BITSAT Biology Sample Paper – 3

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. The modern cell theory — that all living organisms are made of cells, the cell is the basic structural/functional unit of life, and all cells arise from pre-existing cells — was formulated by:

(A) Robert Hooke alone (1665), who observed cork cells

(B) Antonie van Leeuwenhoek alone, who first saw microorganisms

(C) Robert Brown (1831), who discovered the nucleus

(D) Schleiden (1838, plants) and Schwann (1839, animals), with Virchow (1858) adding "omnis cellula e cellula"

Q2. The nucleolus (a dense, non-membrane-bound region within the nucleus) is primarily the site of:

(A) DNA replication

(B) Protein synthesis on free ribosomes

(C) Ribosomal RNA transcription and assembly of ribosomal subunits, which are exported through nuclear pores to the cytoplasm

(D) Nuclear envelope formation

Q3. The Na^+/K^+ ATPase pump of the plasma membrane, per ATP hydrolysed, moves:

(A) $3\ Na^+$ out and $2\ K^+$ in — generating the resting membrane potential and the Na^+ gradient used by many secondary active transporters

(B) $2\ Na^+$ out and $3\ K^+$ in

(C) $1\ Na^+$ out and $1\ K^+$ in

(D) Equal numbers of Na^+ and K^+ in both directions

Q4. Microtubules of the eukaryotic cytoskeleton differ from microfilaments in that microtubules:

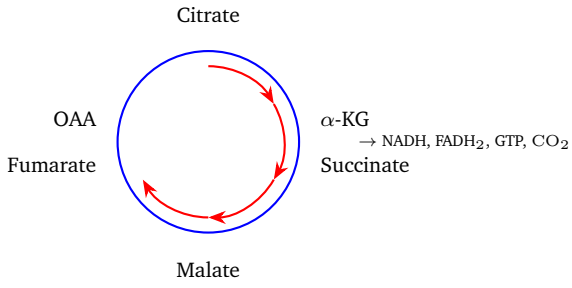
(A) Are made of actin

(B) Are hollow cylinders ($\sim 25\,\text{nm}$ diameter) polymerised from α- and β-tubulin dimers; they form the spindle, cilia, flagella and centriole walls

(C) Have smaller diameter than microfilaments

(D) Are made primarily of keratin

Q5. The schematic below shows the citric-acid (Krebs) cycle. In a eukaryotic cell, this pathway takes place in:



(A) Cytoplasm

(B) The mitochondrial matrix — where pyruvate (after conversion to acetyl-CoA) is fully oxidised, producing NADH, $FADH_2$, GTP and CO_2

(C) Endoplasmic reticulum

(D) Nucleus

Q6. In the first level of chromatin packaging in eukaryotic nuclei, a stretch of ~ 146 base pairs of DNA is wrapped (in ~ 1.65 negative superhelical turns) around:

(A) A histone octamer (two molecules each of H2A, H2B, H3, H4), forming the nucleosome "bead-on-a-string" structure; H1 links between nucleosomes

(B) A single histone protein

(C) Two histone proteins only

(D) tRNA molecules

Q7. At which cell-cycle checkpoint is the completion and integrity of DNA replication verified before the cell commits to mitosis?

(A) G_1/S checkpoint (commits cell to enter S phase)

(B) M checkpoint (spindle-assembly checkpoint, just before anaphase)

(C) G_0 checkpoint

(D) G_2/M checkpoint — DNA-replication and DNA-damage checkpoint; cyclin-B/CDK1 activity must rise to drive entry into mitosis

Q8. Glycolysis, the 10-step pathway converting one glucose (6C) to two pyruvate (3C) with net yield of 2 ATP and 2 NADH, takes place in:

(A) Mitochondrial matrix

(B) Inner mitochondrial membrane

(C) The cytosol/cytoplasm of the cell — universal across prokaryotes and eukaryotes; the only step of cellular respiration that does not require oxygen

(D) Nucleus

Q9. The role of bile salts in fat digestion is to:

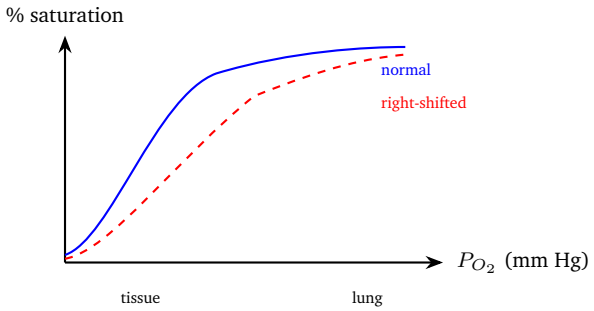
(A) Chemically break triglycerides into fatty acids and glycerol

(B) Directly activate pancreatic lipase from its zymogen form

(C) Neutralise stomach acid in the duodenum

(D) Act as biological detergents (with hydrophobic and hydrophilic faces) that emulsify large fat globules into tiny droplets, vastly increasing the surface area for pancreatic lipase action

Q10. The oxygen–haemoglobin dissociation curve (shown below) shifts to the RIGHT, releasing more O_2 to tissues, when:



(A) Tissue pH falls, CO_2 partial pressure rises, temperature rises, and 2,3-BPG rises — collectively, the Bohr effect, ensuring greater O_2 delivery to actively metabolising tissues

(B) Only pH rises (this shifts the curve to the left)

(C) Only P_{O_2} falls

(D) No physiological factor alters the curve

Q11. In a healthy resting adult, the typical brachial arterial blood pressure (systolic/diastolic) is approximately:

(A) $80/40\,\text{mm Hg}$

(B) $120/80\,\text{mm Hg}$ — systolic during ventricular contraction, diastolic during ventricular relaxation

(C) $200/100\,\text{mm Hg}$

(D) $60/40\,\text{mm Hg}$

Q12. Glomerular filtration in the kidney is best described as:

(A) Active transport requiring ATP

(B) Filtration based on molecular weight alone

(C) Passive ultrafiltration driven by the net hydrostatic pressure in the glomerular capillaries (opposed by capsular pressure and plasma oncotic pressure); cells and large plasma proteins are retained, water and small solutes pass into Bowman's capsule

(D) A process driven primarily by ADH

Q13. A simple monosynaptic reflex arc, such as the knee-jerk (patellar) reflex, consists of:

(A) Receptor (muscle spindle) $\rightarrow$ afferent (sensory) neuron $\rightarrow$ spinal-cord integration (single synapse onto motor neuron) $\rightarrow$ efferent (motor) neuron $\rightarrow$ effector (skeletal muscle)

(B) Receptor directly to muscle, no neurons

(C) Only motor neurons

(D) Only sensory neurons

Q14. Cortisol, the principal glucocorticoid in humans (which raises blood glucose, suppresses inflammation and modulates the stress response), is secreted by:

(A) Adrenal medulla (this secretes adrenaline/noradrenaline)

(B) Posterior pituitary

(C) Thyroid gland

(D) Adrenal cortex (zona fasciculata), under the control of pituitary ACTH which is in turn driven by hypothalamic CRH

Q15. Stomatal opening in most plants during the day occurs primarily because:

(A) ABA accumulates in guard cells, raising their turgor

(B) K^+ ions are actively pumped into guard cells; water follows osmotically; turgor rises; the differentially thickened guard-cell walls bow outward, opening the pore

(C) Guard cells lose water and shrink

(D) Stomata open only at night

Q16. Transpiration in plants:

(A) Is wasteful, with no physiological benefit

(B) Only loses water

(C) Provides the tension (cohesion-tension theory) that pulls the water column up through the xylem, aids the uptake of soil minerals dissolved in water, and cools the leaf by evaporation

(D) Stops completely at night

Q17. Sickle-cell anaemia, an autosomal recessive haemoglobinopathy, results from:

(A) A single point mutation at codon 6 of the β-globin gene: GAG $\rightarrow$ GTG, substituting valine for glutamic acid, giving HbS instead of HbA

(B) Complete deletion of the β-globin gene

(C) Trisomy of chromosome 21

(D) X-linked recessive inheritance

Q18. Pleiotropy is the genetic phenomenon in which:

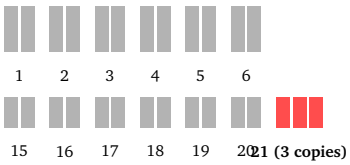
(A) Multiple genes contribute to one trait (this is polygenic inheritance)

(B) A single gene affects multiple, often apparently unrelated, phenotypic traits — e.g. phenylketonuria (PKU), where one defective *PAH* gene causes mental retardation, fair skin/hair, and a musty body odour

(C) Two genes are physically linked on the same chromosome

(D) A trait is sex-linked

Q19. The karyotype shown below (with an extra copy of chromosome 21, highlighted) corresponds to which clinical condition?



(A) Patau syndrome (trisomy 13)

(B) Edwards syndrome (trisomy 18)

(C) Klinefelter syndrome (47,XXY)

(D) Down syndrome — karyotype 47,XX,+21 or 47,XY,+21; features include characteristic facies, learning disability, hypotonia, and increased risk of congenital heart defects

Q20. RNA interference (RNAi) is a post-transcriptional gene-silencing mechanism mediated by:

(A) Long protein-coding mRNAs

(B) tRNA molecules carrying amino acids

(C) Small interfering RNAs (siRNAs, $\sim$ 21–23 nt) and microRNAs (miRNAs), which guide the RISC complex (Argonaute-containing) to complementary target mRNAs, leading to cleavage or translational repression

(D) Ribosomal proteins

Q21. Convergent evolution is best illustrated by:

(A) The forelimbs of a bat and a human (these are homologous)

(B) The vestigial vermiform appendix and the human coccyx

(C) The wings of birds, bats and insects — all flight surfaces with the same function but independently evolved from very different ancestral structures (modified forelimb in birds and bats, cuticular outgrowth in insects)

(D) The forelimbs of all mammals

Q22. Human oogenesis is unique in that:

(A) It begins in the foetal ovary; all primary oocytes are formed before birth and arrest in prophase I of meiosis until puberty, when one oocyte per cycle resumes meiosis at ovulation and completes meiosis II only on fertilisation

(B) It begins only at puberty, as in spermatogenesis

(C) It begins at menopause

(D) It occurs in the fallopian tube

Q23. The phases of the human uterine (endometrial) cycle, in their correct chronological order, are:

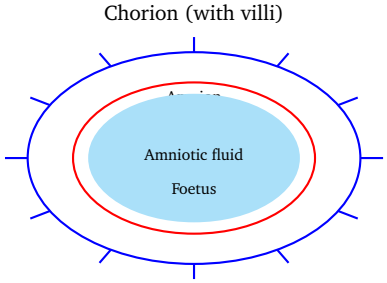
(A) Proliferative $\rightarrow$ secretory $\rightarrow$ menstrual (wrong order)

(B) Menstrual $\rightarrow$ ovulatory $\rightarrow$ luteal (mixes ovarian and uterine terms)

(C) Only follicular and luteal phases (these are ovarian-cycle terms)

(D) Menstrual (days 1–5) $\rightarrow$ proliferative (days 5–14, oestrogen-driven endometrial thickening) $\rightarrow$ secretory (days 14–28, progesterone-driven glandular development for implantation)

Q24. In the diagram of human foetal membranes below, which membrane forms the foetal portion of the placenta, develops chorionic villi that interdigitate with maternal endometrium, and secretes hCG?



