1.2 The heart, lungs and homeostasis

Name: _____ Class: _____ Date: _____ **Total: 30 marks**

KEY WORDS sinoatrial node • stroke volume • cardiac output • tidal volume • partial pressure • negative feedback

Objective

Build the skills to answer exam questions on the **heart** and **lungs**, **cardiac output**, ventilation and gas exchange, and **homeostasis** during exercise.

You must be able to:

- describe the conduction of the heartbeat and calculate cardiac output
- describe breathing, lung volumes and minute ventilation
- explain gas exchange using partial pressure
- explain temperature and blood glucose regulation as negative feedback
- explain the effects of heat and altitude, and acclimatization

1 Key knowledge and worked examples

■ Heart, lungs and homeostasis

Heart: four chambers; **double circulation** (right side → lungs; left side → body). The heartbeat starts in the **sinoatrial (SA) node** (pacemaker) → atria contract → **atrioventricular (AV) node** (short delay) → **bundle of His** → **Purkinje fibres** → ventricles contract.

$$\text{cardiac output } Q = \text{heart rate (HR)} \times \text{stroke volume (SV)}$$

e.g. HR 70 beats min^{-1} × SV 70 ml = 4900 ml min^{-1} ≈ 4.9 L min^{-1}.

Venous return rises in exercise by the **muscle pump** (contracting muscles squeeze veins; valves stop backflow), the **respiratory pump** and **venoconstriction**.

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Breathing in (rest): the **diaphragm** contracts and flattens; the external **intercostal** muscles lift the ribs; chest volume rises, pressure falls, air flows in. In exercise, extra muscles help, and breathing out becomes active.

volume	meaning
tidal volume (TV)	air in or out per breath (about 0.5 L at rest)
vital capacity	most air you can breathe out after the deepest breath in
residual volume	air left in the lungs after the hardest breath out

$$\text{minute ventilation } V_E = \text{TV} \times \text{breathing rate}$$

Gas exchange: O_2 and CO_2 move by **diffusion** from high to low **partial pressure**. Alveoli have a huge surface area, walls one cell thick and a rich capillary supply. **Chemoreceptors** detect rising CO_2 (lower pH) and increase breathing.

Homeostasis keeps the internal environment stable by **negative feedback**: a change is detected and the response reverses it.

- **Temperature:** sweating (evaporation removes heat) and **vasodilation** of skin vessels.
- **Blood glucose:** if it falls, the pancreas releases **glucagon**, so the liver breaks glycogen into glucose; if it rises, **insulin** helps cells take it up.

AHL – environment: in heat and humidity, sweat evaporates poorly; **heat acclimatization** (about 1–2 weeks) brings earlier, more dilute sweating and a larger plasma volume. At altitude the air is still 20.9% oxygen, but **barometric pressure is lower**, so the **partial pressure** of O_2 is lower and less O_2 diffuses into the blood. Over weeks, more **EPO** is released, so red blood cells and haemoglobin rise.

Answer shapes: for a calculation, write the formula, the numbers with units, and the answer with units.

2 Practice

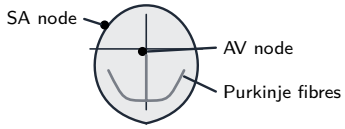
2.1 An athlete has a heart rate of 150 beats min^{-1} and a stroke volume of 120 ml. Calculate the cardiac output in L min^{-1}. [2]



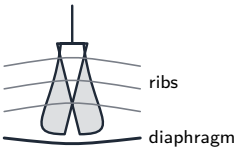
HR 150 beats min^{-1}

SV 120 ml

2.2 Describe how the electrical impulse that starts each heartbeat spreads through the heart. [3]



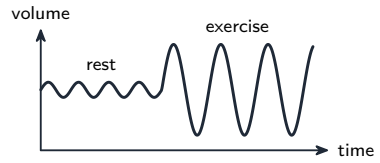
2.3 Describe the mechanics of breathing in at rest. [3]



