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About A LEVEL

BIOLOGY
Paper 4
(TOPICAL)

About Learning Corner

This section reveals the extra/relevant information that are not required as part of the model answers but to expand the student's knowledge in the respective fields. At the same time, it induces eagerness and interest into their learning process.

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Tel No: 042-35201010
Mobile No: 0300-8447654
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CONTENTS

☞ *A LEVEL*

Revision

TOPIC I

Energy and Respiration

Energy is a fundamental concept in biology. All living organisms require a source of cellular energy to drive their various activities. All organisms respire by using enzyme-catalysed reactions to release energy from energy-rich molecules such as glucose and fatty acids and transfer that energy to ATP. ATP is the universal energy currency of cells. In eukaryotes, aerobic respiration occurs in mitochondria.

The practical activities in this topic give opportunities for candidates to plan investigations, analyse and interpret data and evaluate experimental procedures and the quality of the data collected.

CONTENT	CANDIDATES SHOULD BE ABLE TO:
1.1 Energy	1 outline the need for energy in living organisms, as illustrated by active transport, movement and anabolic reactions, such as those occurring in DNA replication and protein synthesis 2 describe the features of ATP that make it suitable as the universal energy currency 3 state that ATP is synthesised by: • transfer of phosphate in substrate-linked reactions • chemiosmosis in membranes of mitochondria and chloroplasts 4 explain the relative energy values of carbohydrates, lipids and proteins as respiratory substrates 5 state that the respiratory quotient (RQ) is the ratio of the number of molecules of carbon dioxide produced to the number of molecules of oxygen taken in, as a result of respiration 6 calculate RQ values of different respiratory substrates from equations for respiration 7 describe and carry out investigations, using simple respirometers, to determine the RQ of germinating seeds or small invertebrates (e.g. blowfly larvae)
1.2 Respiration	1 State where each of the four stages in aerobic respiration occurs in eukaryotic cells: • glycolysis in the cytoplasm • link reaction in the mitochondrial matrix • Krebs cycle in the mitochondrial matrix • oxidative phosphorylation on the inner membrane of mitochondria 2 outline glycolysis as phosphorylation of glucose and the subsequent splitting of fructose 1,6-bisphosphate (6C) into two triose phosphate molecules (3C), which are then further oxidised to pyruvate (3C), with the production of ATP and reduced NAD

3 explain that, when oxygen is available, pyruvate enters mitochondria to take part in the link reaction

4 describe the link reaction, including the role of coenzyme A in the transfer of acetyl (2C) groups

5 outline the Krebs cycle, explaining that oxaloacetate (4C) acts as an acceptor of the 2C fragment from acetyl coenzyme A to form citrate (6C), which is converted back to oxaloacetate in a series of small steps

6 explain that reactions in the Krebs cycle involve decarboxylation and dehydrogenation and the reduction of the coenzymes NAD and FAD

7 describe the role of NAD and FAD in transferring hydrogen to carriers in the inner mitochondrial membrane

8 explain that during oxidative phosphorylation:
- hydrogen atoms split into protons and energetic electrons
- energetic electrons release energy as they pass through the electron transport chain (details of carriers are not expected)
- the released energy is used to transfer protons across the inner mitochondrial membrane
- protons return to the mitochondrial matrix by facilitated diffusion through ATP synthase, providing energy for ATP synthesis (details of ATP synthase are not expected)
- oxygen acts as the final electron acceptor to form water

9 describe the relationship between the structure and function of mitochondria using diagrams and electron micrographs

10 outline respiration in anaerobic conditions in mammals (lactate fermentation) and in yeast cells (ethanol fermentation)

11 explain why the energy yield from respiration in aerobic conditions is much greater than the energy yield from respiration in anaerobic conditions (a detailed account of the total yield of ATP from the aerobic respiration of glucose is not expected)

12 explain how rice is adapted to grow with its roots submerged in water, limited to the development of aerenchyma in roots, ethanol fermentation in roots and faster growth of stems

13 describe and carry out investigations using redox indicators, including DCPIP and methylene blue, to determine the effects of temperature and substrate concentration on the rate of respiration of yeast

14 describe and carry out investigations using simple respirometers to determine the effect of temperature on the rate of respiration

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Question 1

During the process of glycolysis, glucose is converted by a series of steps into two molecules of pyruvate.

Fig. 6.1 outlines glycolysis.

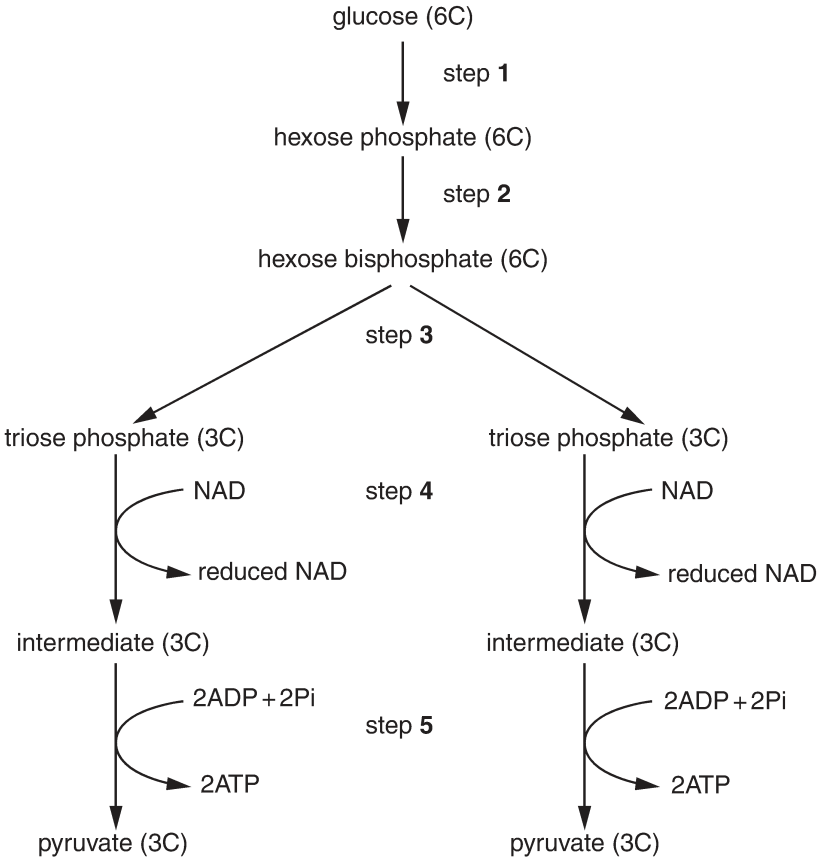


Fig. 6.1

(a) With reference to Fig. 6.1, state the process occurring at:

(i) steps **1** and **2** [1]

(ii) step **3** [1]

(iii) step **4**. [1]

(b) Explain why glucose needs to be converted to hexose bisphosphate. [2]

(c) Pyruvate can enter a mitochondrion when oxygen is present.
Describe what happens to pyruvate in a yeast cell when oxygen is **not** present. [4]

[Total: 9] (N11/P4/Q6)

Solution

(a) **(i)** steps **1** and **2**: Phosphorylation

(ii) step **3**: Lysis

(iii) step **4**: Dehydrogenation

(b) Glucose is relatively stable molecule, so in order to split and enter into biochemical pathway of respiration, some ATP is needed which phosphorylates it to provide activation energy.

(c) In the absence of oxygen, pyruvate is decarboxylated and carbon dioxide is given off. As a result ethanal is produced. Dehydrogenation also occurs to reduce NAD. This reduced NAD is again dehydrogenated to oxidise it and hydrogen removed binds with ethanal to produce ethanol.

Answer Tips

(b) Initially 2 ATP molecules are hydrolysed to make 2 ADP and 2 Pi which bind with glucose to produce hexose biphosphate or fructose biphosphate. In this way activation energy is provided to glucose.

(c) In the presence of oxygen, pyruvate is converted to acetyl. Coenzyme A which starts Krebs cycle inside a mitochondrion. Also ETC is initiated to make more ATP. In the absence of oxygen only glycolysis occurs and hence lesser ATP is produced.

Question 2

(a) Explain the role of ATP in active transport of ions **and** in named anabolic reactions. [7]

(b) Outline the process of anaerobic respiration in both mammal and yeast cells. [8]

[Total: 15] (J12/P4/Q9)

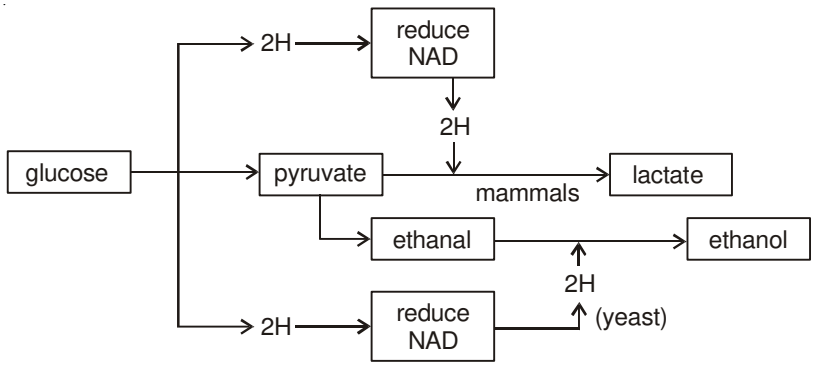
Solution

(a) **Active transport:** ATP is energy currency of cells which provides energy for active transport and anabolic reactions. In active transport substances like ions or salts / minerals move from lower to higher concentration, i.e., against the concentration gradient. Special carrier or transporter proteins in the cell membrane are used for active uptake of ions. Specific carriers bind to specific ions and transport them out or into the cell. Some carrier proteins undergo conformational changes. Such changes in their shape help movement of ions across the membrane.

Anabolic reactions: In anabolic reactions, synthesis of complex substances occurs from simpler ones, e.g., polysaccharides are made from monosaccharides. Glucose is used to synthesize glycogen, starch and cellulose. Glycosidic bond is made between glucose molecules to make long chains of polysaccharides. Lipids are also large molecules made from fatty acids and glycerol, e.g., triglycerides are synthesized from 3 fatty acids and one glycerol which develop ester bonds. Similarly phospholipids are made from two fatty acids, one glycerol and a phosphate group. Proteins are made up of polypeptide chains, which in turn, are synthesized from amino acids. Amino acids are joined by peptide bond. Polysaccharides, fats / lipids and proteins, all are synthesized by condensation reactions, in which water is released when glycosidic, ester or peptide bond is made.

(b) Anaerobic respiration or anaerobiosis occurs when there is deficiency of oxygen. During anaerobic respiration only glycolysis occurs and no Krebs cycle or electron transport chain takes place. Release of hydrogen atoms causes reduction of NAD, but little energy or ATP is produced, as hydrogen atoms are not carried by FAD or other carriers.

In mammals reduced NAD provides hydrogen atoms to convert pyruvate to lactate, which is stored in liver and muscle cells. However, in yeast, pyruvate is converted to acetaldehyde or ethanal and carbon dioxide is produced by decarboxylation of pyruvate. Ethanal is then reduced as it accepts hydrogen from reduced NAD (which is then reoxidised) and ethanol or alcohol is formed. Reoxidised NAD allows glycolysis to continue in mammals as well as in yeast.



Answer Tips

(b) In mammals, lactate can be converted to pyruvate in the presence of oxygen, so it is reversible process, however, in yeast it is irreversible. In mammals conversion of pyruvate to lactate is one step reaction but in yeast it is two step, i.e., first ethanal and then ethanol is made.

