MEGA LECTURE

IB DP BIOLOGY

Theme D · Continuity and Change

MARK SCHEME

D1 DNA & Protein Synthesis · D2 Cell Division
D3 Reproduction & Inheritance · D4 Natural Selection

Standard and Higher Level · Syllabus 2025

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Original exam-style questions written for the IB Diploma Programme Biology course (first assessment 2025)

Section A — Multiple Choice: Answer Key (15 marks)

1. Answer: **B** — In semi-conservative replication, the two strands of the parental DNA molecule separate, and each acts as a template for a new complementary strand, so each resulting DNA molecule retains one original strand and gains one newly synthesized strand.

2. Answer: **B** — DNA helicase unwinds and separates the two strands of the DNA double helix, by breaking the hydrogen bonds between complementary base pairs, allowing replication to proceed.

3. Answer: **B** — RNA contains uracil instead of thymine; during transcription, adenine on the DNA template strand pairs with uracil on the newly synthesized mRNA strand.

4. Answer: **C** — Ribosomes are the site of translation, where the sequence of codons on mRNA is used to assemble a specific sequence of amino acids into a polypeptide chain.

5. Answer: **B** — Mitosis produces two daughter cells that are genetically identical to each other and to the parent cell, each with the same (diploid) chromosome number, used for growth and repair.

6. Answer: **B** — Meiosis involves two divisions and produces four genetically different daughter cells, each with half the chromosome number (haploid) of the parent cell, used to form gametes.

7. Answer: **B** — A gene (point) mutation is a change in the nucleotide sequence of DNA, which may arise spontaneously or be caused by mutagens, and can potentially alter the protein produced.

8. Answer: **B** — Interphase (comprising G1, S, and G2 phases), during which the cell grows and replicates its DNA, generally makes up the majority of the total cell cycle duration, with mitosis being comparatively brief.

9. Answer: **C** — Crossing Aa × Aa gives genotypes 1 AA : 2 Aa : 1 aa; since A is dominant, AA and Aa both show the dominant phenotype, giving an expected phenotype ratio of 3 (dominant) : 1 (recessive).

10. Answer: **B** — Continuous variation typically arises from the combined, additive effects of many different genes (polygenic inheritance), together with environmental influences, producing a smooth range of phenotypes rather than distinct categories.

11. Answer: **B** — Phenotype refers to the observable physical, physiological, or biochemical characteristics of an organism, which result from the interaction between its genotype and the environment.

12. Answer: **A** — Natural selection acts on heritable variation between individuals in a population; individuals with advantageous heritable traits are more likely to survive and reproduce, passing those traits to their offspring.

13. Answer: **B** — The peppered moth example (industrial melanism) is a classic example of natural selection: dark moths were better camouflaged (and so survived better) on soot-darkened trees during periods of high pollution.

14. Answer: **B** — Evolution can be defined, at the population genetics level, as a change in the allele frequencies of a population over successive generations.

15. Answer: **B** — Genetic drift is the random fluctuation of allele frequencies from one generation to the next due to chance events (rather than selection); its effects are proportionally much greater in small populations.

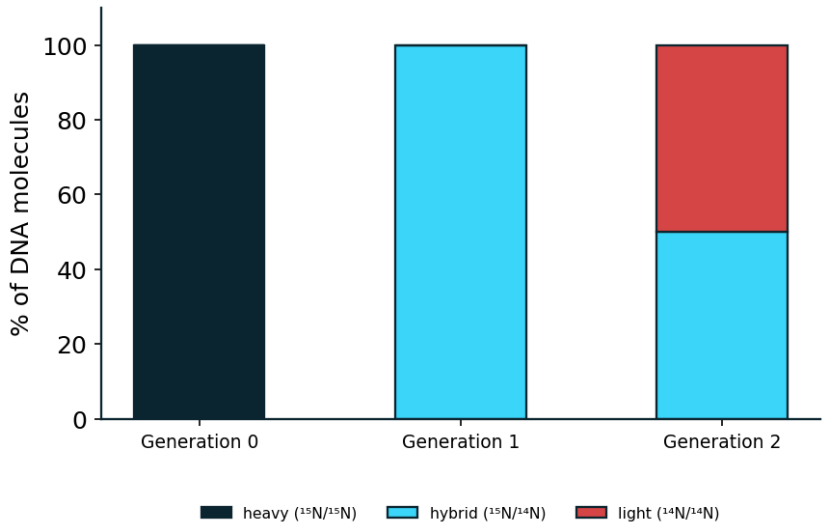
Section B — Structured Questions: Worked Solutions (65 marks)

Mark-scheme notation: M = method mark, A = accuracy mark (dependent on the preceding M mark), R = reasoning mark.