(A) Amnion — the innermost, fluid-filled sac surrounding the foetus

(B) Chorion — outermost; develops chorionic villi that invade the endometrium, forms the foetal half of the placenta, and is the source of hCG in early pregnancy

(C) Yolk sac

(D) Allantois

Q25. Vasectomy, a popular surgical method of male sterilisation, involves:

(A) Surgical removal of both testes (orchidectomy — not vasectomy)

(B) Tying the fallopian tubes (this is female tubectomy)

(C) Insertion of an intrauterine device

(D) Cutting and ligating both vas deferens, blocking sperm from joining the semen; the man continues to produce sperm and testosterone normally, but the ejaculate is sperm-free

Q26. Apomixis in flowering plants refers to:

(A) The production of seeds without fertilisation, in which the embryo develops from a somatic cell of the ovule or from an unreduced diploid egg — the offspring are genetically identical to the mother; agriculturally important as a means of fixing hybrid vigour

(B) Sexual reproduction with high genetic recombination

(C) Cross-pollination between unrelated species

(D) Self-pollination within the same flower

Q27. The plant hormone responsible for fruit ripening (loss of green colour, softening, sugar accumulation, flavour development) is:

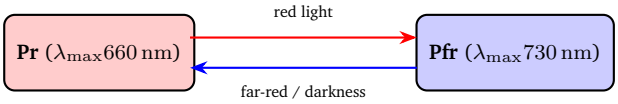
(A) Auxin (IAA)

(B) Ethylene — a gaseous hydrocarbon hormone whose own synthesis is autocatalytic in climacteric fruits (banana, apple, tomato, mango); commercial ripening uses ethephon or controlled ethylene exposure

(C) Gibberellin (this causes stem elongation, bolting)

(D) Abscisic acid (ABA) (this causes dormancy and stomatal closure)

Q28. Phytochrome, the plant photoreceptor that regulates photomorphogenesis, exists in two photointerconvertible forms. Identify the biologically active form and the way they interconvert.



(A) Pr is the active form only

(B) Pfr is the active form only, and is irreversibly produced

(C) Pr (red-absorbing, inactive) is converted to Pfr (far-red-absorbing, biologically active) by red light; Pfr reverts to Pr under far-red light or slowly in darkness — regulating seed germination, flowering, shade avoidance and de-etiolation

(D) Phytochrome cannot interconvert

Q29. Tobacco mosaic virus (TMV), the first virus ever discovered (Iwanowski 1892; Beijerinck 1898), is structurally:

(A) A double-stranded DNA virus

(B) A single-stranded RNA plant virus with a helical, rod-shaped capsid made of ~ 2130 identical coat protein subunits arranged around the RNA genome

(C) A bacteriophage

(D) A retrovirus

Q30. Phaeophyta (brown algae such as *Fucus*, *Laminaria*, *Sargassum*) owe their characteristic brown colour to:

(A) Chlorophyll a only

(B) Phycoerythrin (the red pigment of Rhodophyta)

(C) Chlorophyll a and c together with the carotenoid fucoxanthin, which masks the green colour

(D) Phycocyanin (a blue pigment of cyanobacteria)

Q31. Pteridophytes (ferns, horsetails, club mosses) are botanically distinguished by:

(A) Vascular tissue (xylem and phloem); true roots, stems and leaves; sporophyte dominant; reproduction by spores; sperm require external water to swim to the egg on the free-living gametophyte (prothallus). Examples: *Selaginella*, *Equisetum*, ferns

(B) Lack of vascular tissue (this is bryophytes)

(C) Production of seeds (these are gymnosperms / angiosperms)

(D) Production of both pollen and seeds (these are seed plants)

Q32. Phylum Arthropoda — the largest phylum in the animal kingdom (over a million described species) — is characterised by:

(A) A soft, unsegmented body

(B) Moist skin used for cutaneous respiration

(C) A vertebral column

(D) Jointed appendages, a chitinous exoskeleton (cuticle), a segmented body grouped into functional regions (tagmata), open circulatory system, and respiration via tracheae, book lungs or gills; examples include insects, arachnids, crustaceans and myriapods

Q33. Malaria in humans is caused by protozoan species of the genus *Plasmodium* and is transmitted by:

(A) Tsetse fly (*Glossina*), which transmits African sleeping sickness

(B) Sand fly (*Phlebotomus*), which transmits leishmaniasis (kala-azar)

(C) *Aedes* mosquito, which transmits dengue, chikungunya and yellow fever

(D) The bite of a female *Anopheles* mosquito; sporozoites are injected into the bloodstream, multiply first in the liver (exo-erythrocytic phase), then in red blood cells (erythrocytic phase, where periodic rupture causes the characteristic fever spikes)

Q34. Type 1 diabetes mellitus is characterised by:

(A) Autoimmune destruction of pancreatic β cells, leading to absolute insulin deficiency; usually presents in childhood/adolescence and requires lifelong exogenous insulin administration

(B) Peripheral insulin resistance with relatively preserved or even elevated insulin levels (this describes Type 2 diabetes)

(C) Excess insulin secretion (this would cause hypoglycaemia)

(D) Selective damage to pancreatic α cells

Q35. Edward Jenner's contribution to medicine (1796) was:

(A) Discovering penicillin

(B) Developing the first vaccine, against smallpox, by inoculating a boy with cowpox material from a milkmaid — the basis of modern vaccination (Latin *vacca*, cow). The WHO declared smallpox globally eradicated in 1980, the only human infectious disease so far eradicated

(C) Identifying the tuberculosis bacillus

(D) Inventing the compound microscope

Q36. Biodiversity hotspots (concept introduced by Norman Myers, 1988) are:

(A) Regions with the highest human population densities

(B) Tundra zones with permafrost

(C) Regions with high species endemism (originally ≥ 1500 endemic vascular plant species) combined with severe habitat loss ($\geq 70\%$ of original vegetation already lost). India has four: the Himalaya, the Western Ghats, Indo-Burma, and Sundaland

(D) Desert regions exclusively

Q37. The phosphorus biogeochemical cycle differs from the nitrogen cycle in that:

(A) There is a major gaseous reservoir of phosphorus in the atmosphere (incorrect)

(B) The main reservoir is sedimentary rock; weathering slowly releases phosphate ions into soil and water, which are taken up by plants, transferred along food chains, and returned to soil by decomposers — there is no significant gaseous phase

(C) Phosphorus enters ecosystems from atmospheric deposition like nitrogen

(D) Phosphorus does not cycle through ecosystems at all

Q38. The IUCN Red List conservation status of the Bengal tiger (*Panthera tigris tigris*) is:

(A) Extinct

(B) Least Concern

(C) Vulnerable (this is the status of the species *Panthera tigris* overall; the Bengal subspecies is one category up)

(D) Endangered — with ongoing threats from habitat loss, prey depletion and poaching; India holds the largest population, protected through Project Tiger (1973) and tiger reserves

Q39. DNA fingerprinting (Alec Jeffreys, 1985), used in forensic identification, paternity testing and pedigree analysis, is based on:

(A) The sequences of protein-coding genes (exons)

(B) Single-copy housekeeping genes

(C) Variations in the lengths of highly polymorphic, repetitive non-coding DNA sequences — Variable Number Tandem Repeats (VNTRs / min-

isatellites) and Short Tandem Repeats (STRs / microsatellites) — which differ between individuals (except identical twins)

(D) Only mitochondrial DNA

Q40. ELISA (Enzyme-Linked Immunosorbent Assay) is widely used to:

(A) Detect and quantify specific antigens or antibodies in a sample by using an enzyme (e.g. HRP, alkaline phosphatase) conjugated to a detection antibody, which then produces a measurable colour change with a chromogenic substrate; used for HIV screening, pregnancy hCG, hepatitis B surface antigen, and many other clinical tests

(B) Sequence DNA

(C) Amplify DNA in vitro

(D) Cut DNA at specific restriction sites

Detailed Solutions

Q1.

Solution

Concept — Origin of the cell theory: A landmark of 19th-century biology, formulated in three steps by three scientists.

Step 1 — Three foundational statements:

- **Schleiden (1838):** all plants are composed of cells.
- **Schwann (1839):** all animals are also composed of cells; cells are the basic unit of life.
- **Virchow (1858):** "omnis cellula e cellula" — every cell arises from a pre-existing cell, ending the long-held belief in spontaneous generation.

Step 2 — Why other options are wrong:

- Hooke (1665) coined the term "cell" from his observations of cork, but he saw only dead cell walls and proposed no theory.
- Leeuwenhoek first observed live microorganisms ("animalcules") but did not formulate the cell theory.
- Brown (1831) discovered the nucleus.

Final Answer: Schleiden, Schwann, Virchow $\Rightarrow$ $\boxed{\text{D}}$

Answer: (D) Go Back to Q1

Q2.

Solution

Concept — The nucleolus: A dense, ribosome-factory organelle inside the nucleus; not enclosed by its own membrane. Forms around the nucleolar organiser regions (NORs) of chromosomes that carry the rRNA gene clusters.

Step 1 — Functions:

- Transcription of $45\,\mathrm{S}$ pre-rRNA by RNA polymerase I.
- Processing of $45\,\mathrm{S}$ pre-rRNA into mature $28\,\mathrm{S}$, $18\,\mathrm{S}$ and $5.8\,\mathrm{S}$ rRNAs ($5\,\mathrm{S}$ rRNA is made by polymerase III elsewhere).
- Assembly of rRNAs with imported ribosomal proteins to form $60\,\mathrm{S}$ and $40\,\mathrm{S}$ ribosomal subunits.
- Export of subunits through nuclear pores; combination into $80\,\mathrm{S}$ ribosomes only in the cytoplasm.

Step 2 — Variation: Cells with high protein-synthesis demand (hepatocytes, secretory cells, growing cancer cells) have prominent, often multiple nucleoli.

Final Answer: rRNA synthesis and ribosome assembly $\Rightarrow$ $\boxed{\text{C}}$

Answer: (C) Go Back to Q2

Q3.

Solution

Concept — Na^+/K^+ ATPase — the primary active transport workhorse: An integral plasma-membrane protein found in essentially all animal cells; consumes $\sim 25\%$ of cellular ATP at rest in many tissues (much higher in neurons and kidney).

Step 1 — Stoichiometry: Per ATP hydrolysed: 3 **Na^+ pumped out + 2 K^+ pumped in**. Net loss of one positive charge per cycle — contributes to the negative resting membrane potential.

Step 2 — Consequences:

- Maintains low intracellular $[Na^+]$ ($\sim 10\,mM$ vs $\sim 145\,mM$ outside) and high intracellular $[K^+]$ ($\sim 140\,mM$ vs $\sim 4\,mM$ outside).
- Establishes the inward Na^+ electrochemical gradient that powers secondary active transporters — Na^+/glucose co-transporter (SGLT) in intestine and kidney, Na^+/H^+ exchanger, Na^+/Ca^{2+} exchanger.
- Sets the resting membrane potential ($\sim -70\,mV$ in neurons); essential for nerve impulse conduction and cell-volume regulation.

