# 1.3 Organisms Exchange Substances with their Environment: 2-hour Pack

AQA 7402 · Calculator allowed · about 120 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

**Answer ALL questions. Show all your working.**

**1** The heart pumps blood around the body in a rhythmic cardiac cycle.

**(a)** Name the blood vessel that carries oxygenated blood away from the left ventricle to the rest of the body. **(1)**

**(b)** Describe one structural difference between the wall of the left ventricle and the wall of the right ventricle, and explain the functional significance of this difference. **(4)**

**(c)** During ventricular systole, the atrioventricular (bicuspid and tricuspid) valves close. Explain the role of these valves at this point in the cardiac cycle. **(3)**

**(d)** A patient at rest has a heart rate of 72 beats per minute and a stroke volume of 70 $cm^3$. Calculate their cardiac output in $dm^3$ per minute. **(3)**

**(e)** During exercise, the same patient's cardiac output increases to 20 $dm^3$ per minute and their stroke volume increases to 120 $cm^3$. Calculate their heart rate during this exercise, to the nearest whole beat per minute. **(3)**

**(Total for Question 1 is 14 marks)**


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**2** A student investigated the effect of exercise on the cardiac cycle. At rest, a subject had a heart rate of 68 beats per minute and a stroke volume of 72 $cm^3$. During moderate exercise, the heart rate increased to 132 beats per minute and the stroke volume increased to 108 $cm^3$.

**(a)** State the equation linking cardiac output, heart rate and stroke volume. **(1)**

**(b)** Calculate the resting cardiac output, in cm3/minute. **(2)**

**(c)** Calculate the cardiac output during exercise, in cm3/minute, and hence calculate the percentage increase in cardiac output caused by exercise. **(3)**

**(d)** Explain, in terms of control of the cardiac cycle, how heart rate increases during exercise. **(3)**

**(Total for Question 2 is 9 marks)**

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**3** A student used a potometer to measure the rate of water uptake by a leafy shoot under different conditions, as a proxy for transpiration rate. An air bubble was introduced into the capillary tube, and its movement was timed over a fixed distance. The internal diameter of the capillary tube was 1.0 mm. The bubble took 150 seconds to travel 60 mm along the tube in still air, and 50 seconds to travel 60 mm in front of a fan.

**(a)** Calculate the volume of water taken up while the bubble moved 60 mm (use volume = $\pi r^2$ x length, with r = 0.50 mm). Give your answer in mm3 to 3 significant figures. **(2)**

**(b)** Calculate the rate of water uptake, in mm3 per second, in still air. **(2)**

**(c)** Calculate the percentage increase in the rate of water uptake caused by the fan, compared with still air. **(3)**

**(d)** Explain, in terms of the water potential gradient at the leaf surface, why moving air increases the rate of water uptake. **(2)**

**(Total for Question 3 is 9 marks)**


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**4** A student prepared a leaf epidermal peel and viewed it under a light microscope using a x40 objective lens, giving a circular field of view of diameter 0.45 mm. Within this field of view the student counted 18 stomata.

**(a)** Calculate the area of the field of view, in mm2, to 3 significant figures (area of a circle = $\pi r^2$). **(2)**

**(b)** Calculate the stomatal density, in stomata per mm2, to 3 significant figures. **(2)**

**(c)** The same leaf has an estimated total surface area of 42 $cm^2$. Using your answer to (b), estimate the total number of stomata on this leaf. **(2)**

**(d)** A xerophytic plant adapted to hot, dry conditions typically has a much lower stomatal density than this leaf, and its stomata are often sunken in pits. Explain how these adaptations reduce water loss by transpiration. **(2)**

**(Total for Question 4 is 8 marks)**

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**5** Water moves from the roots to the leaves of a tall tree through xylem vessels, against the force of gravity, without the use of metabolic energy by the xylem itself.