Question 3

(a) Fig. 8.1 is an electronmicrograph of a section through a mitochondrion.

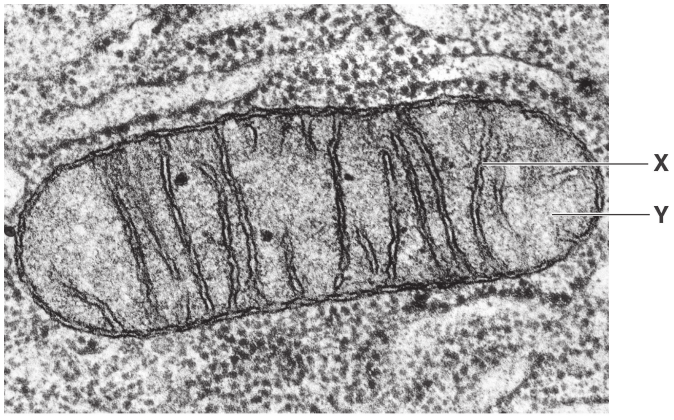


Fig. 8.1

Name **X** and **Y**. [2]

(b) Fig. 8.2 outlines the early stages of respiration.

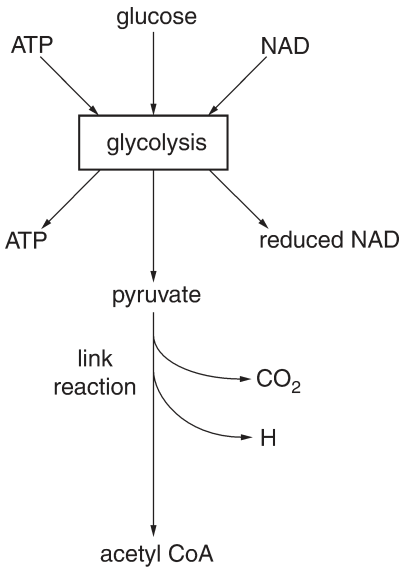


Fig. 8.2

With reference to Fig. 8.2:

(i) explain why ATP is needed at the start of glycolysis [1]

(ii) state the role of NAD in glycolysis [1]

(iii) state how many molecules of ATP are produced from one molecule of glucose during glycolysis [1]

(iv) name the two types of reaction that occur during the conversion of pyruvate to acetyl CoA in the link reaction [2]

(v) name the location, in the mitochondrion, of the link reaction [1]

(vi) describe what happens to the hydrogen released during the link reaction. [2]

(c) Explain why ATP is regarded as the universal energy currency in organisms. [5]

[Total: 15] (N12/P4/Q8)

Solution

(a) **X**: Crista / inner membrane

Y: Matrix

(b) **(i)** ATP is needed at the start of glycolysis to raise chemical potential energy (PE) of glucose. Glucose is normally less reactive, so ATP provided acts as activation energy.

(ii) Nicotinamide Adenine Dinucleotide (NAD) removes hydrogen at some stage of glycolysis. It acts as hydrogen carrier as well as coenzyme.

(iii) Gross production is 4 ATP while net production is 2 ATP

(iv) 1. Dehydrogenation or removal of hydrogen (H).

2. Decarboxylation or removal of carbon dioxide (CO_2)

(v) Matrix

Answer Tips

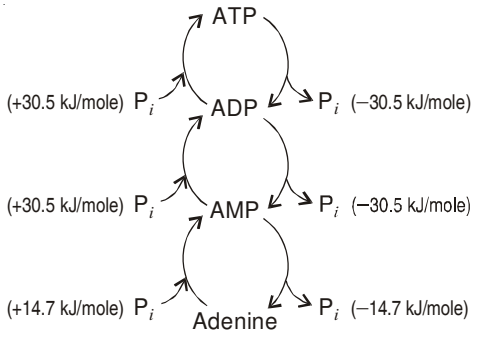
(b) (i) Activation energy (Ea) is the minimum amount of energy required to start a reaction. It raises the internal energy of substrate or reactant.

(iii) Activation energy to break down glucose molecule is 2 ATP while at the end of glycolysis 4 ATP are produced. So net ATP produced
= 4 – 2 = 2 ATP

(b) (iv) ATP synthase complex contains proton pump which removes H^+ outside the crista or inner membrane. When H^+ move inside through concentration gradient, energy produced binds a P*i* to ADP to make ATP. This reaction is called phosphorylation. At the end of ETC, 3 ATP are formed (net 2.5 ATP).

(vi) Hydrogen released during the link reaction is accepted by NAD and then is passed on to carriers of electron transport chain (ETC). As it moves from carrier to carrier, oxidative phosphorylation occurs and ATP is formed. Proton pump moves H^+ across the inner membrane and by chemiosmosis, ATP is synthesized.

(c) ATP is found in all organisms, i.e., bacteria, fungi, algae, animals, plants etc. Whenever ATP is hydrolysed, phosphate is removed and energy is released. Usually 30.5 kJ per mole energy is released. $ATP \rightarrow ADP + Pi + 30.5\ kJ\ mole^{-1}$. Similarly when phosphate is added to ADP in a reversible reaction, ATP is formed, which stores same amount of energy. $ADP + Pi \rightarrow ATP$. ATP molecules are like small packets of energy which are small and water soluble, so can move around cell and when energy has to be used by cell, it immediately acts as energy donor. ATP is a link between energy yielding and energy requiring reactions, so it has high turnover rate. Some of the examples of processes in which ATP is used are active transport, muscle contraction, protein synthesis, Calvin cycle.



Question 4

(a) The production of ATP by oxidative phosphorylation takes place in the electron transport chain in a mitochondrion.

(i) State the part of the mitochondrion in which the electron transport chain is found. [1]

(ii) Describe briefly where the electrons that are passed along the electron transport chain come from. [3]

(iii) Describe the role of oxygen in the process of oxidative phosphorylation. [2]

(J13/P4/Q4 a)

Answer Tips

(a) (i) At different steps in glycolysis, link reaction and Krebs cycle, hydrogen atoms are produced which release electrons. During ETC, electrons are released from different reduced carriers, which are re oxidised by releasing H^+ and e^-.

(ii) Electrons keep flowing, as oxidation of NAD, FAD and other carriers allow these to be reduced again. Equation for oxygen producing water is as follows:

$$2H^+ + 2e^- + \frac{1}{2}O_2 \rightarrow H_2O$$

Solution

(a) (i) Inner membrane or cristae.

(ii) Electrons come from hydrogen atoms found in reduced NAD or FAD. When reduced NAD or FAD are dehydrogenated in oxidation reactions, hydrogen atoms release electrons. Electrons are also released from different substances in Krebs cycle, link reaction and glycolysis. Hydrogen atoms are also found in matrix of mitochondria and in cytoplasm of cell.

(iii) Oxygen is the final acceptor of electrons, as it accepts electrons from last carrier, which is usually cytochrome. When oxygen accepts the electron, the carrier is reduced again. Hence electrons continue to flow along electron transport chain (ETC) and ETC can keep working. Oxygen accepts electrons and combines with H^+ to form water.

Question 22

(a) All organisms respire. The ATP produced as a result of respiration is used as the energy currency of the cell.

(i) Outline **two** examples of movement in cells that use ATP. [2]

(ii) ATP cannot be stored in cells so it has to be continually re-synthesised to meet the demands of an organism.

A person with a total quantity of 0.2 moles of ATP needs to hydrolyse 150 moles of ATP per day.

Calculate how many times the total quantity of 0.2 moles of ATP has to be re-synthesised per hour to meet the demand of 150 moles per day.

Show your working and give your answer to the nearest whole number. [2]

(iii) Name the stages in which chemiosmosis occurs in respiration and in photosynthesis. [2]

(b) Fur seals are mammals that are adapted to live in cold temperatures. Fur seals have large quantities of a type of fat tissue known as brown adipose tissue. Brown adipose cells contain many mitochondria. These mitochondria contain a transport protein called thermogenin.

Fig. 2.1 shows the role of thermogenin in a mitochondrion of a brown adipose cell when external temperatures are cold.

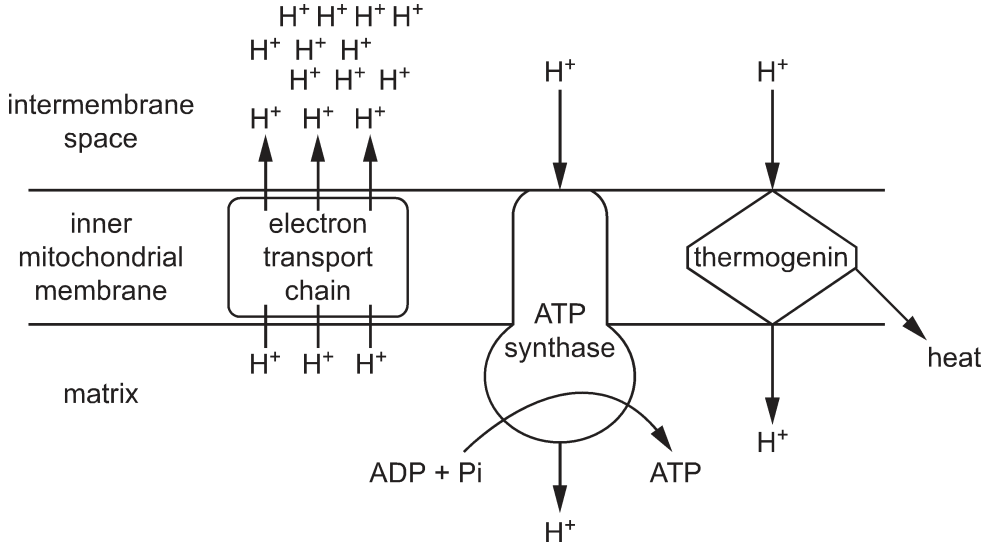


Fig. 2.1

(i) With reference to Fig. 2.1, describe **and** explain the effect of thermogenin on ATP synthesis. [3]

(ii) When the external temperature is warm, thermogenin cannot function.

When the external temperature becomes cold, thermogenin is able to function as a result of cell signalling:

- adrenaline is released
- adrenaline acts on brown adipose cells
- a sequence of events is triggered that results in the activation of the enzyme lipase
- lipase hydrolyses triglycerides in the cells into fatty acids
- fatty acids enter the mitochondrion
- thermogenin starts to function.

Outline the stages of cell signalling that trigger the functioning of thermogenin. [3]

[Total: 12] (J21/P4/Q2)

Solution

(a) (i) ATP is used for contraction of sarcomere or movement of muscle fibre. It is also used for active transport of Na^+ or K^+ ions and molecules against the concentration gradient. Movement of golgi vesicles occurs through cytoplasm which then fuse with cell membrane for exocytosis of proteins.

(ii) $\frac{150}{0.2} = 750$

$\frac{750}{24} = 31$ times

(iii) Respiration: Oxidative phosphorylation or ETC.

Photosynthesis: Photophosphorylation or light dependent stage.

(b) (i) Thermogenin reduces the synthesis of ATP as less ATP reacts with Pi to make ATP. Protons (H^+) diffuse through thermogenin which causes reduced concentration gradient of H^+ in intermembrane space. Due to reduced proton gradient, fewer H^+ pass through ATP synthase and less ATP is synthesised.