Step 3 — Pharmacology: Cardiac glycosides (digoxin, ouabain) inhibit the pump $\Rightarrow$ rising intracellular Na^+ $\Rightarrow$ less Ca^{2+} extruded by Na^+/Ca^{2+} exchanger $\Rightarrow$ stronger cardiac contraction — the rationale for treating heart failure.

Final Answer: $3\ Na^+$ out, $2\ K^+$ in per ATP $\Rightarrow$ $\boxed{A}$

Answer: (A) Go Back to Q3

Q4.

Solution

Concept — The three cytoskeletal filaments:

- **Microtubules:** $25\,\text{nm}$ hollow tubes; α- and β-tubulin heterodimers; polarity ($+$ and $-$ ends); dynamic instability.
- **Microfilaments (actin filaments):** $7\,\text{nm}$ thin double helix of G-actin monomers.
- **Intermediate filaments:** $10\,\text{nm}$ ropelike; keratin, vimentin, lamins, neurofilaments — tissue-specific.

Step 1 — Microtubule functions:

- Mitotic spindle.
- Cilia and flagella ($9+2$ axoneme arrangement).
- Centrioles ($9+0$ triplets).
- Intracellular transport via kinesin (anterograde, towards $+$ end) and dynein (retrograde, towards $-$ end) motors.
- Maintenance of cell shape.

Step 2 — Pharmacology:

- Colchicine, vinblastine, vincristine: depolymerise microtubules $\rightarrow$ arrest mitosis (antimitotic, used in chemotherapy and gout).
- Taxol (paclitaxel): hyperstabilises microtubules $\rightarrow$ also arrests mitosis (chemotherapy).

Final Answer: Hollow $25\,\text{nm}$ tubulin cylinders $\Rightarrow$ $\boxed{\text{B}}$

Answer: (B) Go Back to Q4

Q5.

Solution

Concept — Citric-acid (Krebs / TCA) cycle: Discovered by Hans Krebs (1937, Nobel 1953). The central oxidative pathway of aerobic metabolism, accepting acetyl-CoA from carbohydrate, lipid and protein catabolism.

Step 1 — Location:

- Eukaryotes: mitochondrial matrix (enzymes are soluble in the matrix; succinate dehydrogenase / Complex II is embedded in the inner membrane).
- Prokaryotes: cytoplasm (no mitochondria).

Step 2 — Per acetyl-CoA, one turn yields:

- $3\,\text{NADH}$, $1\,\text{FADH}_2$, $1\,\text{GTP}$ (or ATP), $2\,\text{CO}_2$.

Per glucose: 2 turns of the cycle (since one glucose yields 2 acetyl-CoA).

Step 3 — Why mitochondrial localisation matters: Pyruvate produced in cytosolic glycolysis must be transported into the mitochondrion, where the pyruvate dehydrogenase complex (also in the matrix) converts it to acetyl-CoA before the cycle. The NADH and FADH_2 produced feed directly into the electron transport chain on the inner membrane.

Final Answer: Mitochondrial matrix $\Rightarrow$ $\boxed{\text{B}}$

Answer: (B) Go Back to Q5

Q6.

Solution

Concept — Nucleosome — the fundamental unit of chromatin: DNA in the human nucleus measures $\sim 2\,\text{m}$ in total length but is packed into a $\sim 6\,\mu\text{m}$ nucleus — a compaction of $\sim 10^4\times$. The first level of compaction is the nucleosome.

Step 1 — Structure:

- Core particle: $\sim$ 146 bp of DNA wrapped $\sim$ 1.65 turns around a histone octamer (two each of H2A, H2B, H3, H4).
- Linker DNA ($\sim$ 20–80 bp) between core particles, bound by histone H1 at its entry/exit point.

Step 2 — Higher-order packing: $10\,\text{nm}$ "beads-on-a-string" $\rightarrow$ $30\,\text{nm}$ fibre (solenoid/zigzag) $\rightarrow$ looped domains attached to scaffold $\rightarrow$ condensed metaphase chromosome.

Step 3 — Significance: Histone post-translational modifications (acetylation, methylation, phosphorylation) on the histone tails regulate chromatin accessibility, providing an epigenetic "histone code" that controls gene expression without changing the DNA sequence.

Final Answer: Histone octamer (H2A, H2B, H3, H4, two each) $\Rightarrow$ $\boxed{\text{A}}$

Answer: (A) Go Back to Q6

Q7.

Solution

Concept — Cell-cycle checkpoints: Surveillance mechanisms that stop the cycle if conditions are unfavourable, ensuring genome integrity.

Step 1 — Major checkpoints:

- **G_1/S (restriction point):** the cell decides whether to commit to division — depends on growth factors, nutrients, cell size and absence of DNA damage. Once past this point, the cell is committed.
- **Intra-S checkpoint:** monitors progress of DNA replication.
- **G_2/M checkpoint:** verifies that DNA replication is *complete* and DNA is undamaged. If damage is detected, p53 stabilises, inducing p21, blocking cyclin-B/CDK1 activation and arresting the cell to allow repair (or directing it to apoptosis if damage is irreparable).
- **Metaphase-to-anaphase (spindle assembly) checkpoint:** ensures all chromosomes are bipolarly attached to spindle microtubules before sister chromatid separation.

Step 2 — Why this matters: Loss of these checkpoints (commonly through p53, Rb, or APC mutations) is a hallmark of cancer — cells proliferate with damaged genomes, accumulating further mutations.

Final Answer: G_2/M checkpoint $\Rightarrow$ $\boxed{\text{D}}$

Answer: (D) Go Back to Q7

Q8.

Solution

Concept — Glycolysis — the Embden–Meyerhof–Parnas pathway: The first stage of glucose catabolism. Universal across all kingdoms.

Step 1 — Location: Cytosol. Glycolysis does not require oxygen, organelles or membranes — it occurs entirely in the soluble cytoplasm.

Step 2 — Overall reaction:

$$\text{Glucose} + 2\,\text{NAD}^+ + 2\,\text{ADP} + 2\,\text{P}_\text{i} \rightarrow 2\,\text{Pyruvate} + 2\,\text{NADH} + 2\,\text{ATP} + 2\,\text{H}_2\text{O}$$

Step 3 — Two phases:

- Preparatory phase (steps 1–5): glucose phosphorylated, isomerised, split; consumes 2 ATP.
- Pay-off phase (steps 6–10): each 3-carbon intermediate generates 2 ATP (substrate-level phosphorylation) and 1 NADH. With two halves, total: 4 ATP, 2 NADH; net ATP $= 4 - 2 = 2$.

Step 4 — Fate of pyruvate:

- Aerobic: pyruvate enters mitochondria $\rightarrow$ acetyl-CoA $\rightarrow$ Krebs cycle.
- Anaerobic: pyruvate $\rightarrow$ lactate (muscle, RBCs) or ethanol (yeast).

Final Answer: Cytosol/cytoplasm $\Rightarrow$ C

Answer: (C) Go Back to Q8

Q9.

Solution

Concept — Bile as a biological detergent: Bile is secreted by hepatocytes into the bile canaliculi → bile ducts → stored and concentrated in the gallbladder → released into the duodenum after a fatty meal (triggered by cholecystokinin).

Step 1 — Bile composition:

- Bile salts (cholic acid, chenodeoxycholic acid conjugated with glycine or taurine) — the active emulsifying agents.
- Phospholipids (lecithin).
- Cholesterol.
- Bilirubin (excretory product of haem degradation).
- Water and bicarbonate.

Step 2 — Emulsification mechanism: Bile salts are amphipathic — they have a hydrophobic steroid face and a hydrophilic face. They coat large fat globules with their hydrophobic face adhering to the lipid and hydrophilic face outward in the aqueous medium. Mechanical mixing (gut motility) plus bile salt action breaks the large globules into many tiny droplets ($\sim 1\,\mu\text{m}$) — a stable emulsion.

Step 3 — Why emulsification is essential: Lipase is a water-soluble enzyme; it can only access the surface of a lipid droplet. Emulsification dramatically increases the surface area (by orders of magnitude), so lipase digestion proceeds at a useful rate. Bile salts do not chemically break the triglycerides themselves — that is the role of pancreatic lipase.

Step 4 — Bile salts also help absorption: After lipase digestion, bile salts form micelles with the products (monoglycerides and fatty acids), shuttling them to the enterocyte brush border for absorption. Without bile, fat absorption is severely impaired (steatorrhoea, fat-soluble vitamin deficiencies).

Final Answer: Biological detergents emulsifying fat droplets $\Rightarrow$ $\boxed{\text{D}}$

Answer: (D) Go Back to Q9

Q10.

Solution

Concept — The Bohr effect (Christian Bohr, 1904): A right-shift of the oxygen-haemoglobin dissociation curve — meaning Hb has a lower affinity for O_2 at any given P_{O_2} — delivers more O_2 to tissues where it is needed most.

Step 1 — Four physiological factors that shift the curve RIGHT (reduce O_2 affinity):

- Decreased pH (acidosis): protonation of histidine residues on Hb stabilises the T (tense, low-affinity) state.
- Increased P_{CO_2}: CO_2 forms carbamino-Hb at α-amino groups, again favouring the T state.
- Increased temperature: weakens O_2 binding thermodynamically.
- Increased 2,3-BPG (bisphosphoglycerate): produced in glycolysing red cells; binds in the central cavity of deoxy-Hb and stabilises the T state.

Step 2 — The physiological scenario in working muscle: Active muscle generates CO_2, lactic acid (lowering pH), heat, and (during chronic exercise/hypoxia) increased 2,3-BPG. All four factors converge to shift the curve right exactly where O_2 is needed most $\Rightarrow$ Hb dumps O_2 to the muscle. In the lungs, conditions are reversed — curve shifts back left, Hb picks up O_2 efficiently.

Step 3 — Foetal vs adult haemoglobin: Foetal Hb (HbF, $\alpha_2\gamma_2$) binds 2,3-BPG more weakly than adult Hb (HbA, $\alpha_2\beta_2$), giving HbF a higher O_2 affinity (curve shifted LEFT) — enabling efficient O_2 transfer from maternal to foetal blood across the placenta.

Final Answer: Bohr effect — pH↓, CO_2↑, T↑, 2,3-BPG↑ $\Rightarrow$ A

Answer: (A) Go Back to Q10

Q11.

Solution

Concept — Normal arterial blood pressure: Pressure varies with the cardiac cycle. The maximum (systolic) is during ventricular ejection; the minimum (diastolic) is during ventricular relaxation just before the next contraction.

Step 1 — Reference values (resting adult, brachial artery):

- **Optimal/normal:** $\sim 120/80\,\text{mm Hg}$.
- Pulse pressure (systolic $-$ diastolic): $\sim 40\,\text{mm Hg}$.
- Mean arterial pressure (MAP) $\approx$ diastolic $+\frac{1}{3}$pulse pressure $\approx 93\,\text{mm Hg}$.

