## Matrix template

| Element of examination | Competence(s) ** | Weight in % | Learning Objective(s) | Questions | Evaluation/Marking | Weight in points |
|---|---|---|---|---|---|---|
| Physiology (35 - 40 points *) | Knowledge and Comprehension | +/-40% | The current syllabuses for the scientific subjects do not have defined Learning Objectives. These will be included in the new syllabuses to be published in February 2021. | | Paper-specific Marking Scheme | |
| | Application | +/-40% | | | Paper-specific Marking Scheme | |
| | Analysis (and Evaluation) | +/-20% | | | Paper-specific Marking Scheme | |
| | | | | | | **(35-40) *** |
| Genetics (35 - 40 points *) | Knowledge and Comprehension | +/-40% | | | Paper-specific Marking Scheme | |
| | Application | +/-40% | | | Paper-specific Marking Scheme | |
| | Analysis (and Evaluation) | +/-20% | | | Paper-specific Marking Scheme | |
| | | | | | | **(35-40) *** |
| Evolution (20 points) | Knowledge and Comprehension | +/-20% | | | Paper-specific Marking Scheme | |
| | Application | +/-40% | | | Paper-specific Marking Scheme | |
| | Analysis (and Evaluation) | +/-40% | | | Paper-specific Marking Scheme | |
| | | | | | | **20** |
| (5 points) | Written communication | (100%) | | Overall | Rubric for Communication *** | **5** |
| **Total exam** | | | | | | **100** |

**N.B.: A single question may encompass more than one competence.**

* In total P and G parts must always be 75 points

| | | |
|---|---|---|
| ** Overall: | **Knowledge and Comprehension:** | **+/- 35%** |
| | **Application:** | **+/- 40%** |
| | **Analysis (and Evaluation):** | **+/20%** |
| | **Written communication:** | **5%** |

*** Rubric for communication:

The mark for written communication is to be allocated globally, taking into account the following criteria:
Candidate employs correct and appropriate scientific **vocabulary** (no penalties for spelling unless content meaning is compromised). Candidate's **graphical representations** (including graphs, diagrams, sketches, etc.) are clear, neatly constructed, suitably sized and scaled, appropriately titled and labelled, and correct. Candidate constructs **logical and concise answers**, subordinating parts to the whole, integrating the data and information provided. Candidate **argues coherently**, employing a clear point of view.
Candidates may not lose all of the points allocated to the assessment of written communication for faults in any single one of the criteria above. A mark of 5 points may be allocated for an overall excellent, but not necessarily flawless, performance.

## Sample paper matrix

| Element of examination | Competence(s) ** | Weight in % | Learning Objective(s) | Questions | Evaluation/Marking | Weight in points |
|---|---|---|---|---|---|---|
| Physiology (35 - 40 points *) | Knowledge and Comprehension | +/-40% | The current syllabuses for the scientific subjects do not have defined Learning Objectives. These will be included in the new syllabuses to be published in February 2021. | i); iii); iv); vi) | Paper-specific Marking Scheme | 15 |
| | Application | +/-40% | | ii); parts of v); viii); ix); xi); xii) | Paper-specific Marking Scheme | 16 |
| | Analysis (and Evaluation) | +/-20% | | Parts of v); vii); x) | Paper-specific Marking Scheme | 9 |
| | | | | | | **40** |
| Genetics (35 - 40 points *) | Knowledge and Comprehension | +/-40% | | Parts of ii); iv); vi); vii); viii), | Paper-specific Marking Scheme | 14 |
| | Application | +/-40% | | i); parts of ii); iii); v); parts of ix); x); xii) | Paper-specific Marking Scheme | 14 |
| | Analysis (and Evaluation) | +/-20% | | Parts of ii); parts of ix); xi) | Paper-specific Marking Scheme | 7 |
| | | | | | | **35** |
| Evolution (20 points) | Knowledge and Comprehension | +/-20% | | i) | Paper-specific Marking Scheme | 4 |
| | Application | +/-40% | | ii); iii); iv) | Paper-specific Marking Scheme | 8 |
| | Analysis (and Evaluation) | +/-40% | | v); vi) | Paper-specific Marking Scheme | 8 |
| | | | | | | **20** |
| (5 points) | Written communication | (100%) | | Overall | Rubric for Communication *** | **5** |
| **Total exam** | | | | | | **100** |

# BIOLOGY

**DATE:**

**DURATION OF EXAMINATION:**

3 hours (180 minutes)

**PERMITTED EQUIPMENT:**

- Calculator TI-Nspire™ in 'Press-to-Test' mode
- Millimetre graph paper
- Pencils for diagrams and graphs

**INSTRUCTIONS:**

- Begin the answer to each question (P, G and E) on a new page.

**Question P**

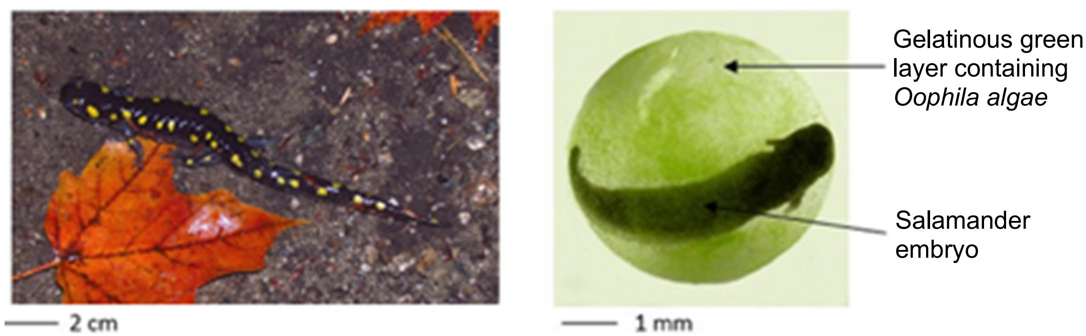
**Page 1/4** | **Marks**

## Algae and Salamander - A Symbiosis?

The eggs of the salamander *Ambystoma maculatum* are very unusual: they are often green. This is because they contain not only the developing salamander embryo, but also a species of single-called green algae, *Oophila amblystomatis,* that is found nowhere else in nature.