(ii) Adrenaline acts on brown adipose cells by binding to receptors on the cell surface membrane of brown fat cells. A G-protein found on inner side of membrane is stimulated which then, activates an enzyme, adenyl cyclase in the membrane. This enzyme synthesises cyclic AMP(cAMP) which acts as second messenger. A cascade of enzymes is activated due to which lipase enzyme becomes active and causes hydrolysis of triglycerides into fatty acids.

Answer Tips

(a) (i) ATP is also needed for phagocytosis or endocytosis. Movement of spindle fibres or chromosomes and chromatids during mitosis/meiosis requires ATP. Wafting or beating of cilia and flagella needs ATP.

(ii) $\frac{150}{24} = 6.25$

and $\frac{6.25}{0.2} = 31$ times

(b) (ii) A typical cell signalling mechanism needs to be described when adrenaline causes synthesis of cAMP as second messenger. Signal is amplified by activation of Kinase enzyme which further activates a signalling cascade, finally causing phosphorylation of lipase to activate it.

Question 23

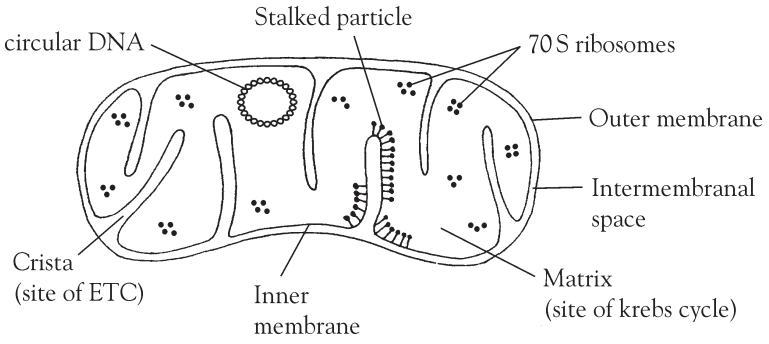
(a) Describe how the structure of a mitochondrion is related to its function. [9]

(b) Explain how rice is adapted to grow with its roots submerged in water. [6]

[Total: 15] (J21/P4/Q9)

Solution

(a)



Mitochondrion makes ATP. It has double membrane outside, i.e. outer and inner membrane making its envelope.
Inner membrane is folded and each fold is called crista. Cristae increase surface area. Stalked particles or ATP synthase are found on this membrane. It also has carrier proteins and cytochromes for ETC, so it is site of oxidative phosphorylation by which ATP is synthesised through chemiosmosis. This membrane is impermeable to protons (H^+).
Intermembrane space has high concentration of protons (H^+), so it has low pH. Protons are pumped into intermembrane space, so a proton gradient is established between matrix and intermembrane space. Protons then diffuse from intermembrane space to matrix, through channel in stalked particle.
Matrix contains coenzymes and enzymes for link reaction and krebs cycle.
Outer membrane is permeable to, pyruvate, reduced NAD and oxygen.
Circular DNA contains genes for protein synthesis.
70S ribosomes are the site of protein synthesis.

(b) Rice is grown in flooded fields, so it is partly submerged in water due to which it faces problems in getting oxygen. To get oxygen, it has special tissue called aerenchyma in stem and roots, through which oxygen moves to or diffuses down to roots and other submerged parts of shoot. It has shallow roots and a thin film of air is trapped on underwater leaves as tiny bubbles between water and leaf surface. Its internode growth is greater, due to which leaves and flowers grow above water level. Growth of plant is regulated by hormone gibberellin or ethene gas. In underwater roots, anaerobic respiration occurs and alcoholic fermentation produces ethanol. It is tolerant to high ethanol concentration due to production of an enzyme called alcohol or ethanol dehydrogenase.

Answer Tips

(b) High concentration of alcohol in surrounding water may be toxic for plant roots, so enzyme alcohol dehydrogenase is produced to break down alcohol by removing hydrogen from it.

Question 24

(a) ATP is needed for many metabolic processes in living organisms.

(i) Describe the properties of ATP that make it suitable for its role as the universal energy currency. [4]

(ii) Suggest why ATP is needed for protein synthesis. [2]

(b) Fig. 6.1 is a diagram of mitochondrion.

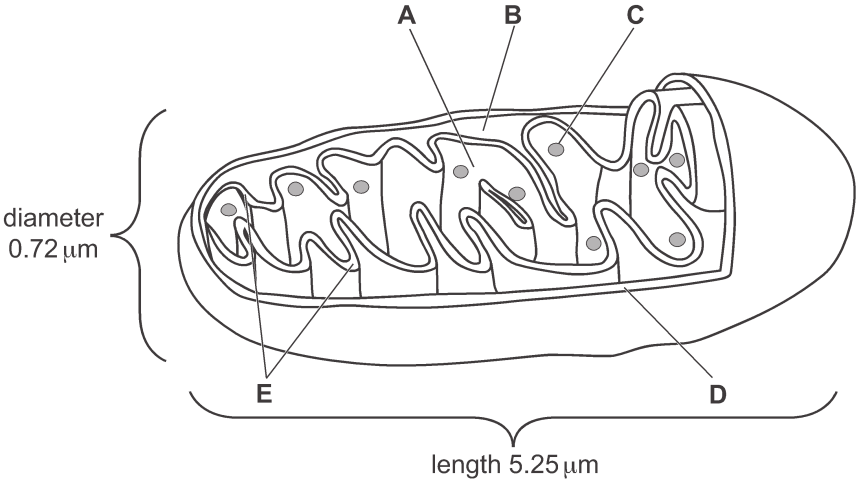


Fig. 6.1

(i) Complete Table 6.1 using the letters **A** to **E** from Fig. 6.1. Each letter may be used once, more than once, or not at all.

Table 6.1

statement	letter
the site of the Krebs Cycle	.....
a phospholipid bilayer impermeable to H^+ ions	.....
the site of translation	.....

[2]

(ii) Assume that the mitochondrion in Fig. 6.1 is a cylinder.

Calculate the surface area of this mitochondrion.

Use the formula: Surface area of cylinder = $2\pi r^2 + 2\pi rh$

Show your working. [2]

(iii) The inner membrane of the mitochondrion has a much larger surface area than the outer membrane because of the presence of cristae.

Different cell types vary in the number of cristae present per mitochondrion. Cardiac muscle cells have mitochondria with a very large number of cristae.

Suggest **and** explain why cardiac muscle cells have mitochondria with very large numbers of cristae. [2]

[Total: 12] (N21/P4/Q6)

Solution

(a) (i) ATP is water soluble, so it is easily transported around the cell. ATP is hydrolysed by ATPase and loses Pi group to release energy immediately in small packets. Due to phosphate group released 30.5 kJ mole^{-1} energy is released. ATP can be regenerated by recycling of this energy, i.e., $ATP \rightleftharpoons ADP + Pi$

(ii) ATP is needed for synthesis of mRNA. It unwinds DNA and activates RNA nucleotides to make single stranded RNA. ATP also helps formation of peptide bonds by joining amino acids to make polypeptide chain.

Answer Tips

(a) (ii) ATP is needed for activation of amino acids, movement of ribosomes along mRNA during translation, movement of mRNA from nucleus after transcription and for post translation modifications.

(b) (i)

statement	letter
the site of the Krebs Cycle	A
a phospholipid bilayer impermeable to H^+ ions	E/D
the site of translation	C

(ii) Surface area $= 2\pi r^2 + 2\pi rh$

$$= \left(2 \times \pi \times (0.36)^2\right) + (2 \times \pi \times 0.36 \times 5.25) = 12.69\ \mu m^2$$

(iii) More cristae results in more ETC due to more carrier proteins and ATP synthase. So more ATP is formed because cardiac muscle must undergo continuous contractions. ATP is needed for muscle contraction.

(b) (ii) Diameter $= 0.72\ \mu m$

Radius $= r = \frac{D}{2}$

$= \frac{0.72}{2} = 0.36$

(iii) More cristae results in more oxidative phosphorylation, so more chemiosmosis and more synthesis of ATP.

Question 25

Aerobic respiration occurs when oxygen is available. A much greater energy yield is obtained from aerobic respiration than from respiration in anaerobic conditions.

(a) Explain why the link reaction only occurs when oxygen is available. [4]

(b) Outline the stage of aerobic respiration that occurs in the cytoplasm of eukaryotic cells. [5]

[Total: 9] (J22/P4/Q3)

Solution

(a) Pyruvate is converted to acetyl group (2C group) in the form of acetyl CoA in link reaction. NAD is needed in link reaction where NAD becomes reduced. Reduced NAD goes to ETC. ETC or oxidative phosphorylation works if oxygen is present because oxygen is the final electron acceptor in ETC. So reduced NAD is oxidized or regenerated.

Answer Tips

(a) Reduction of NAD is needed to initiate ETC in which electrons pass on from carrier to carrier, and at the end oxygen accepts electrons and protons to produce water.

(b) Glycolysis occurs in the cytoplasm of cells, which begins by phosphorylation of glucose and glucose is converted to fructose (1,6) bisphosphate. Then this hexose sugar splits into two triose phosphates or TP. TP is oxidized due to dehydrogenation by which glycerate phosphate or GP is produced. Two GP are produced by conversion of two NAD to reduced NAD. Finally GP is converted to two pyruvate molecules and net 2 ATP are also produced during the glycolysis.

Question 26

Yeast cells can respire in anaerobic conditions.

(a) (i) Outline how yeast carries out respiration in anaerobic conditions. [4]

(ii) Explain why respiration in anaerobic conditions is an advantage to yeast. [2]

Bioethanol is a type of biofuel produced from maize starch on an industrial scale. In the high temperature method, heating to 120 °C is used to break apart starch molecules. The enzymes α-amylase and glucoamylase are added to the resulting starch suspension once it has cooled down. These enzymes hydrolyse the starch to glucose. Yeast cells are then added and maintained in anaerobic conditions to produce ethanol.

The high temperature method is expensive to carry out, so a new method has been developed which heats starch to a lower temperature of 80 °C.

In the lower temperature method, enzymes catalysing the hydrolysis of starch do **not** need to be added to the starch suspension. A genetically modified (GM) strain of the same yeast species is used. The GM strain of yeast has genes that allow the cell to produce α-amylase and glucoamylase and to attach these enzymes to the external surface of the cell surface membrane. The GM yeast cells are added to the starch that was heated to 80 °C and are maintained in anaerobic conditions to produce ethanol.

(b) An investigation was carried out to compare the GM strain of yeast with the yeast that had **not** been genetically modified (non-GM strain).

In this investigation, the starch suspension produced after heating to 80 °C was allowed to cool to 30 °C before adding yeast cells.

The results are shown in Fig. 2.1.

