1.3 Organisms Exchange Substances with their Environment: 1-hour Pack

AQA 7402 · Calculator allowed · about 60 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 Fish gills use a countercurrent system to maximise oxygen uptake from water. Water flows over the gill lamellae in the opposite direction to the flow of blood inside them. The table shows the percentage oxygen saturation of the water and of the blood at four equally spaced positions (1 to 4) along the length of a lamella, in the direction of water flow.

Position along lamella: 1, 2, 3, 4
Oxygen saturation of water (%): 90, 70, 50, 30
Oxygen saturation of blood (%): 80, 60, 40, 20

(a) Name the structures on a gill filament, referred to in the table above, across which gas exchange takes place. **(1)**

(b(i)) Use the data in the table to explain how the countercurrent arrangement maintains a diffusion gradient for oxygen along the whole length of the lamella. **(3)**

(b(ii)) Calculate the difference in oxygen saturation between the water and the blood at each of the four positions, and state what this shows about the diffusion gradient along the lamella. **(2)**

(c) In a hypothetical parallel-flow (concurrent) system, blood and water would flow in the same direction and their oxygen saturations would tend to equalise part-way along the lamella. Explain why the countercurrent system found in fish gills results in a greater overall uptake of oxygen by the blood than a parallel-flow system would. **(3)**

(Total for Question 1 is 9 marks)

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2 Insects exchange gases using a tracheal system consisting of tracheae and tracheoles that carry air directly to respiring tissues, largely relying on diffusion rather than a mass transport system for gases.

(a) Name the pores in the exoskeleton through which air enters the tracheal system, and name the structures that control their opening and closing. **(2)**

(b) Suggest why the reliance on diffusion through the tracheal system, without a mass transport system to carry oxygen around the body, limits the maximum body size of insects. **(3)**

(c) During flight, an insect's flight muscles respire anaerobically for short periods, producing lactic acid. Explain how this can temporarily increase the rate of gas exchange at the ends of the tracheoles. **(4)**

(d) Some larger, more active insects use rhythmic abdominal pumping movements to ventilate the tracheal system. Suggest why this mass movement of air is necessary for these insects, in addition to diffusion. **(2)**

(Total for Question 2 is 11 marks)

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3 Gas exchange in a leaf occurs mainly through pores in the lower epidermis. A student compared the leaves of a mesophyte (a plant adapted to average water availability) and a xerophyte (a plant adapted to a dry habitat) using a light microscope with a circular field of view of diameter 0.5 mm. The xerophyte leaf had a stomatal density of 50 stomata per mm^2, and the mesophyte leaf had a stomatal density of 200 stomata per mm^2.

(a) Name the pores described above, and name the specialised cells that control their opening and closing. **(2)**

(b) Explain, in terms of water potential and ion movement, how guard cells open a stoma in the light. **(4)**

(c) Calculate the number of stomata expected in one full field of view for the xerophyte leaf and for the mesophyte leaf. Use area of a circle = $\pi \times r^2$, and π = 3.142. Give each answer to the nearest whole stoma. **(4)**

(d) State two structural adaptations, other than a lower stomatal density, that a xerophyte leaf may have to reduce water loss by transpiration. **(2)**

(e) Evaluate the extent to which a lower stomatal density is an effective adaptation for a xerophyte, considering both its benefit in a dry habitat and any disadvantage it may cause. **(3)**

(Total for Question 3 is 15 marks)

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4 The data below show how the percentage oxygen saturation of haemoglobin changes with the partial pressure of oxygen (pO2), for maternal haemoglobin, for fetal haemoglobin, and for maternal haemoglobin exposed to a raised carbon dioxide concentration (a Bohr shift), as found in actively respiring muscle tissue.

Resting curves (pO2 in kPa: 2, 4, 6, 8, 10, 12):

Maternal haemoglobin, % saturation: 20, 55, 80, 92, 96, 98

Fetal haemoglobin, % saturation: 35, 68, 88, 95, 97, 99

Bohr-shifted curve, representing blood near actively respiring muscle (pO2 in kPa: 2, 4, 6, 8, 10, 12):

Maternal haemoglobin, % saturation: 10, 40, 65, 80, 90, 95

(a) Define what is meant by the partial pressure of oxygen. **(1)**

(b) Use the resting maternal haemoglobin data to state the percentage saturation of maternal haemoglobin at a pO2 of 4 kPa. **(1)**

(c) Calculate the difference in percentage saturation between fetal haemoglobin and maternal haemoglobin (both resting curves) at a pO2 of 4 kPa. **(1)**

(d) Explain the significance of fetal haemoglobin having a higher affinity for oxygen than maternal haemoglobin, in terms of the transfer of oxygen across the placenta. **(3)**