2.4 The table shows breathing data for a student.

	tidal volume (L)	**breaths min^{-1}**
rest	0.5	12
hard exercise	2.5	40

(a) Calculate the minute ventilation at rest and in exercise. [2]



(b) Calculate how many times larger it is in exercise. [1]

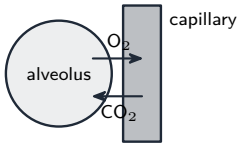
(c) Name the receptors that detect the rise in blood CO_2. [1]

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3 Exam-style questions

3.1 The diagram shows an alveolus and a capillary.

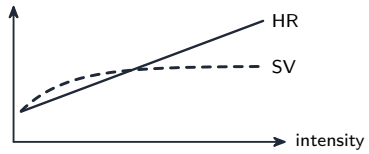
(a) Explain how oxygen moves from the alveolus into the blood. [2]



(b) Explain **two** features of the alveoli that make gas exchange fast. [2]

3.2 The graph shows stroke volume and heart rate as exercise intensity rises.

(a) Describe how stroke volume changes as intensity rises. [2]



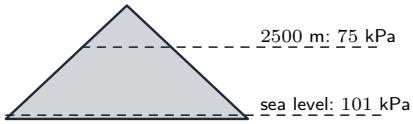
(b) Explain why heart rate rises just before exercise starts. [2]

(c) Explain how venous return increases during exercise. [2]

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3.3 A team trains at 2500 m, where air pressure is about 75 kPa (sea level: 101 kPa). Air is 20.9% oxygen at both heights.

(a) Calculate the partial pressure of oxygen at sea level and at 2500 m. [2]



(b) Explain why less oxygen enters the blood at altitude. [2]

(c) Describe **two** adaptations after several weeks at altitude. [2]

(d) Explain how heat acclimatization helps an athlete compete in a hot climate. [2]

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Solutions

Marking: **M1** a correct method, **A1** the correct answer, **B1** an independent mark.

Each answer shows the steps, then the **result**.

2.1

$Q = 150 \times 120 = 18\,000$ ml min^{-1} = **18** L min^{-1}

2.2

the impulse starts at the SA node and spreads over the atria, which contract; it reaches the AV node, which delays it so the ventricles can fill; it passes down the bundle of His and through the Purkinje fibres, so the ventricles contract from the bottom up

2.3

the diaphragm contracts and flattens; the external intercostal muscles contract, moving the ribs up and out; chest volume rises so pressure in the lungs falls below air pressure, and air flows in

2.4

(a) rest $0.5 \times 12 =$ **6** L min^{-1}; exercise $2.5 \times 40 =$ **100** L min^{-1}

(b) $100 \div 6 \approx$ **17** times

(c) chemoreceptors

3.1

(a) by diffusion; from a higher partial pressure of O_2 in the alveolus to a lower partial pressure in the blood

(b) any two, explained: walls one cell thick, so a short diffusion distance; a huge surface area; dense capillary network keeps the gradient high; moist lining

3.2

(a) stroke volume rises at low to moderate intensity; then levels off (plateau) at about 40–60% of maximum

(b) anticipation of exercise activates the sympathetic system; adrenaline is released and raises heart rate (anticipatory rise)

(c) any two: muscle pump: contracting muscles squeeze veins, with valves stopping backflow; respiratory pump: pressure changes in the chest during deeper breathing; venoconstriction

3.3

(a) sea level $0.209 \times 101 =$ **21.1** kPa; altitude $0.209 \times 75 =$ **15.7** kPa

(b) the partial pressure of O_2 in the alveoli is lower; so the gradient between alveoli and blood is smaller and less O_2 diffuses in / haemoglobin is less saturated

(c) any two: more EPO, so more red blood cells and haemoglobin; more capillaries in muscle; higher breathing rate; more mitochondria / myoglobin

(d) sweating starts earlier and more sweat is produced, so more heat is lost; plasma volume rises, so stroke volume stays higher and heart rate is lower at the same work

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