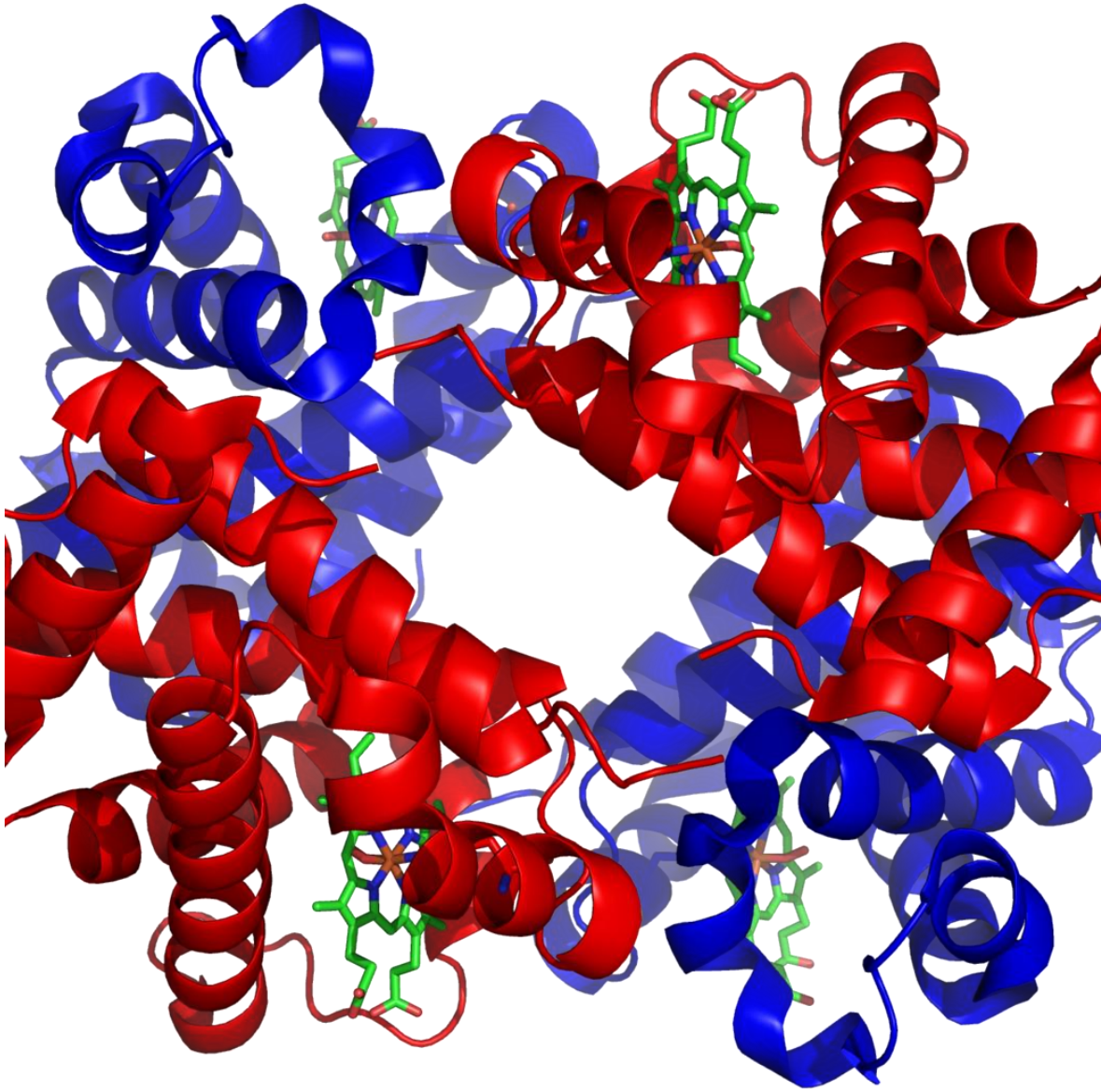
DP Biology – B3.1 (HL extension)

Haemoglobin and oxygen

- What adaptations let multicellular organisms exchange gases?
- How do flowering plants and mammals differ, and resemble each other, in gas exchange?