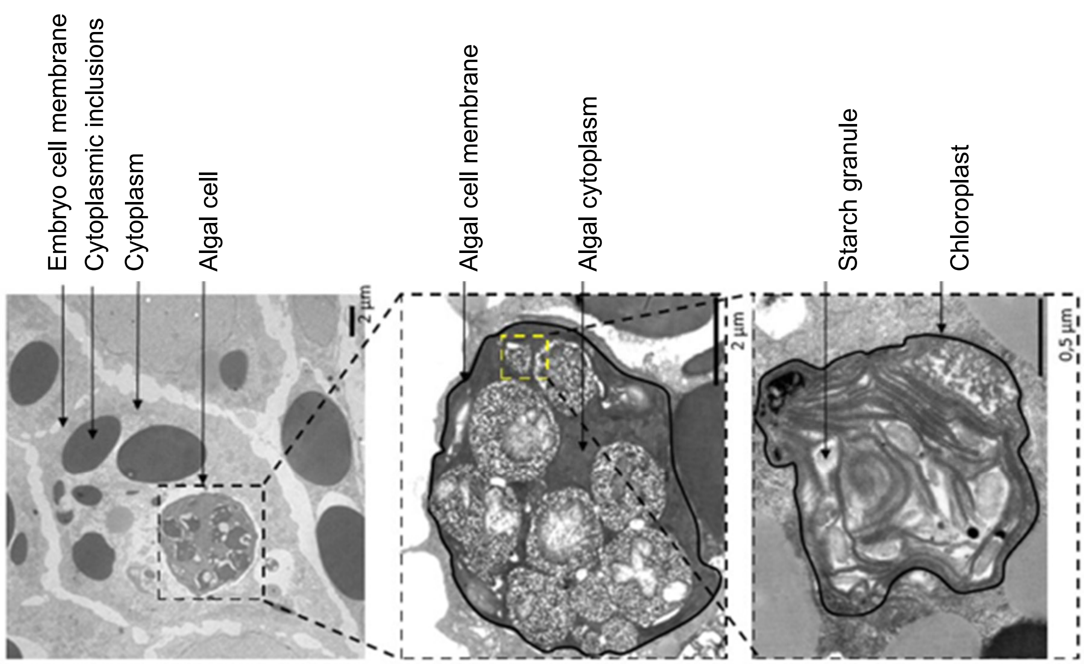
Female *Ambystoma maculatum* lay their eggs in spring in clear freshwater in snowmelt ponds. Cells of the alga, *Oophila amblystomatis,* can penetrate and live in the salamander eggs and the developing salamander embryos. These algae are only found in association with *Ambystoma*; they are unable to live independently. However, the salamanders are also found without the algae.

**Figure 1**: The association between salamander and algae.




*Ambystoma maculatum* adult | Green salamander egg

**Figure 2**: Electron micrographs of salamander embryo cells at several magnifications (see scale bars).

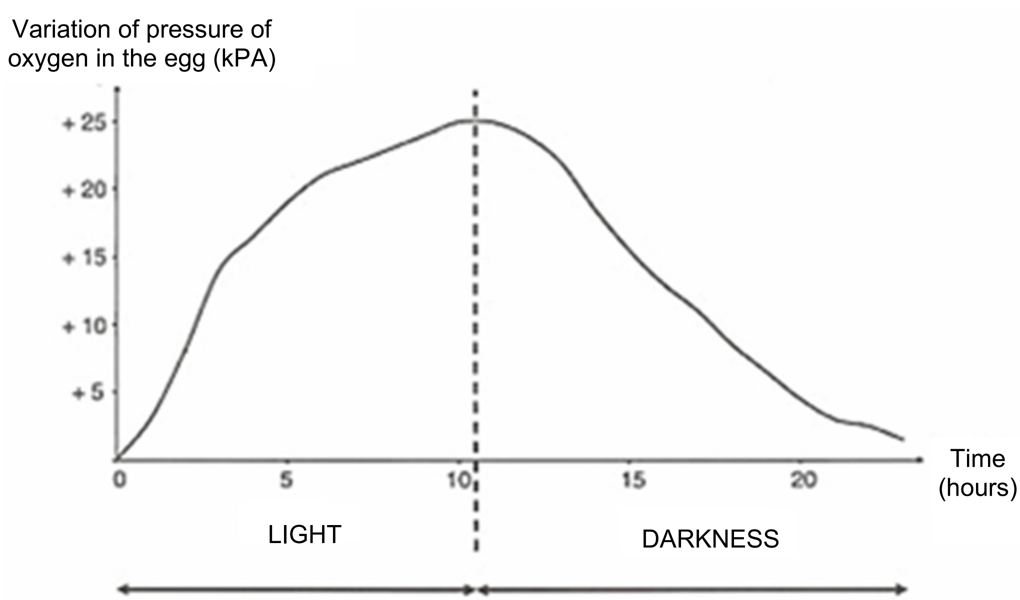


**Question P**

| Page 2/4 | Marks |
|---|---|
| i. Sketch and label the structures of a chloroplast. | 5 |
| ii. Using figure 2, estimate the diameter of an *Oophila* chloroplast. Explain your reasoning. | 2 |
| iii. In your sketch for question i, indicate where each of the two stages of photosynthesis takes place. | 2 |
| iv. Name the reactants and products of each stage and explain how the stages are related by these reactants and products. | 4 |

**Figure 3** shows the variation of partial pressure of oxygen in the gelatinous layer of a salamander egg containing an embryo and algae, over the course of a full day, first in light and then in darkness. Note: If the egg does <u>not</u> contain algae, the oxygen level remains approximately constant.