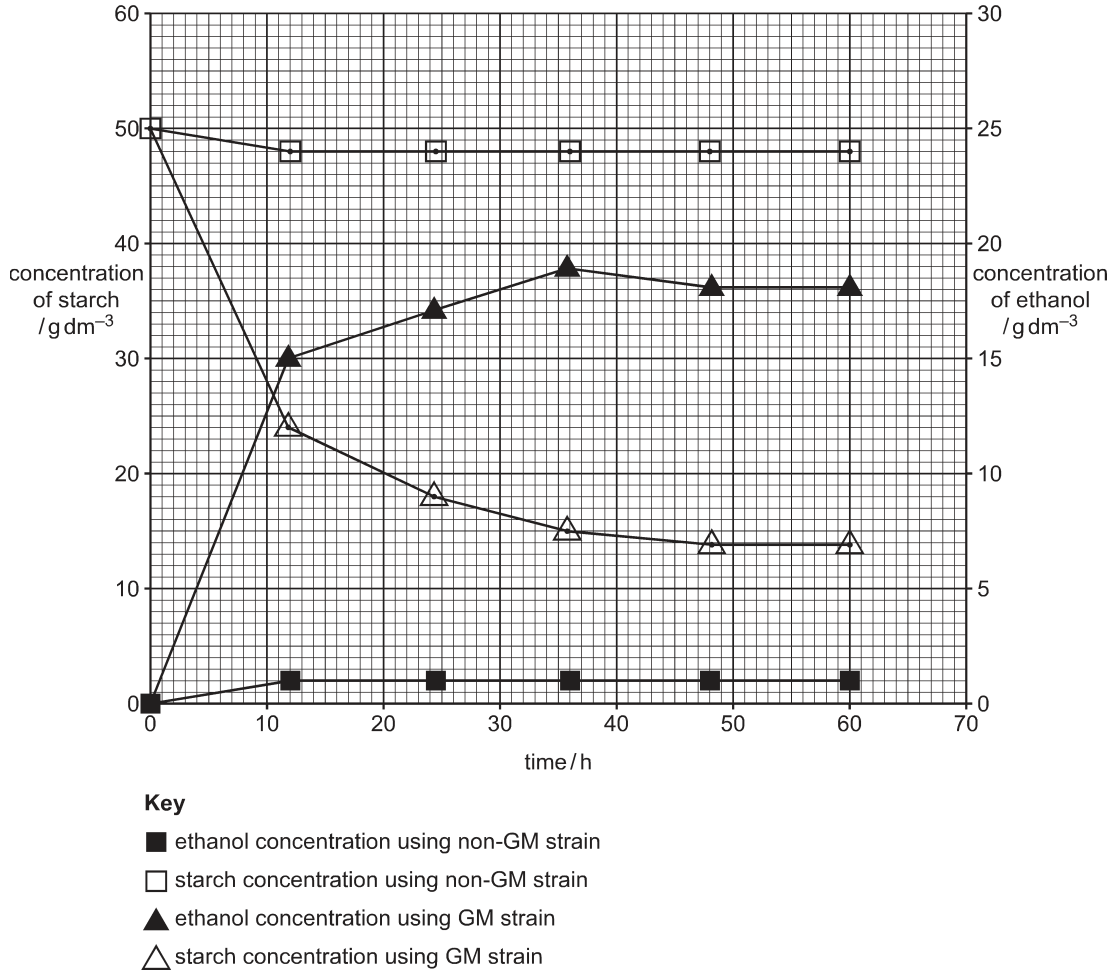


Fig. 2.1

With reference to Fig. 2.1, describe the trends in the data for **ethanol** production by the GM strain compared to the non-GM strain. [2]

(c) The rate of ethanol production is similar for the lower temperature method and the higher temperature method.

Suggest why using the lower temperature method has a similar rate of production of ethanol to the higher temperature method. [2]

(d) Suggest **one** reason why the high temperature method is expensive to carry out. [1]

[Total: 11] (N22/P4/Q2)

Solution

(a) (i) During anaerobic conditions, only glycolysis occurs, in which glucose is converted to two pyruvate molecules. Pyruvate undergoes decarboxylation (removal of CO_2) and ethanal or acetaldehyde is formed. It is then hydrogenated or reduced to make ethanol. Hydrogen is provided by reduced NAD, which is converted to oxidised NAD by removal of hydrogen.

(ii) Yeast can survive in absence of oxygen, because ATP is still produced from glycolysis. Glycolysis can continue because NAD is recycled.

(b) GM strain produces higher concentration of ethanol compared to non-GM strain. Both in GM and non-GM strains, ethanol production increases and then levels off. Maximum concentration of ethanol for non-GM strain is 1 g dm^{-3} but for GM strain it is 19 g dm^{-3}. It levels off at 1 g dm^{-3} for non-GM but at 18 g dm^{-3} for GM strain.

(c) In both methods, similar or same concentration of starch is hydrolysed, so similar or same concentration of glucose is available to yeast. In both methods, enzymes work at the same rate. GM yeast cells produce more enzymes.

(d) For high temperature, more fuel or electricity is needed. It also needs to add enzymes.

Answer Tips

(a) (i) Pyruvate is catalysed by decarboxylase enzyme to remove CO_2, while dehydrogenase enzyme removes hydrogen used to make ethanol or alcohol.

(ii) NAD accepts hydrogen and is reduced. Then its hydrogen is removed and it gets oxidised or regenerated.

(b) GM strain has steeper increase in concentration of ethanol or production of ethanol.

(d) High temperature method takes longer or more time consuming. Cost of additional enzymes also makes it more expensive.

Question 27

(a) Glycolysis is a biochemical pathway that occurs in the cytoplasm of cells.

In glycolysis, a molecule of glucose is metabolised to two molecules of pyruvate. The process is outlined in Fig. 1.1.

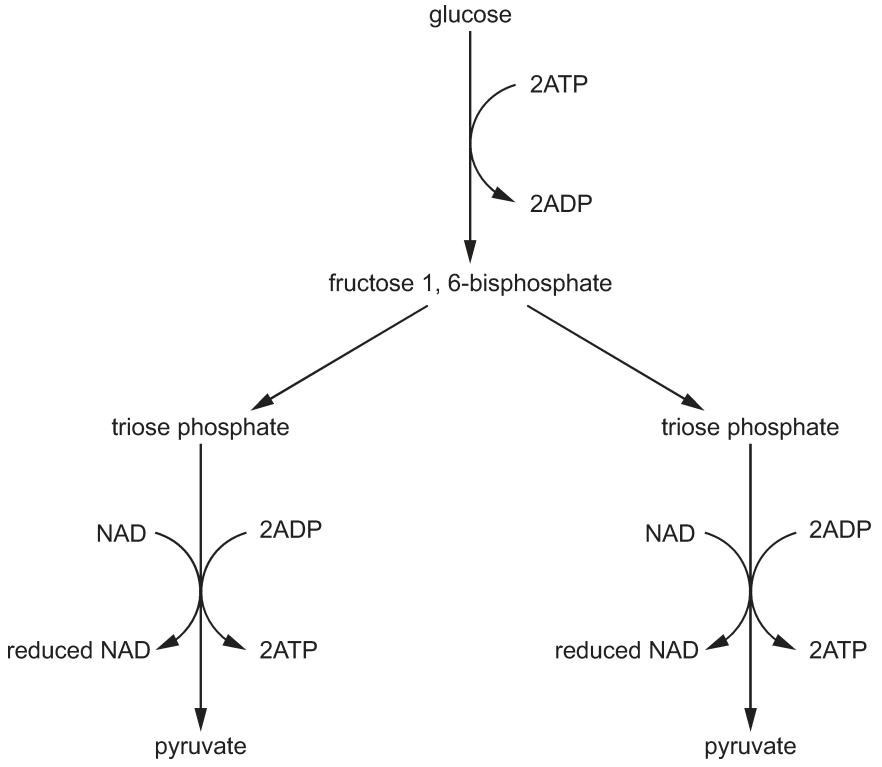


Fig. 1.1

(i) Explain why glucose is phosphorylated at the beginning of glycolysis. [1]

(ii) Suggest **one** use of the reduced NAD that is produced in glycolysis. [1]

(iii) Name the type of phosphorylation reaction by which ATP is made during glycolysis. [1]

(b) Pyruvate can enter the mitochondrion by active transport.

Describe the main conditions that are required for pyruvate to enter the mitochondrion by active transport. [3]

(c) Pyruvate is involved in the link reaction in the matrix of the mitochondrion.

Describe the link reaction. [3]

[Total: 9] (J23/P4/Q1)

Solution

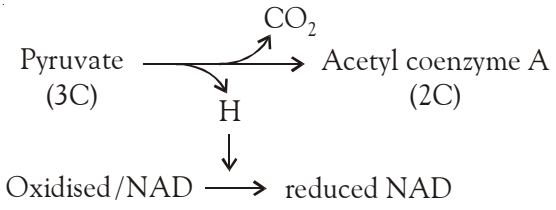
(a) (i) Phosphorylation activates glucose and it becomes unstable. Its energy level is increased.

(ii) It acts as carrier and acceptor of hydrogen atoms and electrons, to be used for redox reactions.

(iii) Substrate-linked or substrate level phosphorylation.

(b) Inner mitochondrial membrane is impermeable to pyruvate. A carrier protein or symport is found in the membrane. When there is lower concentration of pyruvate outside mitochondrion, then carrier protein pushes pyruvate against concentration gradient. Process occurs when oxygen is available and carrier also requires ATP or energy for active transport.

(c) In the link reaction. Pyruvate is decarboxylated as well as dehydrogenated. Oxidation of pyruvate occurs and reduced NAD is produced. Remaining molecule is used for the formation of, acetyl coenzyme A or acetyl-CoA.



Answer Tips

(a) (i) Concentration gradient is maintained and now glucose cannot leave the cell. It becomes more reactive.

(ii) It becomes provider of H^+ ions and electrons. It is also used to reduce ethanal or pyruvate.

(b) Carrier is also called MPC or mitochondrial pyruvate carrier.

Question 28

(a) Some organisms carry out respiration in anaerobic conditions when oxygen is not available or when there is a low concentration of oxygen. In yeast and some plants, this is called ethanol fermentation. In mammals, it is called lactate fermentation.

Fig. 1.1 outlines ethanol fermentation and lactate fermentation.

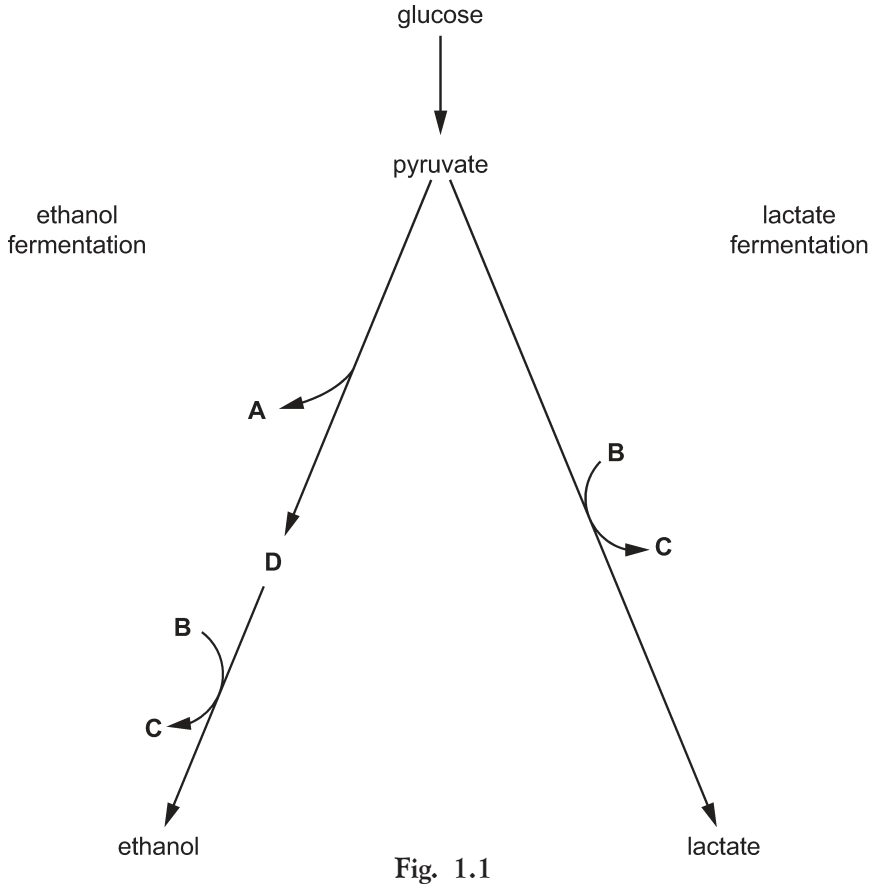


Fig. 1.1

Identify substances **A–D**. [3]

(b) Explain how processes such as ethanol fermentation and lactate fermentation allow cells to continue to function in the absence of oxygen. [3]

(c) The cereal crop rice, *Oryza sativa*, grows in fields that are flooded with water. The roots of the rice plants are submerged in water that contains very little oxygen.