D1 DNA & Protein Synthesis

Question 1 [7 marks]

The Meselson-Stahl experiment provided evidence for semi-conservative DNA replication. Bacteria were grown in a medium containing only the heavy isotope ^{15}N, then transferred to a medium containing only the light isotope ^{14}N; DNA density was analysed after each round of replication (given data).



Proportion of heavy, hybrid, and light DNA over two generations of replication (given data).

(a) Using the graph, describe the composition of the DNA after one generation of replication in ^{14}N medium. **[2]**

After one generation, **100% of the DNA is 'hybrid'** density (one ^{15}N strand and one ^{14}N strand), with no fully heavy or fully light DNA remaining. **A1 A1**

(b) Explain how the results after two generations support the semi-conservative model of replication (rather than a conservative model). **[2]**

After two generations, the DNA is **50% hybrid and 50% light**, with **no heavy DNA remaining**. This matches the semi-conservative model, in which each strand of hybrid DNA separates and is used as a template, producing one hybrid and one light molecule from each hybrid molecule. A conservative model would instead predict a mixture of only fully heavy and fully light DNA, with no hybrid DNA – which is not observed. **R1 R1**

(c) Predict the percentage of hybrid and light DNA that would be present after a third round of replication (Generation 3). **[3]**

After a third generation, the proportion of hybrid DNA would **halve again**, giving approximately **25% hybrid** DNA and **75% light** DNA (since each hybrid molecule again produces one hybrid and one light molecule on replication, while all light DNA remains light). **M1 M1 A1**

Question 2 [6 marks]

Protein synthesis involves the processes of transcription and translation, sometimes referred to as the 'central dogma' of molecular biology.

(a) State where, in a eukaryotic cell, transcription takes place, and where translation takes place. **[2]**

Transcription takes place in the **nucleus**. Translation takes place at **ribosomes** (in the cytoplasm, either free or bound to the rough endoplasmic reticulum). **A1 A1**

(b) Outline the process of transcription. **[2]**

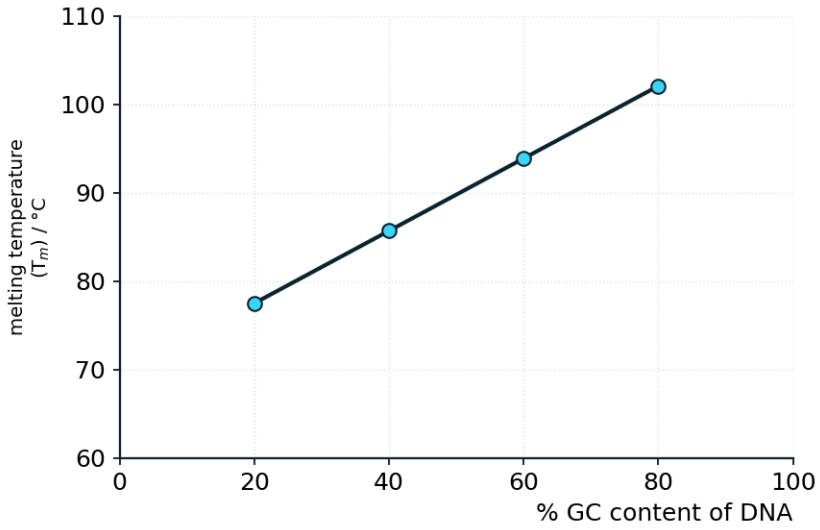
RNA polymerase binds to DNA and **unwinds a section of the double helix**; it then moves along the template strand, synthesizing a **complementary mRNA molecule** by adding RNA nucleotides according to base-pairing rules (using uracil in place of thymine). **A1 A1**

(c) Outline the process of translation. **[2]**

The ribosome moves along the mRNA, reading each **codon (triplet of bases)** in turn; a complementary **tRNA anticodon**, carrying a specific amino acid, binds to each codon, and the ribosome joins the amino acids together by **peptide bonds** to form a growing polypeptide chain. **A1 A1**

Question 3 [7 marks]

The graph shows how the melting temperature (T_m) of a DNA sample – the temperature at which the two strands separate – varies with its percentage GC content (computed using a simplified empirical model).



DNA melting temperature vs %GC content (computed, simplified model).