**Fig. 3**




| | |
|---|---|
| v. Explain which types of metabolism are occurring during each phase shown on the graph in figure 3. | 5 |
| vi. ATP is the primary molecule used by cells for energy transfer. Give an overview of the steps of ATP synthesis common to both types of metabolism taking place in algal and salamander cells. | 4 |

**Question P**

**Page 3/4** | **Marks**

Scientists have experimented with removing salamander embryos from eggs, leaving only the algae. The results are shown in **figure 4**.

**Fig. 4**: Algal development in the gelatinous layer of salamander eggs, with or without salamander embryos, under normal day and night light conditions.

| *Number of + indicates the relative strength of the phenomenon below* | Algae in the gelatinous layer, with embryo present | Algae in the gelatinous layer, without embryo present |
|---|---|---|
| Algal synthesis of organic compounds | +++ | + |
| Algal reproduction | +++ | + |

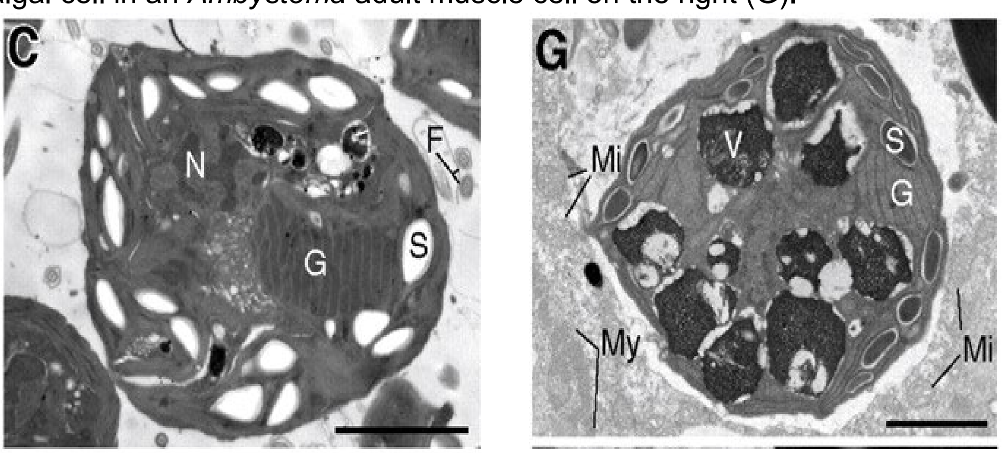
vii. Describe the results of the experiment shown in figure 4. **4**

viii. Explain which product of the embryo is used by the algae. Name the process that produces it and the process that uses it. **2**

ix. Explain which product of the algae is used by the embryo. Name the process that produces it and the process that uses it. **2**

The results that we have discussed so far make it appear that the algae and the salamanders coexist in a happy symbiosis, mutually beneficial to each partner. However, the situation may not be so clear. While the salamanders can live without the algae, the *Oophila* algae are completely dependent on the salamanders: they must infiltrate the salamander's body in order to reach the next generation of eggs. It's dark inside a salamander, making photosynthesis impossible. A team of Canadian scientists led by Ryan Kerney and John Burns found algal cells within adult salamander muscle cells. These algae show clear signs of stress and oxygen deprivation. **Figure 5** compares an alga found in a salamander egg with an alga found in a muscle cell.

**Fig. 5**: Electron micrograph of an algal cell in a salamander egg on the left (C), and an algal cell in an *Ambystoma* adult muscle cell on the right (G).




N: nucleus. G: chloroplast grana. S: starch granule. The scale bar shows 2 µm.

| Question P | |
|---|---|
| **Page 4/4** | **Marks** |
| x. Give two significant differences between the algal cells depicted in figure 5 that indicate the stress referred to in the text above. | **2** |
| xi. Taking figure 5 and the conditions for intramuscular algal cells described above into account, propose a hypothesis about the energy metabolism employed by *Oophila* algae, between salamander egg generations, to ensure their survival. | **3** |
| xii. Given all the information in this section (the P Question), evaluate whether the relationship between algae and salamanders can be characterized as entirely mutually beneficial. In your answer, consider the different types of metabolism carried out by both salamanders and algae at different stages of the salamander's life cycle. | **5** |

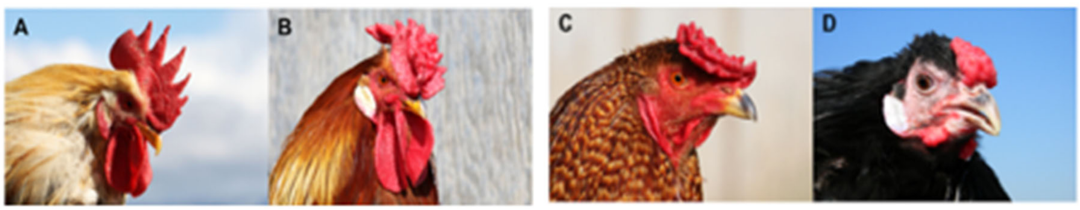
## Question G

**Page 1/4** **Marks**

Chickens (*Gallus gallus domesticus*) are among the best-studied of vertebrates; they are useful model organisms because of their economic importance, relatively fast generation time, the relative ease of studying embryonic development, and the many breeds humans have created by artificial selection in at least 5000 years of domestication.