Step 2 — Categories (AHA/JNC8 & newer guidelines):

- Hypotension: $< 90/60$ mm Hg.
- Hypertension stage 1: 130–$139/80$–89 mm Hg.
- Hypertension stage 2: $\geq 140/90$ mm Hg.

Step 3 — Measurement: Sphygmomanometer with stethoscope (Korotkoff sounds) or oscillometric (digital) devices. The cuff is inflated above systolic pressure and slowly released; the first sound heard is systolic, the disappearance of sound is diastolic.

Final Answer: $120/80\,\text{mm Hg} \Rightarrow \boxed{\text{B}}$

Answer: (B) Go Back to Q11

Q12.

Solution

Concept — Glomerular filtration — a physical, not active process: The renal corpuscle (glomerulus + Bowman's capsule) filters $\sim 180\,\mathrm{L}$ of plasma per day in adults, generating the glomerular filtrate that becomes urine.

Step 1 — Driving force — net filtration pressure (NFP):

$$\mathrm{NFP} = \mathrm{P_{GC}} - (\mathrm{P_{BC}} + \pi_{\mathrm{GC}})$$

where:

- P_{GC} = glomerular capillary hydrostatic pressure ($\sim 55\,\mathrm{mm\,Hg}$, much higher than in other capillaries because both afferent and efferent arterioles offer high resistance, with the afferent dilated and efferent constricted).
- P_{BC} = Bowman's capsule hydrostatic pressure ($\sim 15\,\mathrm{mm\,Hg}$, opposing filtration).
- π_{GC} = colloid osmotic pressure of plasma proteins ($\sim 30\,\mathrm{mm\,Hg}$, opposing filtration since albumin is not filtered).
- NFP $\approx 55 - 15 - 30 = 10\,\mathrm{mm\,Hg}$ favouring filtration.

Step 2 — The filtration barrier (three layers):

(a) Fenestrated capillary endothelium (with 70–90 nm pores, no diaphragms).
(b) Basement membrane (rich in negatively charged proteoglycans).
(c) Podocyte foot processes with slit diaphragms (key proteins: nephrin, podocin).

Cells, platelets and most plasma proteins (especially negatively charged albumin) are retained. Water, ions, glucose, amino acids, urea, and small molecules pass freely.

Step 3 — GFR regulation: Normal GFR $\approx 125\,\mathrm{mL\,min^{-1}}$. Autoregulated by the myogenic reflex and tubuloglomerular feedback. The juxtaglomerular apparatus monitors NaCl at the macula densa and adjusts afferent/efferent arteriolar tone.

Final Answer: Passive ultrafiltration driven by capillary hydrostatic pressure $\Rightarrow$ C

Answer: (C) Go Back to Q12

Q13.

Solution

Concept — The reflex arc: A reflex is an involuntary, rapid, stereotyped response to a stimulus, mediated by a fixed neural circuit. The patellar (knee-jerk) reflex is the classic monosynaptic example.

Step 1 — Five components:

(a) **Receptor:** muscle spindle in the quadriceps (a stretch receptor).
(b) **Afferent (sensory) neuron:** Ia fibre, cell body in the dorsal root ganglion.
(c) **CNS integration:** the sensory neuron synapses *directly* on the alpha motor neuron in the spinal cord ventral horn (monosynaptic) — no interneuron in between.
(d) **Efferent (motor) neuron:** alpha motor neuron, axon exiting via the ventral root.
(e) **Effector:** the same quadriceps muscle, which contracts and extends the lower leg.

Step 2 — Time course: The whole reflex completes in ~ 50 milliseconds. Because no brain is involved, the response is much faster than a voluntary movement.

Step 3 — Polysynaptic reflexes: Most reflexes (e.g. withdrawal from a hot stove, blink reflex, gag reflex) involve at least one interneuron between sensory and motor neurons. They allow coordination across multiple muscle groups but are slower.

Step 4 — Clinical significance: Reflexes are tested neurologically because abnormalities (hyperreflexia, areflexia) reveal lesions in the corresponding spinal segment or in the upper motor neurons.

Final Answer: Receptor $\rightarrow$ sensory neuron $\rightarrow$ CNS $\rightarrow$ motor neuron $\rightarrow$ effector $\Rightarrow \boxed{\text{A}}$

Answer: (A) Go Back to Q13

Q14.

Solution

Concept — The adrenal gland — two endocrine organs in one:

- **Adrenal cortex** (outer): a true endocrine gland; secretes steroid hormones from three zones.
- **Adrenal medulla** (inner): a modified sympathetic ganglion; secretes catecholamines (adrenaline and noradrenaline).

Step 1 — Hormones of the cortex (the "three Ss" — "salt, sugar, sex"):

- **Zona glomerulosa** (outermost): mineralocorticoids — chiefly aldosterone (salt and water balance, Na^+ retention and K^+ excretion in the DCT/collecting duct).
- **Zona fasciculata** (middle, thickest): glucocorticoids — chiefly cortisol.
- **Zona reticularis** (innermost): adrenal androgens (DHEA, DHEA-S).

Step 2 — Cortisol actions:

- Raises blood glucose by promoting gluconeogenesis, lipolysis and protein catabolism.
- Anti-inflammatory and immunosuppressive (basis of medical use of corticosteroids).
- Modulates the stress response ("flight-or-fight" hormone over hours-days, complementing the rapid adrenaline response).
- Permissive effect on catecholamine action on blood vessels (maintains vascular tone).

Solution

Step 3 — Control: HPA axis: Hypothalamus secretes CRH (corticotropin-releasing hormone) $\rightarrow$ anterior pituitary secretes ACTH (adrenocorticotropic hormone) $\rightarrow$ adrenal cortex secretes cortisol $\rightarrow$ cortisol feeds back negatively on both hypothalamus and pituitary.

Step 4 — Disorders:

- Excess: Cushing's syndrome (truncal obesity, moon facies, striae, glucose intolerance).
- Deficiency: Addison's disease (fatigue, weight loss, hyperpigmentation, hypotension).

Final Answer: Adrenal cortex (zona fasciculata) $\Rightarrow$ $\boxed{\text{D}}$

Answer: (D) Go Back to Q14

Q15.

Solution

Concept — The K^+-pump model of stomatal opening: Stomatal pores in the leaf epidermis are flanked by two specialised guard cells. Opening and closing depend entirely on the turgor state of these cells.

Step 1 — The trigger for opening:

- Blue light activates a photoreceptor (phototropin) in guard cells.
- A plasma-membrane H^+-ATPase pumps protons out of the guard cells, hyperpolarising the membrane.
- Voltage-gated inward K^+ channels open; K^+ ions flood into the guard cells (driven by the electrochemical gradient).
- Cl^- enters too, and malate^{2-} is synthesised from starch by PEP carboxylase — maintaining electrical neutrality.

Step 2 — Water and turgor: The accumulated solutes lower the water potential of the guard cells. Water enters by osmosis from neighbouring epidermal cells. Turgor rises.

Step 3 — The mechanical opening: Guard cells have unequal wall thickness — the wall facing the pore (inner wall) is thicker than the outer wall. Microfibrils are oriented radially. When turgor rises, the thinner outer wall stretches more than the inner wall $\Rightarrow$ the cells bow outward, opening the stomatal pore.

Step 4 — Stomatal closing:

- ABA (abscisic acid), produced under water stress (drought), binds to PYR/PYL receptors in guard cells.
- ABA opens anion channels, K^+ leaves, water follows, turgor drops, guard cells collapse $\Rightarrow$ stomata close — conserving water.

Final Answer: K^+ influx, osmotic water uptake, increased turgor $\Rightarrow$ $\boxed{\text{B}}$

Answer: (B) Go Back to Q15

Q16.

Solution

Concept — Transpiration — "necessary evil" or vital function? 95–99% of the water absorbed by plant roots is lost as water vapour through the stomata (chiefly) and the cuticle (small amount). Despite the apparent waste, transpiration is essential for plant survival.

Step 1 — Three major benefits:

(a) **Water ascent:** the evaporation of water from leaf mesophyll cells creates the tension (negative pressure) that pulls the entire water column upward through the xylem — the cohesion-tension theory (Dixon & Joly, 1894). Without transpiration, tall trees (30–$100\,\mathrm{m}$) could not supply their canopies.

(b) **Mineral absorption and translocation:** dissolved minerals from the soil are pulled into the root xylem with the transpiration stream and distributed throughout the plant.

(c) **Leaf cooling:** water has a high latent heat of vaporisation ($\sim 2400\,\mathrm{J\,g^{-1}}$). Transpiration dissipates incident solar heat, preventing leaf overheating — crucial in hot, sunny conditions where leaf temperatures might otherwise exceed protein denaturation thresholds.

Step 2 — Quantitative scale:

- A single large tree may transpire several hundred litres of water on a hot summer day.
- In a wheat field, transpiration may pull $\sim 4{,}500\,\mathrm{L}$ of water out of the soil per kilogram of grain produced.

Step 3 — Diurnal variation: Stomata generally open during the day (allowing transpiration alongside CO_2 uptake for photosynthesis) and close at night to conserve water. CAM plants (cactus, pineapple) invert this rhythm to minimise water loss in arid environments.

Final Answer: Provides ascent force, aids mineral uptake, cools the leaf $\Rightarrow$ $\boxed{\text{C}}$

Answer: (C) Go Back to Q16

Q17.

Solution

Concept — Sickle-cell anaemia — the molecular disease: The first human disease whose molecular basis was traced to a single amino-acid substitution (Linus Pauling, 1949; Ingram, 1956).

Step 1 — The mutation:

- Gene: *HBB* on chromosome 11p15.5, encoding the β-globin chain.
- DNA change: A $\rightarrow$ T transversion at the 17th nucleotide of the coding region.
- Codon change: GAG (glutamic acid) $\rightarrow$ GTG (valine), at position 6 of β-globin.
- Resulting protein: HbS instead of normal HbA.

Step 2 — Pathophysiology: At low oxygen tension (in venous blood, exercise, dehydration, infection), deoxy-HbS molecules polymerise into long fibres inside the red blood cell, distorting it into the characteristic sickle shape. Sickled cells are stiff, fragile (shortened lifespan $\sim$ 10–20 days vs normal 120), and occlude small blood vessels, causing vaso-occlusive crises (severe pain), tissue infarction (stroke, splenic infarcts, avascular necrosis), and chronic haemolytic anaemia.

Step 3 — Inheritance:

- Homozygotes (Hb^SHb^S): full sickle-cell disease.
- Heterozygotes (Hb^AHb^S, "sickle-cell trait"): usually asymptomatic; only severe hypoxia can trigger sickling. They have substantial resistance to malarial parasite *Plasmodium falciparum* — a heterozygote advantage that explains the persistence of the allele in malaria-endemic regions of Africa, the Mediterranean and India. A classic case of *balancing selection*.

Step 4 — Treatment: Hydroxyurea (raises foetal HbF, which inhibits HbS polymerisation), blood transfusions, bone-marrow/stem-cell transplantation, and gene therapy (CRISPR-based, recently approved).