**(a)** State two structural features of xylem vessels that adapt them for the transport of water. **(2)**

**(b)** Explain, using the cohesion-tension theory, how water is transported through the xylem from the roots to the top of a tall tree, without the use of metabolic energy. **(6)**

**(c)** Suggest why an air bubble (embolism) that becomes lodged in a xylem vessel would prevent water transport through that particular vessel. **(2)**

**(Total for Question 5 is 10 marks)**


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**6** This final question draws together ideas about gas exchange, mass transport and exchange surfaces across different organisms.

**(a)** A fish has a countercurrent gas exchange system across its gills, achieving up to 80% extraction of the dissolved oxygen from water passing over the gill lamellae. Explain why a countercurrent system is more efficient than a parallel (concurrent) flow system would be. **(3)**

**(b)** Unlike a fish, an insect's tracheal system delivers oxygen directly to respiring tissues by diffusion (and, in some species, mass movements of air) through air-filled tracheae and tracheoles, without the involvement of a blood pigment such as haemoglobin. Suggest one advantage and one limitation of this system compared with a blood-based (circulatory) gas transport system, particularly in relation to insect body size. **(3)**

**(c)** A mammal's circulatory system is described as a double, closed circulation. Explain why a double circulatory system, in which blood passes through the heart twice on each complete circuit of the body, is necessary to maintain a high blood pressure (and hence a fast delivery rate of oxygen) to body tissues. **(3)**

**(Total for Question 6 is 9 marks)**


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**7** A biologist compared the oxygen dissociation curve of adult human haemoglobin (Hb) with that of a diving mammal's myoglobin and with fetal haemoglobin (HbF). At a partial pressure of oxygen of 4.0 kPa, percentage saturation values were: adult Hb 25%, HbF 45%, myoglobin 85%.

**(a)** Explain what is meant by saying that myoglobin has a 'higher affinity for oxygen' than adult haemoglobin, using the data given. **(2)**

**(b)** Explain the functional significance of myoglobin's high oxygen affinity in a diving mammal's muscle tissue. **(2)**

**(c)** Explain why fetal haemoglobin (HbF) has a higher affinity for oxygen than adult haemoglobin, and why this is essential for the fetus. **(3)**

**(d)** During intense exercise, muscle tissue produces more $CO_2$ and becomes more acidic (the Bohr effect). Explain how this shifts the oxygen dissociation curve of adult haemoglobin and why this is beneficial. **(1)**

**(Total for Question 7 is 8 marks)**


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**8** Glucose is absorbed from the lumen of the ileum into epithelial cells against its concentration gradient by co-transport with sodium ions, then moves into the blood by facilitated diffusion.

**(a)** Describe the role of the sodium-potassium pump, located on the basal membrane of the epithelial cell, in maintaining the concentration gradient needed for glucose co-transport. **(3)**

**(b)** Explain how the co-transporter protein allows glucose to move into the epithelial cell against its own concentration gradient, using the energy of the sodium ion gradient. **(2)**

**(c)** Explain why a poison that inhibits ATP production (e.g. cyanide) would eventually stop glucose absorption by this route, even though the co-transporter protein itself does not directly use ATP. **(2)**

**(Total for Question 8 is 7 marks)**

**9** A potometer measures the rate of water uptake by a shoot, which is used as an estimate of transpiration rate, but it is not a direct measure of transpiration itself. Evaluate how reliable a potometer is as a measure of transpiration rate.

**(Total for Question 9 is 6 marks)**


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# Mark scheme · 1.3 Organisms Exchange Substances with their Environment: 2-hour Pack

## Question 1

(a) aorta **B1**

**(a) Answer: Aorta.**

(b) the left ventricle wall is thicker (has more cardiac muscle) than the right ventricle wall oe **B1**

(b) the left ventricle must pump blood at high pressure all the way around the body (the systemic circulation), overcoming greater resistance, so needs a thicker, more powerful muscular wall oe **B1**

(b) the right ventricle wall is thinner (less muscular) than the left oe **B1**

(b) the right ventricle only needs to pump blood a short distance to the lungs (the pulmonary circulation) at lower pressure, to avoid damaging the delicate capillaries in the lungs oe **B1**

