8. Transport in Mammals

8.2 Transport of Oxygen and Carbon Dioxide

Paper 2

Question Paper

1 Malaria is an infectious disease caused by the protoctist, *Plasmodium*.

As part of its lifecycle, *Plasmodium* infects human red blood cells. Researchers can compare haemoglobin from the red blood cells of a healthy person with haemoglobin from a person with malaria.

(b) In the laboratory, oxygen at different partial pressures can be bubbled through a solution of haemoglobin to determine the percentage saturation of haemoglobin at each partial pressure. A graph constructed from the results is known as an oxygen dissociation curve.

Fig. 5.1 is an oxygen dissociation curve for **normal** adult haemoglobin in **humans**.

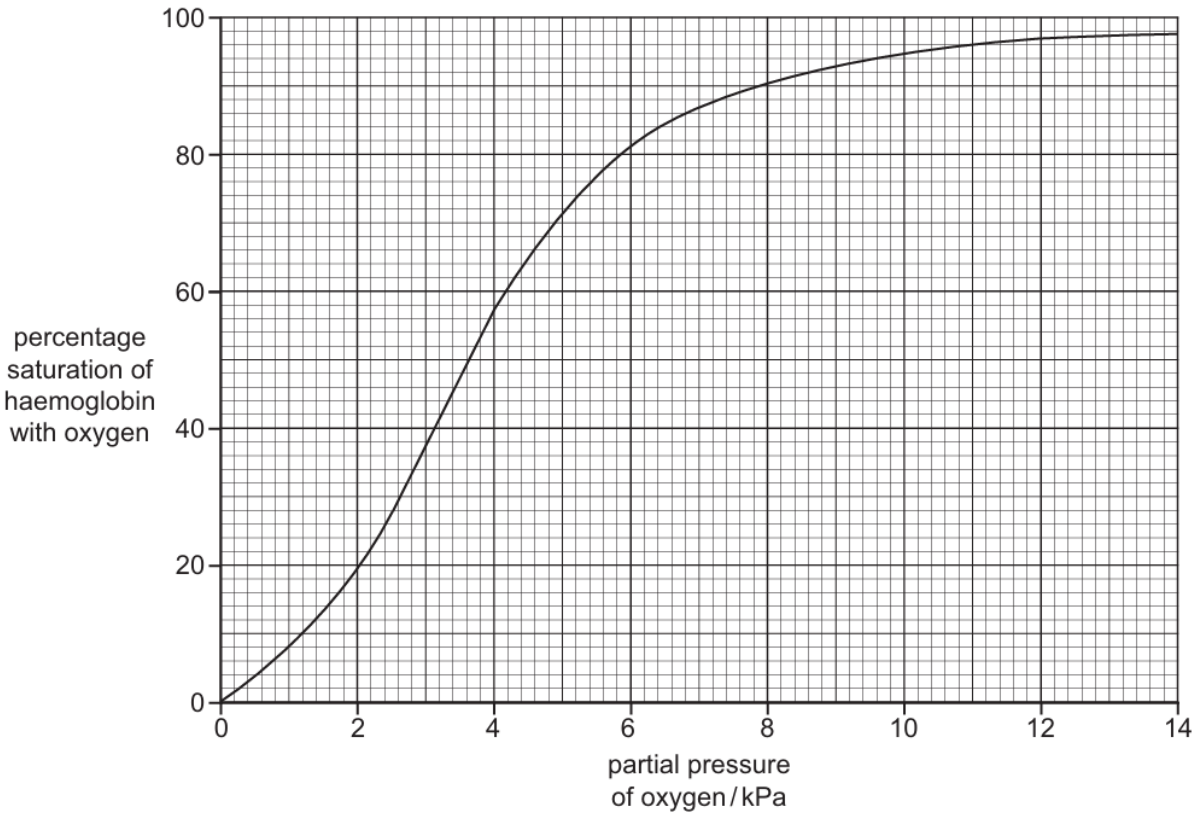


Fig. 5.1

(i) In the experiment used to obtain the results shown in Fig. 5.1, the temperature and pH were standardised.

Explain what the researchers would consider when deciding which temperature and pH to use in the experiment.

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(ii) Using a different, more rapid technique, researchers compared the haemoglobin contained in red blood cells of a healthy person with the haemoglobin of a person with malaria who had been infected with *P. vivax*.

By analysing the results, the researchers concluded that the oxygen dissociation curve of a person with malaria would be shifted to the right.

With reference to Fig. 5.1, explain how a shift to the right of the oxygen dissociation curve would affect oxygen loading in the lungs, and unloading in respiring tissues, in a person with malaria.

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(c) A red blood cell that is infected with *Plasmodium* cannot carry out its function as effectively as a normal red blood cell.

Describe how the size **and** structure of a red blood cell is related to its function, **other than** the fact that it contains a very large number of haemoglobin molecules.

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2 **(c)** Fig. 2.3 shows a Galapagos penguin, *Spheniscus mendiculus*, swimming in the water.



Fig. 2.3

Penguins are birds that live on land but spend a lot of time swimming underwater hunting for food. Penguins can remain underwater for up to twenty minutes. During this time they do not breathe but their tissues continue to respire.

Haemoglobin in the red blood cells of penguins has a higher affinity for oxygen than haemoglobin in other birds that do not swim underwater.

Fig. 2.4 shows the oxygen dissociation curve for a bird that does **not** swim underwater.

(i) Draw a line on Fig. 2.4 to suggest the position of the oxygen dissociation curve for penguin haemoglobin. [2]

