

IB Biology – Theme A: Unity and Diversity

IB Biology SL & HL (2023 syllabus) · Total marks: 40 · Answers on the last page

Questions on molecules and cells, viruses (HL), classification and cladistics, and evolution. A calculator is needed for the magnification and surface-area-to-volume questions.

Section A – Molecules and Cells (SL and HL)

1. State two features common to all living cells, and one feature that distinguishes prokaryotic cells from eukaryotic cells. [3]
2. A drawing of a cell organelle measures 45 mm in length on the page. The actual length of the organelle is 15 μm . Calculate the magnification of the drawing. [3]
3. The table below gives the surface area and volume of three cube-shaped cells of side length 1 mm, 2 mm and 4 mm.
 - (a) Calculate the surface-area-to-volume ratio for each cube.
 - (b) Explain why cell size is limited by the surface-area-to-volume ratio. [5]
4. Explain the role of enzymes as biological catalysts, including reference to activation energy and the induced-fit model. [3]

Section B – Viruses (HL) (HL only)

5. Explain why viruses are not classified as living organisms, despite containing genetic material. [3]
6. Describe the basic structure of a virus, and outline the general steps by which a virus replicates inside a host cell. [4]
7. Explain why viruses such as influenza and HIV mutate rapidly, and explain the consequence this has for developing effective, long-lasting vaccines against them. [3]
8. State one difference between a DNA virus and an RNA virus in terms of their replication, and explain why RNA viruses such as SARS-CoV-2 are often described as having a higher mutation rate than DNA-based organisms. [3]

Section C – Classification and Evolution (SL and HL)

9. Explain the binomial system of naming species, and state why a universal naming system is useful to scientists. [3]
10. Explain how a cladogram is constructed using evidence from DNA base sequences, and state what is meant by a clade. [3]
11. Outline the process of natural selection as an explanation for evolutionary change, using the four key ideas: variation, overproduction, selection and heredity. [4]
12. Distinguish between homologous structures and analogous structures, giving one named example of each, and explain what each type of structure provides evidence for. [3]

Answers

Check your working against these. If an answer does not match, try the question again before looking for the method.

- Common features (any two): a plasma membrane enclosing the cytoplasm; DNA as the genetic material; cytoplasm containing ribosomes for protein synthesis; metabolic reactions catalysed by enzymes. Distinguishing feature: prokaryotic cells lack a nucleus and membrane-bound organelles (their DNA is free in the cytoplasm, in a nucleoid region), whereas eukaryotic cells have a true nucleus and membrane-bound organelles.
- Convert to the same units: $45\text{ mm} = 45000\text{ }\mu\text{m}$. Magnification = $\frac{\text{image size}}{\text{actual size}} = \frac{45000}{15} = 3000\times$.
- (a) For side 1 mm: $SA = 6\text{ mm}^2$, $V = 1\text{ mm}^3$, ratio = 6 : 1. For side 2 mm: $SA = 24\text{ mm}^2$, $V = 8\text{ mm}^3$, ratio = 3 : 1. For side 4 mm: $SA = 96\text{ mm}^2$, $V = 64\text{ mm}^3$, ratio = 1.5 : 1.
(b) As a cell increases in size, its volume increases faster than its surface area, so the surface-area-to-volume ratio decreases. Since the exchange of substances (e.g. oxygen, nutrients, waste) with the environment occurs across the surface but is needed to supply the whole volume, a larger cell has proportionally less membrane area available to service its metabolic demands, limiting the maximum size a cell can reach before diffusion becomes too slow.
- Enzymes are globular proteins that catalyse specific biochemical reactions by lowering the activation energy needed for the reaction to proceed, increasing the rate of reaction without themselves being used up. According to the induced-fit model, the active site is not a rigid, exact fit for the substrate; instead, binding of the substrate causes a change in the shape of the active site, which improves the fit and can strain bonds in the substrate, facilitating the reaction.
- Viruses lack a cellular structure (no cytoplasm, ribosomes or membrane-bound organelles of their own), cannot carry out metabolic reactions independently, and cannot replicate without infecting a host cell and using the host's enzymes, ribosomes and energy supply. Because they cannot independently carry out all the characteristic life processes (metabolism, growth, and independent reproduction), most biologists do not classify viruses as living organisms.
- A virus consists of genetic material (DNA or RNA) enclosed within a protein coat (capsid); some viruses also have an outer lipid envelope. Replication: the virus attaches to and enters a specific host cell (or injects its genetic material); the host cell's machinery (enzymes, ribosomes, nucleotides) is used to replicate the viral genetic material and synthesise viral proteins; new virus particles are assembled; the new viruses are released from the host cell, often by lysis (bursting) of the cell, to infect further cells.
- RNA viruses such as influenza and HIV replicate using error-prone RNA-dependent enzymes that lack proofreading (error-correcting) ability, so mutations accumulate quickly during replication; this is worsened when a host is infected by two different strains at once, allowing genetic material to be exchanged (reassortment). Consequence: rapidly changing surface proteins (antigens) mean antibodies produced against one strain, whether from a previous infection or a vaccine, may no longer recognise a newly mutated strain, so vaccines can lose effectiveness over time and may need to be regularly updated (e.g. the annual flu vaccine).
- A DNA virus typically uses the host cell's own DNA polymerase (which has proofreading ability) to replicate its genome, whereas an RNA virus uses its own RNA-dependent RNA polymerase to copy its RNA genome directly. RNA viruses have a higher mutation rate because RNA-dependent RNA polymerases generally lack proofreading (error-correcting) mechanisms, so replication errors (mutations) are copied into the new genome and are not corrected, unlike most DNA replication.
- In the binomial system, each species is given a two-part Latin name: the first part is the genus

name (capitalised) and the second is the species epithet (lower case), e.g. *Homo sapiens*, usually written in italics (or underlined by hand). A universal naming system avoids the confusion of different common names being used for the same species in different languages or regions, allowing scientists worldwide to communicate unambiguously about a specific species.

10. DNA base sequences (or amino acid sequences) from different species are compared; the number of differences between sequences is used as a measure of evolutionary (genetic) relatedness, with fewer differences indicating a more recent common ancestor. Species are then grouped on a branching diagram (cladogram) according to these relationships, with each branch point representing a common ancestor. A clade is a group consisting of a common ancestor and all of its descendants.
11. Within a population there is natural, often heritable, variation between individuals (variation). Populations tend to produce more offspring than the environment can support (overproduction), leading to competition for limited resources. Individuals whose variations make them better suited to their environment are more likely to survive and reproduce, passing on the alleles responsible for the advantageous variation to their offspring (selection and heredity). Over many generations, the frequency of advantageous alleles increases in the population, leading to a gradual change in the characteristics of the population, i.e. evolution.
12. Homologous structures have a similar underlying structure inherited from a common ancestor but may have different functions, e.g. the pentadactyl limb of a human arm and a bat wing; these provide evidence for divergent evolution from a common ancestor. Analogous structures have a similar function but a different underlying structure and evolved independently (not from a recent common ancestor), e.g. the wings of a bat and the wings of an insect; these provide evidence for convergent evolution, where unrelated organisms evolve similar adaptations to similar environmental pressures.

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