**(b) Answer: Left ventricle wall is thicker to generate high pressure for the systemic circulation; right ventricle wall is thinner as it only pumps blood the short distance to the lungs at lower pressure.**

(c) as the ventricles contract (ventricular systole), pressure in the ventricles rises above the pressure in the atria oe **M1**

(c) this pressure difference pushes the atrioventricular valves shut oe **M1**

(c) preventing the backflow of blood from the ventricles into the atria, ensuring blood is forced out through the semilunar valves into the aorta/pulmonary artery instead, maintaining efficient one-way flow oe **A1**

**(c) Answer: Rising ventricular pressure during systole closes the AV valves, preventing backflow into the atria and ensuring blood is forced forward into the arteries.**

(d) cardiac output = heart rate x stroke volume = 72 x 70 **M1**

(d) = 5040 $cm^3$/min **M1**

(d) = 5.04 $dm^3$/min cao **A1**

**(d) Answer: 5.04 $dm^3$/min.**

(e) heart rate = cardiac output / stroke volume = 20000 $cm^3$/min / 120 $cm^3$ **M1**

(e) = 166.67 (dependent on correct rearrangement and unit conversion of cardiac output to $cm^3$/min) **dM1**

(e) = 167 beats per minute (nearest whole beat) awrt 167 **A1**

**(e) Answer: 167 beats per minute.**

## Question 2

(a) cardiac output = heart rate x stroke volume **B1**

**(a) Answer: Cardiac output = heart rate x stroke volume.**

(b) 68 x 72 **M1**

(b) 4896 $cm^3$/minute, cao **A1**

**(b) Answer: 4896 $cm^3$/minute**

(c) exercise cardiac output = 132 x 108 = 14256 $cm^3$/minute **M1**

(c) percentage increase = (14256 - 4896)/4896 x 100, ft **M1**

(c) 191% (accept 190-192%), awrt **A1**

**(c) Answer: Cardiac output during exercise = 14256 $cm^3$/minute; a 191% increase.**

(d) exercise increases $CO_2$ concentration in the blood (and decreases blood pH), detected by chemoreceptors in the aortic and carotid bodies (and the medulla) oe **B1**

(d) chemoreceptors send impulses to the cardiovascular (cardiac) centre in the medulla oblongata oe **B1**

(d) the cardiovascular centre increases the frequency of impulses along the sympathetic nerve to the sinoatrial node (SAN), increasing the rate at which it generates excitation waves, increasing heart rate oe **B1**

**(d) Answer: Rising $CO_2$ (falling pH) is detected by chemoreceptors, which signal the cardiovascular centre in the medulla; this increases sympathetic stimulation of the SAN, raising heart rate.**

## Question 3

(a) volume = π x $(0.50)^2$ x 60 **M1**

(a) 47.1 $mm^3$, awrt **A1**

**(a) Answer: 47.1 $mm^3$**

(b) rate = volume / time = 47.1 / 150, ft from (a) **M1**

(b) 0.314 $mm^3$/s, awrt **A1**

**(b) Answer: 0.314 $mm^3$/s**

(c) rate with fan = 47.1 / 50 = 0.942 $mm^3$/s, ft **M1**

(c) percentage increase = (0.942 - 0.314)/0.314 x 100, ft **M1**

(c) 200% (accept 199-201%), awrt **A1**

**(c) Answer: Approximately 200%**

(d) moving air removes water vapour molecules from the leaf surface (boundary layer) as soon as they diffuse out of the stomata, preventing a build-up of humid air oe **B1**

(d) this maintains a steep water potential (concentration) gradient between the inside of the leaf and the air outside, increasing the rate of diffusion of water vapour out of the stomata (transpiration), and so the rate of water uptake by the shoot oe **B1**

**(d) Answer: Moving air sweeps away water vapour at the leaf surface, maintaining a steep water potential gradient that increases the rate of diffusion of water out of the stomata and therefore the rate of water uptake.**