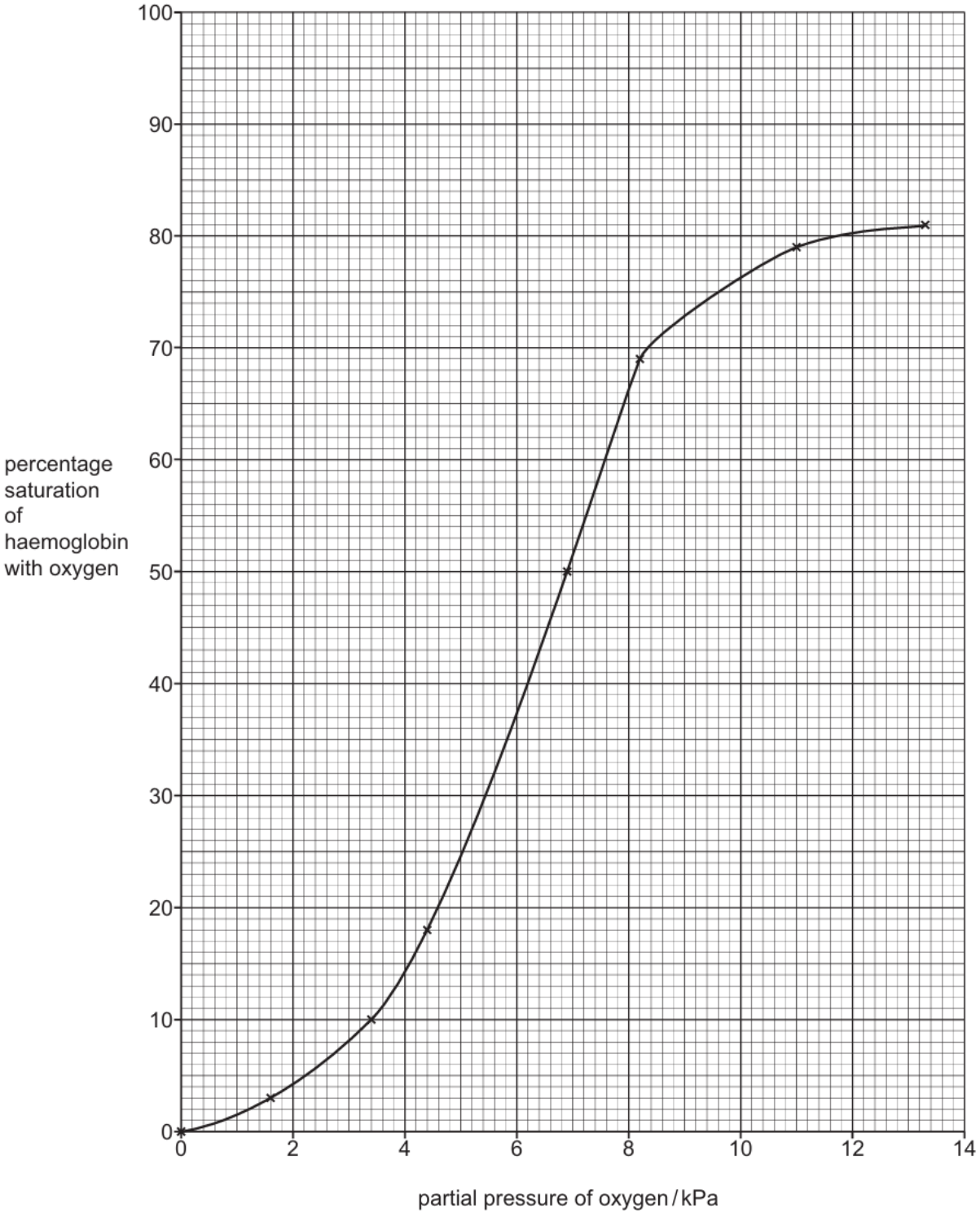

percentage saturation of haemoglobin with oxygen
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
partial pressure of oxygen / kPa

Fig. 2.4

(ii) Penguin haemoglobin is very sensitive to a decrease in pH caused by an increase in the carbon dioxide concentration in the blood.

Explain how a decrease in pH affects penguin haemoglobin, **and** suggest how this helps the penguin to swim underwater for a long time.

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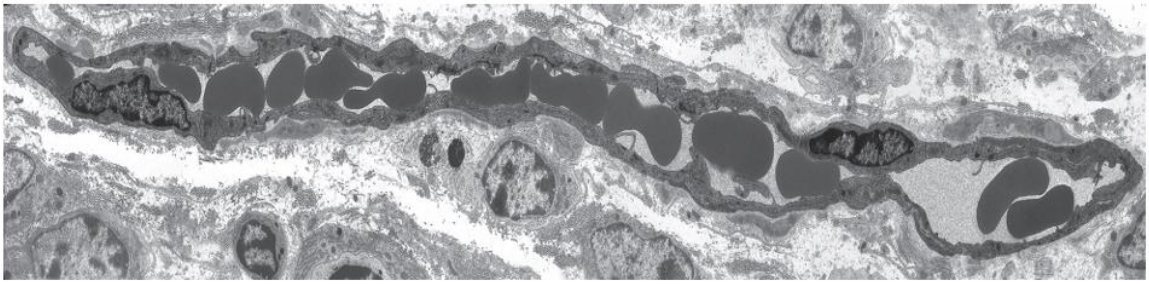
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3 Fig. 5.1 is a longitudinal section of a capillary in muscle tissue as viewed with a transmission electron microscope.



magnification ×2000

Fig. 5.1

(c) Fig. 5.2 is a diagram showing some of the events that occur as blood flows through a capillary in a respiring tissue.

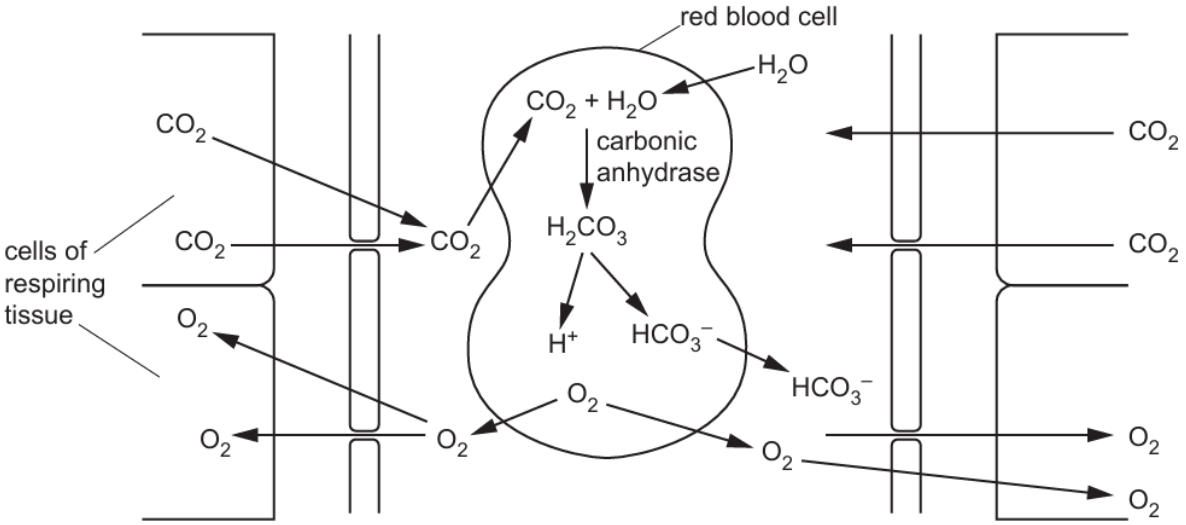


Fig. 5.2

(i) An increase in respiration results in an increase in the carbon dioxide concentration in the blood and the release of more oxygen from red blood cells to tissues.

Explain how an increase in carbon dioxide in the blood leads to the release of more oxygen from red blood cells.

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(ii) Chloride ions are a constituent of blood plasma. The concentration of chloride ions in the plasma of deoxygenated blood is between 2–4 $mmol\,dm^{-3}$ lower than in the plasma of oxygenated blood.

Explain why the concentration of chloride ions in the blood plasma of deoxygenated blood is lower than in the plasma of oxygenated blood.

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..... [2]

4 The enzyme carbonic anhydrase has been found in a wide range of organisms and acts as a catalyst in many tissues.

Studies have shown that there are differences in the protein structure of the enzyme and differences in the number and organisation of introns and exons of the gene coding for the enzyme.

All carbonic anhydrase enzymes catalyse the same reversible reaction, shown in Fig. 4.1.

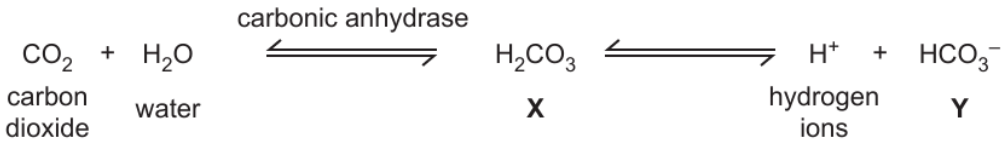


Fig. 4.1

(a) With reference to Fig. 4.1, name **X** and **Y**.