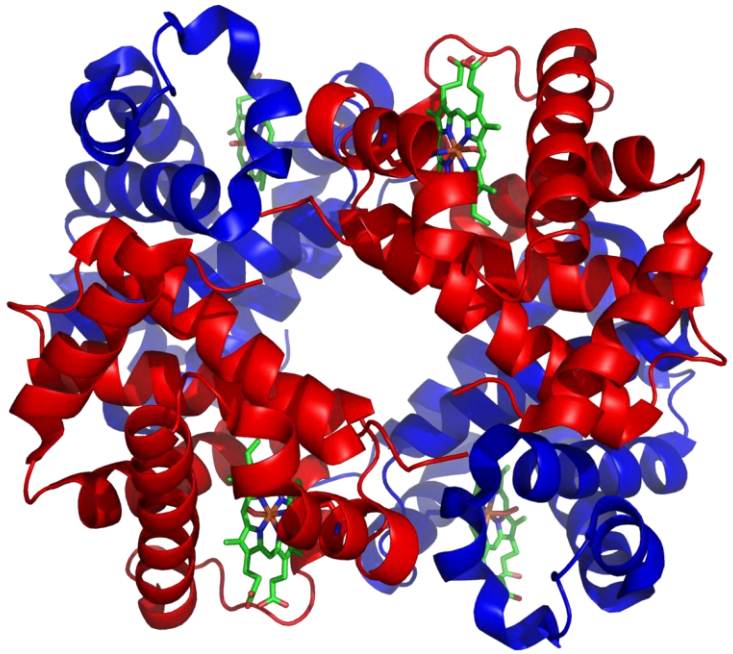
HL statements B3.1.11–13. Textbook pp. 292–294.
Image: haemoglobin, four subunits with their haem groups. Zephyris, CC BY-SA 3.0.

Objectives for each class

Class	Statements	By the end of the class, you can...
1	B3.1.13	Read oxygen dissociation curves and explain their S shape by cooperative binding
2	B3.1.11	Compare foetal and adult haemoglobin, including the allosteric effect of CO_2
3	B3.1.12	Explain the Bohr shift and how it helps actively respiring tissues

Haemoglobin carries oxygen

B3.1.11



Haemoglobin: two alpha (red) and two beta (blue) chains. Zephyris, CC BY-SA 3.0.

- Four polypeptide subunits, each with a **haem group** containing iron
- Each haem binds one O_2 molecule, so one haemoglobin carries up to **four** O_2
- A red blood cell holds about 280 million haemoglobin molecules
- Binding is reversible: O_2 is loaded in the lungs and unloaded in the tissues

Link

Quaternary structure and conjugated proteins (B1.2). A change in shape in one subunit is passed to the others.

