A-Level Biology

Haemoglobin

Question Paper

Time available: 85 minutes
Marks available: 69 marks

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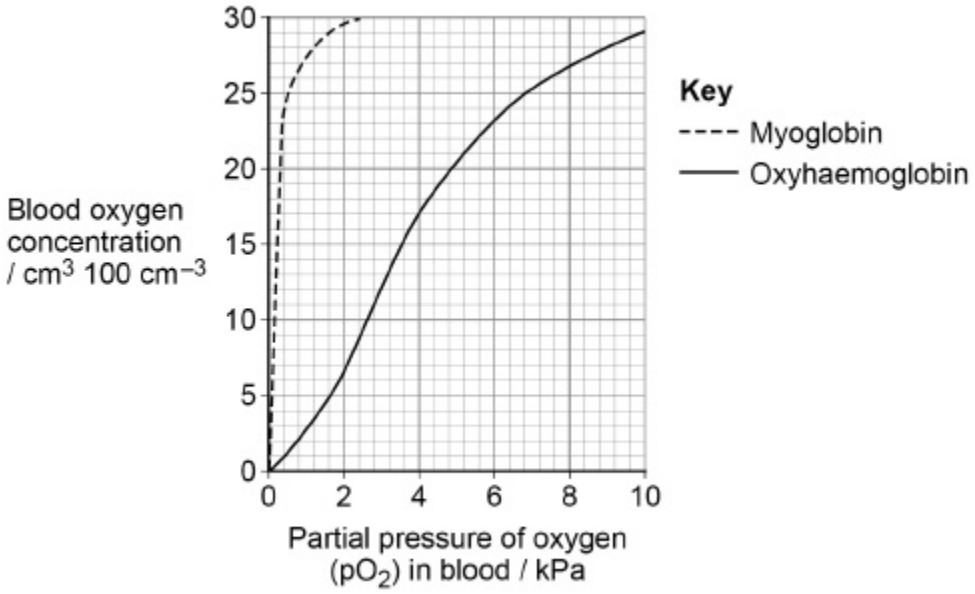
1. (a) Describe and explain the effect of increasing carbon dioxide concentration on the dissociation of oxyhaemoglobin.

(2)

Seals are diving mammals. They fill their lungs with air before they dive and hold their breath during the dive.

The graph shows the dissociation curves for seal oxyhaemoglobin and seal myoglobin. Myoglobin is an oxygen-carrying protein found in muscles.



(b) Use information in the graph to explain how the seal's myoglobin dissociation curve shows the seal is adapted for diving.

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(2)

(c) Scientists measured the oxygen carrying capacity of seal blood.
They found the haemoglobin in a 190 kg seal contained 1.07×10^4 cm^3 oxygen.
When the seal dived, it used 5.2 cm^3 oxygen per minute per kg of body mass.

Use this information to calculate the maximum number of minutes the seal can remain under water. Assume that all of the oxygen attached to the haemoglobin is released during the dive.

Answer = _____ minutes

(2)

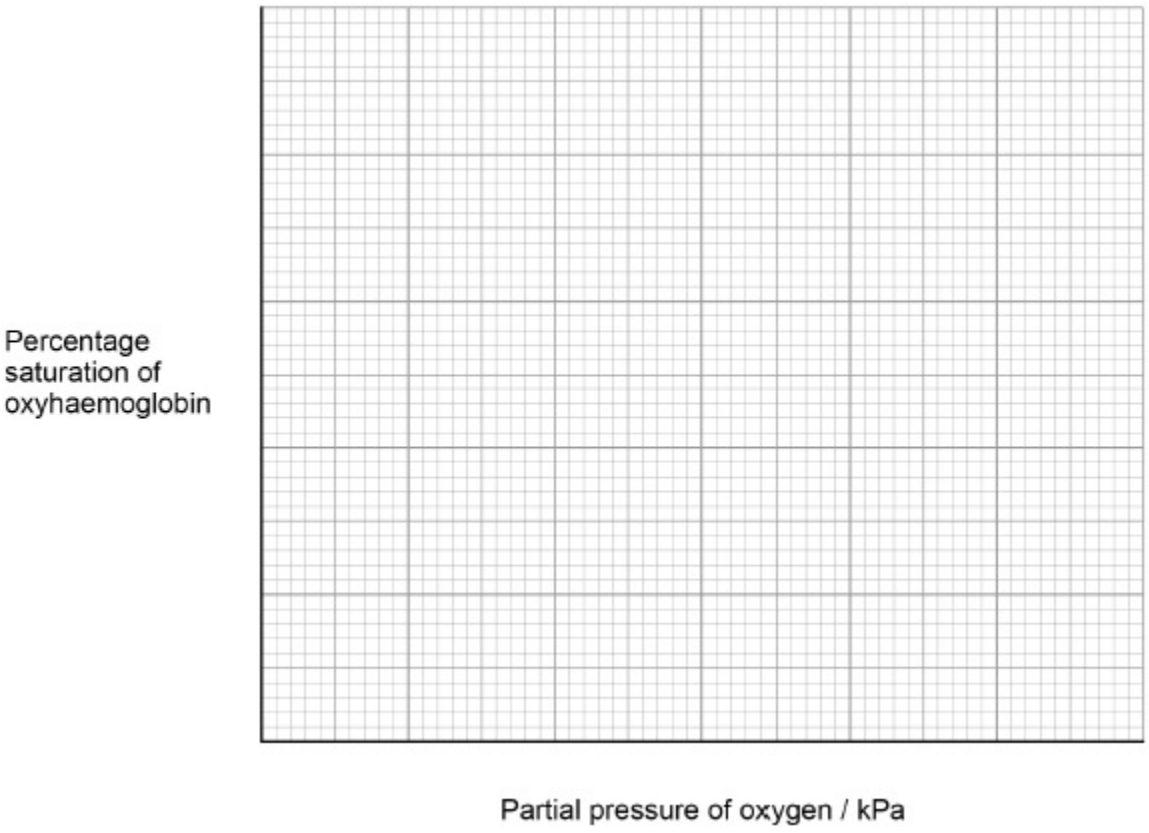
(Total 6 marks)