X .....

Y .....

[2]

5 The enzyme carbonic anhydrase has been found in a wide range of organisms and acts as a catalyst in many tissues.

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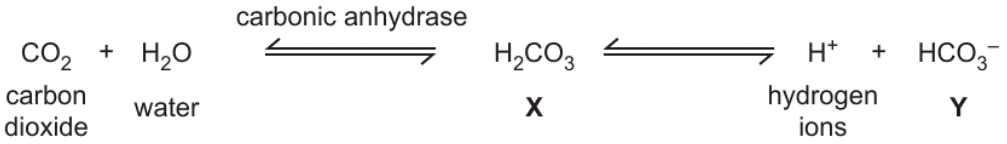


Fig. 4.1

All mammals have the same type of carbonic anhydrase, known as α-carbonic anhydrase. Many different forms, or isoforms, of α-carbonic anhydrase have been identified in mammals.

There are 15 isoforms of α-carbonic anhydrase (CA) in humans. Cells of different tissues have one or more isoforms. Within cells the isoforms may be in different locations.

(d) Red blood cells contain two isoforms, CA1 and CA2.

Suggest the location of CA1 and CA2 in red blood cells **and** give a reason for your answer.

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6 Fig. 1.1 and Fig. 1.2 are photomicrographs showing the distribution of tissues in the lungs.

Fig. 1.1 is a photomicrograph of a section through part of the lungs.

Fig. 1.2 is a high-power view of the area indicated on Fig. 1.1.

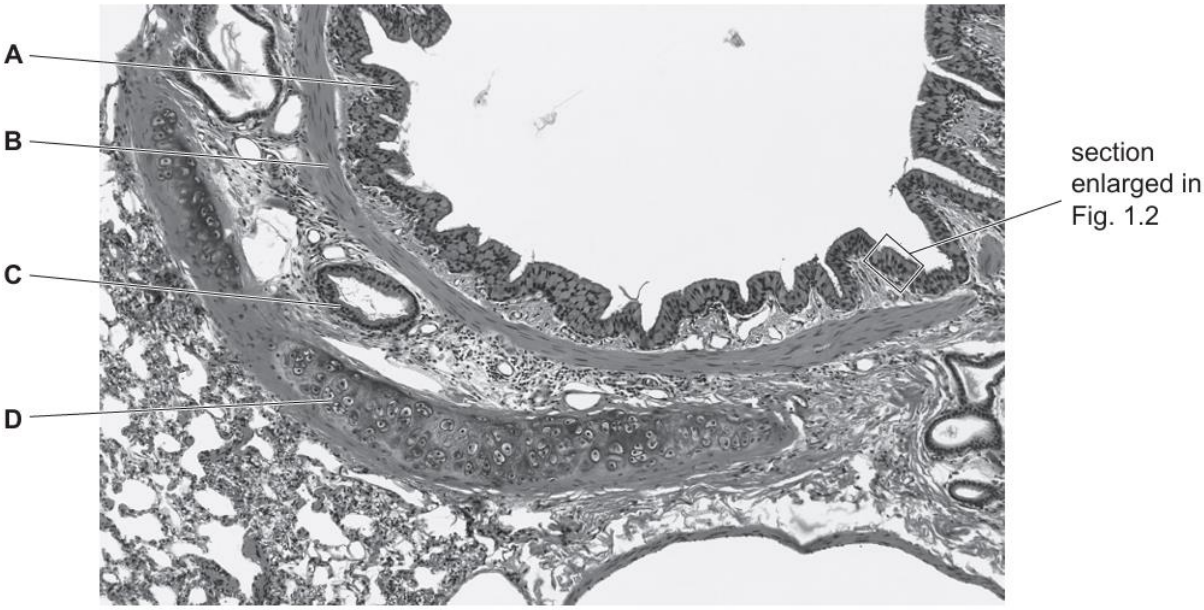


Fig. 1.1

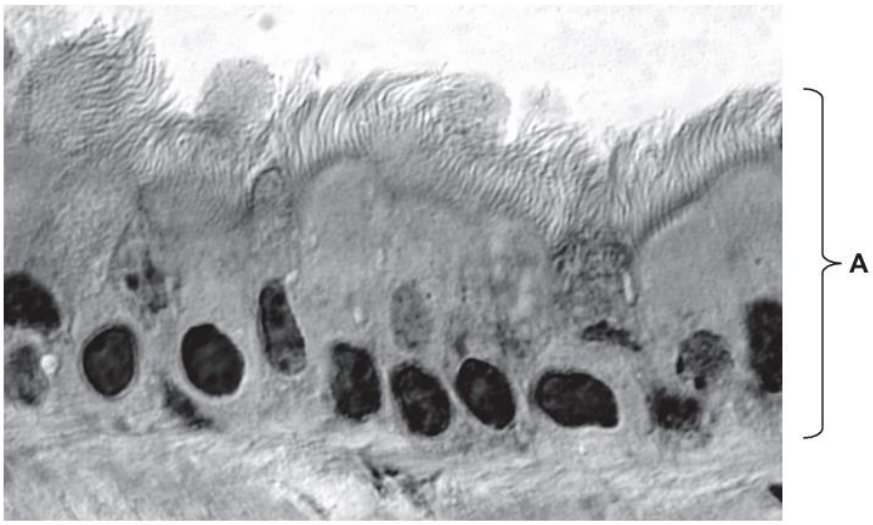


Fig. 1.2

(c) Hyperventilation occurs when a person breathes too fast or too deeply.

The effects of hyperventilation are:

- a decrease in the partial pressure of carbon dioxide in alveolar air
- an increase in the pH of the blood.

Fig. 1.3 shows the change in the oxygen dissociation curve as a result of hyperventilation.