(a) Using the graph, describe the relationship between %GC content and DNA melting temperature. **[2]**

As %GC content **increases, the melting temperature also increases**; the graph shows a positive, roughly linear relationship between the two variables. **A1 A1**

(b) Explain, in terms of hydrogen bonding, why DNA with a higher GC content has a higher melting temperature. **[2]**

A guanine-cytosine (G–C) base pair is held together by **three hydrogen bonds**, whereas an adenine-thymine (A–T) base pair is held together by only **two hydrogen bonds**. DNA with a higher %GC content therefore has **more hydrogen bonds overall** holding the two strands together, requiring more thermal energy (a higher temperature) to break these bonds and separate the strands. **R1 R1**

(c) Using the trend shown, predict the melting temperature of a DNA sample with a GC content of 55%. **[3]**

Using the trend ($T_m \approx 69.3 + 0.41 \times \%GC$), for %GC = 55: $T_m \approx 69.3 + (0.41 \times 55) = 69.3 + 22.55 =$ **91.8°C**. **M1 M1 A1**

D2 Cell Division

Question 4 [6 marks]

Mitosis and meiosis are both forms of nuclear division, but they serve very different biological roles.

(a) State two differences between mitosis and meiosis. **[2]**

Any two of: mitosis produces **2 daughter cells**, meiosis produces **4 daughter cells**; mitosis produces **genetically identical (diploid)** cells, meiosis produces **genetically different (haploid)** cells; mitosis involves **one division**, meiosis involves **two divisions**; only meiosis involves **crossing over and independent assortment** (sources of genetic variation). **A1 A1**

(b) State the biological role of mitosis, and the biological role of meiosis. **[2]**

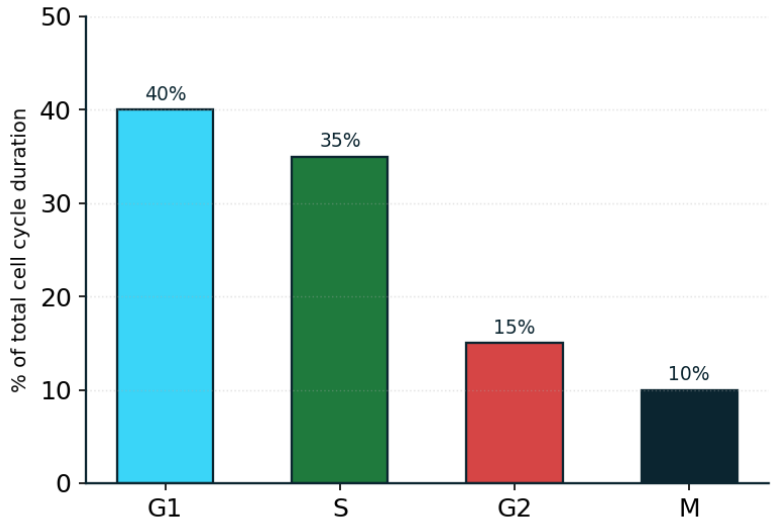
Mitosis is used for **growth, repair, and asexual reproduction** (producing genetically identical cells). Meiosis is used to produce **gametes (sex cells)** for sexual reproduction, introducing genetic variation. **A1 A1**

(c) Explain how meiosis contributes to genetic variation among offspring. **[2]**

During meiosis, **crossing over** between homologous chromosomes exchanges genetic material, creating new allele combinations; **independent assortment** of homologous chromosome pairs (and of sister chromatids) means each gamete receives a different, random combination of chromosomes. Together with random fertilization, this produces genetically varied offspring. **R1 R1**

Question 5 [7 marks]

The bar chart shows the relative duration of each phase of the cell cycle for a typical dividing cell with a 24-hour cell cycle (given data).



Relative duration of cell cycle phases (given data, % of a 24-hour cycle).

(a) Using the graph, identify which phase of the cell cycle occupies the greatest proportion of time. **[2]**

G1 occupies the greatest proportion of the cell cycle, at 40% of the total 24-hour cycle. **A1 A1**

(b) Calculate the actual time, in hours, spent in the M (mitosis) phase of this 24-hour cell cycle. **[2]**

Time in M phase = 10% × 24 hours = **2.4 hours**. **M1 A1**

(c) Describe what occurs during the S phase of the cell cycle. **[3]**

During the **S (synthesis) phase**, the cell replicates its **DNA** (each chromosome is copied to produce two identical sister chromatids joined at a centromere), so that each daughter cell produced by the subsequent mitosis will receive a complete, identical copy of the genome. **A1 A1 A1**

Question 6 [6 marks]

Mutations are changes in the nucleotide sequence of DNA, and can have a range of effects.