Describe **and** explain how rice plants are adapted to grow in flooded fields. [3]

[Total: 9] (N23/P4/Q1)

Solution

(a) **A:** Carbon dioxide (CO_2)

B: reduced NAD (NADH)

C: oxidised NAD (NAD^+)

D: Ethanal/acetaldehyde

(b) In both, NAD is recycled and from NAD, reduced NAD is produced, which is used in glycolysis and also in process of ATP production by substrate-linked phosphorylation.

(c) Leaves and stem of rice contain aerenchyma tissue, which continues to roots. Oxygen from air passes through this tissue for aerobic respiration. In root cells, submerged in water, there is higher concentration of ethanol dehydrogenase enzyme which causes high tolerance for ethanol. It allows higher rate of ethanol fermentation during anaerobic respiration. Rice plants have fast growth, so due to tallness, their leaves mostly grow out of water and exposed to air.

Answer Tips

(b) In anaerobic respiration, hydrogen removed during glycolysis binds with NAD to produce reduced NAD. This hydrogen cannot enter ETC, so it is recycled when reduced NAD, leaves it to make oxidised NAD. This hydrogen is used to make ethanol and lactate.

(c) There are also ridges in submerged leaves of rice, in which air is trapped.

TOPIC VI

Selection and Evolution

In 1858, Charles Darwin and Alfred Russel Wallace proposed a theory of natural selection to account for the evolution of species. A year later, Darwin published *On the Origin of Species*, providing evidence for the way in which aspects of the environment act as agents of selection and determine which phenotypic forms survive and which do not. The individuals best adapted to the prevailing conditions are most likely to succeed in the 'struggle for existence'.

CONTENT	CANDIDATES SHOULD BE ABLE TO:
6.1 Variation	1 explain, with examples, that phenotypic variation is due to genetic factors or environmental factors or a combination of genetic and environmental factors 2 explain what is meant by discontinuous variation and continuous variation 3 explain the genetic basis of discontinuous variation and continuous variation 4 use the *t*-test to compare the means of two different samples (the formula for the *t*-test will be provided, as shown in the Mathematical requirements)
6.2 Natural and artificial selection	1 explain that natural selection occurs because populations have the capacity to produce many offspring that compete for resources; in the 'struggle for existence', individuals that are best adapted are most likely to survive to reproduce and pass on their alleles to the next generation 2 explain how environmental factors can act as stabilising, disruptive and directional forces of natural selection 3 explain how selection, the founder effect and genetic drift, including the bottleneck effect, may affect allele frequencies in populations 4 outline how bacteria become resistant to antibiotics as an example of natural selection 5 use the Hardy–Weinberg principle to calculate allele and genotype frequencies in populations and state the conditions when this principle can be applied (the two equations for the Hardy–Weinberg principle will be provided, as shown in the Mathematical requirements) 6 describe the principles of selective breeding (artificial selection) 7 outline the following examples of selective breeding: • the introduction of disease resistance to varieties of wheat and rice • inbreeding and hybridisation to produce vigorous, uniform varieties of maize • improving the milk yield of dairy cattle

6.3 Evolution	1 outline the theory of evolution as a process leading to the formation of new species from pre-existing species over time, as a result of changes to gene pools from generation to generation 2 discuss how DNA sequence data can show evolutionary relationships between species 3 explain how speciation may occur as a result of genetic isolation by: • geographical separation (allopatric speciation) • ecological and behavioural separation (sympatric speciation)

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Question 1

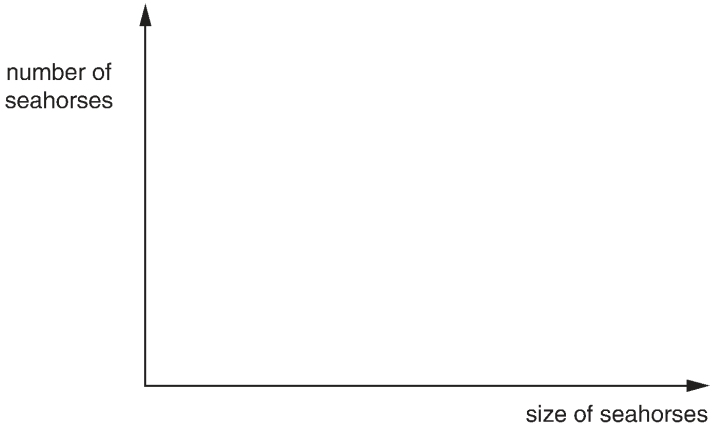
The seahorse, *Hippocampus,* is an unusual small fish. It gives birth to live young and it is the male rather than the female that becomes pregnant.
Fig. 1.1 shows a seahorse.

Fig. 1.1

(a) In one species of seahorse, a type of natural selection called disruptive selection occurs.This is where the extreme phenotypes are more likely to survive and reproduce than the intermediate phenotypes.

- Within a population, large females mate with large males and small females mate with small males.
- Few intermediate-sized individuals are produced and they have a low survival rate.

(i) Sketch a graph on the axes below to show the distribution in size of seahorses as a result of disruptive selection.

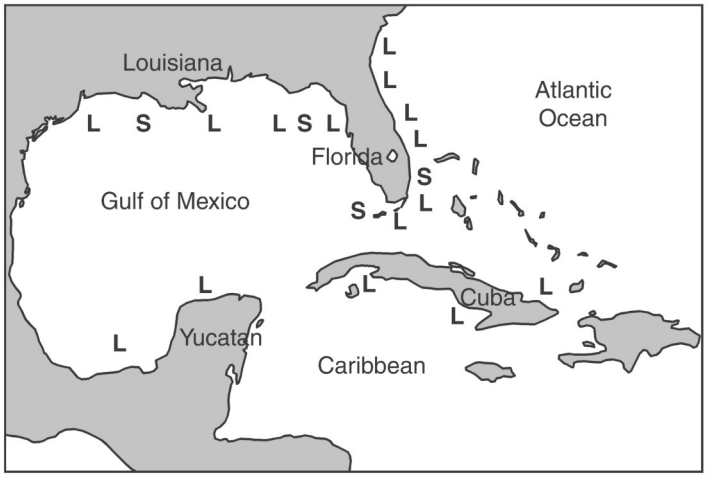


[2]

(ii) Explain how disruptive selection has been maintained in this species of seahorse. [3]

(iii) State the term given to the type of selection where variation in a characteristic is maintained in its existing form over time. [1]

(b) Two different species of seahorse are found in the coastal waters shown in Fig. 1.2.



Key: L = large seahorse *H. erectus* **S** = small seahorse *H. zosterae*

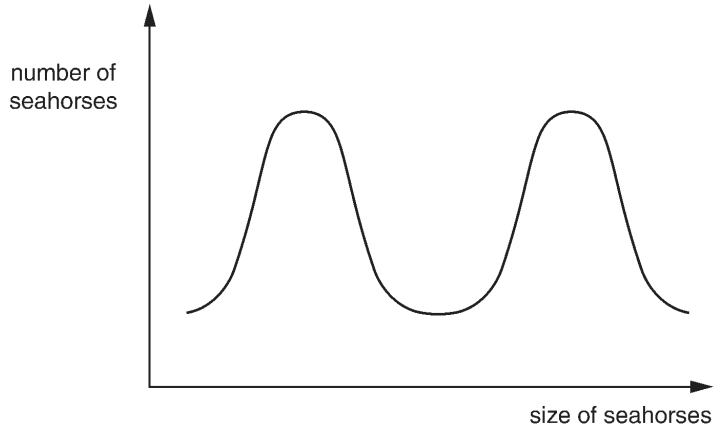
Fig. 1.2

Suggest how these two different species of *Hippocampus* could have arisen. [2]

[Total: 8] (J12/P4/Q1)

Solution

(a) (i)



Answer Tips

(a) (i) Graph should show two peaks for extreme phenotypes of size while a dip in the middle connecting the peaks. Dip shows some intermediate sizes of seahorse population.

(ii) In seahorse, mates are selected usually by size. Similar sized animals are more likely to mate together, with the intermediates being selected against. Large females and males mate while small females mate with small males. Only few intermediate sizes are produced but natural selection is against them, so they have low survival rate. Extreme phenotypes are more likely to survive and reproduce. Hence alleles for more extreme phenotypes are more likely to be passed on.

(iii) Stabilising selection.

(b) These two species could have arisen due to allopatric speciation. Some members of ancestral species may have undergone physical separation by geographical barriers and their next generations may have passed through different selection pressure. Eventually reproductive isolation has occurred and their populations are unable to interbreed with members of ancestral species. Thus, the new species could have arisen.

Answer Tips

(a) (ii) Habitats for intermediate sizes of seahorse may no longer be available. Difference in predation may cause survival of extreme sizes while decline of intermediate sizes.

(b) Sympatric speciation could also produce the new species in the same location, in which the chromosome number of descendant species may have increased by auto-or allopolyploidy. Same location may be Gulf of Mexico along the coastal waters of Louisiana and Florida.

Question 2

The Death Valley region of Nevada in the USA used to have an extensive lake system. Approximately 20 000 years ago the lakes started to dry up and now consist of isolated small pools. Four different species of the desert pupfish have been found living in these pools. Evidence indicates that over 20 000 years ago there was only one species of pupfish living in the lake system.

Fig. 8.1 shows a desert pupfish.

Fig. 8.1

(a) Explain how the change from an extensive lake system to just a few pools could have resulted in the evolution of four new species of desert pupfish. [5]

(b) State how environmental factors can act as stabilising forces of natural selection in an isolated pool, after the initial evolution of a new species of desert pupfish. [2]

(c) Suggest what may happen to the desert pupfish if water levels rise and the pools once more form an extensive lake system. [3]

[Total: 10] (J13/P4/Q8)

Solution

(a) New species of pupfish might have evolved by allopatric speciation. Different populations of fish became isolated as extensive lake system restricted to just a few pools. Due to geographical or physical land barrier, interbreeding between these populations was then prevented, so gene or allele flow between populations did not occur. Each pool would be subject to different selection pressures of different environmental conditions. It had affected the allele frequency. Mutations might have occurred giving rise to advantageous alleles which would confer a selective advantage on the fish. This advantage would therefore be passed on to offsprings. So after several generations, gene pool of population changed to the extent that chromosome number would become different. Ultimately, new fish populations were reproductively isolated and could not interbreed.

(b) In a pool, environmental conditions remain the same over a long period, so best adapted fish to conditions in pool survive. Stabilising forces of natural selection in the isolated pools would cause better adapted fish to survive while the extreme phenotypes would be selected against.

(c) Number of all species will increase initially due to more breeding space and more food availability. Then competition will occur between four species for access to resources like food. It will cause possible reduction in numbers within some or all species. All species may not survive. Different species restricted to different areas will occupy different niches and thus interbreed or hybridisation may occur. Species will be subjected to new selection pressures of the environment. So interspecific competition may give survival advantage to one or more species.