Among the characters breeders have singled out for attention is the *comb* (the fleshy crest on top of the head). Chickens' wild ancestors had what breeders call a *single comb*, but many other types have spontaneously appeared from time to time and then been selected for by breeders (see **figure 1**).

**Fig. 1:** Some types of combs found in various chicken breeds.




A: single comb. B: rose comb. C: pea comb. D: walnut comb.

The British scientists William Bateson and Reginald Punnett carried out important breeding experiments on chickens in the early 20th century, demonstrating that Mendel's ideas applied to animals as well as plants. In one of these experiments, they bred Leghorn chickens, which have white feathers and single combs, with Indian Game chickens, which have dark feathers and pea combs.

They found that white plumage (W) and pea combs (P) are dominant traits.

i. Construct the Punnett square for a dihybrid cross for plumage color (W/w) and comb shape (P/p) between the chickens produced in the cross above. **2**

Bateson and Punnett also found that comb shape is controlled by genes at multiple loci; for example, whether a chicken has a rose comb (see **figure 1**) is determined by an entirely different gene from the one that gives a pea comb. First, Bateson and Punnett crossed chickens with rose combs with others with single combs. All F1 individuals had rose combs, and when F1s were crossed with each other, a 3:1 ratio of rose to single combs resulted.

Then, when they crossed pure-breed individuals with rose combs with pure-breed individuals with pea combs, they found that a new phenotype was generated: all of the offspring had walnut combs (see **figure 1**).

When these walnut-comb F1s were crossed with each other, all four phenotypes (walnut, pea, rose, and single) reappeared, in a ratio of 9:3:3:1 respectively in the F2.

ii. Name and explain the phenomenon that gives rise to the walnut phenotype. **3**

iii. Deduce the genotype of chickens with walnut combs. **1**

**Question G**

| **Page 2/4** | **Marks** |
|---|---|

Bateson and Punnett, together with a third collaborator, Edith Saunders, are also famous in the history of genetics for the discovery of a phenomenon shown in the following data.

When purebred white chickens having a crest (a tuft of long feathers on top the head, genotype CCWW) were crossed with purebred dark chickens without a crest (genotype ccww), the F1 were all white and crested.

These F1 were then test-crossed/back-crossed.

iv. Explain what a test cross is and why it is useful. **2**

The following results were obtained:

| | *Number of offspring* |
|---|---|
| crested, white | 337 |
| no crest, dark | 337 |
| crested, dark | 34 |
| no crest, white | 46 |
| *Total* | 754 |

Similar results are obtained when crossing white chickens with normal feathers with coloured birds having "frizzled" feathers (see **figure 2**); white frizzled birds and dark normal-feathered birds together make up about 17% of the total number of chicks.

**Fig. 2**. A Tolbunt Polish Frizzle hen.


A trait called "fray", which causes defective feathers, is also associated with this group of traits, which have all been localized to chromosome 7. Breeding experiments have shown 46% recombination between fray and crest, and 27.6% recombination between crest and frizzle. A series of breeding experiments have yielded a figure of 73.6% between fray and frizzle.

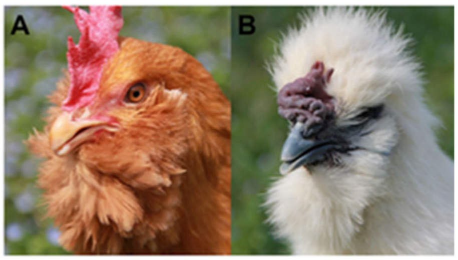
v. Draw a map to scale of the section of chromosome 7 that includes the traits for white plumage, crest, frizzle, and fray. Justify with the information given above. **4**

**Question G**

**Page 3/4** **Marks**

One autosomal locus in chickens, with two incompletely dominant alleles, Mb and mb, gives rise to three possible phenotypes. Muffs-and-beards (Mb/Mb) is shown in **figure 3**, below right. Beards (Mb/mb) is the intermediate phenotype (below left). Individuals with mb/mb genotype have neither muffs nor beards.

**Fig. 3**




A) Huiyang Bearded (HB) chicken

B) Silky-feather chicken with muffs and beard.

A study by Y. Guo et al. showed that the Mb allele is a structural mutation resulting from duplications of three regions on chicken chromosome 27. Two of these regions have also been translocated and inserted between the repeats of the first duplication. To find the exact insertion loci, PCR was performed in both Mb/Mb and mb/mb chickens.

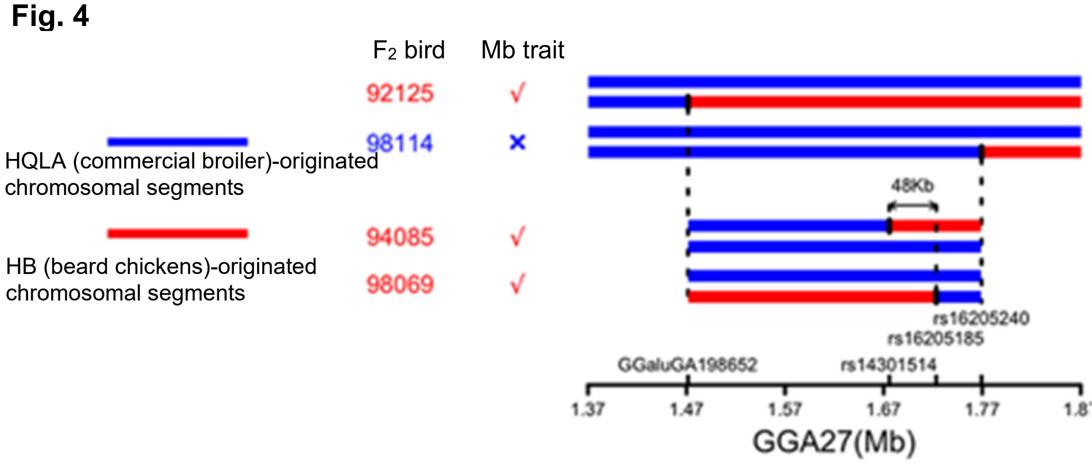
vi. Give an overview of the three main steps of the process of PCR. **3**

vii. Define duplication and translocation and explain with sketches how and when they happen. **5**

viii. Sketch the overall structure of a gene in a eukaryote such as a chicken (without details of nucleotide sequences), labelling regions as appropriate. **3**