(a) Distinguish between a substitution mutation and a deletion mutation. **[2]**

A **substitution mutation** occurs when one nucleotide base is **replaced by a different base**. A **deletion mutation** occurs when one or more nucleotides are **removed** from the DNA sequence. **A1 A1**

(b) Explain why a deletion mutation is often more harmful to the resulting protein than a substitution mutation. **[2]**

A deletion mutation typically causes a **frameshift**: since codons are read in groups of three, removing one or two bases shifts the reading frame for **every subsequent codon**, usually altering most of the amino acid sequence downstream. A substitution mutation usually only changes **a single codon** (and therefore at most one amino acid), so its effect is often more limited. **R1 R1**

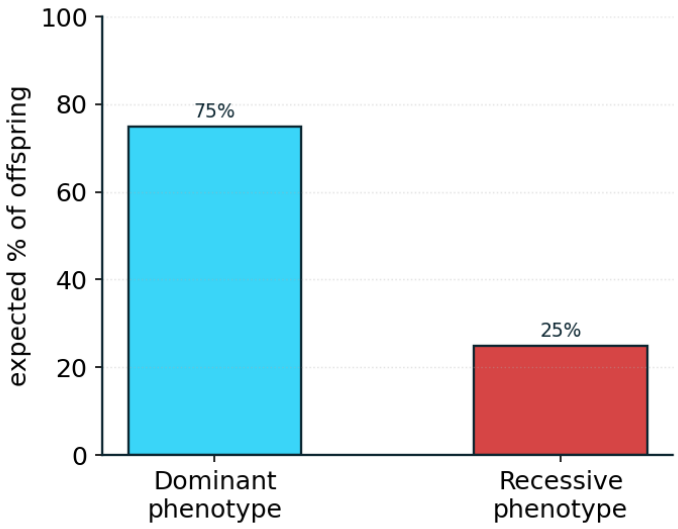
(c) Explain why most mutations do not have a significant effect on an organism's phenotype. **[2]**

Many mutations occur in **non-coding regions of DNA** that do not code for protein. Due to the **degeneracy (redundancy) of the genetic code**, some substitution mutations do not change the amino acid produced (silent mutations). Additionally, some mutations occur in **body (somatic) cells** and are not passed on to offspring. **R1 R1**

D3 Reproduction & Inheritance

Question 7 [7 marks]

The bar chart shows the expected phenotype ratio among the offspring of a monohybrid cross between two heterozygous individuals, Aa × Aa, where A (dominant) codes for the dominant phenotype and a (recessive) codes for the recessive phenotype (computed).



Expected phenotype ratio for a monohybrid cross, Aa × Aa (computed).

(a) Using the graph, state the expected phenotype ratio (dominant : recessive) for this cross. **[2]**

The expected phenotype ratio is **3 (dominant) : 1 (recessive)**, i.e. 75% of offspring show the dominant phenotype and 25% show the recessive phenotype. **A1 A1**

(b) Using a Punnett square (or genotype reasoning), explain why this 3:1 ratio arises from an Aa × Aa cross. **[2]**

Each parent (Aa) produces gametes carrying either A or a with equal probability. Combining these gives offspring genotypes in the ratio **1 AA : 2 Aa : 1 aa**. Since A is dominant, both AA and Aa individuals show the dominant phenotype, giving **3 parts dominant phenotype to 1 part recessive phenotype**. **R1 A1**

(c) In a large sample of 200 offspring from this cross, calculate the expected number showing the dominant phenotype. **[3]**

Expected number = 75% × 200 = **150 offspring** (with the remaining 50 expected to show the recessive phenotype). **M1 M1 A1**

Question 8 [6 marks]

Variation among individuals in a population can be classified in different ways.

(a) Distinguish between continuous variation and discontinuous (discrete) variation, giving one example of each. **[2]**

Continuous variation shows a smooth, unbroken range of phenotypes (e.g. human height or skin colour). **Discontinuous (discrete) variation** shows a small number of distinct, separate categories with no intermediates (e.g. human ABO blood group, or pea plant seed shape: round or wrinkled). **A1 A1**

(b) Explain why discontinuous variation is usually controlled by a single gene, while continuous variation is usually polygenic. **[2]**

A trait controlled by a **single gene** with a small number of alleles typically produces a **limited number of distinct phenotype categories** (discontinuous variation). A trait influenced by **many different genes** (polygenic), each contributing a small additive effect, produces a much wider, smoothly graded range of possible phenotypes (continuous variation). **R1 R1**