2. A scientist investigated the affinity for oxygen of horse haemoglobin and mouse haemoglobin.

Some of their results are shown in the table.

Animal	Partial pressure of oxygen when haemoglobin is 50% saturated / kPa	Partial pressure of oxygen when haemoglobin is 25% saturated / kPa	Body mass of one animal / g
Horse	3.2	1.9	550 000
Mouse	6.5	3.3	23

(a) Plot the haemoglobin saturation data from the graph and use these points to sketch the full oxyhaemoglobin dissociation curves for a horse and a mouse.



(3)

(b) The following equation can be used to estimate the metabolic rate of an animal.

$$\text{Metabolic rate} = 63 \times BM^{-0.27}$$

BM = body mass in grams

Use this equation to calculate how many times faster the metabolic rate of a mouse is than the metabolic rate of a horse.

Answer = _____ times faster

(2)

(c) The data in the table above show differences between the oxyhaemoglobin dissociation curve for a mouse and the oxyhaemoglobin dissociation curve for a horse.

Suggest how these differences allow the mouse to have a higher metabolic rate than the horse.

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(2)

(d) Mammals such as a mouse and a horse are able to maintain a constant body temperature.

Use your knowledge of surface area to volume ratio to explain the higher metabolic rate of a mouse compared to a horse.

(3)

(Total 10 marks)

3. (a) Binding of one molecule of oxygen to haemoglobin makes it easier for a second oxygen molecule to bind.

Explain why.

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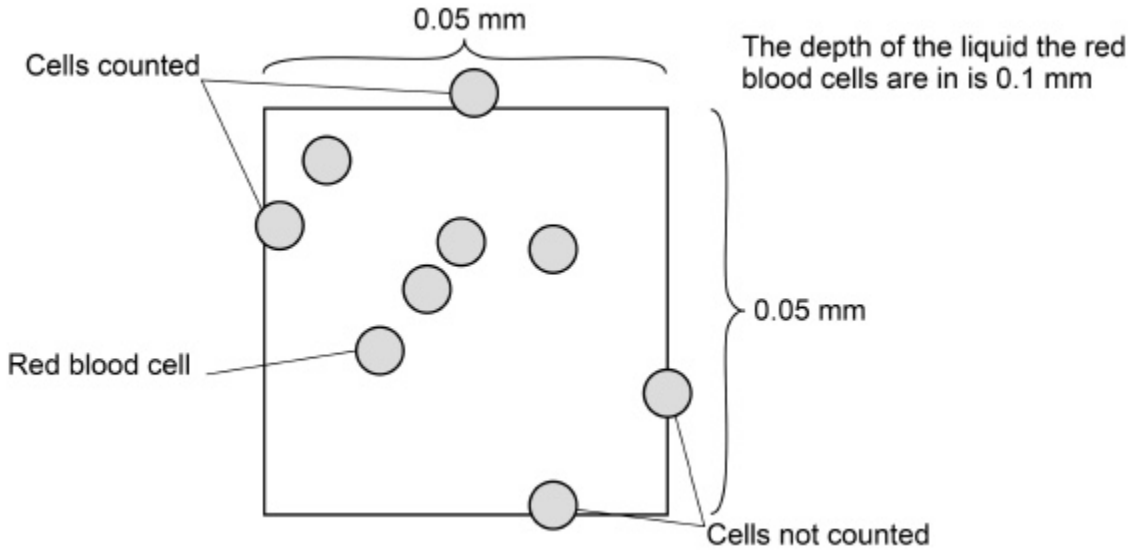
(2)

A haemocytometer is a special microscope slide which can be used to count the numbers of blood cells in a sample of blood.

