A-LEVEL BIOLOGY • EXERCISE SHEET

8.2 Transport of oxygen and carbon dioxide

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

KEY WORDS carbon dioxide 二氧化碳 • bohr shift 波尔位移 • carbonic anhydrase 碳酸酐酶 • oxygen dissociation curve 氧解离曲线 • haemoglobinic acid 血红蛋白酸

Objective

Build the skills to answer exam questions on the **transport of oxygen and carbon dioxide** — the **oxygen dissociation curve** 氧解离曲线, the **Bohr shift** 波尔位移, and how carbon dioxide is carried.

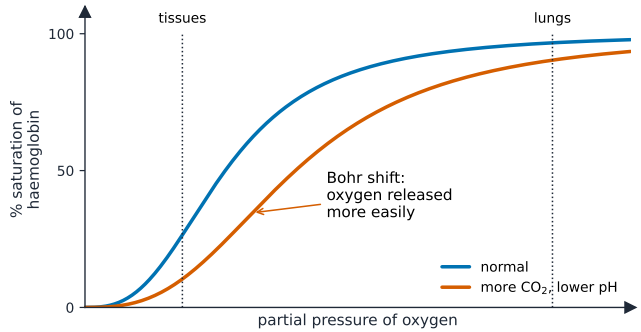
You must be able to:

- 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** 氯转移

1 Worked examples

The oxygen dissociation curve

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



Bohr shift (right): ↑ CO_2/ ↓ pH → lower O_2 affinity → unload at tissues

Haemoglobin loads O_2 in the lungs (high pO_2) and unloads it in tissues (low pO_2); the Bohr shift moves the curve right

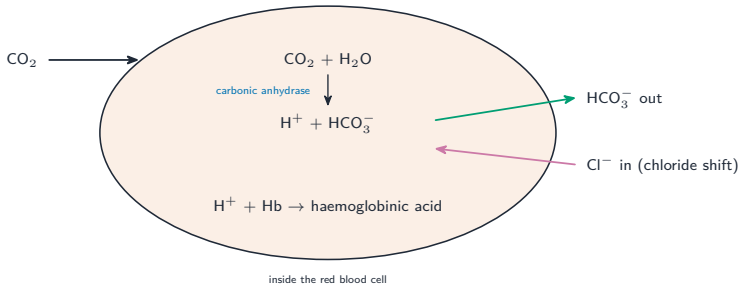
- in the lungs (high pO_2), haemoglobin becomes almost fully saturated (loads O_2).
- in respiring tissues (low pO_2), haemoglobin unloads O_2 for the cells.

Reading the curve: O_2 unloaded = saturation in lungs − saturation in tissues. E.g. 98% → 40% means 58% of the oxygen is released.

The Bohr shift

Active tissues make more **carbon dioxide** 二氧化碳, 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** 碳酸氢根离子: **carbonic anhydrase** 碳酸酐酶 catalyses CO_2 + water → carbonic acid → $H^+ + HCO_3^-$. HCO_3^- leaves the red cell and **chloride ions** move in (the chloride shift) to balance the charge; H^+ binds haemoglobin (**haemoglobinic acid** 血红蛋白酸).

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

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 respires 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; $CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$, catalysed inside the red cell by carbonic anhydrase.