**Figure 4** below shows part of chicken chromosome 27. The blue and red bars represent the Mb locus on chicken chromosome 27 (labeled GGA27 below), for four birds produced from an F2 cross between F1 hybrids of bearded chickens (Mb/Mb) and commercial broiler chickens (mb/mb).

**Fig. 4**



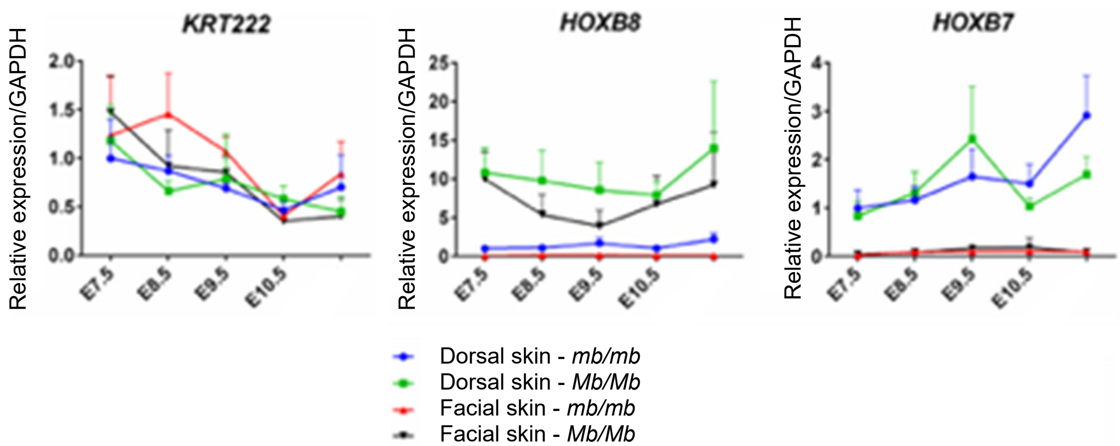

ix. With reference to figure 4 and the information about the Mb trait given above, deduce why the second bird ($F_2$ bird 98114) does not exhibit the Mb trait, while the other three birds do. **4**

**Question G**

| | **Page 4/4** | **Marks** |
|---|---|---|

Guo et al. performed gene expression analyses in dorsal and facial skin tissue from embryos and chicks. Samples from Mb/Mb and mb/mb chickens were collected at embryonic (E) days 7.5, 8.5, 9.5, 10.5 and two weeks after hatching. The expression of three genes, KRT222, HOXB8, and HOXB7 in the developing chick's skin (dorsal refers to back of the head, and facial to the front and sides) was normalized to the expression of GAPDH, a gene for an enzyme that catalyses the sith step og glycolysis. The results are shown in **figure 5** below.

**Fig. 5. E**xpression of three genes during the critical stages of feather development, relative to the expression of GADPH.