Measuring oxygen as partial pressure

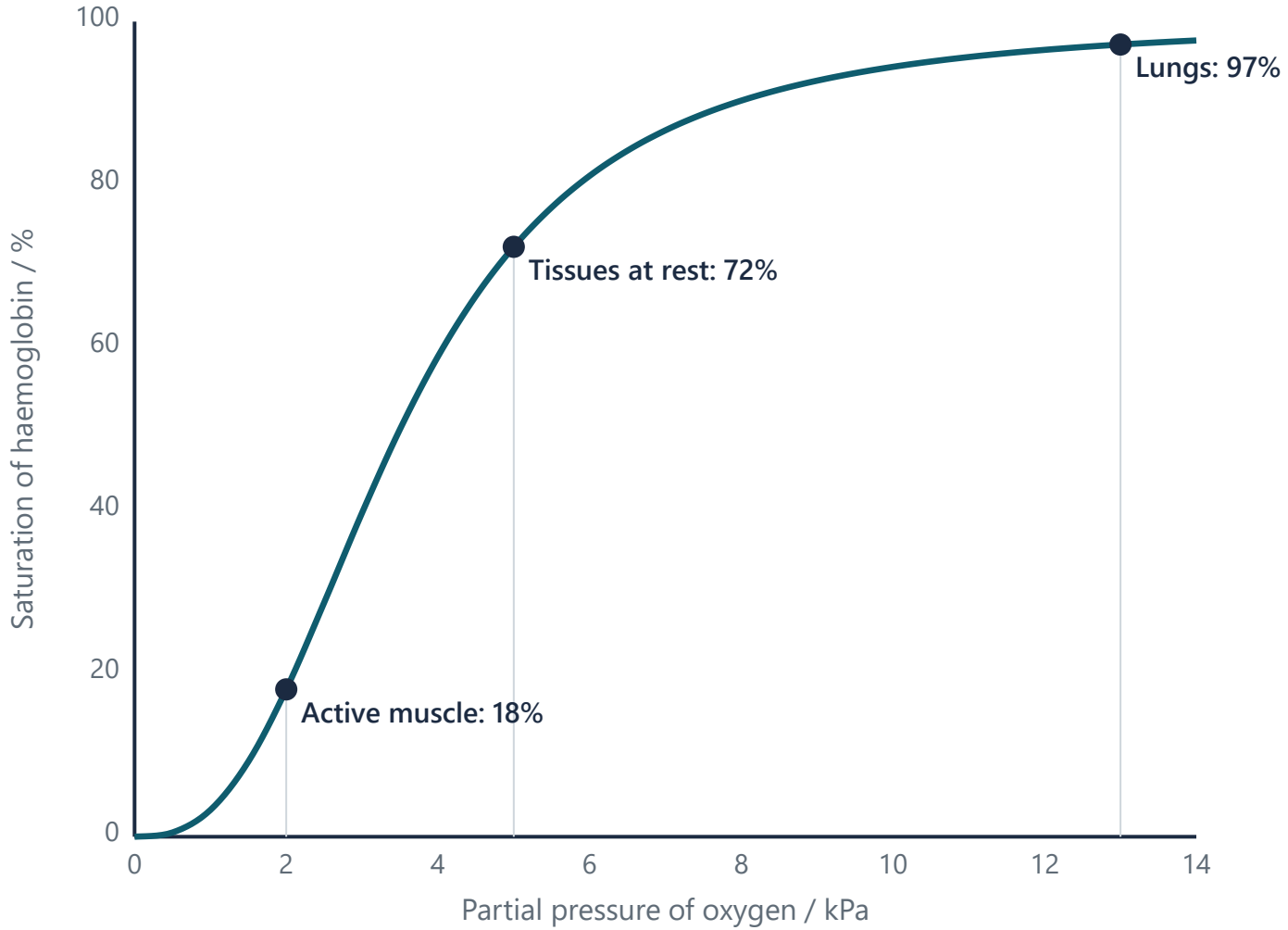
- Air is a mixture of gases; each gas contributes part of the total pressure
- The **partial pressure of oxygen** (pO_2) is the share due to oxygen, in kPa
- At sea level, air is 101.3 kPa and about 21% oxygen, so pO_2 is about 21 kPa
- Air in the alveoli has less oxygen and more water vapour, so pO_2 there is lower

Place	Typical pO_2 / kPa
Dry air at sea level	21
Air in the alveoli	13
Tissues at rest	5
Muscle in hard exercise	1–2

Key idea

Oxygen diffuses from high to low partial pressure: from alveoli into blood, and from blood into respiring tissues.

The oxygen dissociation curve



Adult haemoglobin. Modelled curve with typical values.

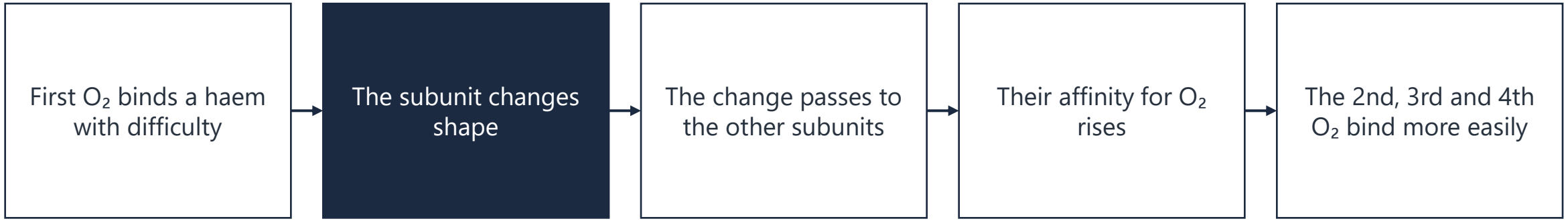
- Shows % saturation of haemoglobin against pO_2
- The curve is **S-shaped** (sigmoid), not a straight line
- Steepest between about 2 and 6 kPa, the pO_2 range found in tissues
- A small fall in pO_2 there releases a lot of oxygen

Try it

How much of its oxygen does blood release between the lungs and resting tissue?