Final Answer: Single point mutation at codon 6 of β-globin — Glu $\rightarrow$ Val $\Rightarrow$ $\boxed{\text{A}}$

Answer: (A) Go Back to Q17

Q18.

Solution

Concept — Pleiotropy (Greek *pleion* = more, *trepein* = turning): A single gene influences multiple, apparently unrelated phenotypic traits.

Step 1 — Distinguish from related terms:

- Pleiotropy: ONE gene → MANY traits.
- Polygenic inheritance: MANY genes → ONE trait (e.g. height, skin colour).
- Epistasis: one gene masks/modifies the effect of another at a different locus.
- Linkage: two genes close on a chromosome, inherited together.

Step 2 — Classic examples:

- **Phenylketonuria (PKU):** defective phenylalanine hydroxylase (*PAH*). Phenylalanine accumulates ⇒ intellectual disability + decreased melanin (pale skin, fair hair, blue eyes) + musty body odour from phenylketones.
- **Sickle-cell anaemia:** the HbS mutation has cascading effects — anaemia, painful crises, splenic dysfunction, infarction of various organs, growth retardation.
- **Marfan syndrome:** *FBN1* (fibrillin-1) mutation affects skeletal (tall stature, long limbs), cardiovascular (aortic aneurysm), and ocular (lens dislocation) systems.
- **Mendel's pea:** seed coat colour, flower colour, and axil pigmentation are all controlled by the same gene.

Final Answer: One gene, multiple phenotypic effects ⇒ $\boxed{\text{B}}$

Answer: (B) Go Back to Q18

Q19.

Solution

Concept — Aneuploidies and Down syndrome: An extra autosomal chromosome is usually lethal (incompatible with life). Trisomies of only three autosomes survive to live birth: chromosome 21, 18, and 13.

Step 1 — Down syndrome (trisomy 21):

- Karyotype: 47,XX,$+21$ (female) or 47,XY,$+21$ (male) — three copies of chromosome 21 instead of two.
- Cause: typically meiotic non-disjunction in the maternal egg (most often meiosis I) — risk rises sharply with maternal age (e.g. ~ 1 in 1500 at age 20, ~ 1 in 30 at age 45).
- Less commonly: Robertsonian translocation between chromosome 21 and an acrocentric (chromosome 14 or 22); $\sim 4\%$ of cases.

Step 2 — Clinical features:

- Distinctive facies: flat nasal bridge, epicanthal folds, upslanting palpebral fissures, small ears, protruding tongue.
- Generalised hypotonia in infancy.
- Intellectual disability (variable severity).
- Congenital heart defects (~ 40–50%): atrioventricular septal defect, ventricular septal defect.
- Increased risk of leukaemia (acute lymphoblastic and acute megakaryoblastic), early-onset Alzheimer's disease (the *APP* gene is on chromosome 21).
- Single transverse palmar crease ("simian crease").

Solution

Step 3 — Other autosomal trisomies:

- Edwards syndrome (trisomy 18): severe developmental defects, rocker-bottom feet; usually fatal in infancy.
- Patau syndrome (trisomy 13): cleft lip/palate, polydactyly, holoprosencephaly; mostly fatal in infancy.

Step 4 — Sex chromosome aneuploidies (for context, not the answer here):

- Klinefelter (47,XXY): infertile males, gynecomastia.
- Turner (45,X): short stature, gonadal dysgenesis in females.

Final Answer: Trisomy 21 = Down syndrome $\Rightarrow \boxed{\text{D}}$

Answer: (D) Go Back to Q19

Q20.

Solution

Concept — RNA interference (Fire & Mello, 1998; Nobel Prize 2006): A natural defence mechanism against viruses and transposons that has been harnessed in molecular biology for sequence-specific gene silencing.

Step 1 — Two key small-RNA classes:

- **siRNA (short interfering RNA, $\sim$ 21–23 nt):** processed from long double-stranded RNA precursors by the enzyme Dicer. Usually triggers mRNA cleavage with $\sim 100\%$ complementarity to target.
- **miRNA (microRNA, $\sim$ 22 nt):** encoded in cellular genomes; transcribed as long primary miRNA, processed in the nucleus by Drosha to pre-miRNA, exported, then by Dicer to mature miRNA. Usually has imperfect complementarity to target; represses translation more than cleaving the mRNA.

Step 2 — The RISC (RNA-Induced Silencing Complex): The mature small RNA is loaded onto an Argonaute (Ago) family protein within the RISC. The siRNA/miRNA guides RISC to complementary mRNA. Outcomes:

- Endonucleolytic cleavage of mRNA (typical for siRNAs).
- Inhibition of translation initiation/elongation.
- Recruitment of de-adenylase/exonuclease for mRNA degradation.

Step 3 — Applications:

- Research: knockdown of specific genes in cell cultures or whole organisms ("loss-of-function" screening).
- Therapy: FDA-approved siRNA drugs — patisiran (for transthyretin amyloidosis), inclisiran (for hypercholesterolaemia), givosiran (for porphyria).
- Crop protection: transgenic plants expressing dsRNA against pest genes (e.g. root-worm-resistant maize).

Final Answer: siRNA and miRNA acting through the RISC complex $\Rightarrow$ C

Answer: (C) Go Back to Q20

Q21.

Solution

Concept — Convergent vs divergent evolution:

- **Convergent evolution:** unrelated lineages, under similar selective pressures, independently evolve similar features (analogous structures). Common ancestor lacked the feature.
- **Divergent evolution:** closely related species evolve different features (homologous structures), often after radiating into different niches.

Step 1 — Classic convergent examples:

- **Wings of birds, bats and insects:** all enable flight but have completely different origins. Bird wing = feathered forelimb. Bat wing = skin membrane stretched over elongated finger bones. Insect wing = chitinous cuticle outgrowth from the thorax.
- Streamlined body shape of dolphins (mammals), sharks (cartilaginous fish) and ichthyosaurs (extinct marine reptiles) — all evolved for fast swimming.
- Eyes of vertebrates (developed from neural ectoderm with inverted retina) and octopuses (developed from skin with non-inverted retina) — the camera-eye design evolved independently.
- Echolocation in bats and dolphins, with parallel mutations in the prestin gene.
- Marsupial wolf (*Thylacinus*, Australian) and placental wolf (*Canis lupus*, Eurasian).

Step 2 — Why option A is wrong: The forelimbs of bat and human share a common pentadactyl skeletal plan inherited from a tetrapod ancestor — they are *homologous*, illustrating divergent evolution.

Final Answer: Wings of birds, bats and insects $\Rightarrow$ C

Answer: (C) Go Back to Q21

Q22.

Solution

Concept — Oogenesis and prolonged meiotic arrest: A defining feature of mammalian female reproductive biology: meiosis is suspended for years to decades.

Step 1 — Foetal phase:

- Primordial germ cells migrate into the developing foetal ovary.
- They multiply by mitosis to form oogonia ($2n$).
- By month ~ 5 of foetal life, all oogonia have entered meiosis I and arrested in prophase I (specifically, late diplotene or "dictyate" stage).
- Each is now a **primary oocyte**, surrounded by a single layer of follicular cells $=$ a **primordial follicle**.
- Total at birth: $\sim$ 1–2 million primordial follicles per ovary.
- By puberty: only $\sim$ 300–400 thousand remain (the rest undergo atresia).

Step 2 — Reproductive years (puberty to menopause):

- One follicle per menstrual cycle is selected to mature (the Graafian follicle).
- Its primary oocyte completes meiosis I just before ovulation, producing a **secondary oocyte** (n) and a first polar body.
- The secondary oocyte arrests again, this time in metaphase II.
- Only on fertilisation does meiosis II complete, releasing the second polar body.

Step 3 — Total ova ovulated: $\sim$ 400–500 over a typical reproductive life span (one per cycle, $\sim$ 13 cycles/year, $\sim$ 40 years).

Step 4 — Why prolonged arrest matters clinically: The longer arrest in primary oocytes is linked to the increased risk of non-disjunction (e.g. Down syndrome) with maternal age — the spindle apparatus and chromosomal cohesion deteriorate over time.

Step 5 — Compare with spermatogenesis: Spermatogenesis begins only at puberty, runs continuously thereafter, takes $\sim$ 64–74 days, and produces 4 sperm from each spermatogonium (vs 1 functional egg + 2–3 polar bodies in oogenesis).

Final Answer: Begins in foetal ovary; oocytes arrest in prophase I until puberty $\Rightarrow$ A

Answer: (A) Go Back to Q22

Q23.

Solution

Concept — The uterine (endometrial) cycle: Parallels the ovarian cycle but described in terms of changes in the endometrial lining of the uterus.

Step 1 — The three uterine phases (typical 28-day cycle):

- **Menstrual phase (days 1–5):** progesterone and oestrogen levels fall (corpus luteum regresses if no pregnancy) → spiral arteries constrict → ischaemia and shedding of the functionalis layer of the endometrium → menstrual bleeding.
- **Proliferative phase (days 5–14, oestrogen-dominant):** growing follicles secrete oestrogen → endometrium regenerates and thickens, glands lengthen, spiral arteries reform. Ends with ovulation on day ~ 14.
- **Secretory phase (days 14–28, progesterone-dominant):** corpus luteum forms and secretes progesterone → endometrial glands become tortuous and secrete glycogen-rich fluid; vascularity increases; endometrium becomes maximally receptive for implantation by day 20–24.

Step 2 — Parallel ovarian cycle phases:

- Follicular phase (days 1–14): follicle maturation → ovulation.
- Luteal phase (days 14–28): corpus luteum function → regression.

Step 3 — If pregnancy occurs: The implanted embryo secretes hCG → corpus luteum is maintained → progesterone continues to support the endometrium → no menstruation. The corpus luteum is replaced by the placenta as the dominant source of progesterone after the first trimester.

Step 4 — Endocrine summary at each phase:

- Menstrual: low oestrogen, low progesterone, rising FSH.
- Proliferative (late): rising oestrogen, rising LH (climbing to surge).
- Secretory: high progesterone, moderate oestrogen.

Final Answer: Menstrual → proliferative → secretory ⇒ $\boxed{\text{D}}$

Answer: (D) Go Back to Q23

Q24.

Solution

Concept — The four extra-embryonic foetal membranes (amniote vertebrates):

- **Amnion:** innermost; fluid-filled cavity directly around the foetus; cushions, prevents desiccation and adhesions.
- **Chorion:** outermost; forms the foetal portion of the placenta.
- **Yolk sac:** site of early embryonic blood formation and germ cell origin; reduced in humans where nutrition comes from the placenta.
- **Allantois:** early waste storage / vascular precursor of the umbilical vessels.

Step 1 — Why the chorion is THE placenta-forming membrane: After implantation (day $\sim$ 6–8), the trophoblast cells of the blastocyst differentiate into the chorion. The chorion develops finger-like projections called **chorionic villi** which invade the maternal endometrium (now called decidua), bringing foetal capillaries very close to maternal blood lacunae.

