humidity storage of seeds; e.g. Svalbard Global Seed Vault.
- **Gene banks:** DNA samples, cryopreserved gametes (sperm, eggs, embryos), tissue cultures.
- **In vitro propagation:** for rare plants.
- **Conservation breeding:** captive populations bred and reintroduced. Examples: California condor, Arabian oryx, golden lion tamarin, Indian crocodile project (gharial), Indian one-horned rhinoceros.

Step 3 — Comparison and complementarity:

- In-situ preserves species in their ecological context; allows ongoing evolution; conserves whole ecosystems.
- Ex-situ provides insurance against catastrophic loss; allows research and education; supports reintroduction efforts.
- Modern conservation integrates both.

Step 4 — Biodiversity hotspots: Identified by Norman Myers (1988): regions with high species endemism AND high threat from human activity. 36 hotspots cover $< 2.5\%$ of Earth's land but contain $> 50\%$ of plant endemics. India has hotspots: Western Ghats, Eastern Himalaya, Indo-Burma, Sundaland (Nicobar Islands).

Step 5 — International frameworks:

- Convention on Biological Diversity (CBD, 1992): conservation, sustainable use, fair benefit-sharing.
- CITES (Convention on International Trade in Endangered Species, 1973): regulates international wildlife trade.
- Ramsar Convention (1971): wetlands.
- IUCN Red List: species threat assessment.

Final Answer: National parks, wildlife sanctuaries, biosphere reserves are in-situ $\Rightarrow \boxed{\text{B}}$

Answer: (B) Go Back to Q38

Q39.

Solution

Concept — Stem cell potency classes: A hierarchy of developmental potential, defined by which cell types a stem cell can give rise to.

Step 1 — Totipotent:

- Can produce all cell types of the embryo PLUS extra-embryonic tissues (placenta, yolk sac).
- Can give rise to a complete organism.
- In mammals, only the zygote (and possibly the early cleavage blastomeres until 4-8 cell stage) are truly totipotent.

Step 2 — Pluripotent:

- Can form all three germ layers (ectoderm, mesoderm, endoderm) + germ cells.
- CANNOT form extra-embryonic tissues.
- Cannot alone produce a complete organism.
- Examples:
  - Embryonic stem cells (ESCs): derived from inner cell mass of blastocyst.
  - Embryonic germ cells: from primordial germ cells of foetus.
  - Induced pluripotent stem cells (iPSCs): adult somatic cells reprogrammed by overexpressing transcription factors (Yamanaka factors: Oct4, Sox2, Klf4, c-Myc; Nobel 2012). Revolutionary — allowed patient-specific pluripotent cells for disease modelling, drug screening, regenerative medicine.

Step 3 — Multipotent:

- Can give rise to a limited range of cell types within one lineage.
- Examples:
  - Haematopoietic stem cells (HSCs): give rise to all blood cell lineages (RBCs, lymphocytes, granulocytes, etc.). Found in bone marrow; basis of bone marrow transplantation.
  - Mesenchymal stem cells: bone, cartilage, fat, etc.
  - Neural stem cells: neurons, astrocytes, oligodendrocytes.
  - Intestinal crypt stem cells.
  - Skin (epidermal) stem cells.

Step 4 — Unipotent (and progenitor cells):

- Can generate only one cell type, but can self-renew (otherwise they would just be progenitors).
- Examples: spermatogonial stem cells (sperm only), satellite cells of skeletal muscle.
- Progenitor cells: similar but typically with limited self-renewal; downstream of stem cells in the hierarchy.

Step 5 — Therapeutic applications and challenges:

- Established: bone marrow / HSC transplantation for leukaemias, lymphomas, aplastic anaemia. The most successful stem cell therapy.
- Clinical use: corneal limbal stem cells for corneal regeneration.
- Emerging clinical trials: ESC- or iPSC-derived therapies for Parkinson's disease (dopaminergic neurons), spinal cord injury, macular degeneration (RPE cells), type 1 diabetes (pancreatic β-cells), heart failure (cardiomyocytes).
- Challenges: tumour formation (teratoma risk with pluripotent cells), immune rejection (less for autologous iPSCs), reproducibility of differentiation.
- Ethical: ESC use raises ethical concerns; iPSCs largely circumvent this.

