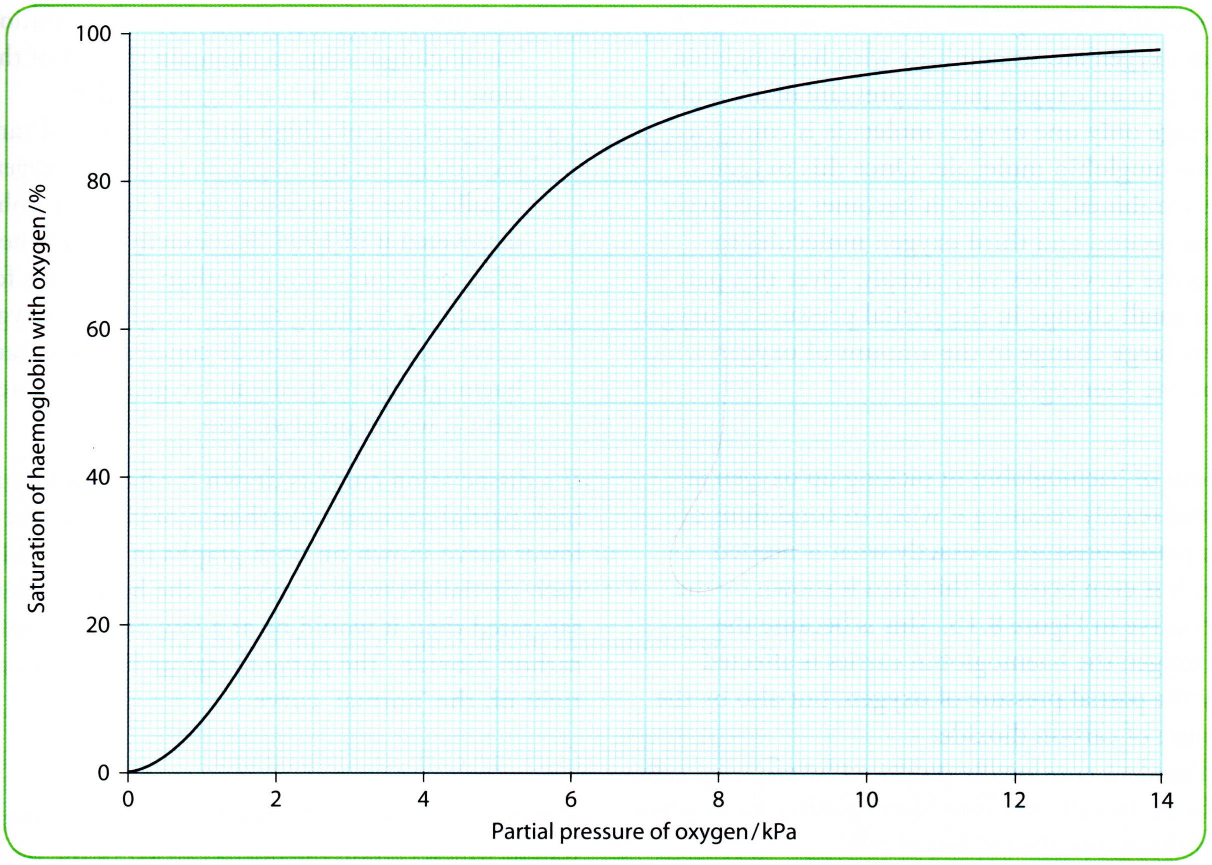

Figure 8.15 The haemoglobin dissociation curve.

…moglobin coming from the lungs carries a lot of oxygen; …it reaches a muscle, it releases around three-quarters of it. …is released oxygen diffuses out of the red blood cell and …to the muscle where it can be used in respiration.

…e S-shaped curve

…e shape of the haemoglobin dissociation curve can be …plained by the behaviour of a haemoglobin molecule as it …mbines with or loses oxygen molecules.

Oxygen molecules combine with the iron atoms in …e haem groups of a haemoglobin molecule. You will …member that each haemoglobin molecule has four haem …oups. When an oxygen molecule combines with one …em group, the whole haemoglobin molecule is slightly …torted. The distortion makes it easier for a second oxygen …lecule to combine with a second haem group. This in …n makes it easier for a third oxygen molecule to combine …th a third haem group. It is then still easier for the fourth …d final oxygen molecule to combine.