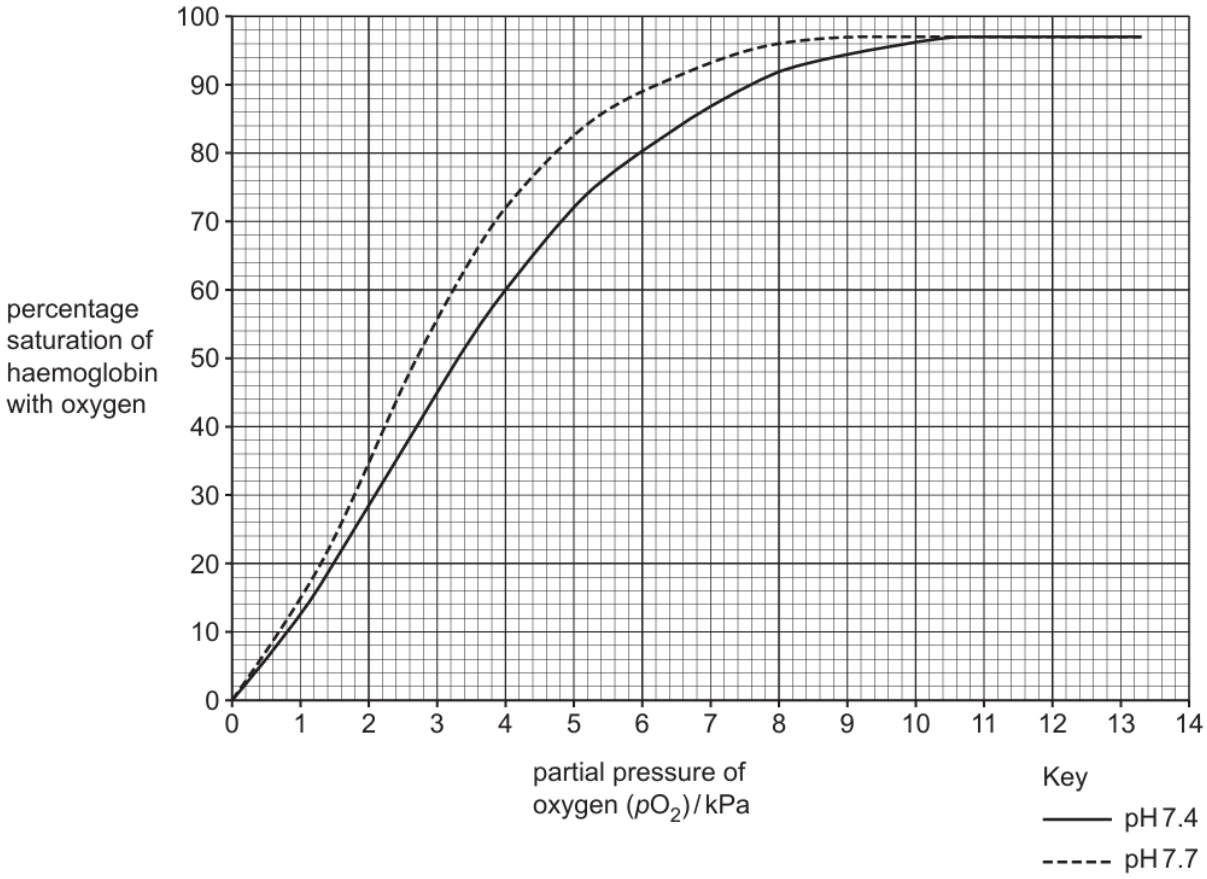


Fig. 1.3

(i) State the percentage saturation of haemoglobin at a pO_2 of 4.0 kPa.

pH = 7.7 ..... kPa

pH = 7.4 ..... kPa [1]

(ii) Use the information in Fig. 1.3 to state **and** explain the effect of hyperventilation on the supply of oxygen to the respiring tissues.

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..... [2]

7 The mammalian circulatory system is adapted for the long-distance transport of the respiratory gases, oxygen and carbon dioxide.

The system is described as a closed double circulation.

(d) The entry of carbon dioxide into red blood cells results in the production of hydrogencarbonate ions. This involves the enzyme carbonic anhydrase.

Complete the passage summarising the production of hydrogencarbonate ions by:

- writing the correct biological term in the spaces provided
- writing the molecular formula for **two** of the terms in the spaces in brackets.

Carbonic anhydrase has an overall spherical shape and is known as a ..... protein. The enzyme acts within the cell so can be described as an ..... enzyme. When blood passes into the capillary network through actively respiring tissues, carbon dioxide (CO_2) diffuses into red blood cells and carbonic anhydrase catalyses a reaction where ..... (.....) is combined with CO_2 to form ..... (H_2CO_3), which rapidly forms ..... ions (.....) and hydrogencarbonate ions (HCO_3^-). [5]

8 Carbonic anhydrase is a globular protein found in red blood cells.

(a) (ii) State the function of carbonic anhydrase in red blood cells.

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9 **(c)** A further investigation found that the K_m for carbonic anhydrase is 12 mmol dm^{-3}.

Describe the role of carbonic anhydrase in the transport of carbon dioxide.

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10 The high blood pressure at the arterial end of a capillary network results in some components of blood leaving the capillaries and forming tissue fluid. At the venous end, the presence of plasma proteins allows movement of water by osmosis back into the capillaries.

Fig. 2.1 is a diagram showing a capillary network. The lymph vessels and the blood vessels at the arterial and venous ends of the network are also shown.

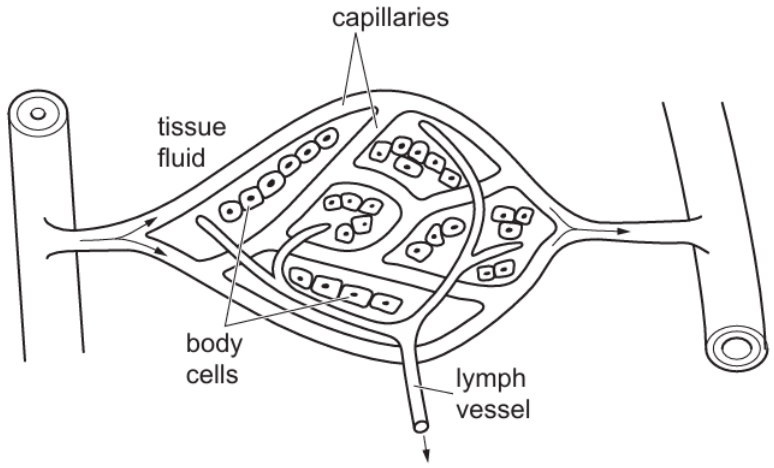


Fig. 2.1

(d) A low blood albumin concentration can lead to a condition known as oedema.

Oedema is a swelling of tissues caused by the accumulation of tissue fluid surrounding the body cells in the capillary network.

Suggest **and** explain how a low blood albumin concentration can lead to oedema.

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11 Fig. 4.1 shows the site of gas exchange in the mammalian lung.

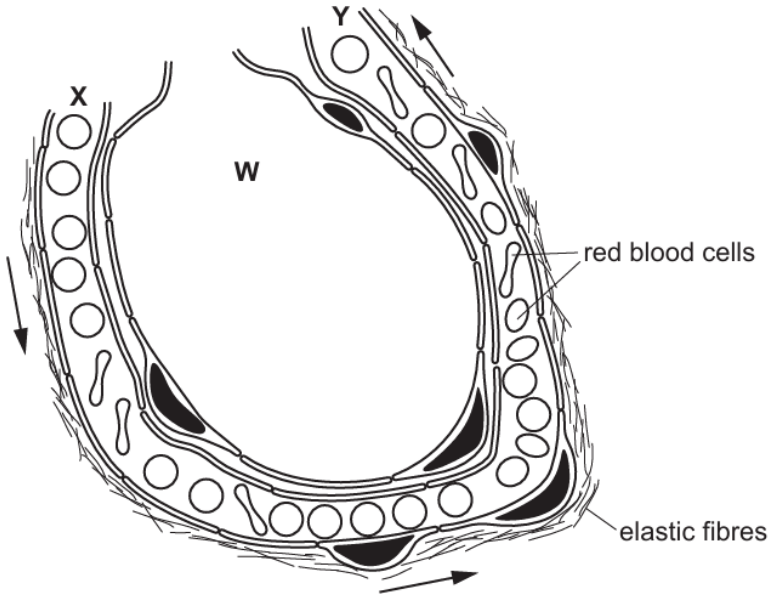


Fig. 4.1

(a) State **two** ways in which carbon dioxide is transported in the blood.

1 .....

2 .....

[2]

(b) Table 4.1 shows the partial pressures of oxygen (pO_2) and carbon dioxide (pCO_2) at locations **W**, **X** and **Y** in Fig. 4.1.