Answer Tips

(a) Species is a group of identical organisms which can interbreed and produce fertile offsprings. Fish populations restricted to different pools, ultimately, interbred among themselves but were not able to breed with their ancestral species. So each fish population would be given status of a new species. Genetic drift would also occur between these species.

(b) Extreme phenotypes may not get selective advantage and hence do not survive.

Question 3

Mammoths are extinct mammals related to elephants. About three million years ago, the ancestors of mammoths migrated from Africa into Europe and Asia. There, about 1.7 million years ago, the steppe mammoth evolved and became adapted to the cooler conditions. Then, about 700 000 years ago, as the climate changed and the Arctic became much colder, the woolly mammoth evolved.

Woolly mammoths showed a number of obvious adaptations to reduce heat loss, including thick fur, small ears and small tails.

(a) Explain how variation and natural selection may have brought about the evolution of the woolly mammoth from the steppe mammoth. [5]

(b) A frozen, 43 000 year old woolly mammoth was found in Siberia. Its DNA was extracted and sequenced. The sequences of the genes coding for the α and β chains of haemoglobin were compared with those of modern Asian elephants.

The results suggested that, when compared with Asian elephants:

- there was only one different amino acid in the woolly mammoth's α chains
- there were three different amino acids in the woolly mammoth's β chains.

Explain the likely effect of these differences on a molecule of mammoth haemoglobin. [3]

(c) Scientists synthesised woolly mammoth haemoglobin in order to investigate whether or not the different haemoglobin was part of the mammoth's adaptation to a cold climate.

The affinity of haemoglobin for oxygen is affected by the changes in temperature that can occur in mammals, for example in active muscle tissue or close to the skin surface.

It is advantageous for Arctic mammals to have haemoglobin whose affinity for oxygen is only slightly affected by changes in temperature. This is often achieved by using substances called 'red cell effectors', which bind to haemoglobin.

Fig. 2.1 compares the effect of temperature on the affinity for oxygen of woolly mammoth and Asian elephant haemoglobin, with and without red cell effectors.

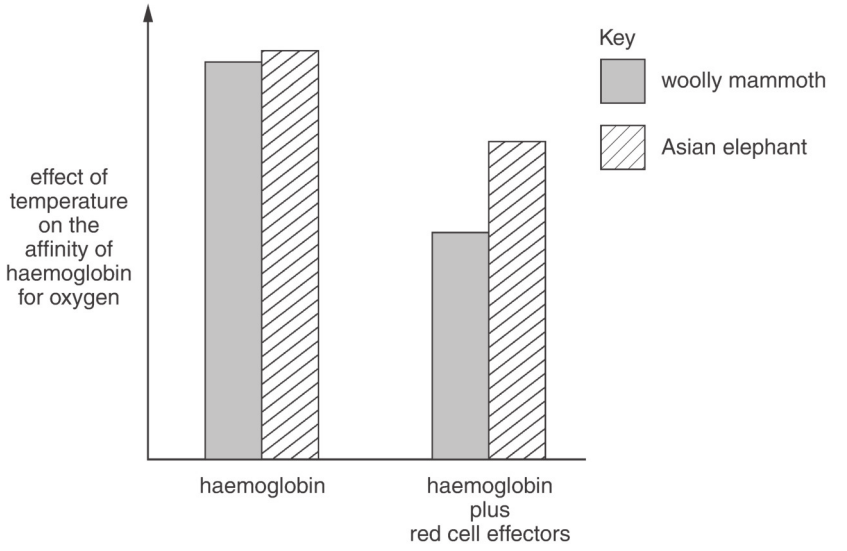


Fig. 2.1

(i) Suggest why it is advantageous for Arctic mammals to have haemoglobin whose affinity for oxygen is only slightly affected by changes in temperature. [2]

(ii) Explain whether or not Fig. 2.1 provides evidence that woolly mammoth haemoglobin is better adapted for a cold climate than Asian elephant haemoglobin. [4]

[Total: 14] (N13/P4/Q2)

Solution

(a) Individual mammoth vary in their phenotypes. Different phenotypic traits variation is caused by genetic variation due to mutations. When there is a change in environmental conditions, selection pressure also increases. Variation increases the chance of some individuals surviving, e.g., in this case cooler conditions by climate changes can develop selection pressure for certain adaptations. Some adaptations include, better insulation and smaller surface area to volume ratio. Surviving individuals breed and produce offsprings. Better adapted alleles are passed on to offsprings and allele frequency is changed in population.

Answer Tips

(a) Woolly mammoth evolved as climate changed and Arctic became much colder. Some of the adaptations caused survival of these mammoth animals to reduce heat loss. Insulation occurred by thick fur with long hair. Surface area to volume ratio reduced due to small ears and small tails.

(b) Due to difference of one amino acid in α-chain and three different amino acids in β-chain, sequence of amino acids in primary structure of polypeptide chain becomes different and it provides different side chains or R-groups. It changes the tertiary or 3-dimensional structure as well as it affects quaternary structure. There is greater effect on β-chain due to difference of 3 amino acids, so it changes properties of mammoth haemoglobin. Hence, its function may be changed.

(c) (i) Affinity for oxygen is slightly affected, so that haemoglobin (Hb) can still be able to offload oxygen in cold temperatures. Surface tissue or skin is colder than core body temperature, so Hb can maintain oxygen supply to surface tissue.

(ii) No, as there are tiny differences in effect of temperature on haemoglobin (Hb) alone, so it is negligible or no evidence of woolly mammoth Hb being better adapted. There is greater reduction in effect of temperature on Hb with red cell effecter in woolly mammoth, so woolly mammoth Hb with red cell effecter is better adapted to cold. Hb may have undergone changes to oxygen binding sites. Hence it can offload oxygen at low temperatures.

Answer Tips

(b) Due to different amino acids, folding process and development of different H-bonds, ionic bonds and disulphide bonds may change, hence 3-D shape of haemoglobin changes.

Question 4

(a) Maize originated in the Americas, and 55% of the world's maize production is from this part of the world.

Fig. 5.1 shows the mean yields of maize in the USA between 1860 and 2010.

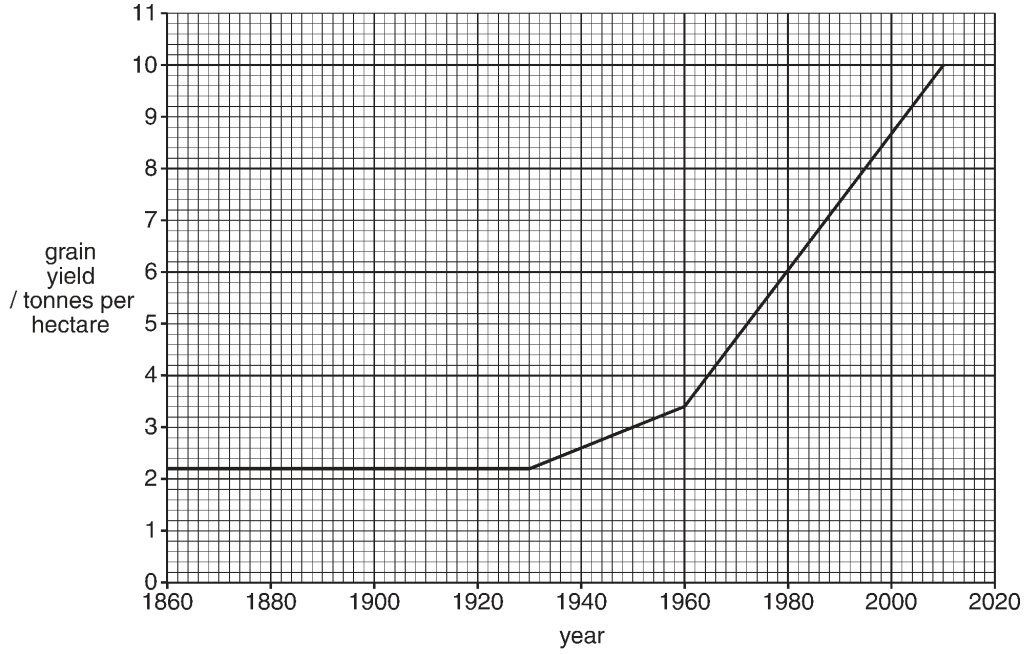


Fig. 5.1

Describe the changes in grain yield between 1860 and 2010. [3]

(b) The greatest improvement in maize yields came after growers realised that maize hybrids have a much greater yield than inbred lines.

Between 1860 and the 1930s, maize was allowed to pollinate naturally in the field. From the 1930s onward, maize seed was produced using 'double-cross' hybrids.

To produce a double-cross hybrid:

- two different maize plants, **A** and **B**, are crossed to produce a hybrid, **C**
- two other maize plants, **X** and **Y**, are crossed to produce a hybrid, **Z**
- the hybrid **C** is then crossed with the hybrid **Z**, to produce the double-cross hybrid.

From 1960 onwards, maize seed was produced using 'single-cross' hybrids. This involves crossing one inbred (entirely homozygous) plant with a different inbred plant.

Explain why single-cross hybrids are genetically uniform, but double-cross hybrids are not. [3]

(c) An experiment was carried out in 1996–1997 to investigate the relative effects of genotype and environment on the yield of maize.

Maize seeds with different 'inbreeding coefficients' were used. The greater the inbreeding coefficient, the greater the degree of homozygosity in the maize plants.

Maize seeds with different inbreeding coefficients were planted in two different areas in 1996, and in the same two areas in 1997.

Fig. 5.2 shows the results.

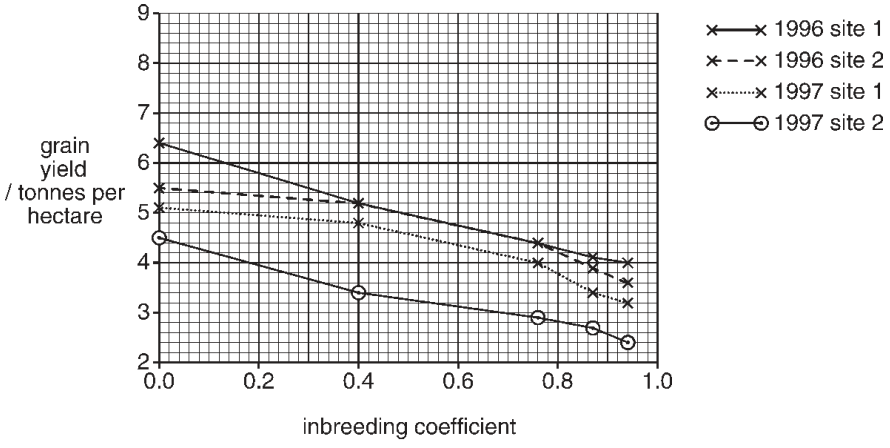


Fig. 5.2

(i) Inbreeding depression is a reduction in vigour that results from inbreeding.

Explain how the results in Fig. 5.2 demonstrate inbreeding depression in maize. [2]

(ii) Explain how the results in Fig. 5.2 show that the environment affects maize yields. [2]

[Total: 10] (N13/P4/Q5)

Solution

(a) There is no change in grain yield between 1860 and 1930. It remains 2.2 tonnes per hectare. Then it starts increasing from 1930 to 2010. In 1930 it is 2.2 tonnes per hectare but in 2010, it increases to 10 tonnes per hectare.

(b) Single cross hybrids have homozygous parents and each has inherited the same alleles, so they are uniformly heterozygous. Double cross hybrids have heterozygous parents so each has inherited different combinations of alleles, i.e., there is a mixture of homozygous dominant, homozygous recessive and heterozygous hybrids.