Cooperative binding

B3.1.13



Why S-shaped?

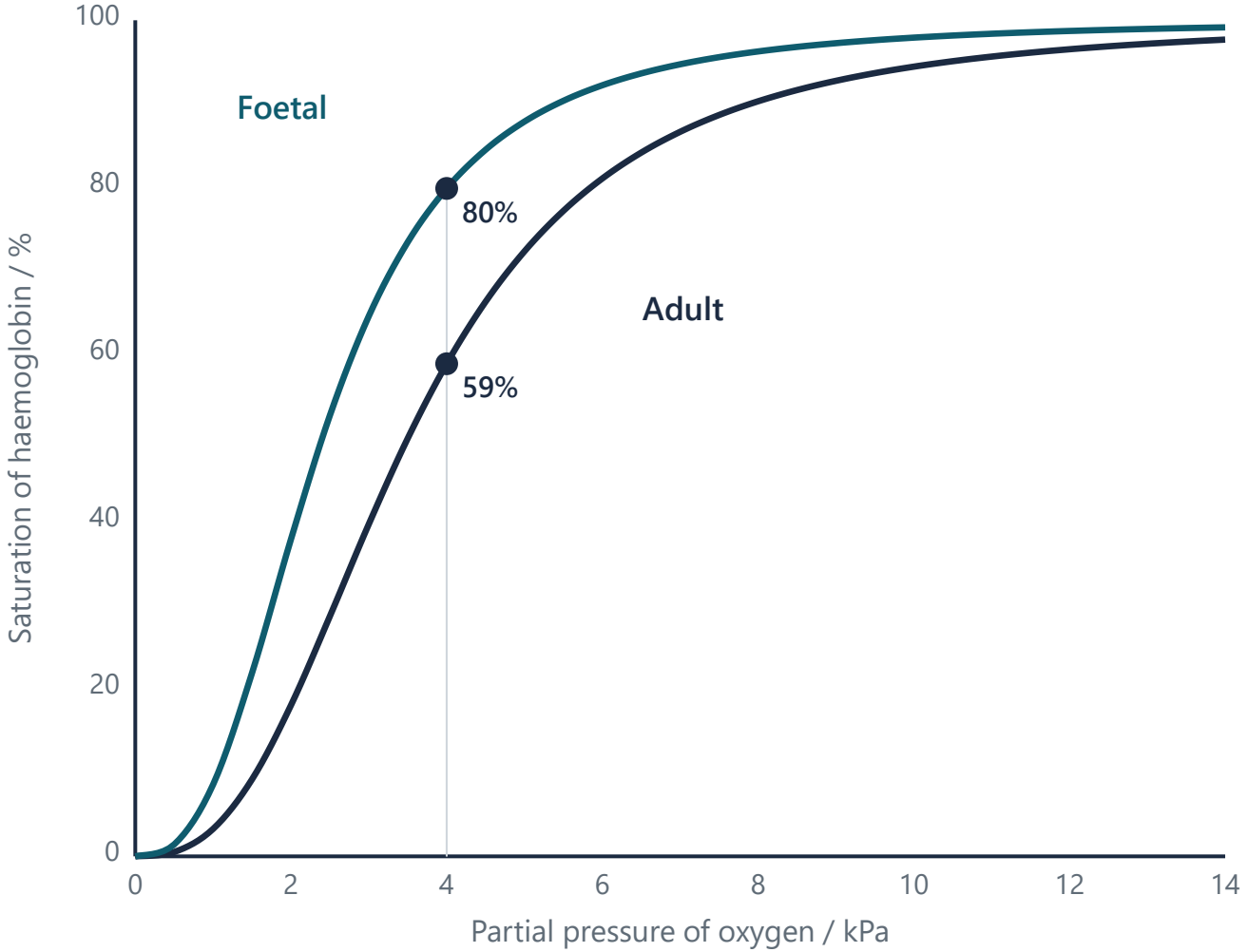
At low pO_2, few haem groups are filled and affinity is low, so the curve starts flat. Once one O_2 binds, affinity rises and the curve climbs steeply. Near saturation few sites are left, so it levels off.

The benefit

Where pO_2 is high (lungs), affinity is high, so haemoglobin loads almost fully. Where pO_2 is low (respiring tissue), affinity falls as O_2 leaves, so unloading is easy. Releasing one O_2 makes the next easier to release.