Step 2 — The mature placenta: A discoid haemochorial organ. Foetal side: chorionic plate, chorionic villi, umbilical cord. Maternal side: decidua basalis. Functions:

- Gas exchange (O_2 in, CO_2 out).
- Nutrient transfer (glucose by facilitated diffusion, amino acids by active transport, lipids).
- Waste removal (urea, creatinine).
- Immunological barrier (most pathogens excluded, though some cross — "TORCH" agents).
- Endocrine: hCG, hPL (placental lactogen), progesterone (after $\sim$ 12 weeks), oestrogens.

Step 3 — Source of hCG: The syncytiotrophoblast layer of the chorion synthesises hCG from day $\sim$ 6–8, peaking at $\sim$ 8–11 weeks. hCG maintains the corpus luteum during the first trimester. Beta-hCG is the basis of pregnancy tests.

Step 4 — Why the amnion is wrong: The amnion is the innermost sac filled with amniotic fluid; it does not develop villi and does not form the placenta. Yolk sac and allantois are reduced in humans and do not form the placenta either.

Final Answer: Chorion (with villi) forms the placenta and secretes hCG $\Rightarrow$ B

Answer: (B) Go Back to Q24

Q25.

Solution

Concept — Vasectomy — male surgical sterilisation: A minor outpatient surgical procedure that provides essentially permanent contraception. Widely used worldwide; an integral part of family-planning programmes.

Step 1 — The procedure:

- Local anaesthesia, typically through a small scrotal incision (conventional vasectomy) or no-scalpel technique (puncture with sharpened forceps).
- Each **vas deferens** (the duct carrying sperm from epididymis to ejaculatory duct) is located, cut, and a 1–$2\,\mathrm{cm}$ section removed or the ends ligated and/or cauterised.
- Both vas deferens (right and left) are treated.

Step 2 — Physiological effects:

- Spermatogenesis continues in the testes; sperm are produced but blocked from reaching the urethra.
- The unejaculated sperm are reabsorbed by the epididymis and testes (no harm).
- Testosterone secretion (Leydig cells) and libido remain unchanged — vasectomy does NOT cause impotence.
- Semen volume is barely affected (most semen volume is from seminal vesicles and prostate, not sperm).

Step 3 — Time to sterility and reversal:

- Sterility is NOT immediate; residual sperm persist in the distal vas, seminal vesicles for ~ 15–20 ejaculations or ~ 3 months. A semen analysis is required to confirm azoospermia before relying on the procedure for contraception.
- Vasectomy can sometimes be surgically reversed (vasovasostomy) with ~ 50–70% patency rate, but pregnancy rates are lower ($\sim$ 30–50%); patients should treat it as permanent.

Step 4 — Female counterpart — tubectomy: Tubal ligation: cutting and tying the fallopian tubes. Prevents the egg from meeting sperm.

Final Answer: Cutting and ligating the vas deferens $\Rightarrow$ $\boxed{\text{D}}$

Answer: (D) Go Back to Q25

Q26.

Solution

Concept — Apomixis — seed-borne asexual reproduction: Greek *apo* = without + *mixis* = mixing. A form of asexual reproduction packaged within the structures of normal sexual reproduction (the ovule and seed).

Step 1 — Types of apomixis:

- **Gametophytic apomixis:** the embryo sac develops from an unreduced ($2n$) megaspore mother cell (or related cell), and the egg develops into an embryo without fertilisation (parthenogenesis). The endosperm may still need fertilisation in some species (pseudogamy).
- **Sporophytic apomixis (adventitious embryony):** the embryo develops directly from a somatic cell of the ovule (nucellus or integument), bypassing the embryo sac entirely. Example: *Citrus* polyembryony (multiple embryos per seed).

Step 2 — Examples:

- Asteraceae: many species (dandelion, hawkweed).
- Grasses: *Paspalum*, *Panicum*, *Tripsacum*.
- *Citrus*, mango (some cultivars).

Step 3 — Agricultural importance:

- Apomictic offspring are genetically identical to the mother.
- This means hybrid vigour (heterosis) achieved in one generation could be "fixed" indefinitely if a hybrid line could be made apomictic — a major goal of plant biotechnology.
- Currently, hybrid seed has to be re-produced every year by manual or chemical hybridisation, raising costs.

Final Answer: Seed production without fertilisation; embryo from somatic cell of ovule $\Rightarrow$ A

Answer: (A) Go Back to Q26

Q27.

Solution

Concept — Ethylene — the only gaseous plant hormone: A simple two-carbon molecule ($CH_2{=}CH_2$) discovered by Russian plant physiologist Neljubow (1901) as the active component of illuminating gas that caused horizontal growth in pea seedlings.

Step 1 — Biosynthesis: The pathway: Methionine → S-Adenosyl methionine (SAM) → ACC (1-aminocyclopropane-1-carboxylate) → Ethylene. ACC synthase is the rate-limiting enzyme; ACC oxidase converts ACC to ethylene in an oxygen-dependent reaction.

Step 2 — Major physiological effects:

- **Fruit ripening:** stimulates softening, sugar accumulation, colour change, aroma production. Classic example: a single ripe banana releases enough ethylene to ripen surrounding fruits.
- **Climacteric vs non-climacteric fruits:** climacteric (banana, apple, mango, tomato) show an autocatalytic ethylene burst at ripening — can ripen post-harvest. Non-climacteric (citrus, strawberry, grape) do not show this and must be picked ripe.
- **Abscission:** promotes leaf, flower and fruit fall.
- **Senescence:** accelerates ageing of flowers and leaves.
- **Triple response:** short, thick, horizontally growing seedling (in dark, under mechanical stress).
- **Promotes flowering in some species:** pineapples, mangoes.

Step 3 — Commercial applications:

- Ripening rooms with controlled ethylene atmosphere for bananas, tomatoes, mangoes shipped green.
- Ethephon (a liquid that releases ethylene when applied to plants) used in agriculture to synchronise flowering in pineapples, promote latex flow in rubber tree, hasten ripening.
- Conversely: ethylene inhibitors (silver thiosulfate; 1-MCP) extend shelf life of cut flowers and produce.

Final Answer: Ethylene ⇒ B

Answer: (B) Go Back to Q27

Q28.

Solution

Concept — Phytochrome — the red/far-red photoreceptor: A chromoprotein discovered by Borthwick & Hendricks (1959). Functions as a molecular light switch controlling many photomorphogenetic responses.

Step 1 — Two interconvertible forms:

- **Pr** ($\lambda_{\max} \sim 660\,\text{nm}$, red): the inactive form, found in dark-grown plants.
- **Pfr** ($\lambda_{\max} \sim 730\,\text{nm}$, far-red): the active form, biologically active.

Step 2 — Photoconversion:

- $\text{Pr} \xrightarrow{\text{red light (660 nm)}} \text{Pfr}$
- $\text{Pfr} \xrightarrow{\text{far-red light (730 nm)}} \text{Pr}$
- $\text{Pfr} \xrightarrow{\text{slow dark reversion}} \text{Pr}$

Step 3 — Biological roles of Pfr:

- **Seed germination:** many small seeds (lettuce, *Arabidopsis*) require red light; far-red inhibits. Filtered light under a leaf canopy (rich in far-red, depleted of red) keeps seeds dormant.
- **De-etiolation:** switches from skotomorphogenic (etiolated, pale, elongated hypocotyl) to photomorphogenic (green, open cotyledons, short hypocotyl) growth.
- **Shade avoidance:** low red:far-red ratio under a canopy triggers stem elongation and competitive growth.
- **Photoperiodism (flowering):** measures the length of dark and light periods, controlling whether short-day or long-day plants flower.

Solution

Step 4 — Molecular action: Pfr translocates from cytoplasm to nucleus, where it interacts with PIF transcription factors (Phytochrome-Interacting Factors) and other regulators, modulating expression of thousands of genes.

Step 5 — Other plant photoreceptors:

- Cryptochromes and phototropins: respond to blue/UV-A light.
- UVR8: responds to UV-B light.

Final Answer: Pr (inactive) $\leftrightarrow$ Pfr (active) interconvert by red/far-red light $\Rightarrow$ $\boxed{\text{C}}$

Answer: (C) Go Back to Q28

Q29.

Solution

Concept — Tobacco mosaic virus (TMV) — a historic landmark: The first virus ever to be discovered, and the first to be crystallised — giving birth to virology and pioneering structural molecular biology.

Step 1 — Discovery timeline:

- Adolf Mayer (1886): showed mosaic disease of tobacco was transmissible by sap.
- Dmitri Iwanowski (1892): infectious agent passed through filters that retain bacteria — "filterable agent".
- Martinus Beijerinck (1898): coined the term "virus" (Latin for poison); showed agent replicates only in living plants.
- Wendell Stanley (1935): crystallised TMV (Nobel 1946); first virus ever crystallised, showing viruses to be chemical entities (proteins + nucleic acid).
- Rosalind Franklin et al (1950s): determined the helical structure by X-ray diffraction.

Step 2 — Structure:

- Genome: single-stranded, positive-sense RNA (~ 6400 nucleotides).
- Capsid: ~ 2130 identical coat-protein subunits arranged in a right-handed helix around the RNA.
- Shape: rigid rod, $\sim 300\,\text{nm}$ long, $\sim 18\,\text{nm}$ in diameter.
- Capable of self-assembly in vitro from purified coat protein and RNA — elegant demonstration by Fraenkel-Conrat & Williams (1955).

Step 3 — Disease and transmission: TMV infects tobacco, tomato, pepper, and many other Solanaceae. Symptoms: mottled light/dark green "mosaic" on leaves, stunting, reduced yield. Transmission is mechanical (handling, contaminated tools, smoking near plants); not insect-vectored.

Solution

Step 4 — Significance in virology and molecular biology:

- Used to demonstrate that RNA can be genetic material (Fraenkel-Conrat reconstitution experiment).
- Used in early demonstrations of virus replication.
- Model system for understanding plant viruses, virus–host interactions, and the spread of viruses through plasmodesmata.

Final Answer: Single-stranded RNA, helical rod-shaped capsid $\Rightarrow$ $\boxed{\text{B}}$

Answer: (B) Go Back to Q29

Q30.

Solution

Concept — Phaeophyta (brown algae): A large group of mainly marine, mostly multicellular algae — the giant kelps (*Macrocystis*, up to $60\,\mathrm{m}$) and the brown seaweeds that form vast underwater forests in temperate seas.

Step 1 — Photosynthetic pigments:

- Chlorophyll a (universal).
- **Chlorophyll** c (instead of chlorophyll b which is in green plants).
- **Fucoxanthin** — a yellow-brown carotenoid that strongly absorbs blue-green light. Fucoxanthin masks chlorophyll, giving the algae their characteristic brown to olive colour.
- Other accessory carotenoids: β-carotene, violaxanthin.

Step 2 — Other characteristics:

- Cell wall: cellulose + algin (alginic acid, a polysaccharide of major commercial importance).
- Stored food: laminarin (β-$1,3$-glucan) and mannitol.
- Body forms: highly variable — simple filaments (*Ectocarpus*), branched thalli (*Sargassum*), large kelps with holdfast/stipe/blade structure (*Laminaria*, *Macrocystis*, *Nereocystis*).
- Reproduction: complex sexual cycles with alternation of generations; flagellated motile spores and gametes.