- The surface of the slide has many small, equal-sized squares marked on it.
- The depth of the liquid under each square is 0.1 mm
- When counting, cells that touch top or left lines are counted but cells that touch right or bottom lines are not counted.

A doctor used a haemocytometer to determine the number of red blood cells per mm^3 in a blood sample. He diluted the original blood sample by a factor of 200 times before putting some on a haemocytometer.

The diagram shows the distribution of cells in a typical small square.



(b) The doctor counted the red blood cells in many small squares.
The **mean** number of red blood cells per small square was 7
The original blood sample was diluted by a factor of 200 times.

Calculate the number of red blood cells per mm^3 in the original blood sample.
Give your answer in standard form.

Answer = _____ red blood cells per mm^3

(2)

(c) When counting, cells that touch top or left lines are counted but cells that touch right or bottom lines **are not** counted.

Suggest **two** reasons for this rule.

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2. _____

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(2)

The doctor also wanted to know how many white blood cells per mm^3 there were in a different sample of blood. To do this he first diluted the sample by a factor of 20 times. He then made the white blood cells clearly visible by using a stain that makes nuclei appear dark blue.

(d) When counting white blood cells, the doctor only diluted the blood sample by a factor of 20 times, instead of 200 times when counting red blood cells.

Suggest why he only diluted the sample by a factor of 20 times.

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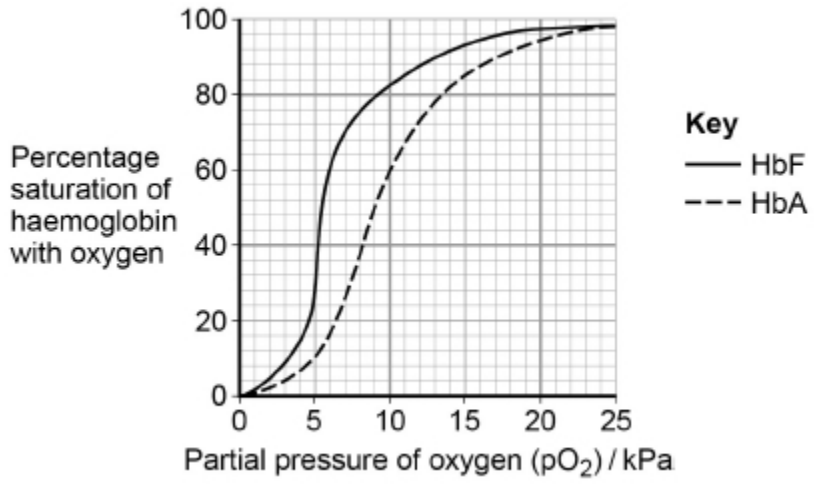
(1)

(e) Explain how the stain allowed the doctor to count the white blood cells amongst all the red blood cells.

(1)

(Total 8 marks)

4. The graph shows the oxyhaemoglobin dissociation curves for fetal haemoglobin (HbF) and adult haemoglobin (HbA).



(a) Explain how changes in the shape of haemoglobin result in the S-shaped (sigmoid) oxyhaemoglobin dissociation curve for HbA.

(2)

(b) At birth 98% of the haemoglobin is HbF. By the age of 6 months, the HbF has usually completely disappeared from the baby's blood and been replaced by HbA.

Use the graph above to explain why this change is an advantage for the baby.

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(2)

(c) Sickle cell disease (SCD) is caused by production of faulty HbA. This results in a reduced ability to transport oxygen to tissues. Scientists investigated the use of a substance called hydroxyurea to treat babies with SCD. Hydroxyurea changes the concentration of HbF in the blood.

The scientists carried out an investigation with 122 babies who had SCD. Each baby was given hydroxyurea for 41 months. The scientists then found the mean change in the concentration of HbF in the babies' blood.

Their results are shown in the table.

Mean concentration of HbF in the babies' blood / arbitrary units	
Before treatment with hydroxyurea (± 1 standard deviation)	**After treatment with hydroxyurea (± 1 standard deviation)**
7.6 (± 4.5)	19.1 (± 6.5)

The scientists concluded that treatment with hydroxyurea would increase the concentration of oxygen in the blood of babies with SCD.

Suggest how the graph and table above support this conclusion.