Foetal and adult haemoglobin

B3.1.11



Modelled curves with typical values.

- Foetal haemoglobin has two gamma chains in place of the two beta chains
- It has a **higher affinity** for O_2: its curve is to the **left**
- At about 4 kPa in the placenta: foetal 80%, adult 59% saturated
- So mother's haemoglobin unloads while foetal haemoglobin loads

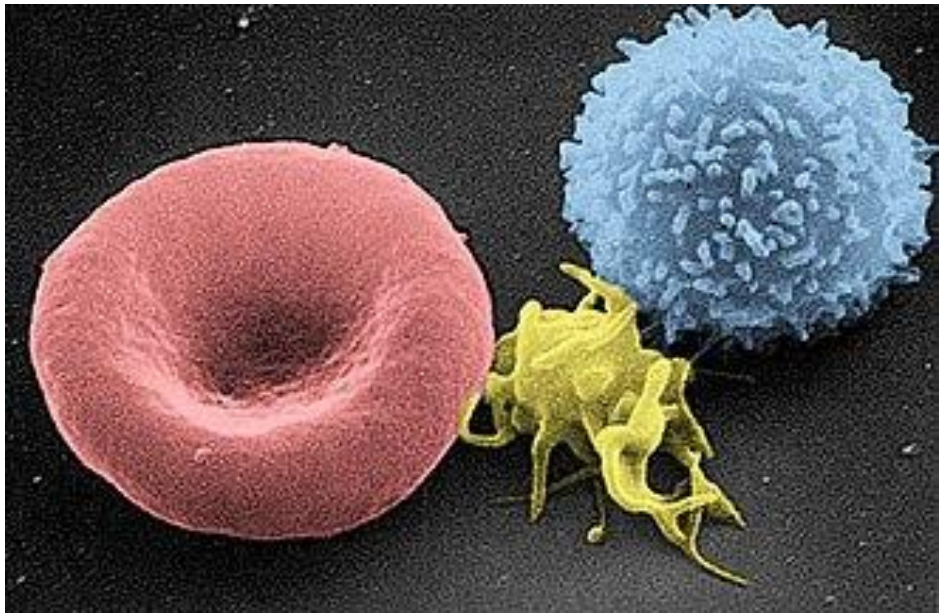
After birth

Foetal haemoglobin is replaced by adult haemoglobin over the first months of life.

Why the foetus needs a different haemoglobin

B3.1.11

- The foetus has no working lungs; its only O_2 comes from the mother's blood in the placenta
- The two bloods come close but do not mix: O_2 must diffuse from maternal to foetal blood
- If foetal affinity were lower, O_2 would pass from foetus to mother
- Haemoglobin is an **allosteric protein**: molecules binding at other sites change its shape
- **CO_2** binds allosterically and lowers affinity for O_2; this effect is weaker in foetal haemoglobin



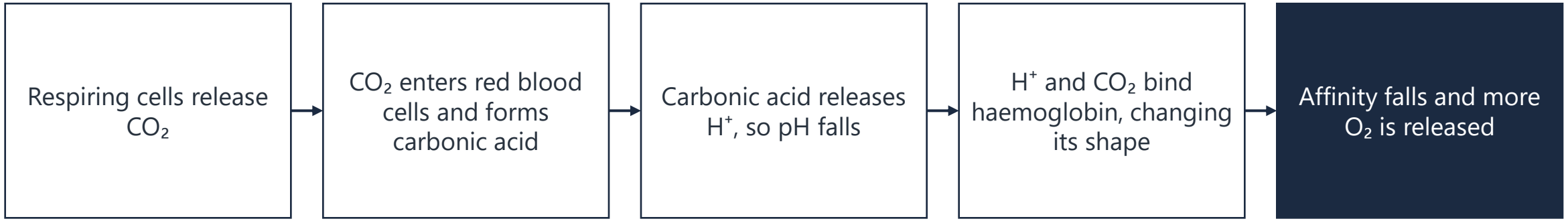
Red blood cell (left) with a platelet and a white blood cell. NCI, public domain.

Beyond the syllabus

Another allosteric molecule, 2,3-BPG, also lowers O_2 affinity. It binds foetal haemoglobin weakly, a major reason for its higher affinity.