Step 6 — CRISPR + iPSC — a powerful combination: Patient-specific iPSCs can be CRISPR-edited to correct disease mutations and then differentiated to produce healthy cells for autologous transplant. Active clinical development for sickle cell, β-thalassaemia, monogenic disorders.

Final Answer: Totipotent (can form complete organism + extra-embryonic tissues) $\Rightarrow$ $\boxed{\text{C}}$

Answer: (C) Go Back to Q39

Q40.

Solution

Concept — Antibody-dependent enhancement (ADE) and severe dengue: A paradoxical phenomenon where sub-neutralising antibodies enhance, rather than block, viral infection. Particularly important for dengue.

Step 1 — The dengue serotype problem:

- Four antigenically distinct DENV serotypes (1, 2, 3, 4).
- Infection with one serotype provides life-long immunity against that serotype but only short-lived ($\sim$ several months) cross-protective immunity against the others.

- Subsequent infection with a different serotype (secondary infection) carries the risk of severe dengue — dengue haemorrhagic fever (DHF) and dengue shock syndrome (DSS).

Step 2 — The ADE mechanism:

(a) During primary infection with, say, DENV-1, the host makes neutralising IgG against DENV-1.
(b) Over time, IgG levels wane to sub-neutralising concentrations; some IgG cross-reacts (but weakly) with the other serotypes.
(c) Secondary infection with DENV-2: the pre-existing antibodies bind DENV-2 but do NOT neutralise it.
(d) The antibody-virus complex is taken up by monocytes/macrophages via Fcγ receptors — they have many more such receptors than primary entry receptors.
(e) Net effect: ENHANCED viral entry and replication in immune cells.
(f) Massive viral replication $\rightarrow$ cytokine storm (TNF, IL-6, complement activation) $\rightarrow$ plasma leakage (loss of endothelial integrity, hypovolaemia, shock), thrombocytopenia, haemorrhage.

Step 3 — Clinical implications:

- Severe dengue almost always occurs in individuals who have had a prior dengue infection of a different serotype.
- Primary infections are usually mild or asymptomatic.
- Risk is highest in children with maternal anti-dengue antibodies that have waned in the second year of life (passive antibodies acting as sub-neutralising).

Step 4 — ADE implications for vaccine design:

- A vaccine providing incomplete protection against all four serotypes could mimic prior infection $\rightarrow$ sub-neutralising antibodies $\rightarrow$ ADE on natural exposure $\rightarrow$ severe disease.
- Dengvaxia (Sanofi-Pasteur, CYD-TDV, 2015): the first dengue vaccine. Initially approved for use in endemic areas. Later analysis showed that vaccination of seronegative individuals INCREASED their risk of severe dengue on subsequent infection (acting like a primary infection). WHO now recommends Dengvaxia ONLY for seropositive individuals (those with confirmed prior dengue).

- Qdenga (Takeda, TAK-003, 2022): a more recent live attenuated tetravalent vaccine; better serotype balance; ongoing evaluation.
- Designing a safe dengue vaccine is one of the great challenges of modern vaccinology — must induce balanced neutralising immunity against ALL four serotypes simultaneously.

Step 5 — ADE in other viral infections:

- Zika virus: structural similarity with dengue; some risk of cross-ADE.
- Yellow fever, West Nile (other flaviviruses).
- Coronaviruses: ADE has been a concern in SARS-CoV vaccine development; carefully assessed for COVID-19 vaccines and not significant in practice.
- HIV (Fc receptor pathways).

Step 6 — Treatment of severe dengue: Supportive (fluids, monitoring); no specific antiviral. Early recognition and management of plasma leakage with careful IV fluids is critical. WHO classification: dengue, dengue with warning signs, severe dengue.

Final Answer: Antibody-dependent enhancement (ADE) $\Rightarrow$ $\boxed{\text{D}}$

Answer: (D) Go Back to Q40

Answer Key

Q	Ans	Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	A	2	A	3	B	4	C	5	D
6	A	7	B	8	D	9	A	10	B
11	C	12	D	13	A	14	B	15	C
16	D	17	A	18	B	19	C	20	D
21	A	22	B	23	C	24	D	25	B
26	C	27	D	28	A	29	B	30	C
31	D	32	C	33	D	34	A	35	B
36	C	37	A	38	B	39	C	40	D