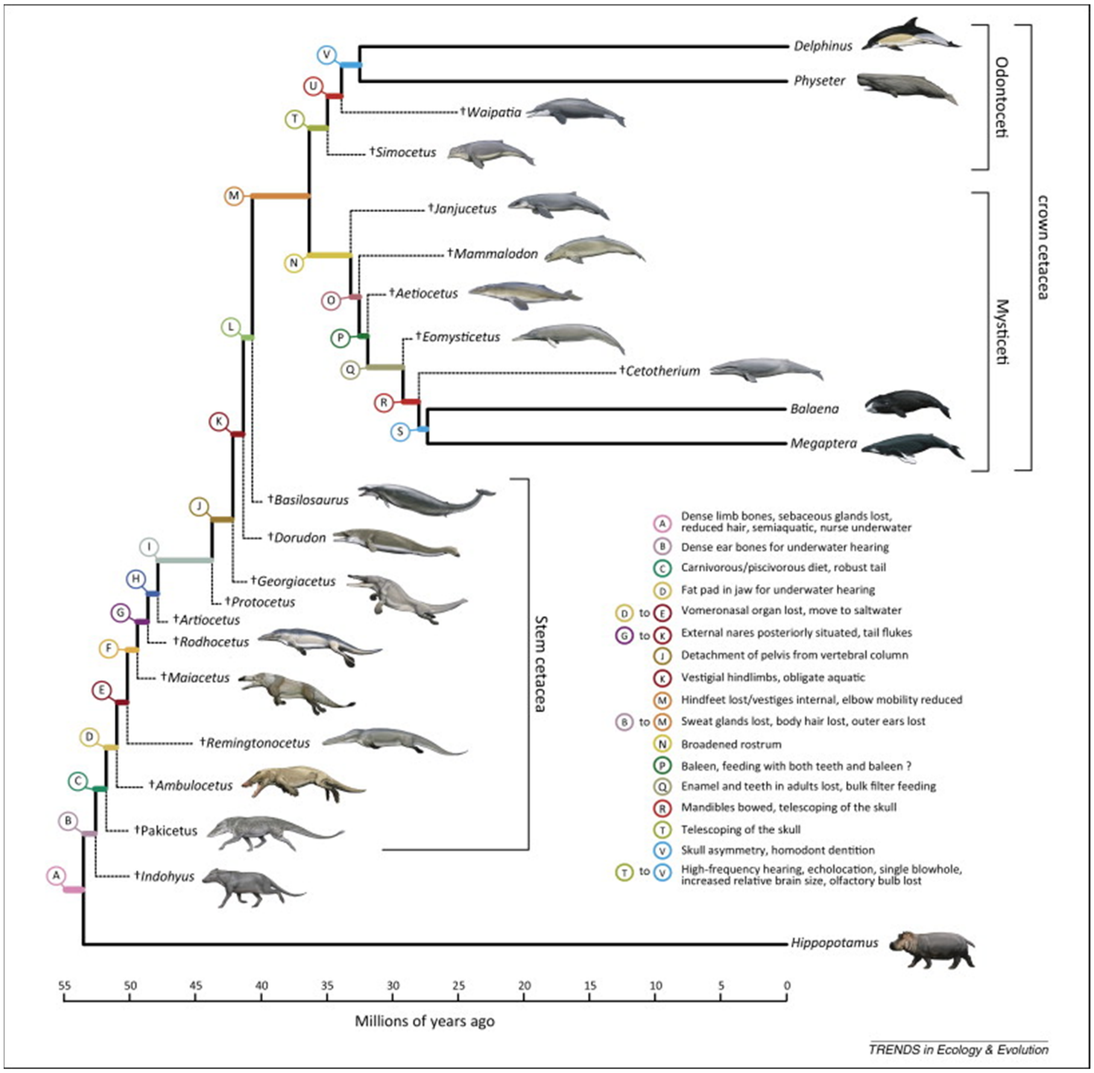



| | Marks |
|---|---|
| x. Deduce the value of using the rate of expression of the GADPH gene, as a basis for comparison. | 2 |
| xi. Deduce which of the three genes in the graph above corresponds to Mb in the production of beards and muffs in chickens. Refer to figure 5 in support of your answer. | 4 |
| xii. Making reference to figure 5 and the process of transcription in your answer, propose a hypothesis about how the expression of the gene you identified in question xi correlates with the muffs-and-beards phenotype. | 2 |

| Question E | |
|---|---|
| **Page 1/2** | **Marks** |

In 2014, scientists Michael McGowen, John Gatesy and Derek Wildman published a synthetic overview of the evolution of the order Cetacea (whales and dolphins), including a diagram proposing a phylogeny for the genera of modern and extinct whales (known from fossils), given here as **figure 1.**

**Fig. 1**




| | | |
|---|---|---|
| i. | Describe four types of evidence scientists may draw on to create phylogenies like this one. | 4 |
| ii. | Using figure 1, give the approximate date of the most recent common ancestor of the crown cetacea and *Georgiacetus.* | 1 |
| iii. | Using figure 1, give the characters that all Odontoceti have in common, which distinguish them from the Mysticeti. | 2 |

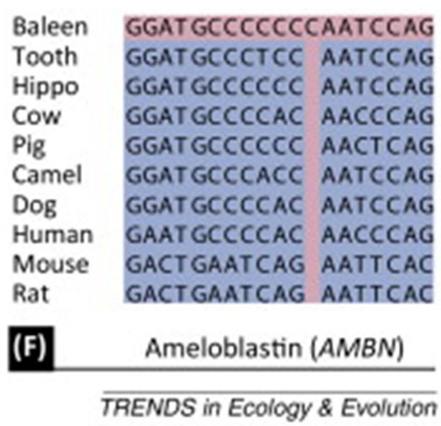
| Question E | |
|---|---|
| **Page 2/2** | **Marks** |

One striking feature of modern cetaceans is the blowhole: the nostrils are located at the top of the skull, so that the animal does not need to surface fully to breathe. The earliest stem cetacea shown in **figure 1** had nostrils at the front of the skull, as in other mammals; the nostrils of *Basilosaurus* and *Dorudon* are midway between the snout and the top of the head.

iv. Explain how natural selection could have led to the evolution of the blowhole as the cetacean lineage shifted to fully aquatic. **5**

**Figure 2** provides comparative DNA sequences for part of the gene for the ameloblastin protein, which is essential to the construction of enamel, the surface coating of teeth. Baleen whales (shown on **figure 1** by the genera *Balaena* and *Megaptera*), do not have teeth, but feed using baleen, combs made of keratin, the same protein of which hair is made. Toothed whales (represented by *Delphinus* and *Physeter*) do have teeth, with enamel, like those of other mammals.

**Fig. 2**. Comparison of DNA sequences for ameloblastin across ten species, aligned for best match. The vertical pink line indicates where there is an extra nucleotide in the baleen whale sequence, not found in any of the others.




v. Identify and name the changes that have created the differences between the baleen and toothed whale sequences, and explain their possible consequences at the protein level. **5**

Scientists describe non-functioning genes such as the one for ameloblastin in baleen whales as pseudogenes.

vi. Propose a hypothesis about why the pseudogene allele was not eliminated from the baleen whale lineage. **3**

# BIOLOGY

Marking scheme

**DATE:** XX June 20XX

This marking scheme was elaborated by the experts for the correctors.

The experts have tried to be as exhaustive as possible and offer a breakdown as to how marks within a question must be allotted.

However, capabilities and knowledge can be expressed in many ways and this should be taken into account by each corrector.

## Overall

**5 marks:**

Candidate employs correct and appropriate scientific **vocabulary** (no penalties for spelling unless content meaning is compromised). Candidate's **graphical representations** (including graphs, diagrams, sketches, etc.) are clear, neatly constructed, suitably sized and scaled, appropriately titled and labelled, and correct. Candidate constructs **logical and concise answers**, subordinating parts to the whole, integrating the data and information provided. Candidate **argues coherently**, employing a clear point of view.