SAQ 8.11

Use the dissociation curve in Figure **8.15** to answer these questions.

a **i** The partial pressure of oxygen in the alveoli of the lungs is about 12 kPa. What is the percentage saturation of haemoglobin in the capillaries in the lungs?

ii If 1 g of fully saturated haemoglobin is combined with 1.3 cm^3 of oxygen, how much oxygen will 1 g of haemoglobin in the capillaries in the lungs be combined with?

b **i** The partial pressure of oxygen in an actively respiring muscle is about 2 kPa. What is the percentage saturation of haemoglobin in the capillaries of such a muscle?

ii How much oxygen will 1 g of haemoglobin in the capillaries of this muscle be combined with?

The shape of the haemoglobin dissociation curve reflects the way that oxygen atoms combine with haemoglobin molecules. Up to an oxygen partial pressure of around 2 kPa, on average only one oxygen molecule is combined with each haemoglobin molecule. Once this oxygen molecule is combined, however, it becomes successively easier for the second and third oxygen molecules to combine, so the curve rises very steeply. Over this part of the curve, a **small** change in the partial pressure of oxygen causes a **very large** change in the amount of oxygen which is carried by the haemoglobin.

The Bohr shift

The behaviour of haemoglobin in picking up oxygen at the lungs, and readily releasing it when in conditions of low oxygen partial pressure, is exactly what is needed. But, in fact, it is even better at this than is shown by the dissociation curve in Figure **8.15**. This is because the amount of oxygen the haemoglobin carries is affected not only by the partial pressure of **oxygen**, but also by the partial pressure of **carbon dioxide.**

Carbon dioxide is continually produced by respiring cells. It diffuses from the cells and into blood plasma, from where some of it diffuses into the red blood cells.

In the cytoplasm of red blood cells there is an enzyme, **carbonic anhydrase**, that catalyses the following reaction:

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} \xrightleftharpoons{\text{carbonic anhydrase}} \underset{\text{carbonic acid}}{H_2CO_3}$$

The carbonic acid dissociates:

$$\underset{\text{carbonic acid}}{H_2CO_3} \rightleftharpoons \underset{\text{hydrogen ion}}{H^+} + \underset{\text{hydrogencarbonate ion}}{HCO_3^-}$$

Haemoglobin readily combines with the hydrogen ions, forming **haemoglobinic acid, HHb**. In so doing, it releases the oxygen which it is carrying.

The net result of this reaction is two-fold.

- The haemoglobin 'mops up' the hydrogen ions which are formed when carbon dioxide dissolves and dissociates. A high concentration of hydrogen ions means a low pH; if the hydrogen ions were left in solution, the blood would be very acidic. By removing the hydrogen ions from solution, haemoglobin helps to maintain the pH of the blood close to neutral. It is acting as a **buffer**.
- The presence of a high partial pressure of carbon dioxide causes haemoglobin to release oxygen. This is called the **Bohr effect**, after Christian Bohr who discovered it in 1904. It is exactly what is needed. High concentrations of carbon dioxide are found in actively respiring tissues, which need oxygen; these high carbon dioxide concentrations cause haemoglobin to release its oxygen even more readily than it would otherwise do.

If a dissociation curve is drawn for haemoglobin at a high partial pressure of carbon dioxide, it looks like the lower curve shown on both graphs in Figure **8.16**. At each partial pressure of oxygen, the haemoglobin is less saturated than it would be at a low partial pressure of carbon dioxide. The curve therefore lies below, and to the right of, the 'normal' curve.

Carbon dioxide transport

The description of the Bohr effect above explains one way in which carbon dioxide is carried in the blood. One product of the dissociation of dissolved carbon dioxide is hydrogencarbonate ions, HCO_3^-. These are initially formed in the cytoplasm of the red blood cell, because this is where the enzyme carbonic anhydrase is found. Most of the hydrogencarbonate ions then diffuse out of the red blood cell into the blood plasma, where they are carried in solution. About 85% of the carbon dioxide transported by the blood is carried in this way.

Some carbon dioxide, however, does not dissociate, but remains as carbon dioxide molecules. Some of these simply dissolve in the blood plasma; about 5% of the total is carried in this form. Other carbon dioxide molecules diffuse into the red blood cells, but instead of undergoing the reaction catalysed by carbonic anhydrase, combine directly with the terminal amine groups ($-NH_2$) of some of the haemoglobin molecules. The compound formed is called **carbamino-haemoglobin**. About 10% of the carbon dioxide is carried in this way (Figure **8.17**, page **158**).