Table 4.1

partial pressure	locations within tissue		
	W	**X**	**Y**
pO_2 / kPa	13.87	5.33	13.87
pCO_2 / kPa	5.33	6.00	5.55

With reference to Fig. 4.1 and Table 4.1, describe the exchanges that occur as blood flows from **X** to **Y**.

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(d) Scientists in Peru investigated the effect of moving from sea level to high altitude on the composition of blood. The scientists studied 10 students. Each student had lived at sea level since birth and then moved to live in the Andes at a height of 4500 metres above sea level.

The scientists took samples of blood from each student before they moved to live at high altitude. The scientists took further blood samples at intervals after the students had moved to high altitude.

The relative proportions of red blood cells and plasma in each sample were determined.

The total volume of blood for each student was also determined at each sampling time. As the students were all of different body mass, the total volumes were converted to a volume per kg of body mass ($cm^3 kg^{-1}$).

Fig. 4.2 shows for each sampling time:

- the mean volume of blood per kg of body mass
- the proportions of red blood cells and plasma.

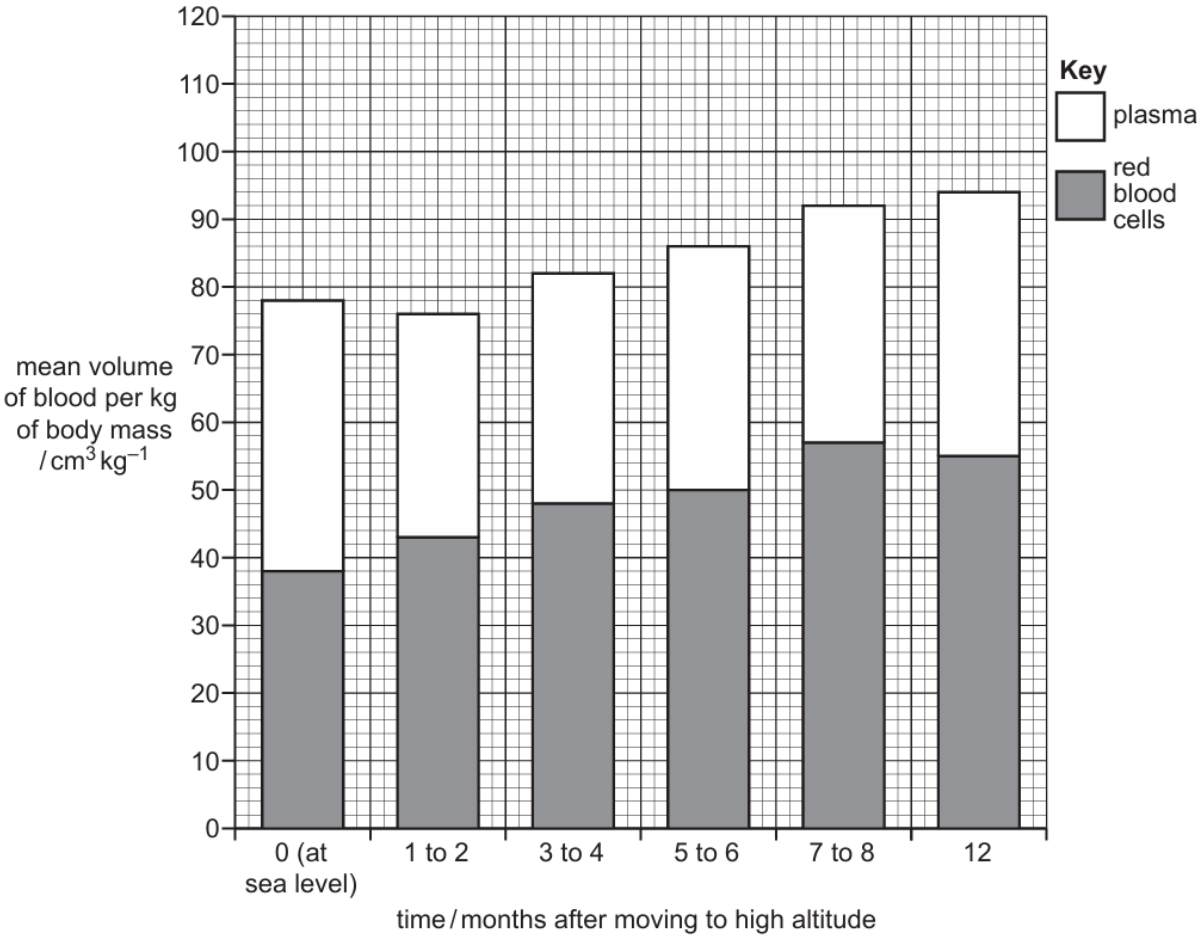


Fig. 4.2

(ii) Describe **and** explain the results in Fig. 4.2.

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12 **(a)** Fig. 6.1 shows an oxygen dissociation curve for adult human haemoglobin.

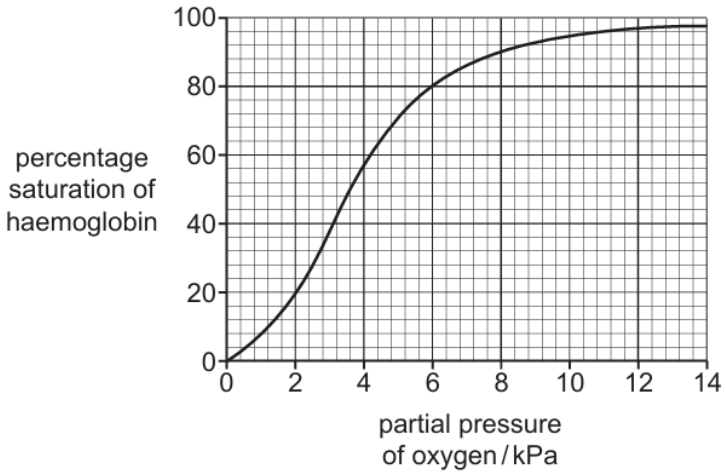


Fig. 6.1

An increase in the partial pressure of carbon dioxide (pCO_2) in respiring tissue causes the Bohr effect.

(i) Sketch on Fig. 6.1 to show how the Bohr effect changes the oxygen dissociation curve. [1]

(ii) Explain how an increase in pCO_2 produces the Bohr effect **and** state the benefit of this effect for the tissue.

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(b) Carbon dioxide (CO_2) is transported across the cell surface membrane of the red blood cell using a different mechanism to the transport of hydrogen carbonate ions (HCO_3^-).

Name the different mechanisms of transport used for CO_2 and for HCO_3^- **and** explain why they are transported across the membrane by different mechanisms.

CO_2 .....

HCO_3^- .....

explanation .....

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[4]

13 People who smoke tobacco are at an increased risk of developing non-infectious diseases of the gas exchange system and the cardiovascular system.

In 2004, a study was carried out on the most popular brands of filter cigarettes from each of the six World Health Organization (WHO) regions.

In this study, the smoke passing through the filter was analysed for the tar, nicotine and carbon monoxide (CO) content for each brand of cigarette. For each WHO region, the mean content of tar, nicotine and carbon monoxide of the different brands of cigarette was calculated.

The results are shown in Fig. 2.1.