(e) Explain why it is advantageous for maternal haemoglobin's affinity for oxygen to be reduced (a Bohr shift) in actively respiring muscle tissue during exercise, compared with resting muscle. **(4)**

(f) Using the resting maternal curve for blood leaving the lungs (pO2 = 12 kPa) and the Bohr-shifted curve for blood at the respiring muscle (pO2 = 4 kPa), calculate the decrease in haemoglobin oxygen saturation, in percentage points, as oxygen is unloaded to the muscle. **(2)**

(Total for Question 4 is 12 marks)

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Mark scheme · 1.3 Organisms Exchange Substances with their Environment: 1-hour Pack

Question 1

(a) (gill) lamellae **B1**

(a) Answer: Lamellae.

(b(i)) blood flows in the opposite direction to the water, so at every position along the lamella, the water has a higher oxygen saturation than the blood flowing alongside it oe **M1**

(b(i)) for example, at position 4 the water is 30% saturated while the blood entering (before picking up oxygen) is only 20%; at position 1 the water is 90% saturated while the blood (about to leave, now highly oxygenated) is 80% oe **M1**

(b(i)) because the oxygen saturation of the water always exceeds that of the blood next to it, a diffusion gradient for oxygen (from water to blood) is maintained along the entire length of the lamella, allowing oxygen to keep diffusing into the blood throughout its passage oe **A1**

(b(i)) Answer: Because blood and water flow in opposite directions, water is always more saturated than the adjacent blood, maintaining a gradient along the whole lamella.

(b(ii)) differences = 90-80, 70-60, 50-40, 30-20 = 10, 10, 10, 10 (%) **M1**

(b(ii)) the difference (gradient) is the same (10%) at every position, showing that a diffusion gradient for oxygen is maintained along the entire length of the lamella, rather than only at one end oe **A1**

(b(ii)) Answer: Difference = 10 percentage points at every position; shows a constant gradient is maintained along the whole lamella.

(c) in a parallel-flow system, oxygen would diffuse from water to blood until their saturations became equal (an equilibrium), at which point no further net diffusion would occur, even though the blood may still be far from fully saturated oe **M1**

(c) in the countercurrent system, blood and water saturations never equalise; the blood is always exposed to water with a higher saturation than itself as it passes along the lamella oe **M1**

(c) so a diffusion gradient for oxygen is maintained along the entire length of the lamella in a countercurrent system, allowing the blood to become much more highly saturated with oxygen than would be possible with a parallel-flow arrangement oe **A1**

(c) Answer: Countercurrent flow avoids the equalisation that limits parallel flow, maintaining a gradient along the whole lamella so blood leaves much more oxygenated.

Question 2

(a) spiracles **B1**

(a) (valves formed by) sphincter/muscular valves **B1**

(a) Answer: Spiracles; controlled by sphincter muscles (valves).

(b) the tracheal system relies on diffusion (and some mass flow of air) along the tracheae/tracheoles to deliver oxygen directly to tissues, without oxygen being carried by a circulatory fluid oe **M1**

(b) diffusion is only efficient over short distances, so as body size (and the diffusion distance from spiracle to the furthest tissues) increases, diffusion alone becomes too slow to supply oxygen fast enough to meet respiratory demand oe **M1**

(b) therefore beyond a certain body size, tissues at the centre of a large insect's body would not receive oxygen quickly enough to support aerobic respiration, limiting the maximum size insects can reach oe **A1**

(b) Answer: Diffusion is only rapid over short distances, so beyond a limited body size tissues far from spiracles would not receive oxygen fast enough, limiting insect size.

(c) lactic acid builds up in the flight muscle cells, lowering their water potential oe **B1**

(c) water moves out of the fluid-filled ends of the tracheoles and into the muscle cells by osmosis, down the water potential gradient oe **B1**

(c) this draws air further along the tracheoles, into the space previously occupied by fluid oe **B1**

(c) increasing the surface area of tracheole exposed directly to air (rather than fluid) and shortening the diffusion pathway for oxygen, increasing the rate of gas exchange to the muscle oe **B1**

(c) Answer: Lactic acid lowers water potential in muscle cells, drawing fluid out of tracheole endings by osmosis, so air is drawn further in, increasing the gas exchange surface/rate.

(d) larger/more active insects have a higher oxygen demand and/or longer diffusion pathways than diffusion alone can supply quickly enough oe **M1**

(d) abdominal pumping movements (changing body volume/pressure) cause mass flow of air in and out of the tracheal system, delivering air more quickly over the longer distances involved than diffusion alone could achieve oe **A1**

(d) Answer: Diffusion alone is too slow over the longer distances/higher demand of active insects; pumping movements produce mass flow of air, speeding up gas delivery.