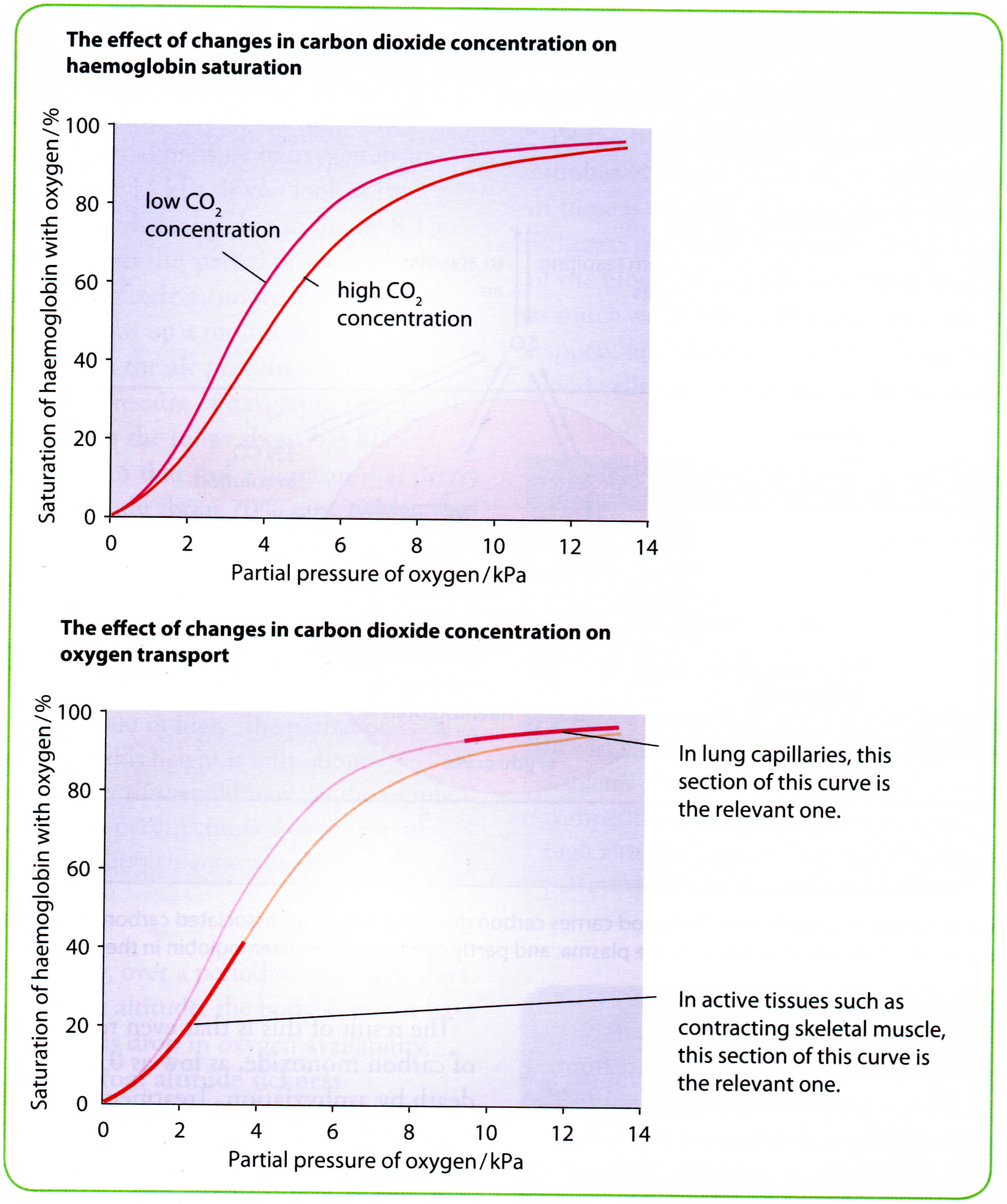

Figure 8.16 Dissociation curves for haemoglobin at two different partial pressures of carbon dioxide. The shift of the curve to the right when the haemoglobin is exposed to higher carbon dioxide concentration is called the Bohr effect.

When blood reaches the lungs, the reactions described above go into reverse. The relatively low concentration of carbon dioxide in the alveoli compared with that in the blood causes carbon dioxide to diffuse from the blood into the air in the alveoli, stimulating the carbon dioxide of carbamino-haemoglobin to leave the red blood cell, and hydrogencarbonate and hydrogen ions to recombine to form carbon dioxide molecules once more. This leaves the haemoglobin molecules free to combine with oxygen, ready to begin another circuit of the body.

Problems with oxygen transport

The efficient transport of oxygen around the body can be impaired by many different factors. We consider some here and in Chapter **11**.

Carbon monoxide

Despite its almost perfect design as an oxygen-transporting molecule, haemoglobin does have one property which can prove very dangerous. It combines very readily, and almost irreversibly, with carbon monoxide.