Key to WHO regions

AFRO = African Region
AMRO = Region of the Americas
EMRO = Eastern Mediterranean Region
EURO = European Region
SEARO = South-East Asia Region
WRPO = Western Pacific Region

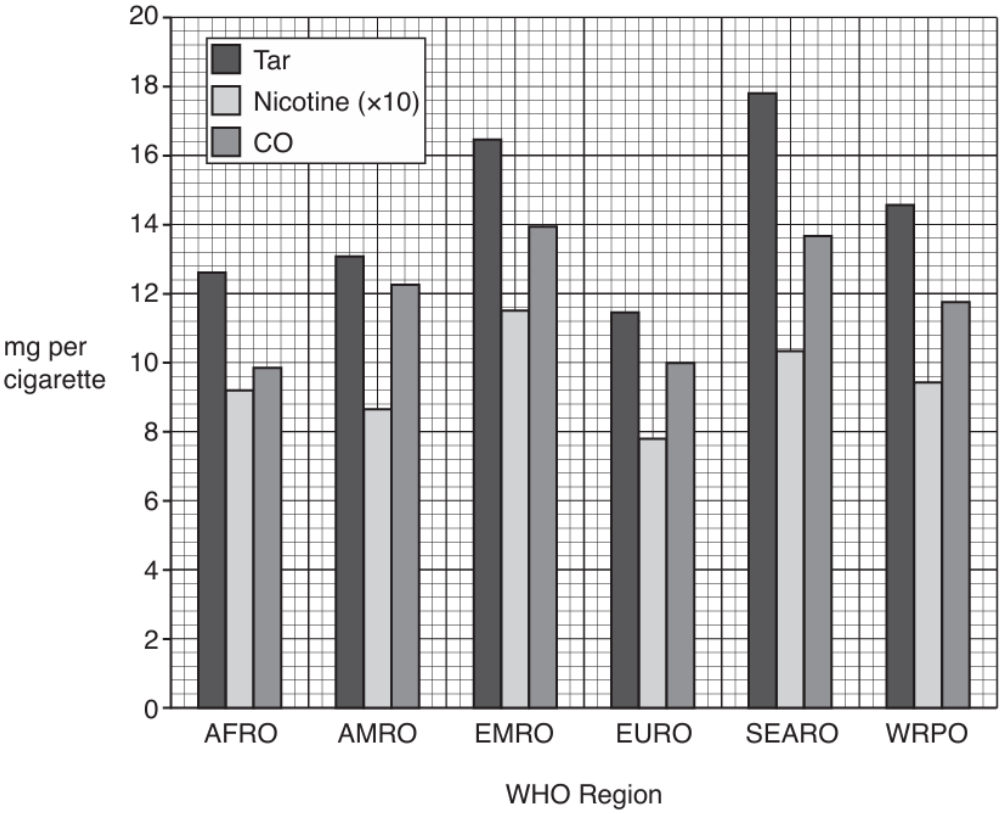


Fig. 2.1

(c) One short-term effect of cigarette smoking is a decrease in the supply of oxygen to body tissues.

Describe **and** explain why cigarette smoking leads to a decrease in the supply of oxygen to body tissues.

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14 A red blood cell goes through a number of stages in the bone marrow before it is released into the circulation to carry out its role of oxygen transport.

Fig. 3.1 is a transmission electron micrograph of developing red blood cells in the bone marrow. Each cell is known as an erythroblast.

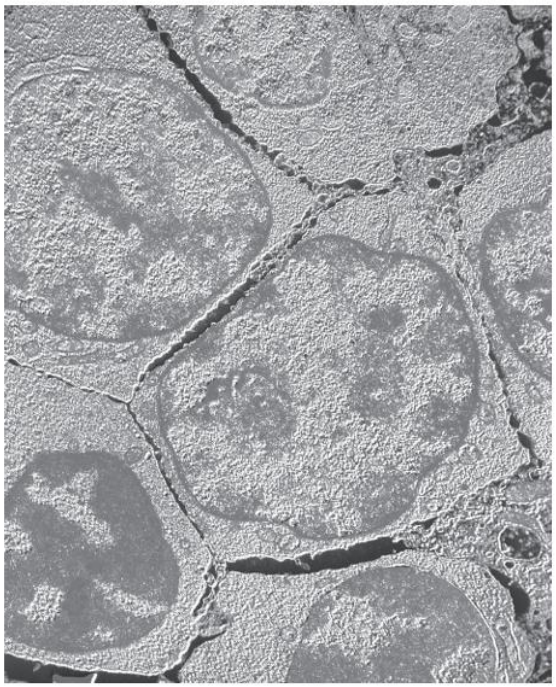


Fig. 3.1

(c) The maturing red blood cell synthesises haemoglobin and other proteins.

(ii) Fig. 3.2 shows a reversible reaction that takes place within red blood cells.

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

Fig. 3.2

Name the protein that catalyses the reaction shown in Fig. 3.2.

..... [1]

The *SPTB* gene codes for a protein that provides stability and support to the cell surface membrane of the red blood cell.

Mutations in *SPTB* result in red blood cells that are spherical in shape. This mutation leads to a disease known as spherocytosis type 2.

(d) Suggest why a person with spherocytosis type 2 has a reduced ability to take up oxygen in the pulmonary capillaries compared with a person who has normal red blood cells.

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15 Fig. 3.1 is a photomicrograph of human blood cells from a healthy individual who lives at sea level. The cells labelled **C**, **D** and **E** are white blood cells.

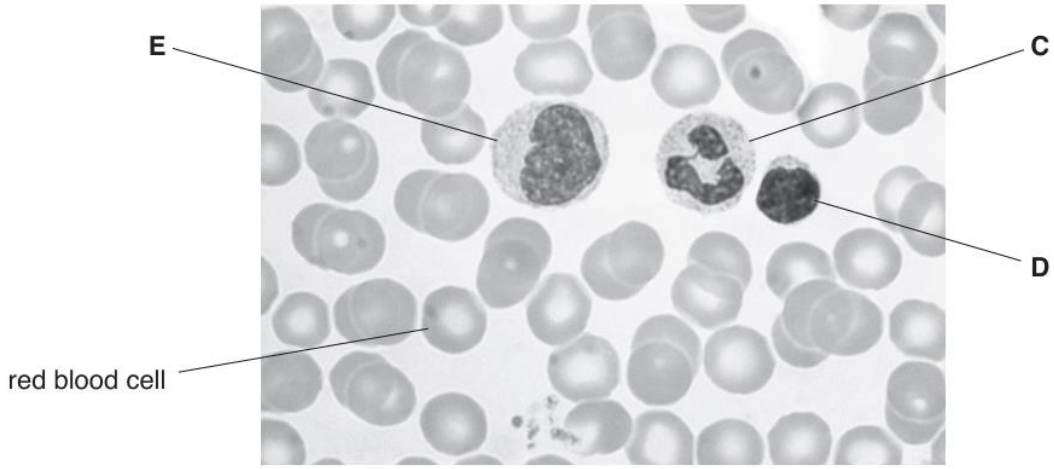


Fig. 3.1

(c) Most of the oxygen that enters the mammalian circulatory system is transported by red blood cells.

(ii) At a high altitude, the partial pressure of oxygen in the atmosphere is lower than at sea level. If a person travels from low altitude to high altitude and remains there for a few weeks, the red blood cell count increases.

Explain why the body needs to respond to high altitude by increasing the number of red blood cells.