The Bohr shift

B3.1.12



Key idea

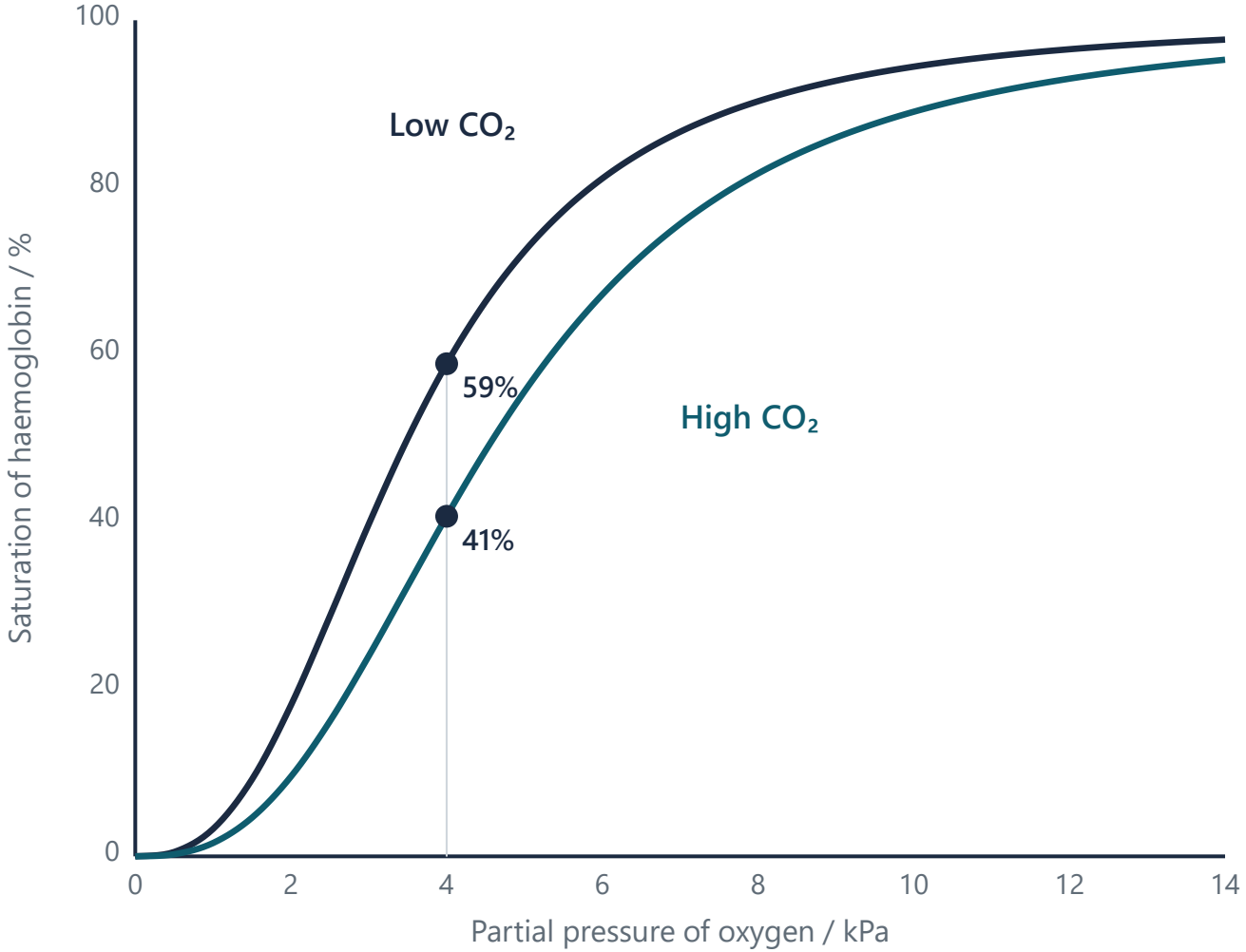
More CO_2 shifts the dissociation curve to the right. At the same pO_2, haemoglobin is less saturated, so it gives up more oxygen exactly where respiration is fastest.

In the lungs

CO_2 diffuses out into the alveoli, pH rises, and affinity goes back up, so haemoglobin loads oxygen again.