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## Question 4

(a) radius = 0.45/2 = 0.225 mm; area = π x $(0.225)^2$ **M1**

(a) 0.159 $mm^2$, awrt **A1**

**(a) Answer: 0.159 $mm^2$**

(b) density = number of stomata / area = 18 / 0.159, ft from (a) **M1**

(b) 113 stomata/mm2 (accept 112-114), awrt **A1**

**(b) Answer: 113 stomata/mm2**

(c) convert 42 $cm^2$ to mm2: 42 x 100 = 4200 $mm^2$, then multiply by density from (b), ft **M1**

(c) approximately 4.75 x $10^5$ stomata (474600, accept a range consistent with ft from (b)), cao **A1**

**(c) Answer: Approximately 4.75 x $10^5$ stomata.**

(d) fewer stomata reduce the total surface area/number of pores available for water vapour to diffuse out of the leaf, reducing transpiration oe **B1**

(d) sunken stomata (in pits) trap a pocket of still, humid air close to the pore, reducing the water potential (concentration) gradient between the leaf interior and the air immediately outside, slowing diffusion of water vapour out oe **B1**

**(d) Answer: A lower stomatal density reduces the total pore area for water loss, and sunken stomata trap humid air close to the pore, reducing the diffusion gradient and further slowing transpiration.**

## Question 5

(a) any one valid structural feature, e.g. dead cells with no cytoplasm/organelles forming hollow tubes; lignified walls; absent end walls; pits in vessel walls oe **B1**

(a) a second distinct valid structural feature oe **B1**

**(a) Answer: Any two of: hollow, dead cells without cytoplasm; lignified walls; absent end walls; pits allowing lateral water movement.**

(b) **L3** A detailed, logically sequenced account linking transpiration, cohesion, tension and adhesion to explain the continuous movement of water from roots to leaves, using accurate scientific terminology throughout (e.g. water potential, hydrogen bonding, negative pressure/tension). **5-6**

(b) **L2** A generally accurate account of the main stages of the cohesion-tension mechanism, but the explanation may be incomplete, may omit a stage (e.g. root uptake or adhesion), or the links between transpiration, tension and cohesion may not be fully explained. Terminology mostly appropriate. **3-4**

(b) **L1** Basic or isolated statements are made about water movement in xylem (e.g. transpiration occurs, or water evaporates from leaves), with little reference to cohesion, tension or the pulling of a continuous water column. Limited use of scientific terminology. **1-2**

(b) **L0** No relevant content is provided. **0**

**(b) Indicative content:**

- Water evaporates from the cells of the mesophyll into the air spaces of the leaf and diffuses out through open stomata (transpiration), lowering the water potential of the mesophyll cells.
- This creates a water potential gradient, so water is drawn out of the xylem vessels in the leaf veins, by osmosis, to replace the water lost.
- Water molecules are attracted to one another by hydrogen bonding (cohesion), so as water leaves the top of the xylem column, it pulls the whole continuous column of water upward behind it.
- This creates a tension (negative pressure) that is transmitted all the way down the column of water in the xylem, from the leaves to the roots.
- Water molecules are also attracted to the (lignified/hydrophilic) walls of the xylem vessels (adhesion), which helps support the column and resists it breaking under tension.
- This tension draws water into the xylem from the root cells, and ultimately from the soil, replacing water lost from the top of the column, without any expenditure of metabolic energy by the xylem tissue itself.
- The lignified walls of the xylem vessels are strong enough to withstand the tension (negative pressure) without collapsing inward.

**(b) Answer: Full marks require the transpiration-driven water potential gradient, cohesion pulling up a continuous unbroken column under tension, and adhesion to vessel walls, to be linked in a coherent account, judged holistically against the level descriptors.**

(c) an air bubble breaks the continuity of the water column in that vessel, since air, unlike water, cannot experience/transmit cohesive forces (hydrogen bonding) between water molecules oe **M1**

(c) so the tension created by transpiration higher up the vessel cannot be transmitted down through the air bubble to pull water up from the roots, and water transport through that vessel stops (although water can often be diverted sideways into a neighbouring vessel through pits) oe **A1**

**(c) Answer: An air bubble breaks the continuous water column, so cohesive tension cannot be transmitted through it, halting water transport in that vessel.**


