

8.2 Transport of oxygen and carbon dioxide

Name: _____ Class: _____ Date: _____

Total: 23 marks

KEY WORDS carbon dioxide

• oxygen dissociation curve

• bohr shift

• haemoglobinic acid

• carbonic anhydrase

Objective

Build the skills to answer exam questions on the **transport of oxygen and carbon dioxide** – the **oxygen dissociation curve**, the **Bohr shift**, and how carbon dioxide is carried.

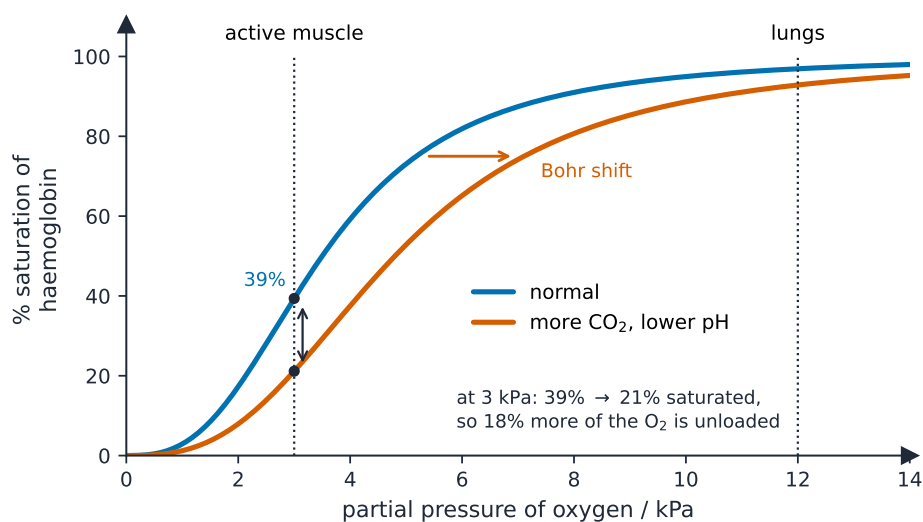
You must be able to:

- describe and explain the oxygen dissociation curve and its importance in the lungs and tissues
- describe and explain the Bohr shift
- describe carbon dioxide transport, including the **chloride shift**

1 Key knowledge and worked examples

■ The oxygen dissociation curve

The S-shaped curve plots **saturation** of haemoglobin against the **partial pressure** of oxygen.



Bohr shift (right): $\uparrow \text{CO}_2 / \downarrow \text{pH} \rightarrow$ lower O_2 affinity $\rightarrow$ unload at tissues

Haemoglobin loads O_2 in the lungs (high $p\text{O}_2$) and unloads it in tissues (low $p\text{O}_2$); the Bohr shift moves the curve right

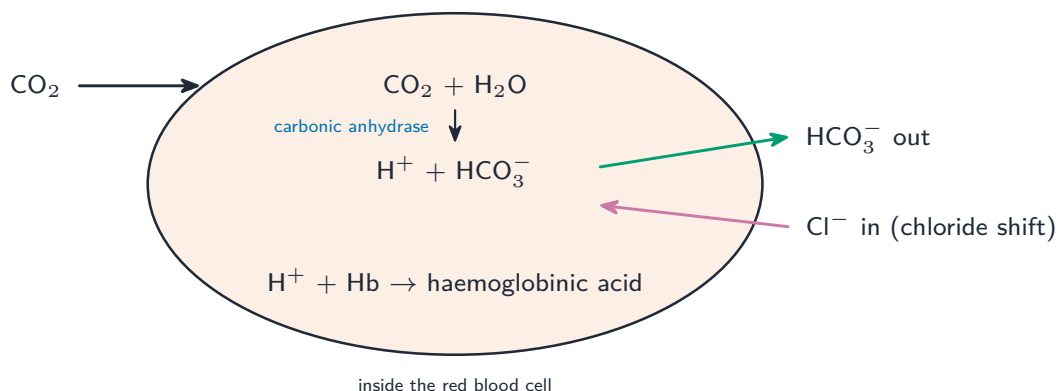
- in the lungs (high $p\text{O}_2$), haemoglobin becomes almost fully saturated (loads O_2).
- in respiring tissues (low $p\text{O}_2$), haemoglobin unloads O_2 for the cells.