Step 3 — Comparison with other algal divisions:

- Chlorophyta (green algae): chlorophyll $a+b$, no fucoxanthin — green colour. Storage as starch.
- Rhodophyta (red algae): chlorophyll a, phycoerythrin (red), phycocyanin — red colour. Storage as floridean starch.
- Cyanobacteria (formerly "blue-green algae"): prokaryotes; chlorophyll a, phycocyanin, phycoerythrin — blue-green to greenish.

Solution

Step 4 — Economic uses:

- Algin (alginic acid): thickener and stabiliser in foods (ice cream, salad dressing), pharmaceuticals, textiles.
- Iodine source (historically).
- Food (*Laminaria* = kombu in Japanese cuisine).
- Habitat: kelp forests support immense marine biodiversity.

Final Answer: Chlorophyll a, c and fucoxanthin $\Rightarrow$ C

Answer: (C) Go Back to Q30

Q31.

Solution

Concept — Pteridophytes — the first vascular land plants: The transitional group between non-vascular bryophytes (mosses, liverworts) and seed plants (gymnosperms, angiosperms). Greek *pteris* = fern, *phyton* = plant.

Step 1 — Diagnostic features:

- True vascular tissue (xylem and phloem) — enabling the first tall land plants in the Devonian.
- True roots, stems and leaves (unlike bryophytes which have only rhizoids and "leaf-like" parts).
- Sporophyte (the visible plant, e.g. the fern frond) is the dominant generation, photosynthetic and independent. This is a major evolutionary innovation over bryophytes, where the gametophyte is dominant.
- Gametophyte: small, short-lived, free-living, photosynthetic prothallus.
- Reproduce by haploid spores (homosporous in most ferns; heterosporous in *Selaginella*, *Salvinia*, *Marsilea*).
- Sperm motile — requires a film of water to swim to the egg on the prothallus. This water-dependence keeps pteridophytes restricted to moist habitats and is overcome only in seed plants (pollen tube + non-motile sperm).

Step 2 — Major classes:

- Psilopsida: *Psilotum*, *Tmesipteris* (the most primitive; reduced leaves, no true roots).
- Lycopsida: club mosses — *Lycopodium*, *Selaginella*.
- Sphenopsida: horsetails — *Equisetum* (jointed stems with silica deposits).
- Pteropsida: true ferns — *Pteridium*, *Adiantum*, *Dryopteris* (largest class).

Step 3 — Evolutionary significance:

- Carboniferous ("coal age", $\sim$ 360–300 Mya): gigantic tree pteridophytes (*Lepidodendron*, *Calamites*, tree ferns) dominated swamp forests and produced the coal deposits exploited today.
- Step toward heterospory (megaspores and microspores) anticipated the evolution of seeds in gymnosperms.

Solution

Final Answer: Vascular, true roots/stems/leaves; water-dependent sperm; sporophyte dominant $\Rightarrow$ $\boxed{\text{A}}$

Answer: (A) Go Back to Q31

Q32.

Solution

Concept — Phylum Arthropoda: The most successful phylum in animal evolution — over 1.2 million described species ($\sim 75\%$ of all known animals), occupying nearly every ecological niche from the deep sea to the highest mountains.

Step 1 — Diagnostic synapomorphies (defining features):

- **Jointed appendages** (Greek *arthros* = joint, *podos* = foot) — give the phylum its name.
- **Chitinous exoskeleton** (cuticle): protective, light, but inextensible — requires periodic moulting (ecdysis) for growth. The exoskeleton is a strong evolutionary innovation, providing protection and reducing water loss on land.
- Segmented body: ancestrally homonomous; secondarily grouped into functional regions (tagmata) like head-thorax-abdomen (insects) or cephalothorax-abdomen (arachnids, many crustaceans).
- Bilateral symmetry; triploblastic; coelomate (haemocoel as adult body cavity).
- Open circulatory system: haemolymph (no haemoglobin in most; oxygen transport via direct diffusion or via dissolved haemocyanin in some).
- Respiration: tracheae (insects), book lungs (spiders, scorpions), gills (crustaceans, horseshoe crabs).
- Compound eyes (with many ommatidia) and/or simple ocelli.
- Sexes typically separate; oviparous.

Step 2 — Major classes:

- **Insecta (Hexapoda):** three body regions, three pairs of legs, usually two pairs of wings. Examples: cockroach, honeybee, butterfly, mosquito.
- **Arachnida:** two body regions, four pairs of legs, no antennae. Examples: spider, scorpion, mite, tick.
- **Crustacea:** two pairs of antennae, biramous appendages, mostly aquatic. Examples: prawn, crab, lobster, woodlouse.
- **Myriapoda:** elongated body with many segments and legs. Examples: centipede (Chilopoda), millipede (Diplopoda).

Solution

Step 3 — Ecological/economic significance:

- Pollinators (bees, butterflies, beetles).
- Pests of crops (locusts, weevils, aphids).
- Vectors of disease (mosquito → malaria, dengue; tsetse fly → sleeping sickness; tick → Lyme disease).
- Food source (prawns, lobsters, crabs).

Final Answer: Jointed appendages, chitinous exoskeleton, segmented body, open circulation ⇒ D

Answer: (D) Go Back to Q32

Q33.

Solution

Concept — Malaria — the world's most deadly vector-borne disease: Caused by protozoan parasites of the genus *Plasmodium*. Five species infect humans: *P. falciparum* (deadliest), *P. vivax* (most widespread), *P. malariae*, *P. ovale*, and *P. knowlesi* (zoonotic from macaques in SE Asia).

Step 1 — Vector: The bite of an infected female *Anopheles* mosquito — only the female takes blood meals (needed for egg development). Several *Anopheles* species are important vectors, including *A. gambiae* in Africa and *A. culicifacies*, *A. stephensi* in India.

Step 2 — Life cycle (alternating between mosquito and human):

(a) **Mosquito bite injects sporozoites** into the human bloodstream.
(b) **Liver (exo-erythrocytic) stage:** sporozoites invade hepatocytes; multiply asexually (schizogony) to produce thousands of merozoites; the hepatocyte ruptures.
(c) **Blood (erythrocytic) stage:** merozoites invade RBCs, multiply, rupture the RBC periodically ($\sim$ every 48 hours for *P. vivax* and *P. falciparum*, $\sim$ 72 hours for *P. malariae*), releasing more merozoites and parasite waste — causing the characteristic fever spikes (paroxysms) with chills, high fever, sweating.
(d) Some merozoites differentiate into male and female gametocytes.
(e) **Mosquito blood meal:** gametocytes are taken up by a feeding mosquito.
(f) In the mosquito midgut: gametes fuse → zygote → ookinete → oocyst → thousands of sporozoites that migrate to salivary glands, ready to infect the next human.

Solution

Step 3 — Symptoms and severity:

- Cyclical fever, chills, sweats, headache, body aches, fatigue.
- Anaemia, splenomegaly.
- *P. falciparum* can cause cerebral malaria (sequestration of infected RBCs in brain capillaries), acute kidney injury, severe anaemia, ARDS — a life-threatening medical emergency.

Step 4 — Treatment and control:

- Artemisinin-based combination therapies (ACTs) are the first-line treatment; chloroquine resistance is now widespread.
- Vector control: insecticide-treated bed nets, indoor residual spraying, larval source management.
- Recent: WHO-recommended RTS,S/AS01 and R21/Matrix-M malaria vaccines for children in high-transmission areas.

Final Answer: Female *Anopheles* mosquito; sporozoites $\rightarrow$ liver $\rightarrow$ RBC stages $\Rightarrow$ $\boxed{\text{D}}$

Answer: (D) Go Back to Q33

Q34.

Solution

Concept — Type 1 vs Type 2 diabetes mellitus: "Diabetes mellitus" (Greek: *diabainein* = to pass through, *mellitus* = honey-sweet) is a metabolic disorder characterised by chronic hyperglycaemia. Two major forms have very different pathophysiology.

Step 1 — Type 1 diabetes mellitus (T1DM):

- Autoimmune destruction of pancreatic islet β cells (mediated by autoreactive T cells and autoantibodies against GAD65, IA-2, ZnT8, insulin).
- Result: absolute insulin deficiency.
- Onset: typically childhood or adolescence (formerly called "juvenile-onset diabetes").
- Genetic predisposition: HLA-DR3/DR4 haplotypes; concordance in identical twins $\sim$ 30–50%.
- Triggers: viral infections (Coxsackie B, enteroviruses), dietary factors — still debated.
- Presentation: classic "three Ps" — polyuria, polydipsia, polyphagia — with weight loss, sometimes diabetic ketoacidosis (DKA) as the first manifestation.
- Treatment: lifelong exogenous insulin (multiple daily injections or insulin pump); no oral hypoglycaemics work because there is no β-cell to stimulate.

Step 2 — Type 2 diabetes mellitus (T2DM, contrast):

- Peripheral insulin resistance + progressive β-cell dysfunction.
- Insulin levels initially normal or high, then decline.
- Onset: typically adulthood, strongly linked to obesity, sedentary lifestyle, and family history.
- Treatment: lifestyle modification, oral hypoglycaemics (metformin, sulfonylureas, SGLT2 inhibitors, DPP-4 inhibitors, GLP-1 agonists), eventually insulin in some.

Solution

Step 3 — Long-term complications (both types):

- Microvascular: retinopathy, nephropathy, neuropathy.
- Macrovascular: coronary artery disease, stroke, peripheral arterial disease.
- Foot ulcers and infections.

Step 4 — Glucagon and Type 1**:** Note that the question is specific to β cells. Damage to α cells (which secrete glucagon, the insulin-counterregulatory hormone) is NOT the cause of diabetes; in fact in advanced T1DM there is some α-cell dysfunction too, but it is not the primary defect.

Final Answer: Autoimmune destruction of pancreatic β cells $\Rightarrow \boxed{\text{A}}$

Answer: (A) Go Back to Q34

Q35.

Solution

Concept — Edward Jenner (1749–1823) — the father of vaccination: A country physician in Berkeley, Gloucestershire, England. His 1796 experiment laid the foundation for modern immunology and ultimately led to the eradication of one of the most lethal diseases in human history.

Step 1 — The classic experiment (1796):

- Jenner had noticed (from local folklore among milkmaids) that those who had recovered from cowpox (a mild illness contracted from infected cow udders) did not subsequently catch smallpox.
- On 14 May 1796: he inoculated 8-year-old James Phipps with pus from cowpox lesions on the hand of a milkmaid, Sarah Nelmes.
- Six weeks later: he challenged the boy with material from a smallpox patient. James did not develop smallpox — protected!
- Jenner coined the term "vaccination" (from Latin *vacca* = cow).

Step 2 — Why it worked: The cowpox virus (vaccinia) is closely related to the smallpox virus (variola), so antibodies and T cells generated against cowpox cross-recognise variola — the first known example of cross-protection. Both are members of the Orthopoxvirus genus.