Candidates may not lose all of the points allocated to the assessment of written communication for faults in any single one of the criteria above. A mark of 5 points may be allocated for an overall excellent, but not necessarily flawless, performance.

## Question P

i. Clear, neatly labelled sketch (2), including: double membrane, thylakoids, stroma, starch granules, ribosomes, DNA (3).

ii. The cell is about 4x the size of the measurement bar of 0.5 μm (1), which gives about 2 μm (1).

iii. Light dependent reactions, across thylakoid membrane or around and inside thylakoids (1); light independent reactions, in the stroma (1).

iv. Light-dependent phase: reactants: $H_20$, NADP, ADP, Pi. Products: $NADPH_2$, ATP, $O_2$ (1).

Light-independent phase: reactants: ATP, $NADPH_2$, $CO_2$, RuBP. Products: G3P, ADP, Pi, NADP (1).

The products of the light-dependent phase are the reactants of the light independent phase (1).

The ATP generated in the light-dependent phase stores energy for the light-independent phase, and the $NADPH_2$ provides protons and electrons/reducing power to it (1).

v. The increasing partial pressure of $O_2$ shows that it is being produced under light conditions: photosynthesis is occurring (1.5). The decreasing pressure of $O_2$ in the dark means it is being consumed (without being replenished): respiration is occurring (1.5). However, respiration must also be occurring under light (since the organisms concerned are alive), even if this cannot be demonstrated using the graph. Any reference to gross and net gains from photosynthesis (2).

vi. The electron transport chain (1) uses electrons to drive the creation of a proton gradient across a membrane (1) (chloroplasts: thylakoid membrane; mitochondria: cristae (1)), which powers ATP synthesis via ATP synthase complexes (1).

vii. When the embryo is present, algae reproduce faster and synthesize more organic compounds than when it is not (1 point corresponding to explanation of each table cell: 4 total).

viii. $CO_2$ produced by the respiration (Krebs cycle) of the embryo is used by the algae (1) (Calvin cycle); any correct explanation related to metabolism (1).

ix. $O_2$ produced by photosynthesis (photo-oxidation of $H_2O$) is used by embryo (1) (in respiration as the final electron acceptor in the electron transport chain); any correct explanation related to metabolism (1).

x. The alga in the muscle cell has fewer and smaller starch granules (1), and smaller thylakoids/chloroplasts (1) than the alga in the egg.

xi. Reduced oxygen means little or no respiration (1); no light means no photosynthesis (1), so they must have to carry out fermentation (1).

xii. Any coherent, well-reasoned answer, incorporating data from the whole P section, is acceptable. (5) For example:

At the egg stage, the association is clearly mutual beneficial (consider figures 3 and 4; see also the answers to questions 5-9): photosynthesis adds energy and oxygen that are available to be used by both organisms. Respiration generates $CO_2$, which algae can use for photosynthesis. (Pupils may also observe that algae benefit from salamander waste as fertilizer.)

After hatching, algal photosynthesis stops because of the lack of light, and algae have to struggle to survive inside salamander cells, which apparently provide them with nothing, until they can reach the next egg generation. The products of algal fermentation may also be toxic to the algae and possibly the salamanders as well.

**Question G**

i. *P*

*Phenotypes: White plumage and single combs x Dark feathers and pea combs*
*Genotypes WWpp x wwPP*
*Gametes all Wp all wP*

*F1*
*Genotypes All WwPp*
*Phenotypes All white with pea combs*
*Gametes WP, Wp, wP, wp*

F2

| | WP | Wp | wP | wp |
|---|---|---|---|---|
| WP | WWPP | WWPp | WwPP | WwPp |
| Wp | WWPp | WWPp | WwPp | Wwpp |
| wP | WwPp | WwPp | wwPP | wwPp |
| wp | WwPp | Wwpp | wwPp | wwpp |

1 mark for gametes
1 mark for F2 genotypes

ii. Polygenic inheritance <u>or</u> a polygenic trait (1), in which two non-allelic genes influence the same trait (1) but interact to produce a phenotype that could not result from the action of either gene independently (1).

iii. R_P_ (1)

iv. A test cross is used to establish the genotype of an individual with the dominant phenotype but an unknown genotype (1) by crossing the individual with the unknown genotype with a homozygous recessive individual. The results reveal the unknown genotype through the proportions of offspring produced (1).

v.

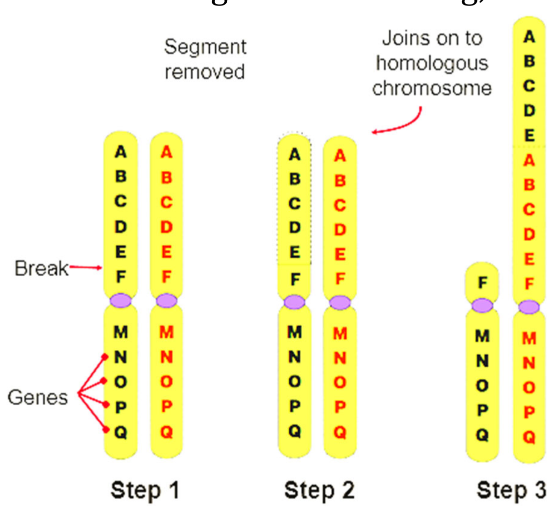
| CROSS | % Recombination |
|---|---|
| Crest (C/c) x White (W/w) | 10.6% |
| White (W/w) / Frizzle (F/f) | 17% |
| Fray (R/r) / Crest (C/c) | 46% |
| Crest (C/c) / Frizzle (F/f) | 27.6% |
| Fray (R/r) / Frizzle (F/f) | 73.6% |

(4)

vi. Polymerase chain reaction or PCR involves the following steps:
Separate the target DNA strands by heating at 98°C for 5 minutes (1).
Add primers, nucleotides (A, T, G and C) and DNA polymerase enzyme (1)
Cool to 60°C and incubate for a few minutes. During this time, primers attach to single-stranded DNA. DNA polymerase synthesizes complementary strands (1)
(Repeat cycle of heating and cooling until enough copies of the target DNA have been produced.)