Reading the Bohr shift

B3.1.12



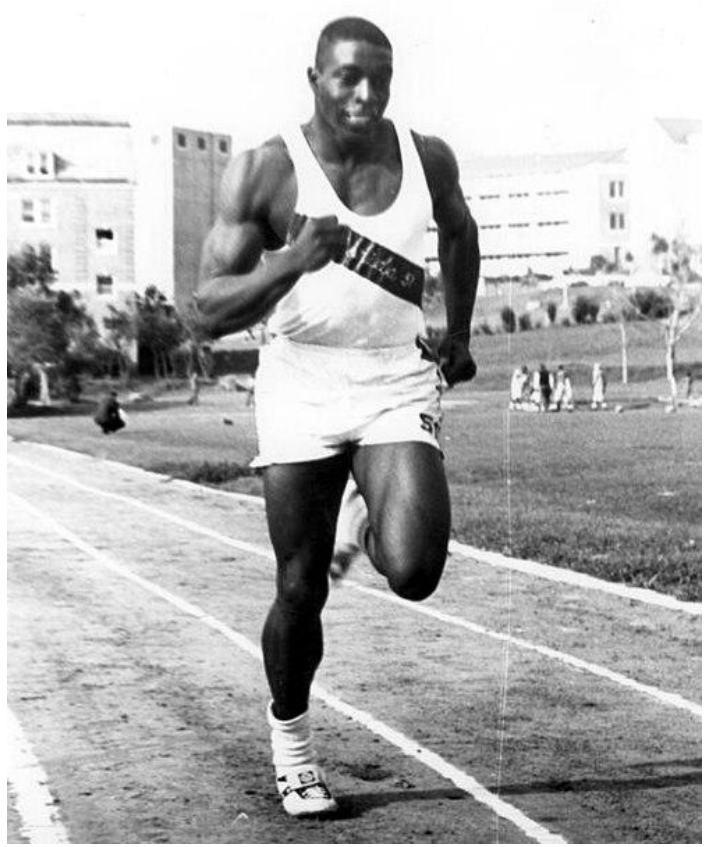
Modelled curves with typical values.

- Both curves are at pO_2 = 4 kPa
- Low CO_2: 59% saturated
- High CO_2: 41% saturated
- So an extra 18% of the oxygen is released in tissue rich in CO_2

Try it

Explain why the two curves almost meet at high pO_2, and why this matters in the lungs.

Who benefits from the Bohr shift?



Athlete training on a track, 1960s. Florida Memory, public domain.

- Muscles working hard produce the most CO_2
- So the curve shifts furthest to the right where O_2 is needed most
- Delivery of oxygen rises automatically with the rate of respiration, with no signal from the brain
- Higher temperature in active muscle shifts the curve the same way

Think about it

Is this an example of negative feedback? What is the variable being regulated?

Left and right shifts

Shift to the left (higher affinity)	Shift to the right (lower affinity)
Foetal haemoglobin	More CO_2
Animals adapted to high altitude, such as llamas	Lower pH
Low CO_2 in the lungs	Higher temperature



A llama. Johann Dreo, CC BY-SA 3.0.

Llama haemoglobin has a high affinity, so it loads oxygen well from thin mountain air.

Activity

Sketch an adult curve. Add a curve for foetal haemoglobin and one for blood in exercising muscle. Label each and explain its position.

Check that you can explain

1. What pO_2 means, and typical values in the lungs and tissues
2. How to read percentage saturation from an oxygen dissociation curve
3. Why the curve is S-shaped (cooperative binding)
4. Why foetal haemoglobin has a higher affinity than adult haemoglobin
5. How CO_2 lowers the affinity of haemoglobin (Bohr shift)
6. How the Bohr shift helps actively respiring tissues

Exit activity: 5 minutes

On your own and without notes. Hand this in as you leave.

1. State what causes the oxygen dissociation curve to be S-shaped.
2. Explain why foetal haemoglobin must have a higher affinity for oxygen than adult haemoglobin.
3. Describe the effect of a rise in CO_2 on the curve and on oxygen delivery.

Image credits

1GZX Haemoglobin.png – Zephyris at English Wikipedia – CC BY-SA 3.0

Red White Blood cells.jpg – Electron Microscopy Facility at The National Cancer Institut – Public domain

FAMU athlete Robert Hayes practices running on the track.jpg – Florida Memory – Public domain

Llama lying down.jpg – Johann "nojhan" Dréo – CC BY-SA 3.0

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