PEARSON EDEXCEL · INTERNATIONAL A-LEVEL · BIOLOGY • EXERCISE SHEET

1.4 Haemoglobin and gas transport

Name: _____ Class: _____ Date: _____ **Total: 23 marks**

KEY WORDS quaternary ( ) • cooperative binding • Bohr effect • dissociation curve • saturation

Objective

Practise statement 1.9: haemoglobin's structure, the sigmoid dissociation curve, cooperative binding and the Bohr effect, with the calculations of percentage saturation the paper asks for.

1 Key knowledge and worked examples

Four subunits, four oxygens, one curve

Haemoglobin is a **quaternary** protein: two α and two β chains, each with a **haem** group whose Fe^{2+} carries one O_2. Binding the first oxygen changes the protein's shape so the next sites bind more easily – **cooperative binding** – giving the S-shaped (sigmoid) curve.

Three readings of the curve

- Lungs ($pO_2 \approx 13$ kPa): curve flat near 100 % – load fully.
- Resting tissue ($\approx$ 2–4 kPa): steep region – a small pO_2 fall unloads a lot of oxygen.
- Hard-working tissue: more $CO_2 \rightarrow$ more H^+ bound to haemoglobin $\rightarrow$ lowered affinity $\rightarrow$ the curve shifts right (**Bohr effect**) – even more oxygen released exactly where respiration is fastest.

Worked example: unloading from curve readings

At 4 kPa: normal blood 60 % saturated; with raised CO_2, 34 %. Unloading $= 60 - 34 = 26$ percentage points. Per 100 mL of blood at that partial pressure, haemoglobin carries about 0.2 g O_2 fully loaded, so the extra unloading is $0.26 \times 0.2 \approx 0.05$ g per 100 mL – delivered to the tissue with no extra flow.

2 Practice

2.1 Describe the structure of a haemoglobin molecule, using the term quaternary. [3]

2.2 Explain why the oxygen dissociation curve is S-shaped rather than a straight line. [3]

2.3 State the effect of increasing carbon dioxide concentration on the position of the dissociation curve and name this effect. [2]

3 Exam-style questions

3.1 The table shows haemoglobin saturation at two carbon dioxide partial pressures: curve A (low CO_2) and curve B (high CO_2).

pO_2 / kPa	Curve A saturation / %	Curve B saturation / %
2	30	14
4	60	34
6	82	62
8	91	80

Calculate the percentage of the total oxygen carried that is unloaded between the lungs (8 kPa) and resting tissue (2 kPa) for each curve, and use your answers to explain the biological advantage of the Bohr effect. [6]

3.2 Myoglobin is a single-chain protein with one haem group; its dissociation curve is hyperbolic, reaching 90 % saturation at 1 kPa. Explain why myoglobin is suited to oxygen storage in muscle while haemoglobin is suited to transport, referring to the shapes of their curves. [5]

3.3 A person at high altitude breathes air with a pO_2 of 8 kPa in the alveoli. Using curve A above, describe the effect on the saturation of haemoglobin leaving the lungs, and explain one way the body compensates over days at altitude. [4]

Solutions

Original-task marking: M1 method, A1 accuracy, B1 reasoning.

2.1 Four polypeptide chains – two α and two β – each folded around a haem group containing Fe^{2+}. A protein of several chains is a quaternary protein.

2.2 At low pO_2 only one site loads with difficulty (low affinity); the first O_2 changes the shape so later sites bind more easily – cooperative binding; at high pO_2 nearly all sites are occupied so saturation flattens – together, a shallow–steep–flat S shape.

2.3 Shifts the curve to the right; the Bohr effect.

3.1 Curve A unloads $91 - 30 = 61\%$ of its carrying capacity; curve B unloads $80 - 14 = 66\%$. The higher-CO_2 curve releases more of its load over the same pO_2 range. Advantage: actively respiring tissue produces the CO_2 that raises its own unloading, so oxygen is redirected to where it is needed most without any change in total blood flow or lung loading.

3.2 Myoglobin's hyperbolic curve reaches high saturation at very low pO_2, so it stays almost fully loaded even when muscle pO_2 is low – it holds oxygen until demand is high. Haemoglobin's sigmoid curve loads fully at alveolar pO_2 and unloads steeply across tissue pO_2 values, and its cooperativity makes it sensitive to small pO_2 changes, ideal for transport. Myoglobin, single chain with no cooperativity, cannot steepen its release this way.

3.3 At 8 kPa curve A gives about 91 % rather than the ~98 % at 13 kPa – modest reduction. Compensation: increased red-cell production (erythropoietin) raises the haemoglobin concentration, so despite lower saturation the total oxygen delivered per unit blood volume is restored; (accept increased ventilation rate or a right-shifted curve aiding tissue unloading).