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..... [3]

16 When tobacco smoke is inhaled, chemicals such as nicotine and carbon monoxide enter the circulatory system through the gas exchange system. Tar builds up on the lining of the gas exchange system.

Many people decide to give up smoking tobacco in order to improve their health.

(c) Fig. 5.2 shows oxygen dissociation curves for adult haemoglobin.

Curve **A** shows measurements obtained from a person who is a heavy smoker.

Curve **B** shows measurements obtained several weeks after the same person stopped smoking.

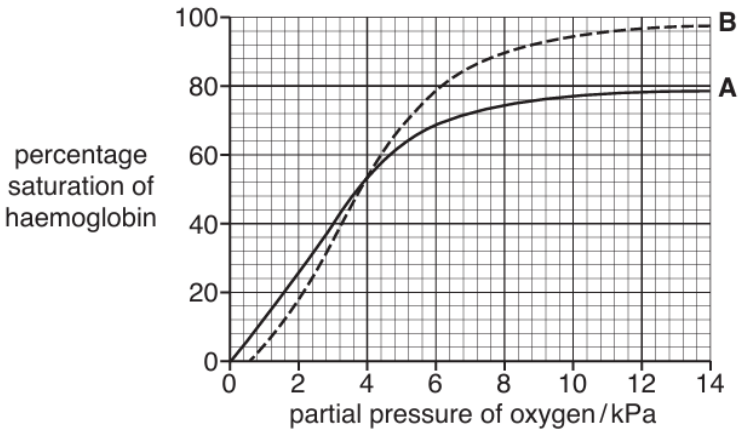


Fig. 5.2

With reference to Fig. 5.2, describe and explain how the results show some of the health benefits of stopping smoking.

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17 Fig. 4.1 is a ribbon model of a molecule of haemoglobin.

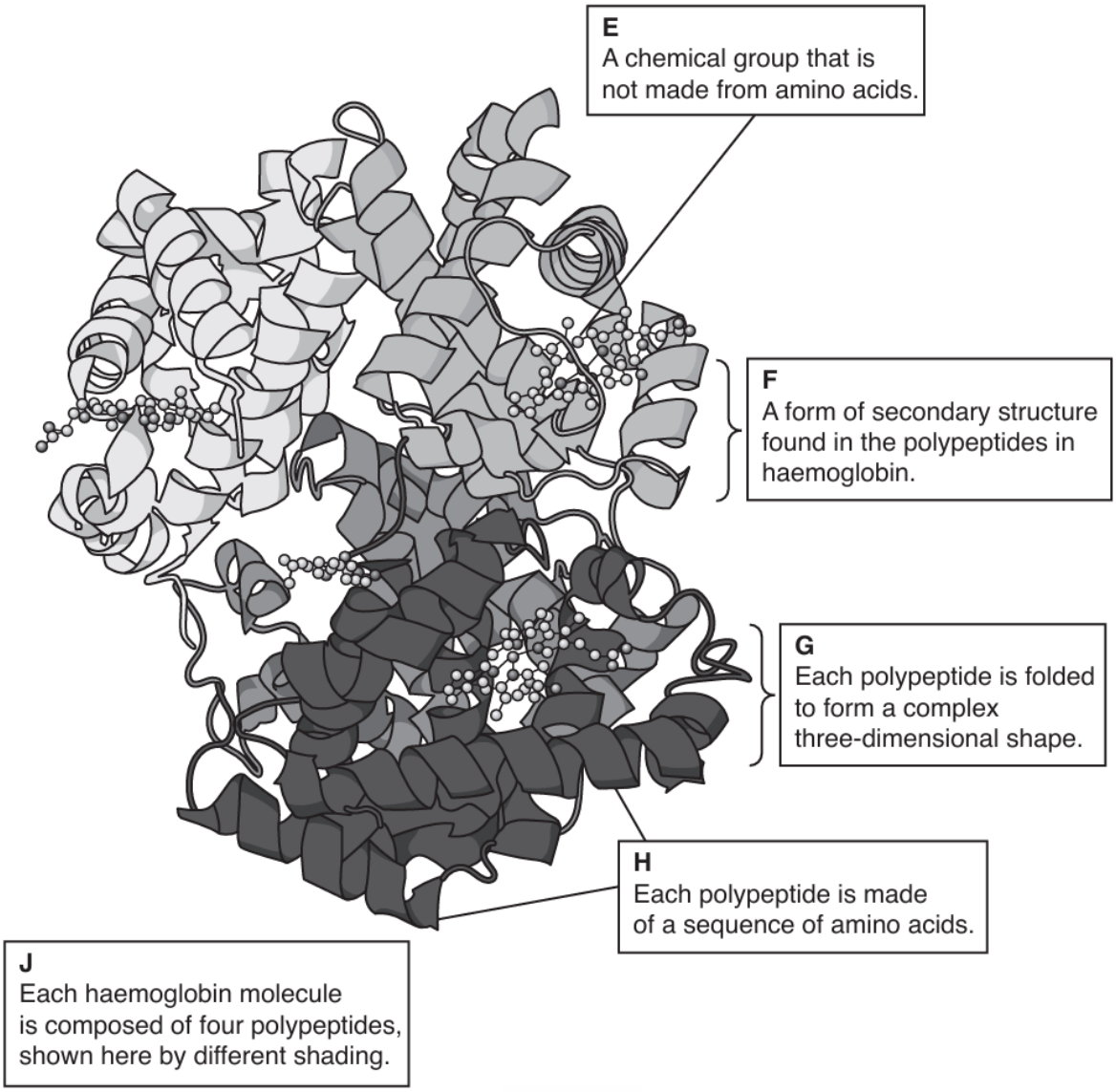


Fig. 4.1

(b) The effect of carbon dioxide on the percentage saturation of haemoglobin with oxygen was investigated.

A sample of mammalian blood was exposed to a gas mixture that contained increasing partial pressures of oxygen (pO_2). Throughout the investigation the partial pressure of carbon dioxide (pCO_2) was maintained at 5.3 kPa. The percentage saturation of haemoglobin in the sample was determined as the pO_2 increased.

The investigation was repeated with a second sample of blood in which the pCO_2 was maintained at 10.7 kPa.

The results are shown in Fig. 4.2.