(c) (i) As the value of inbreeding coefficient increases, the yield decreases in each site in each year. In 1996, at site 1, grain yield in tonnes per hectare is 5.8 when inbreeding coefficient is 0.2, but as it increases to 0.8, the yield per hectare decreases to 4.3 tonnes.

(ii) The grain yield at different sites is different in different years, for the same inbreeding coefficient. e.g., in 1996 at site 2, grain yield is 5.4 tonnes per hectare but in 1997 at site 2, it is 4 tonnes per hectare for inbreeding coefficient of 0.2. Different environmental factors like rainfall, temperature and mineral content of soil may affect grain yield at different sites in different years.

Answer Tips

(a) Grain yield increases from 2.2 in 1930 to 3.4 tonnes per hectare in 1960, but after that it increases rapidly.

(b) Single cross hybrid has mostly heterozygous alleles like Aa, Bb, Cc, Dd, Ee, Ff... etc, but double cross hybrid may have AA, BB, CC, Dd, Ee, ff, gg... etc combinations.

(c) (i) Similarly in 1997 at site 2, grain yield is 4 tonnes per hectare when inbreeding coefficient is 0.2 but it decreases to 2.8 tonnes per hectare when inbreeding coefficient is 0.8.

(ii) For inbreeding coefficient of 0.4, yield in tonnes per hectare is 5.2 in 1996 at site 1, but in 1997 at site 2, it is 3.4 tonnes per hectare.

Question 5

Collared lizards, *Crotaphytus collaris*, show variation in body length and running speed.

Fig. 4.1 shows a collared lizard.

Fig. 4.1

An investigation was carried out to find out whether body length and running speed affected the number of offspring that a male lizard sired (fathered). The lizards reproduce sexually, and females lay eggs after mating with males.

A large number of male lizards was captured during the breeding season.

For each lizard:

- body length was measured
- it was chased down a small race track and its fastest running speed over 1 m recorded
- a blood sample was taken and DNA sequences at 10 different loci were analysed.

The lizards were then released back into the place where they were captured, to allow mating to occur.

Several weeks later, after the lizards' eggs had hatched, as many young hatchlings as possible were captured. DNA testing was carried out on each hatchling to determine which male was the father. The results were used to determine the number of offspring sired by each of the male lizards in the first sample.

(a) Outline how DNA analysis can be carried out and then used to establish which male lizard sired each hatchling. [3]

(b) Fig. 4.2 shows the number of offspring sired plotted against the body length of the adult male lizards.

Fig. 4.3 shows the number of offspring sired plotted against the fastest running speed (sprint speed) of the adult male lizards.

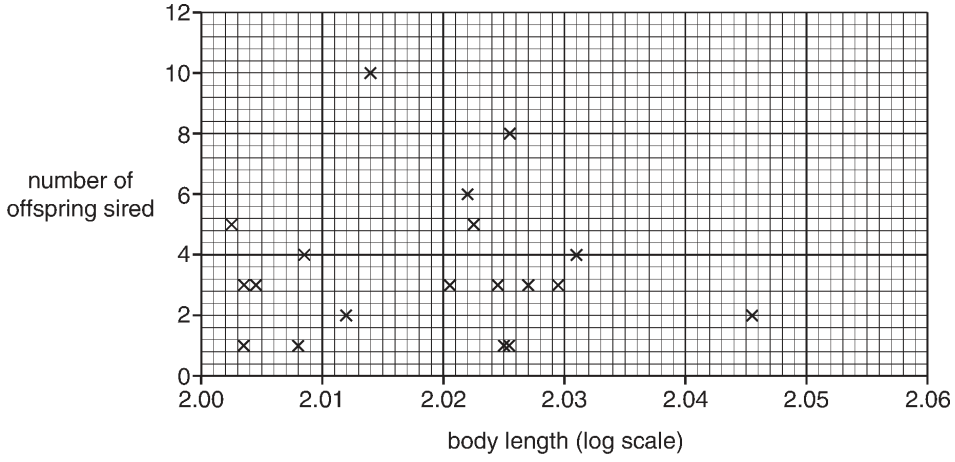


Fig. 4.2

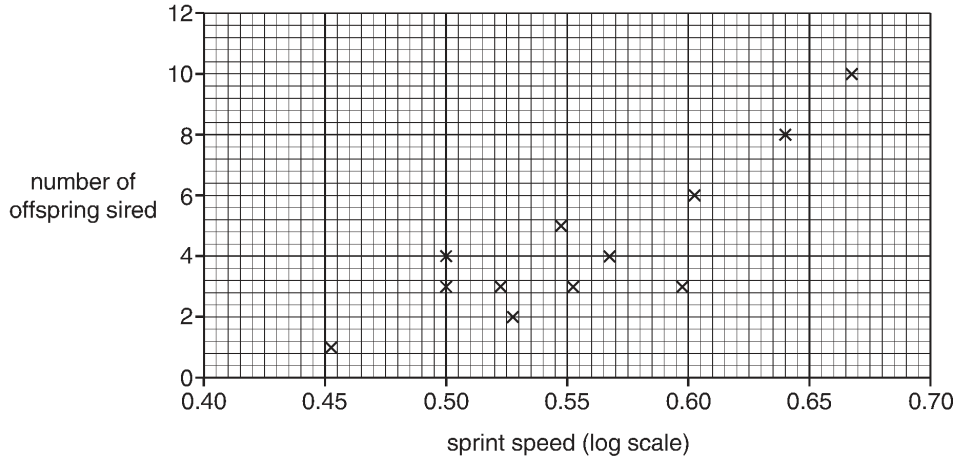


Fig. 4.3

(i) With reference to Fig. 4.2 and Fig. 4.3, describe the relationships between

- body length and the number of offspring produced
- sprint speed and the number of offspring produced. [4]

(ii) Research has also shown that, in a population of collared lizards with varying leg lengths, those with longer hind legs are able to run faster.

With reference to the results shown in Fig. 4.3, explain how, over time, this could lead to a change in the mean hind leg length in a population of collared lizards. [3]

(c) Small islands often contain species of lizards that are not found on other islands or on the mainland.

Explain how a population of collared lizards that became isolated on an island could evolve to form a new species. [5]

[Total: 15] (J14/P4/Q4)

Solution

(a) DNA is cut by restriction enzymes or endonucleases. Mixture of different DNA fragments is loaded into wells of agarose or polyacrylamide gel slab at negative end or cathode of gel. Methylene blue or some fluorescent dye is also mixed with samples to monitor movement in the gel. Gel electrophoresis tank is filled with an electrolyte solution or buffer. As power supply is turned on, an electric potential is produced, whereby negatively charged DNA fragments move towards anode or positive electrode. Due to electric field or potential difference different sized fragments are separated. Short pieces of smaller mass move faster. Fluorescent dye or radioactive DNA probes are used to identify the bands of DNA pieces. Comparison of bands of male lizard and hatchlings is done.

(b) (i) ***body length***: There is no distinct relationship between body length and number of offsprings as graph points are scattered. However, it shows that lizards of small and intermediate body lengths produce more offsprings.

sprint speed: Graph shows a distinct relationship between sprint speed and number of offsprings sired by male lizards. Lizards with greater sprint speed sire more offsprings, e.g., lizards having speed between 0.60 to 0.70 at log scale sire between 6 to 10 offsprings.

(ii) Lizards with longer hind legs will tend to have more offspring, so due to more offsprings, they will have greater chance of passing on their alleles to next generations. Over time the frequency of such alleles for long hind legs will increase in lizard population. So mean length of hind legs will also increase, as it occurs in case of directional selection.

(c) Evolution of new species of such collared lizards occurs by allopatric speciation mechanism. Due to isolation on small islands, there is no breeding between different lizard populations, so allele or gene flow between lizard population stops. Different islands have different environmental conditions and different selection pressure. Mutations also occur over a period of time. So advantageous alleles are selected and passed on to next generations. It causes change in gene or allele frequency, thus causing a genetic drift. After many generations, these isolated populations are eventually unable to interbreed with ancestral species and finally become a new species.

Answer Tips

(a) Gel electrophoresis procedure is described briefly. Comparison of DNA finger prints or banding pattern shows similarity or differences in DNA of male lizard with hatchlings.

(b) (i) Sprint means a race or run for short distance, 1m in this case. Male lizards with sprint speed between 0.45 to 0.60 at log scale sire less offsprings, i.e., between 1 to 5.

(ii) Lizards with longer hind legs are able to run faster and those which run faster also sire more offsprings. Due to more offsprings population size of such lizards increases and allele frequency of long hind legs also increases in gene pool of such lizards.

(c) Explanation of detailed mechanism of allopatric speciation is required which occurs due to some geographical isolation barrier.

Question 26

Bison are a type of large wild cattle. Ancestors of modern bison appeared in Asia 2.5 million years ago. This ancestral bison species increased its range into Europe and North America.

While the ancestral species is now extinct, its descendants include *Bison bonasus*, the European bison, and *Bison bison*, the American bison.

Fig. 5.1 shows an American bison.

Fig. 5.1

(a) After the end of the last ice age, populations of the ancestral bison were separated by sea and by forests that were not suitable as habitats. The separation resulted in the evolution of the European bison and the American bison.

Explain how this separation resulted in the evolution of the two bison species. [4]

(b) Table 5.1 compares features of European bison and American bison.

Table 5.1

feature	European bison, *B. bonasus*	American bison, *B. bison*
type of food	grass and higher vegetation such as leaves of bushes and trees	grass and low vegetation
height / m	2.1	2.0
maximum mass / kg	1000	1270

Assess the relative importance of natural selection and genetic drift in producing the different heights and masses of the two species of bison. [3]

(c) The European bison has a nuclear genome that is very similar to that of the American bison. The European bison has a mitochondrial genome that is more similar to that of wild cattle of the genus *Bos* than to the American bison.

Discuss what this implies about the evolutionary history of the European bison. [3]

(d) Outline how practical techniques could be used to test the hypothesis that farmed cattle are closely related to European bison. [4]

[Total: 14] (J22/P4/Q5)

Solution

(a) It occurred due to geographical isolation by sea and forest barriers. Interbreeding did not occur between European and American populations of bison. There were different environmental conditions in which different random mutations also occurred. Different alleles or genes were selected in altered environments resulting in changes of allele frequency. Populations had different morphological, physiological and behavioural features, so after a long time, over many generations, reproductive isolation occurred, thus both became different species by this mechanism of allopatric speciation.

(b) It is not possible, rather difficult to come to a reliable conclusion because there are small differences in height, so natural selection is not more important than genetic drift. Taller and lighter bison may have advantage in reaching higher vegetation so in this case natural selection may be important. Differences in mass may not be due to genetic factors. These may be due to nutrient value or quantity of diet or food. However, genetic drift in ancestral population may have led to European bison being taller and lighter.

(c) European bison has a close and recent common ancestor with that of cattle *Bos*. European bison may have interbred with cattle *Bos*. Mitochondria are inherited from mother or female parent, so mitochondrial DNA shows more similarity to that of cattle *Bos* than to the American bison.

(d) Obtain or use blood, cells, tissues or DNA from both species, i.e. from farmed cattle and European bison. Use PCR technique to replicate or amplify DNA. Then DNA profiling or finger printing is done by running fragments of DNA on electrophoresis gels. Compare the banding patterns to see genetic differences. DNA sequencing is done to count or identify percentage difference or similarity. Genome DNA can be used in microarray procedure for bioinformatics or database computer software. It may indicate close relationship or more recent splits between different species.