Reading the curve: O_2 unloaded = saturation in lungs – saturation in tissues.
E.g. $98\% \rightarrow 40\%$ means 58% of the oxygen is released.

■ The Bohr shift

Active tissues make more **carbon dioxide**, lowering pH; this makes haemoglobin release O_2 more easily, so the curve shifts **right** – O_2 is given up where it is most needed.

■ Carbon dioxide transport



Most CO_2 travels as hydrogencarbonate ions; the chloride shift balances charge; haemoglobin mops up H^+

Most CO_2 is carried as **hydrogencarbonate ions** : **carbonic anhydrase** catalyses $\text{CO}_2 + \text{water} \rightarrow \text{carbonic acid} \rightarrow \text{H}^+ + \text{HCO}_3^-$. HCO_3^- leaves the red cell and **chloride ions** move in (the chloride shift) to balance the charge; H^+ binds haemoglobin (**haemoglobinic acid**).

2 Practice

2.1 State where on the dissociation curve haemoglobin (a) loads oxygen and (b) unloads oxygen. [2]

2.2 Name the enzyme that catalyses the reaction of carbon dioxide with water. [1]

3 Exam-style questions

3.1 In which form is **most** carbon dioxide carried in the blood? [1]

- ☐ **A** dissolved in plasma
☐ **B** as hydrogencarbonate ions
☐ **C** as carbaminohaemoglobin
☐ **D** as carbonic anhydrase

3.2 The Bohr shift moves the oxygen dissociation curve to the right. This means that, at a given partial pressure of oxygen, haemoglobin: [1]

- ☐ **A** is more saturated with oxygen
B releases oxygen more readily
C carries more carbon dioxide directly
D has a higher affinity for oxygen

3.3 Use the dissociation curve idea: in the lungs haemoglobin is 98% saturated; in an exercising muscle it falls to 25%.

(a) Calculate the percentage of oxygen unloaded to the muscle. [1]

(b) Explain how the Bohr shift increases the oxygen delivered to exercising muscle. [3]

3.4 Explain the importance of the chloride shift. [2]

3.5 The graph described below shows two oxygen dissociation curves for human haemoglobin: curve **P** at a carbon dioxide partial pressure of 5 kPa, and curve **Q** at 9 kPa, which lies to the right of **P**.

(a) Explain the shape of curve **P**, referring to the effect of binding the first oxygen molecule. [3]

(b) Name the shift from **P** to **Q**, and explain how carbon dioxide causes it. [3]

(c) Explain the benefit of this shift to a person during vigorous exercise. [3]

(d) Describe **two** ways, other than as carbaminohaemoglobin, in which carbon dioxide is carried in the blood, and give the equation for the main one. [3]

Solutions

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

2.1

(a)

- at high partial pressure of oxygen (in the lungs)

(b)

- at low partial pressure of oxygen (in respiring tissues)

2.2

- carbonic anhydrase

3.1 B

- Most CO_2 is carried as hydrogencarbonate ions

3.2 B

- Shifting right means lower affinity, so haemoglobin releases oxygen more readily

3.3

(a)

- $98 - 25 = 73\%$

(b)

- exercising muscle releases more CO_2 , lowering pH; this shifts the curve right, so at the same pO_2 haemoglobin is less saturated and releases more oxygen; so more oxygen is delivered exactly where respiration is fastest

3.4

- as HCO_3^- leaves the red cell, chloride ions move in to keep the charge balanced inside the cell

3.5

(a)

- The curve is **S-shaped** (sigmoid). At low partial pressures it is hard for the first oxygen to bind, so the curve rises slowly; binding it changes the shape of the haemoglobin so that the remaining sites are more accessible, and the next molecules bind much more readily – the steep middle section – until the molecule saturates and the curve levels off

(b)

- The **Bohr shift**. Dissolved carbon dioxide forms carbonic acid, which dissociates and lowers the pH; the extra hydrogen ions bind to haemoglobin and change its shape,

lowering its affinity for oxygen, so at any given oxygen partial pressure less oxygen is held

(c)

- Exercising muscle respire faster and releases more carbon dioxide; the curve shifts right in exactly those tissues; so haemoglobin unloads more oxygen precisely where the demand is greatest, while the lungs – with low carbon dioxide – still load it fully

(d)

- About 5% dissolves directly in the plasma; most, about 85%, is carried as **hydrogencarbonate ions** in the plasma; $\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^-$, catalysed inside the red cell by carbonic anhydrase