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Question 3

(a) stomata (singular: stoma) **B1**

(a) guard cells **B1**

(a) Answer: Stomata; guard cells.

(b) in the light, guard cells actively transport (pump) potassium ions (K^+) into themselves from surrounding epidermal cells, using ATP oe **B1**

(b) this lowers the water potential inside the guard cells oe **B1**

(b) water moves into the guard cells by osmosis, down the water potential gradient, and the guard cells become turgid oe **B1**

(b) guard cells have unevenly thickened cellulose walls (thicker on the inner wall next to the pore), so as they become turgid they bend/change shape and pull apart, opening the stoma oe **B1**

(b) Answer: Active K^+ uptake lowers water potential, water enters by osmosis, guard cells become turgid and their uneven wall thickening makes them bend apart, opening the stoma.

(c) radius of field of view = 0.5/2 = 0.25 mm; area = 3.142 x 0.25^2 = 0.196 mm^2 (3 s.f.) **M1**

(c) xerophyte: 0.196 x 50 = 9.8, so 10 stomata (nearest whole number) **A1**

(c) mesophyte: 0.196 x 200 **M1**

(c) = 39.3, so 39 stomata (nearest whole number) awrt 39 **A1**

(c) Answer: Xerophyte: about 10 stomata per field of view. Mesophyte: about 39 stomata per field of view.

(d) any one valid adaptation, e.g. thick waxy cuticle; sunken stomata/stomata in pits; rolled leaves; leaf hairs; reduced leaf surface area/needle-shaped leaves oe **B1**

(d) a second distinct valid adaptation oe **B1**

(d) Answer: Any two of: thick waxy cuticle, sunken stomata, rolled leaves, leaf hairs, or reduced leaf surface area.

(e) a lower stomatal density reduces the total area available for water vapour to diffuse out of the leaf, reducing the rate of transpiration/water loss, which is beneficial for surviving in a dry habitat with limited water availability oe **M1**

(e) however, fewer stomata also reduces the total area available for carbon dioxide to diffuse into the leaf for photosynthesis oe **M1**

(e) so while lower stomatal density conserves water, it may limit the rate of photosynthesis/growth compared with a plant with a higher stomatal density, showing a trade-off between water conservation and gas exchange for photosynthesis oe **A1**

(e) Answer: Fewer stomata conserve water (beneficial in drought) but also limit CO_2 uptake for photosynthesis, showing a trade-off.

Question 4

(a) the pressure exerted by oxygen alone within a mixture of gases (or dissolved in a liquid), which is a measure of the concentration of oxygen present oe **B1**

(a) Answer: The pressure contributed by oxygen alone in a gas mixture/dissolved in a liquid; a measure of oxygen concentration.

(b) 55% cao **B1**

(b) Answer: 55%.

(c) 13 (percentage points) cao (68 - 55) **B1**

(c) Answer: 13 percentage points.

(d) at any given pO2 (e.g. in the placenta), fetal haemoglobin has a higher percentage saturation than maternal haemoglobin, i.e. a higher affinity for oxygen oe **B1**

(d) this means that where maternal blood and fetal blood are close together in the placenta, oxygen will tend to dissociate from (be released by) maternal haemoglobin oe **B1**

(d) and associate with (be picked up by) fetal haemoglobin, allowing oxygen to be transferred efficiently from mother to fetus across the placenta oe **B1**

(d) Answer: Fetal haemoglobin's higher oxygen affinity means oxygen released by maternal haemoglobin is preferentially picked up by fetal haemoglobin, enabling efficient placental oxygen transfer.

(e) actively respiring muscle produces more carbon dioxide, which lowers the pH of the blood (forms carbonic acid/releases H^+ ions) oe **M1**

(e) the raised carbon dioxide concentration/lowered pH causes haemoglobin to change shape slightly, reducing its affinity for oxygen (shifting the dissociation curve to the right) oe **M1**

(e) this means that at the same (relatively low) pO2 found in respiring muscle, haemoglobin releases/unloads more oxygen than it would at rest oe **M1**

(e) supplying the actively respiring muscle cells with more oxygen for (aerobic) respiration, to meet their increased oxygen demand during exercise oe **A1**

(e) Answer: More CO_2/lower pH in exercising muscle reduces haemoglobin's oxygen affinity, so more oxygen is unloaded at the muscle's pO2, meeting increased demand.

(f) % saturation leaving lungs (resting curve, 12 kPa) = 98%; % saturation at muscle (Bohr-shifted curve, 4 kPa) = 40% **M1**

(f) oxygen unloaded = 98 - 40 = 58 (percentage points) cao **A1**

(f) Answer: 58 percentage points of oxygen saturation are unloaded to the muscle.

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