Answer Tips

(a) Different environmental factors exerted different selection pressures, so new or mutant alleles were selected in the gene pool of both populations. After many generations, both were unable to interbreed and produce fertile offsprings.

(b) If differences in mass are not due to genetic factors, then natural selection is unimportant to bring about these differences. Due to quantity of food or its nutritional value, American bison became shorter and heavier.

(c) European bison is more closely related to cattle of genus *Bos* than to American bison.

(d) DNA is sequenced to compare the nucleotide or base sequence. Farmed cattle and European bison can be bred to produce viable offsprings if they are closely related.

Question 27

Myosotis is a genus of small flowering plants. Many different *Myosotis* species grow on the islands of New Zealand, which are an important site of *Myosotis* evolution. Lowland *Myosotis* species grow at low altitude while alpine *Myosotis* species grow at high altitude at the tops of mountains.

(a) Scientists wanted to obtain molecular data to determine the evolutionary relationships of New Zealand's *Myosotis* species. They extracted DNA from individuals of *Myosotis* species collected from three different islands in New Zealand.

To carry out a polymerase chain reaction before DNA sequencing, the DNA samples were mixed with primers, deoxynucleotides and *Taq* polymerase and put through 35 cycles of treatment. Each treatment cycle involved one minute at 95 °C, followed by one minute at 50 °C and then four minutes at 72 °C.

Describe what happened to the DNA at each temperature.

[3]

(b) Fig. 5.1 shows the three largest New Zealand islands.

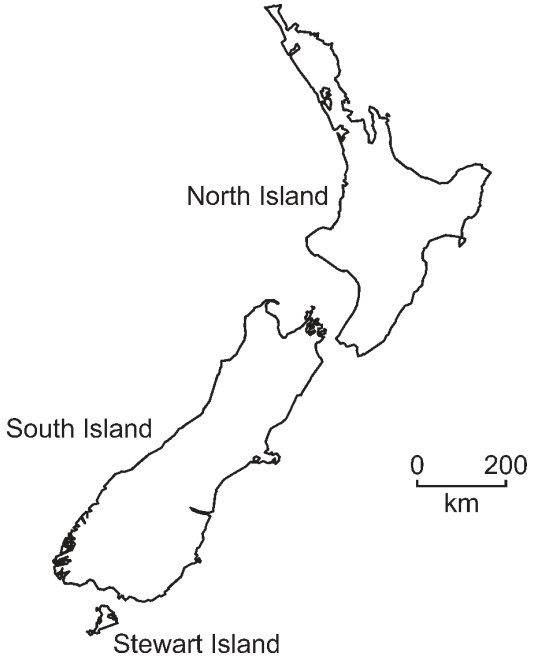


Fig. 5.1

North Island has mostly lowland habitat. South Island and Stewart Island have mountains with alpine habitats that are above the tree line.

DNA sequence data for three *Myosotis* species were compared. The results are described in the bullet points.

- In the alpine species *M. pygmaea*, individuals on South Island showed genetic differences from individuals of *M. pygmaea* on Stewart Island.

- In the alpine species *M. pulvinaris*, individuals from different mountains on South Island showed genetic differences.
- In the lowland species *M. pottsiana*, individuals from different areas of North Island showed overall genetic similarity.

Discuss reasons for the results in the three species. [5]

(c) State **two** factors, other than natural selection, that could drive genetic changes in populations of *Myosotis*. [2]

[Total: 10] (N22/P4/Q5)

Solution

(a) 1. At 95 °C, DNA denatures, i.e., dsDNA splits into single strands by breaking of H-bonds.
2. At 50 °C, primers anneal or bind to ssDNA.
3. At 72 °C, complementary or second DNA strand is made.

(b) *M. pygmaea* populations are geographically isolated by sea or water. *M. pulvinaris* populations are geographically separated due to mountain tops. *M. pygmaea* or *M. pulvinaris* species have no or little interbreeding, so their selection pressures of environment are also different. Both populations have undergone different random mutations and there are different changes in allele frequencies. Hence, allopatric speciation could have occurred within either species. *M. pottsiana* or north island species have no geographical isolation, so interbreeding or gene flow occurs between populations. Hence, they have similar selection pressure of environment.

(c) Different factors may be:
1. Genetic drift or bottleneck or founder effect.
2. Migration, i.e., immigration or emigration.
3. Mutations.
4. Artificial selection by selective breeding.

Answer Tips

(a) dsDNA means double stranded DNA and ssDNA means single stranded DNA. At 72 °C, *Taq* polymerase replicates ssDNA to dsDNA.

(b) Species of south island or stewart island didn't have gene flow between their populations and they have different gene pools.

Question 28

(a) The sea blush, *Plectritis congesta*, is a flowering plant that grows on the west coast of North America.

Individual sea blush plants produce fruit that is either winged or wingless. Investigations have shown that this characteristic is controlled by a single gene with two alleles:
- a dominant winged fruit allele
- a recessive wingless fruit allele.

Fig. 3.1 shows the difference in structure between winged fruit and wingless fruit phenotypes.

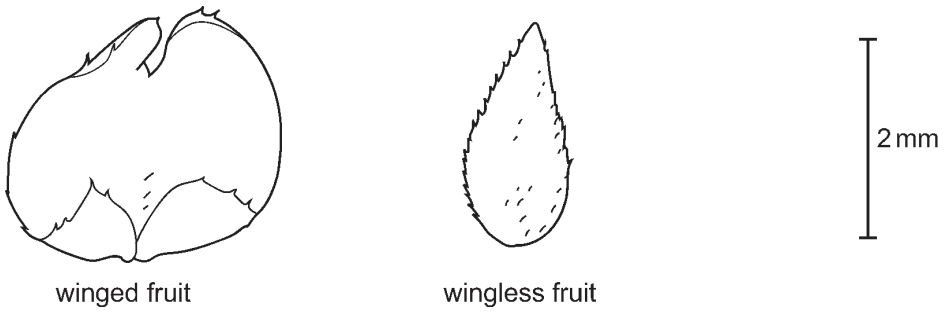


Fig. 3.1

(i) A large sample of sea blush fruits was collected and their fruit-wing characteristic was recorded.

Name the type of variation that is shown for the fruit-wing characteristic of the sea blush. [1]

(ii) Different sea blush plants can have fruit with different colours.

Suggest **two** ways in which a new fruit colour could naturally occur in a sea blush population. [2]

(iii) Early taxonomists classified sea blush plants with winged fruits as a different species to sea blush plants with wingless fruits.

Since this time, evidence from observations and experiments has confirmed that the plants belong to the same species.

Suggest **three** examples of the evidence obtained that helped to confirm that these sea blush plants belong to the same species. [3]

(b) Natural selection occurs in populations, such as in populations of sea blush plants.

Explain why natural selection occurs in populations. [5]

[Total: 11] (J23/P4/Q3)

Solution

(a) (i) Discontinuous variation.

(ii) Due to mutation in DNA sequence, a new allele may be formed controlling a new fruit colour. Selection pressure of environment may change a colour.

(iii) Both type of plants can interbreed and produce fertile offsprings. Both types occupy the same niche and have similar morphology, physiology, biochemistry etc. Also they contain many genes which are same and their genome has similar DNA sequence.

Answer Tips

(a) (ii) Due to cross pollination, hybrid plants may develop a different colour due to some combination of new alleles, like co-dominant alleles.

(iii) Both types are not reproductively isolated. Many of their proteins are similar and have same amino acid sequences.

(b) Populations have reproductive potential and can produce many offsprings. Genetic variation also occurs in populations due to mutations, sexual reproduction, gamete formation due to meiosis and random fertilisation. There is competition for food, other resources and selection of mates. Selection pressure of environment also occurs so some individuals have advantageous genes/alleles for adaptation to selection pressure and show or express their traits or phenotypes. Such individuals survive and reproduce due to selective advantage. Hence, they are able to pass on their alleles to their offsprings, due to which the allele frequency of advantageous alleles increases in a population.

Question 29

(a) Warfarin is a poison used to kill rats. Some rats are resistant to warfarin and can survive the effects of the poison. Warfarin resistance is due to a mutant dominant allele at a single gene locus.

Researchers investigated the population of brown rats on a large island where there are no predators of rats. On this island, warfarin is used to try to control the rat population.

The researchers found that 40% of the population of rats was resistant to warfarin.

(i) Use Hardy–Weinberg equation 1 and equation 2 to calculate the percentage of the population of rats on the island that is heterozygous for warfarin resistance.

equation 1 $p + q = 1$

equation 2 $p^2 + 2pq + q^2 = 1$

Show your working. [3]

(ii) In natural populations, it is usual to find that only some of the conditions of the Hardy–Weinberg principle are met.

Suggest **and** explain which of the conditions of the Hardy–Weinberg principle are most likely to be met for the island population of brown rats. [4]

(b) Dominant advantageous alleles and recessive advantageous alleles both naturally occur in populations.

Explain why, when a new **dominant** advantageous allele occurs, its frequency increases more quickly in the population than when a new **recessive** advantageous allele occurs. [3]

[Total: 10] (J23/P4/Q5)

Solution

(a) (i) $q^2 = 0.6$, so $q = \sqrt{0.6} = 0.775$

$p = 1 - q$

$= 1 - 0.775$

$= 0.225$

$2pq = 2 \times 0.225 \times 0.775$

$= 0.35 \times 100$

$= 35\%$

(ii) Some of the conditions are as follows:

1. There should be no migration or no flow of alleles into or out of population.
2. Population is isolated by a geographical barrier.
3. Random mating occurs among individuals.
4. A large population of rats moving around the island.
5. Rats should have high reproductive rate.
6. Rats have diploid chromosome number.
7. Gene should have two different alleles to be heterozygous.

(b) New alleles are initially found in heterozygous condition. A new dominant advantageous allele is always expressed in heterozygous form but a new recessive advantageous allele is not expressed in heterozygote due to dominant allele. Selection can act on individuals with dominant allele straight away, but selection can only act on individuals who are homozygous recessive for new advantageous recessive allele.

Answer Tips

(a) (ii) No migration means neither immigration nor emigration. Different land or topographical barriers separate population from others. Predators to be absent. No genetic drift or any natural disaster.

(b) Recessive allele can only express in homozygous recessive genotype. It takes time for homozygous recessive genotype to occur.

Question 30

Research suggests that selective breeding began about 10 000 years ago. Selective breeding has been important in satisfying the global demand for food.

(a) The introduction of disease resistance to varieties of wheat is an example of selective breeding.

Outline the steps involved in the introduction of disease resistance to varieties of wheat. [5]

(b) Suggest **two** possible disadvantages of selective breeding. [2]

[Total: 7] (N23/P4/Q3)

Solution

(a) Wheat plants resistant to disease are selected by exposing plants to specific disease to show resistance. Breeding is done between resistant plants and among their offsprings, those plants are selected which show resistance. Such plants are bred together and again resistant ones are selected. This process of breeding and selection is repeated for so many generations until highly resistant variety of wheat is developed.

(b) Genetic variation is reduced due to increase in homozygosity. Hybrid vigour decreases and inbreeding depression increases. Harmful recessive alleles may come together and expressed.

Answer Tips

(a) Named plants having certain disease occurring in wheat may be described. For example, wheat varieties with rust and smut disease or having powdery mildew infection.

(b) Heterozygosity is decreased and gene pool gets smaller. Population becomes susceptible to new diseases due to environmental change. Disadvantageous traits occur and fertility is reduced. Metabolic disorders may also increase.