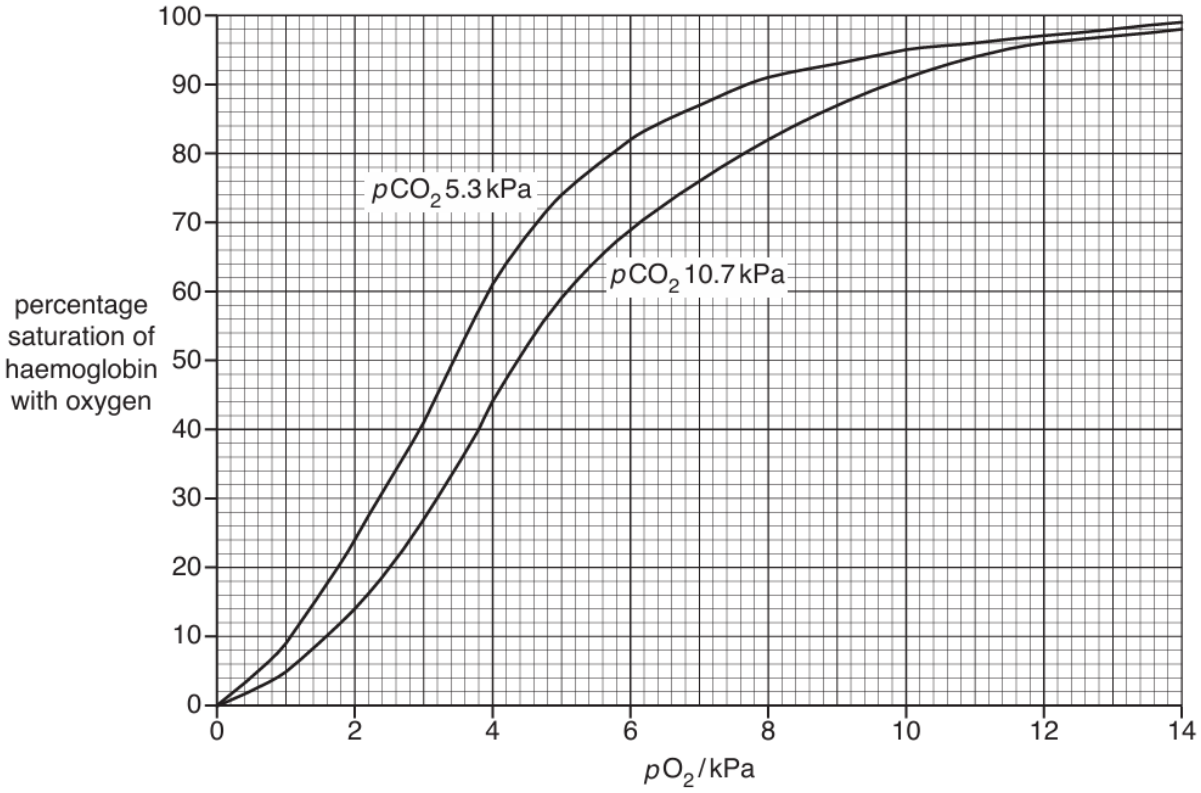


Fig. 4.2

(i) The pO_2 in alveolar air is 13.0 kPa and the pCO_2 is 5.3 kPa.

Use Fig. 4.2 to suggest the percentage saturation of haemoglobin in blood entering the pulmonary veins.

.....[1]

(ii) Use the information in Fig. 4.2 to state **and** explain the effect of increasing pCO_2 in muscle tissues during strenuous exercise.

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.....[4]

18 As a red blood cell matures, cell organelles are lost from the cell. This provides more space for the haemoglobin molecules that have been synthesised.

(b) State the most appropriate term to match each of the descriptions **A** to **C**.

A The part of the haem group that binds oxygen in each haemoglobin polypeptide.

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B The compound formed when carbon dioxide binds to haemoglobin.

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C The compound formed when hydrogen ions (H^+) bind to haemoglobin.

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[3]

19 **(b)** Llamas are mammals that are adapted to live at high altitudes.

Fig. 6.1 shows oxygen dissociation curves for haemoglobin of llamas and humans.

(i) The partial pressure of oxygen in the lungs of mammals at 3500 m is 6.4 kPa.

Use Fig. 6.1 to state the percentage saturation of haemoglobin of llamas and humans at an oxygen partial pressure of 6.4 kPa.

llamas ..... %

humans ..... % [1]

(ii) With reference to Fig. 6.1, explain the advantage to llamas of having an oxygen dissociation curve positioned to the left of the curve for humans.

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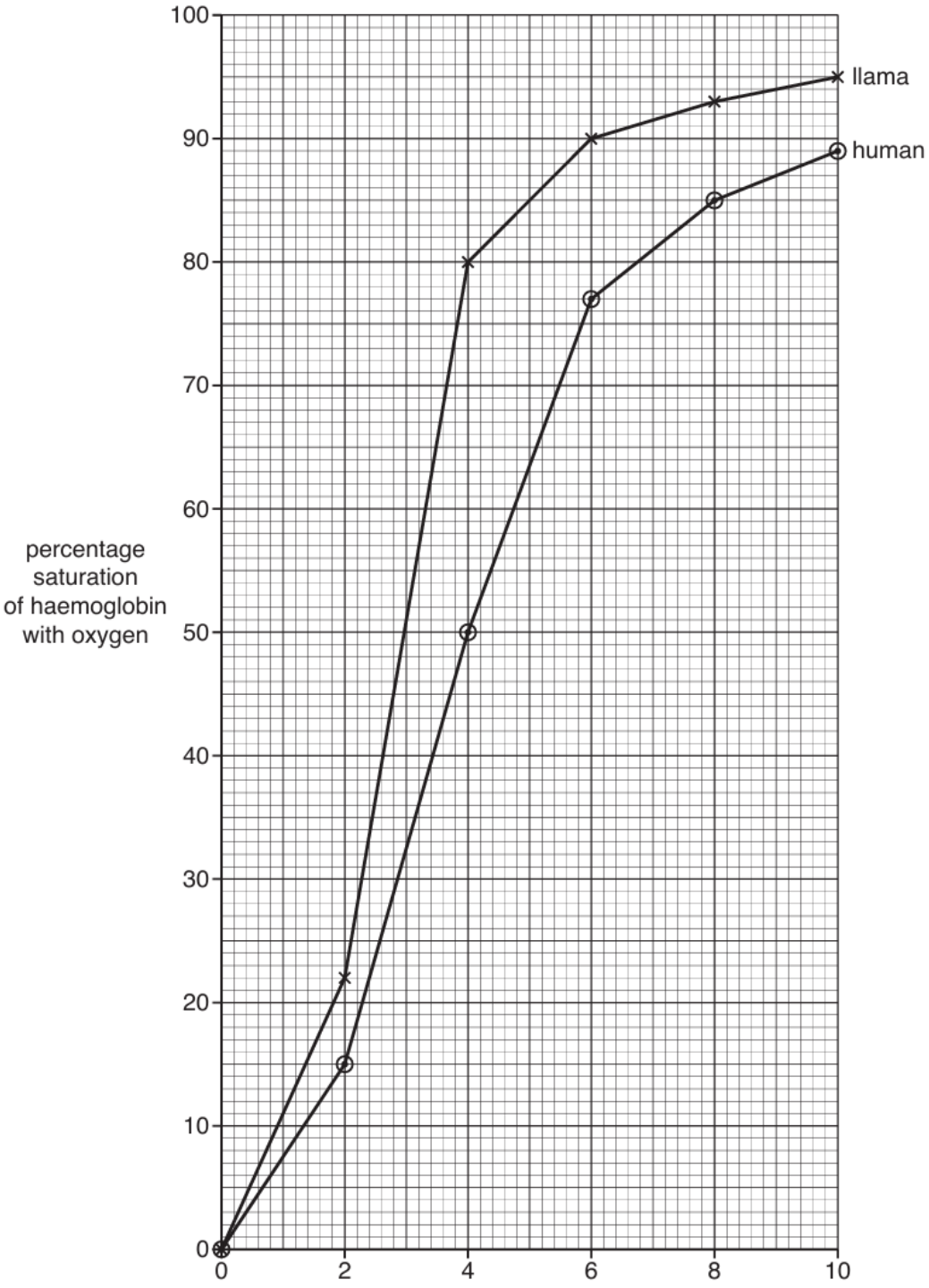

percentage saturation of haemoglobin with oxygen
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
llama
human

Fig. 6.1