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## Question 6

(a) in a countercurrent system, blood and water flow in opposite directions, so blood with a relatively low oxygen concentration always meets water that has already had some oxygen removed, but still has a higher concentration than the blood oe **B1**

(a) this means a diffusion gradient favouring oxygen movement into the blood is maintained along the entire length of the lamella oe **B1**

(a) in a parallel system, blood and water would reach equilibrium partway along the lamella, so no further net diffusion could occur over the remaining length, giving lower overall extraction oe **B1**

**(a) Answer: Opposite flow of blood and water maintains a diffusion gradient along the whole gill lamella, unlike a parallel system where blood and water would equalise partway along and diffusion would stop, so countercurrent exchange extracts far more oxygen.**

(b) advantage: diffusion of gases through air is much faster than diffusion through a liquid (blood plasma), so oxygen can reach tissues rapidly and directly without needing a circulatory pigment oe **B1**

(b) limitation: diffusion alone is only efficient over short distances, so as insects increase in body size, tracheal air-filled tubes cannot supply oxygen to central tissues fast enough, limiting the maximum body size of insects oe **B1**

(b) a further valid point, e.g. some larger/more active insects supplement diffusion with abdominal pumping movements to ventilate the tracheal system oe **B1**

**(b) Answer: An advantage is that diffusion through air is much faster than through blood plasma, delivering oxygen quickly without a circulatory pigment; a limitation is that diffusion is only efficient over short distances, which is thought to limit the maximum body size insects can reach, though some species use abdominal pumping to help ventilate larger tracheal systems.**

(c) blood pressure falls substantially as blood passes through the narrow capillaries of the lungs (pulmonary circulation), because of the resistance of the many small vessels oe **B1**

(c) if blood then went straight to the body without returning to the heart, it would arrive at the body tissues at too low a pressure to be delivered efficiently/quickly oe **B1**

(c) by returning to the heart after the lungs, blood pressure is boosted again by a second pumping chamber (left ventricle) before being sent to the body, maintaining a high pressure and rapid delivery of oxygenated blood to respiring tissues oe **B1**

**(c) Answer: Pressure drops sharply across the narrow capillaries of the lungs; a double circulation returns blood to the heart to be re-pressurised by the left ventricle before travelling to the body, maintaining high pressure and a fast rate of oxygen delivery to tissues.**

## Question 7

(a) at the same partial pressure of oxygen (4.0 kPa), myoglobin is more saturated with oxygen (85%) than adult haemoglobin (25%) oe **B1**

(a) so myoglobin binds/holds on to oxygen more readily, and only releases it at very low partial pressures of oxygen, whereas adult Hb readily releases oxygen at this partial pressure oe **B1**

**(a) Answer: At 4.0 kPa myoglobin is 85% saturated compared with 25% for adult Hb, showing myoglobin binds oxygen more strongly and only releases it at very low oxygen partial pressures.**

(b) myoglobin acts as an oxygen store within the muscle, loading oxygen readily from the blood oe **B1**

(b) it only releases this stored oxygen at the very low partial pressures found in actively respiring muscle during a prolonged dive, supplying the muscle with oxygen when the animal cannot breathe oe **B1**

**(b) Answer: Myoglobin stores oxygen in muscle and releases it only at the very low oxygen partial pressures reached during a dive, supplying respiring muscle when the animal cannot breathe.**

(c) HbF has a different structure (different polypeptide chains) from adult Hb, giving it a higher affinity for oxygen at any given partial pressure oe **B1**

(c) in the placenta, fetal blood and maternal blood are close together but do not mix, so oxygen must diffuse from maternal Hb to fetal Hb oe **B1**

(c) because HbF has a higher affinity, it can load oxygen from the maternal blood (where the adult Hb is releasing it), ensuring the fetus is not oxygen-deprived oe **B1**

**(c) Answer: HbF's different structure gives it a higher oxygen affinity than adult Hb, which allows it to take up oxygen from maternal blood across the placenta at a partial pressure where maternal Hb is releasing oxygen, ensuring adequate oxygen transfer to the fetus.**