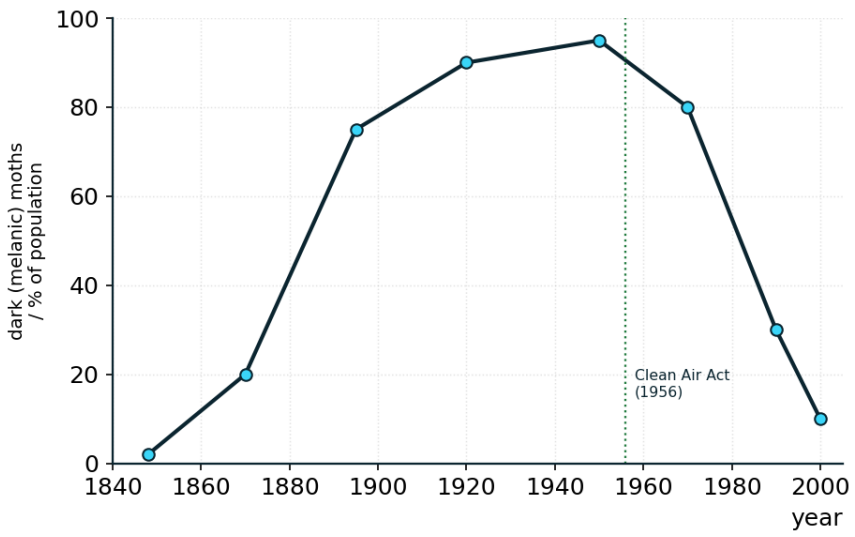
(c) Explain how the environment can contribute to variation, even between individuals with identical genotypes. **[2]**

Environmental factors (such as diet, temperature, light, or exercise) can influence how a genotype is expressed as a phenotype. For example, identical twins (same genotype) may differ in **height or body mass** due to differences in **diet or exercise**, showing that phenotype depends on both genotype and environment. **R1 A1**

D4 Natural Selection

Question 9 [7 marks]

The graph shows the percentage of dark (melanic) peppered moths in a population near an industrial city, from 1848 to 2000 (given data), a classic example of natural selection.



Percentage of dark (melanic) peppered moths over time (given data).

(a) Using the graph, describe how the percentage of dark moths changed between 1848 and 1950. **[2]**

The percentage of dark moths **increased steadily** from about 2% in 1848 to about 95% in 1950, a total rise of approximately 93 percentage points. **A1 A1**

(b) Explain, in terms of natural selection, why dark moths became more common during this period of heavy industrial pollution. **[2]**

Industrial pollution darkened tree bark and killed lichen, making **dark moths better camouflaged** from bird predators (and light moths more conspicuous). Dark moths therefore **survived and reproduced more successfully**, passing on the melanic allele to more offspring, so the allele (and dark phenotype) became more frequent in the population over successive generations. **R1 R1**

(c) Using the graph, describe and explain the change in the percentage of dark moths after 1950. **[3]**

After 1950, the percentage of dark moths **decreased** (falling by about 85 percentage points to 2000), most noticeably after the Clean Air Act (1956). As **pollution was reduced**, tree trunks became lighter again (and lichen recolonized), so **light moths regained a camouflage advantage** over dark moths; light moths were then selected for, increasing their frequency again while the melanic allele frequency declined. **A1 R1 R1**

Question 10 [6 marks]

Evolution by natural selection requires several key conditions to operate.

(a) State three conditions necessary for natural selection to occur in a population. **[2]**

Any three of: **variation** must exist among individuals; this variation must be **heritable** (passable to offspring); organisms must produce **more offspring than the environment can support** (overproduction); individuals must face a **struggle for survival/competition for resources**, leading to differential survival and reproduction. **A1 A1**

(b) Distinguish between natural selection and genetic drift. **[2]**

Natural selection is a non-random process in which certain heritable traits give individuals a survival/reproductive advantage, causing allele frequencies to change in a consistent direction. **Genetic drift** is a **random, chance change** in allele frequencies, unrelated to any survival or reproductive advantage, and has a proportionally greater effect in small populations. **A1 A1**

(c) Outline two forms of evidence (other than direct observation of natural selection) that support the theory of evolution. **[2]**

Any two of: the **fossil record** (showing a chronological sequence of gradually changing forms); **comparative anatomy** (e.g. homologous structures shared by related species, such as the pentadactyl limb); **molecular/DNA sequence comparisons** (showing greater similarity between more closely related species); **biogeography** (distribution patterns of species consistent with common ancestry and geographic isolation). **A1 A1**