Step 3 — Smallpox eradication: Smallpox was one of the most devastating diseases in history — with mortality rates of $\sim 30\%$, killing an estimated 300 million people in the 20th century alone before its elimination.

- WHO launched a global eradication campaign in 1967, using ring vaccination of contacts of cases.
- Last natural case: 1977 in Somalia.
- WHO declared smallpox eradicated on 8 May 1980 — the only human infectious disease to have been deliberately eradicated. Polio is the second candidate, on the verge of eradication.

Step 4 — Modern legacy: The vaccinia virus continues to be used as the smallpox vaccine and as a vector for other vaccines (e.g. in MVA-based COVID, Ebola vaccines).

Final Answer: First vaccine, against smallpox, using cowpox (vaccinia) $\Rightarrow$ B

Answer: (B) Go Back to Q35

Q36.

Solution

Concept — Biodiversity hotspots (Norman Myers, 1988): A conservation prioritisation strategy: focus on regions where the most biodiversity faces the most pressing threat.

Step 1 — Two criteria (must satisfy BOTH):

(a) **Endemism:** the region must contain at least 1500 species of vascular plants that occur nowhere else on Earth (endemic species).
(b) **Threat:** the region must have lost at least 70% of its original primary vegetation.

Step 2 — Global picture:

- 36 hotspots have been recognised globally (updated count by Conservation International).
- Together they occupy only $\sim 2.4\%$ of Earth's land surface but contain $\sim 50\%$ of the world's endemic plant species and $\sim 43\%$ of endemic land vertebrate species.
- Conservation in hotspots gives the maximum return on investment.

Step 3 — Four Indian hotspots:

(a) **The Himalaya:** including Nepal, Bhutan, parts of NE India. Endangered species: red panda, snow leopard, Himalayan tahr.
(b) **The Western Ghats and Sri Lanka:** along India's west coast. Endangered species: lion-tailed macaque, Nilgiri tahr, many endemic amphibians.
(c) **Indo-Burma:** parts of NE India, Myanmar, Thailand, Vietnam. Rich in primates, freshwater fish, reptiles.
(d) **Sundaland:** includes Nicobar Islands (along with Indonesia, Malaysia). Orangutans, proboscis monkey, Rafflesia (the world's largest flower).

Step 4 — Famous hotspots elsewhere: Madagascar, Mediterranean basin, Cape Floristic Region (South Africa), California Floristic Province, Caucasus, Mesoamerica, Tropical Andes.

Final Answer: Regions of high endemism and high habitat loss $\Rightarrow$ C

Answer: (C) Go Back to Q36

Q37.

Solution

Concept — The phosphorus cycle — a sedimentary cycle: Unlike the carbon and nitrogen cycles, the phosphorus cycle has no significant gaseous component (no P_2, PO_x, PH_3 in the atmosphere at relevant scales). It is therefore much slower, operating on geological timescales.

Step 1 — The main reservoir — sedimentary rock:

- Phosphorus is locked up as phosphate ions (PO_4^{3-}) in rocks — apatite, $Ca_5(PO_4)_3(OH, F, Cl)$.
- Weathering (chemical + physical) of these rocks slowly releases phosphate into soil and water.
- Bird and bat guano deposits (e.g. on Pacific islands) are concentrated sources mined for fertiliser.

Step 2 — Biological cycling:

- Plants take up $H_2PO_4^-$ from soil solution through roots.
- Plants incorporate P into DNA, RNA, ATP, NADPH, phospholipids, NADH/$NADP^+$, sugar phosphates.
- Animals obtain P by eating plants/other animals.
- Decomposers mineralise dead organic matter, returning phosphate to soil.
- Some P is leached to streams $\rightarrow$ rivers $\rightarrow$ oceans, where it eventually sediments out to form new rock — closing the very slow geochemical loop.

Step 3 — Why P is often the limiting nutrient: Because cycling is slow and most soil phosphate is in unavailable mineral forms, P often limits primary productivity — especially in freshwater ecosystems. Agriculture relies on mining phosphate rock (Morocco holds $\sim 70\%$ of world reserves).

Solution

Step 4 — Human impact:

- Mining of phosphate for fertilisers $\rightarrow$ runoff into waterways.
- Sewage and detergent phosphates.
- These cause eutrophication — algal blooms, oxygen depletion (hypoxia), fish kills.

Step 5 — Compare with nitrogen cycle:

- N cycle: huge atmospheric reservoir (78% N_2); rapid biological turnover via fixation, nitrification, denitrification.
- P cycle: no atmospheric reservoir; geological timescales.

Final Answer: Main reservoir is sedimentary rock; no significant gaseous phase $\Rightarrow \boxed{\text{B}}$

Answer: (B) Go Back to Q37

Q38.

Solution

Concept — IUCN Red List of Threatened Species: The world's most authoritative inventory of the conservation status of plants and animals, maintained by the International Union for Conservation of Nature.

Step 1 — IUCN categories (in increasing order of risk):

- **LC** — Least Concern.
- **NT** — Near Threatened.
- **VU** — Vulnerable: high risk of endangerment.
- **EN** — Endangered: very high risk of extinction in the wild.
- **CR** — Critically Endangered: extremely high risk.
- **EW** — Extinct in the Wild (survives only in captivity).
- **EX** — Extinct.
- Other categories: Data Deficient (DD), Not Evaluated (NE).

Step 2 — The Bengal tiger (*Panthera tigris tigris*):

- One subspecies of *Panthera tigris*; native to the Indian subcontinent (India, Bangladesh, Nepal, Bhutan).
- IUCN Red List status: **Endangered** (EN).
- The species *Panthera tigris* as a whole is listed as Endangered as of 2022 assessment; some sources separately list Bengal tiger as Endangered.
- Estimated wild population in India: $\sim 3{,}600$ (according to All India Tiger Estimation 2022).

Step 3 — Threats:

- Habitat loss and fragmentation (agricultural expansion, infrastructure, deforestation).
- Prey depletion (poaching of deer, wild boar).
- Poaching for skins, bones (illegal traditional medicine trade).
- Human-wildlife conflict.
- Climate change (affecting Sundarbans tigers — sea-level rise).

Solution

Step 4 — Conservation:

- Project Tiger (1973, Government of India): network of tiger reserves, currently 54 reserves covering $\sim 75{,}000\,\text{km}^2$.
- Strict anti-poaching enforcement.
- National Tiger Conservation Authority (NTCA): coordinates conservation policy and monitoring.
- India hosts $\sim 75\%$ of the world's wild tiger population, making it the global stronghold for the species.

Final Answer: Endangered $\Rightarrow \boxed{\text{D}}$

Answer: (D) Go Back to Q38

Q39.

Solution

Concept — DNA fingerprinting / DNA profiling: Discovered by Alec Jeffreys at the University of Leicester (1985); now an indispensable technique in forensic science, paternity testing, kinship analysis, anthropology, and conservation biology.

Step 1 — Underlying principle: The human genome contains many short DNA sequences that are repeated in tandem (head-to-tail) hundreds to thousands of times. The number of repeats at any one locus varies between individuals — creating a powerful source of genetic individuality. These regions are non-coding and selectively neutral, so they accumulate variation rapidly.

Step 2 — Two main types of repetitive markers:

- **VNTRs (Variable Number Tandem Repeats / minisatellites):** repeat units of 10–60 bp; clusters span hundreds of base pairs. Used in early DNA fingerprinting via Southern blotting with multilocus probes.
- **STRs (Short Tandem Repeats / microsatellites):** repeat units of 1–6 bp (e.g. "CAG" repeats); much shorter total length. Modern DNA fingerprinting uses panels of 13–20 STR loci, amplified by multiplex PCR and analysed by capillary electrophoresis.

Step 3 — Procedure (modern STR-based):

(a) DNA extraction from a sample (blood, saliva, hair root, semen, bone — even degraded forensic samples).
(b) PCR amplification of standardised STR loci using fluorescently labelled primers.
(c) Capillary electrophoresis separates fragments by size.
(d) Software determines the number of repeats (allele) at each locus.
(e) The resulting allele profile is matched against a reference (suspect, family member, database such as CODIS in the US, NDNAD in the UK).

Step 4 — Statistical power: With 13 unlinked STR loci, the probability of two unrelated individuals having identical profiles is in the range of 1 in 10^{12} or smaller — essentially uniquely identifying.

Solution

Step 5 — Applications:

- Forensic identification (criminal, mass-disaster victim).
- Paternity and kinship testing.
- Pedigree analysis in conservation (e.g. identifying individual tigers).
- Ancient DNA studies (using SNP/STR panels on archaeological samples).
- Identification of remains (e.g. Romanov family identification, 1991; Holocaust victims).

Final Answer: Variations in repetitive non-coding DNA (VNTRs/STRs) $\Rightarrow$ $\boxed{\text{C}}$

Answer: (C) Go Back to Q39

Q40.

Solution

Concept — ELISA (Enzyme-Linked Immunosorbent Assay): Developed independently by Engvall & Perlmann and by van Weemen & Schuurs in the early 1970s. ELISA replaced radioimmunoassays (RIA) for most clinical and research applications, since it does not require radioactive reagents.

Step 1 — General principle: ELISA uses the highly specific binding of antibody to antigen, coupled to an enzyme that catalyses a colour-producing reaction with a substrate. The intensity of the colour is proportional to the amount of analyte. Three main formats:

Step 2 — Direct ELISA:

(a) Coat plate well with antigen.
(b) Add enzyme-conjugated antibody specific to antigen.
(c) Wash; add substrate; measure colour.

Step 3 — Indirect ELISA (commonly used to detect ANTIBODIES, e.g. HIV testing):

(a) Coat plate with antigen (e.g. HIV proteins).
(b) Add patient serum; specific antibodies (if present) bind.
(c) Wash; add enzyme-conjugated anti-human IgG.
(d) Wash; add substrate; measure colour.

Step 4 — Sandwich ELISA (for measuring ANTIGEN concentration):

(a) Coat plate with "capture" antibody.
(b) Add sample containing antigen.
(c) Add "detection" antibody (against a different epitope on the same antigen), often enzyme-labelled.
(d) Wash; add substrate; measure colour.

This is the basis of pregnancy tests (sandwich ELISA for β-hCG), HBsAg testing, troponin assays, and many others.

Solution

Step 5 — Common enzymes and substrates:

- HRP (horseradish peroxidase) with TMB or OPD substrate $\rightarrow$ blue/yellow colour.
- Alkaline phosphatase with PNPP substrate $\rightarrow$ yellow.

Step 6 — Applications in medicine:

- HIV screening (anti-HIV antibodies, then confirmatory Western blot or PCR).
- Hepatitis B and C diagnosis.
- Allergen-specific IgE testing.
- Pregnancy testing.
- Tumour markers (CEA, AFP, PSA).
- COVID-19 antibody serosurveillance and antigen detection.

Final Answer: Detect antigens/antibodies via enzyme-conjugated antibody + chromogenic substrate $\Rightarrow$ $\boxed{\text{A}}$

Answer: (A) Go Back to Q40

Answer Key

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