(d) increased $CO_2$/lower pH shifts the dissociation curve to the right, decreasing haemoglobin's affinity for oxygen, so more oxygen is released/unloaded to respiring tissues at a given partial pressure oe **B1**

**(d) Answer: Higher $CO_2$ and lower pH shift the curve right, reducing Hb's affinity for oxygen so more oxygen is released to the actively respiring muscle.**


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## Question 8

(a) the sodium-potassium pump actively transports (using ATP) sodium ions out of the epithelial cell, into the blood, against their concentration gradient oe **B1**

(a) this maintains a low concentration of sodium ions inside the epithelial cell compared with the lumen of the ileum oe **B1**

(a) this creates a concentration (electrochemical) gradient for sodium ions to diffuse from the lumen into the epithelial cell down their gradient, via a co-transporter protein oe **B1**

**(a) Answer: The sodium-potassium pump actively removes sodium from the epithelial cell into the blood, keeping intracellular sodium low and so maintaining a steep gradient for sodium to re-enter from the lumen via the co-transporter.**

(b) the co-transporter protein binds both a sodium ion and a glucose molecule at the same time oe **B1**

(b) as sodium ions diffuse into the cell down their concentration gradient through the co-transporter, glucose is carried in with them, even though glucose itself is moving against its own concentration gradient oe **B1**

**(b) Answer: The co-transporter binds sodium and glucose together; as sodium moves in down its gradient it drags glucose in with it, even against glucose's own concentration gradient.**

(c) the sodium-potassium pump requires ATP to actively transport sodium ions out of the cell oe **B1**

(c) without ATP, the pump stops working, so the sodium concentration gradient across the epithelial cell membrane cannot be maintained/collapses, removing the driving force for the co-transporter, so glucose absorption stops oe **B1**

**(c) Answer: Without ATP the sodium-potassium pump stops, the sodium gradient collapses, and with no gradient to drive it the co-transporter can no longer bring glucose into the cell.**

## Question 9

**Level 3** A detailed, well-structured evaluation that explains why water uptake is used as a proxy for transpiration, identifies at least two valid reasons the two measurements can differ (e.g. water used in photosynthesis/turgidity/metabolism, air bubbles affecting resistance, time lag), and discusses how the design of the potometer (e.g. cutting the shoot underwater, sealing joints) improves validity, reaching a supported overall judgement on the reliability of the potometer as a measure of transpiration. **5-6**

**Level 2** A reasonably clear evaluation identifying at least one valid reason why water uptake differs from water lost by transpiration, and some reference to potometer design features that affect validity, but the discussion is not fully developed or balanced. **3-4**

**Level 1** Limited evaluation; may simply state that the potometer measures water uptake rather than transpiration without explaining why this matters, or lists a feature of the apparatus with no evaluative comment. **1-2**

**Indicative content:**

- A potometer measures the volume of water taken up by the cut shoot per unit time, not the volume of water vapour lost through the stomata.
- Not all the water taken up is lost by transpiration: a small proportion is used in photosynthesis, retained to maintain cell turgidity, or used in other metabolic reactions, so water uptake slightly overestimates transpiration in this respect.
- Conversely, some water uptake can lag behind water loss because of the shoot's own water storage capacity (used to refill cells that have lost water), so uptake and loss are not perfectly synchronised moment to moment, though they are similar over longer time periods.
- The apparatus must be set up carefully to give valid readings: the shoot is cut underwater and under the surface of water in the apparatus to prevent air entering the xylem (which would block water columns and give false low readings).
- All joints must be airtight/watertight (e.g. sealed with petroleum jelly) to prevent water loss or air entry that would introduce error unrelated to the plant's own water uptake.
- Despite these limitations, because the overwhelming majority of water taken up by a shoot is indeed lost by transpiration, and because uptake is easy to measure precisely (via bubble movement) whereas water vapour loss is very difficult to measure directly, the potometer is widely regarded as a good, practical proxy for the pattern (though not the exact absolute value) of transpiration rate and how it responds to variables such as wind speed, humidity, light and temperature.


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