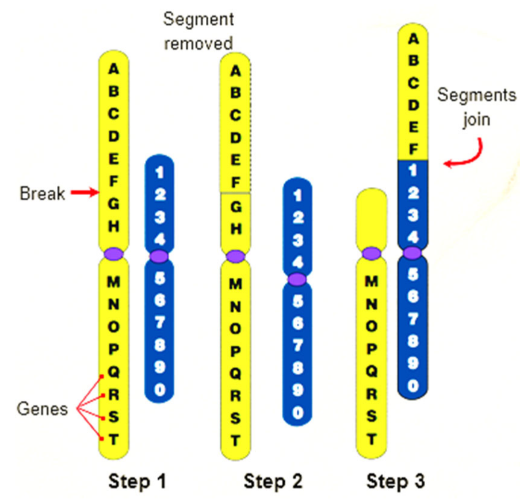
vii. Both occur during prophase I of meiosis (1).
Duplication: a segment is lost from one chromosome and is added to its homologue (1).

1 mark for a suitable diagram as below e.g;




Translocation involves the movement of a group of genes between different chromosomes. A piece of one chromosome breaks off and joins on to another non-homologous chromosome (1).

1 mark for a suitable diagram as below e.g.




viii. Half mark for diagram and half mark for each correct label e.g.


ix. Bird 98114 does not have a chromosome segment that originated from HB chromosomal segments between 1.47 and 1.77, at the mb locus on chromosome 27 (1).
The other three birds, 92125, 94085, and 98069, all have HB chromosomal segments at the Mb locus (1).
Therefore, in this cross, the presence of the Mb trait is determined by the presence or absence of chromosomal segments originating from the HB parent at the Mb locus (2).

x. Answer should contain the following elements:
GADPH is required for glycolysis and so, as it is essential for the cell, transcribed at a constant rate (1).
This provides a baseline for comparison with the rate of a gene of variable expression, illustrating changes in the rate of expression in the gene being studied (1).

xi. The data indicate that the HOXB8 gene is responsible for the production of muffs and beards in chickens (1), since HOXB8 is expressed at a higher rate in both the dorsal and facial skin of Mb/Mb chickens when compared to mb/mb chickens (1). It is unlikely to be either of the other two, because, for the KRT222 gene, the rate of expression in both Mb/Mb chickens and mb/mb chickens is similar for all four tissues, indicating no relationship to the presence or absence of beards (1); and for the HOXB7 gene, the rate of expression is highest in the dorsal skin regardless of genotype, rather than in the facial skin where beards are produced—even chickens with muffs and beards have a lower rate of gene activity in their facial skin than on the dorsal skin (1).

xii. Possible answers:
Student proposes a model such as gene induction:
HOXB8 could produce an inducer molecule (1).
Inducer binds to repressor allowing transcription to occur leading to production of muffs and beards (1).

OR

HOXB8 functions as a switch or a regulator during development, controlling the timing of feather development (1).
The mutated Mb allele might be activated too early, leading to the overgrowth seen in muffs and beards (1).

Or any suitable suggestion.

**Question E**

i. Possible answers may include any four (1 point per correct answer) among, e.g.:
   - Fossils
   - Biogeographical data
   - Comparative morphology
   - Comparative embryology
   - Comparative gene sequencing
   - Karyotype analysis
   - Genomic analysis
   - Protein sequencing

ii. 43-45 MYA (1)

iii. The characters keyed as T, U, and V on the phylogeny, viz.: Telescoping of the skull; skull asymmetry; high-frequency hearing; echolocation; single blowhole; increased relative brain size; olfactory bulb lost. (1 point for each of the branch points T, U, V. Points may be awarded either for the recognition of T, U, V on the phylogeny plus awareness that they correspond to the characters listed in the key; or for the listing of the characters themselves.)

iv. One possible answer: Among the ancestor population of all Cetacea was a normal range of variation in the configuration of skulls and placement of the nostrils. Individuals that spent more time in the water and had slightly higher-placed nostrils were at an advantage in breathing in the aquatic environment and were thus slightly more likely to survive and reproduce. Their offspring tended to inherit their variations, and as higher nostrils were always advantageous, directional selection continued to push them ever higher in the skull. Once the lineage was fully aquatic (at latest around the time of *Dorudon* and *Basilosaurus*, around 43 mya), directional selection presumably acted even more strongly, until the nostrils were fully on top of the skull, as in the modern Cetacea. (Crucial elements: variation among individuals in a population (1), inheritance of variations by offspring (1), struggle for existence (1), long time span (1), natural selection (1).)

v. The sequences are identical except for two differences: a substitution (1) of T for C (1) at position 9 in the toothed whales, and the insertion of a C between nucleotides 11 and (originally) 12 in the baleen whales (1). Possible consequences of substitution: same-sense/silent, no change to protein; mis-sense, possible change in protein structure and function; non-sense, protein truncated (1). Consequence of insertion: frameshift, altering the whole protein structure (1).

vi. Any well-reasoned answer (3), such as the following:

The insertion in the baleen whale lineage leads to a frameshift mutation, completely altering or breaking the ameloblastin protein. As baleen whales have lost the ability to construct teeth, however, this pseudogenising mutation was irrelevant and thus unaffected by natural selection. (Or, possibly, the gene mutated first, before the loss of teeth, and this was linked somehow to the appearance of baleen.)