(3)

(Total 7 marks)

5. Haemoglobin transports oxygen around the body of many animals.

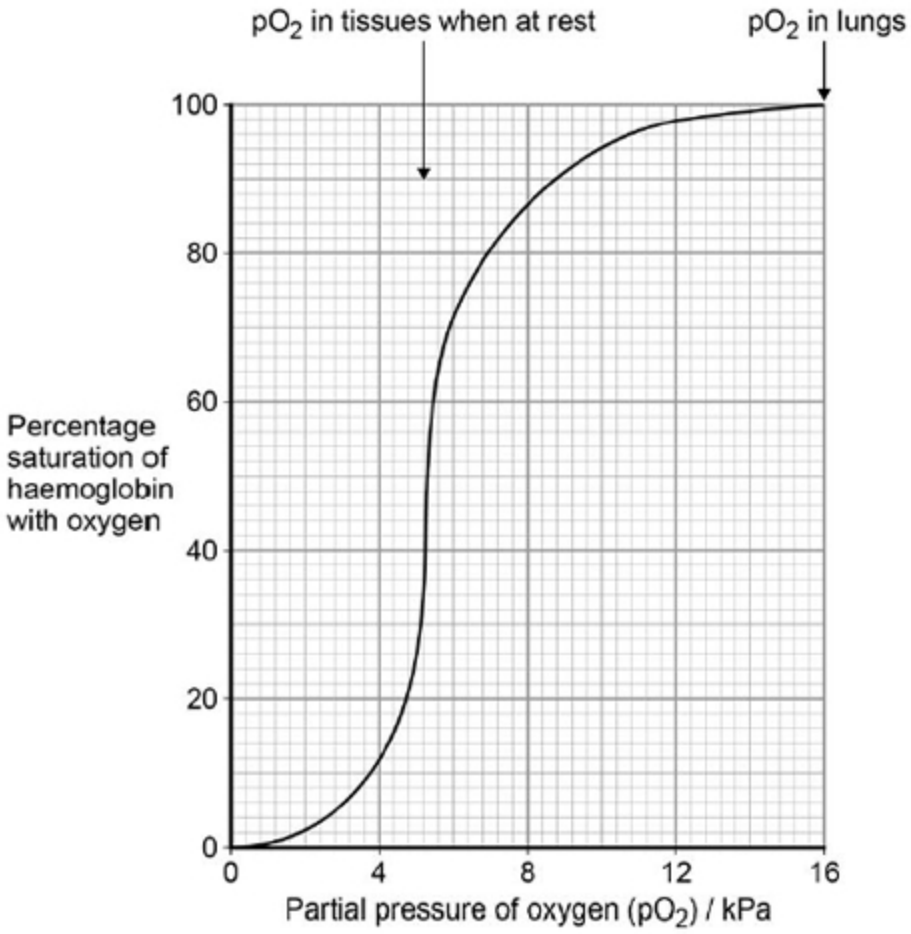
(a) Haemoglobin is a protein with a quaternary structure.

Explain the meaning of **quaternary structure**.

(1)

(b) When fully saturated, each molecule of haemoglobin is bound to four molecules of oxygen.

The graph shows the percentage saturation of haemoglobin with oxygen at different partial pressures.



Give the formula for calculating the percentage saturation of haemoglobin with oxygen.

Percentage saturation of haemoglobin with oxygen = _____

(1)

(c) The first molecule of oxygen to bind causes a change in the shape of the haemoglobin molecule.

This change of shape makes it easier for other oxygen molecules to bind to the haemoglobin molecule.

Explain how the graph provides evidence for this.

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(2)

(d) Suggest **one** advantage of this change in the affinity of haemoglobin for oxygen.

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(1)

(e) Tests on the man whose blood was used to construct the graph gave the following data.

- Concentration of haemoglobin in blood = 150 g dm^{-3}.
- Volume of oxygen carried by fully saturated haemoglobin = 1.35 cm^3 g^{-1}.
- Resting heart rate = 60 beats $minute^{-1}$.
- Volume of blood pumped out of left ventricle each beat = 60 cm^3.

Use these data and information from the graph to calculate the volume of oxygen released to the man's tissues per minute whilst he was at rest.

Show your working.

Answer = _____ cm^3 $minute^{-1}$

(3)

(Total 8 marks)

6. Haemoglobin is a protein. It is made of two alpha polypeptides and two beta polypeptides. Each alpha polypeptide has 141 amino acids and each beta polypeptide has 146 amino acids.

(a) What term is used to describe the structure of a protein made of two or more polypeptides?

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(1)

(b) Calculate the minimum number of DNA bases needed to code for the number of amino acids in one alpha polypeptide.

Answer = _____

(1)

(c) Describe the role of haemoglobin in supplying oxygen to the tissues of the body.

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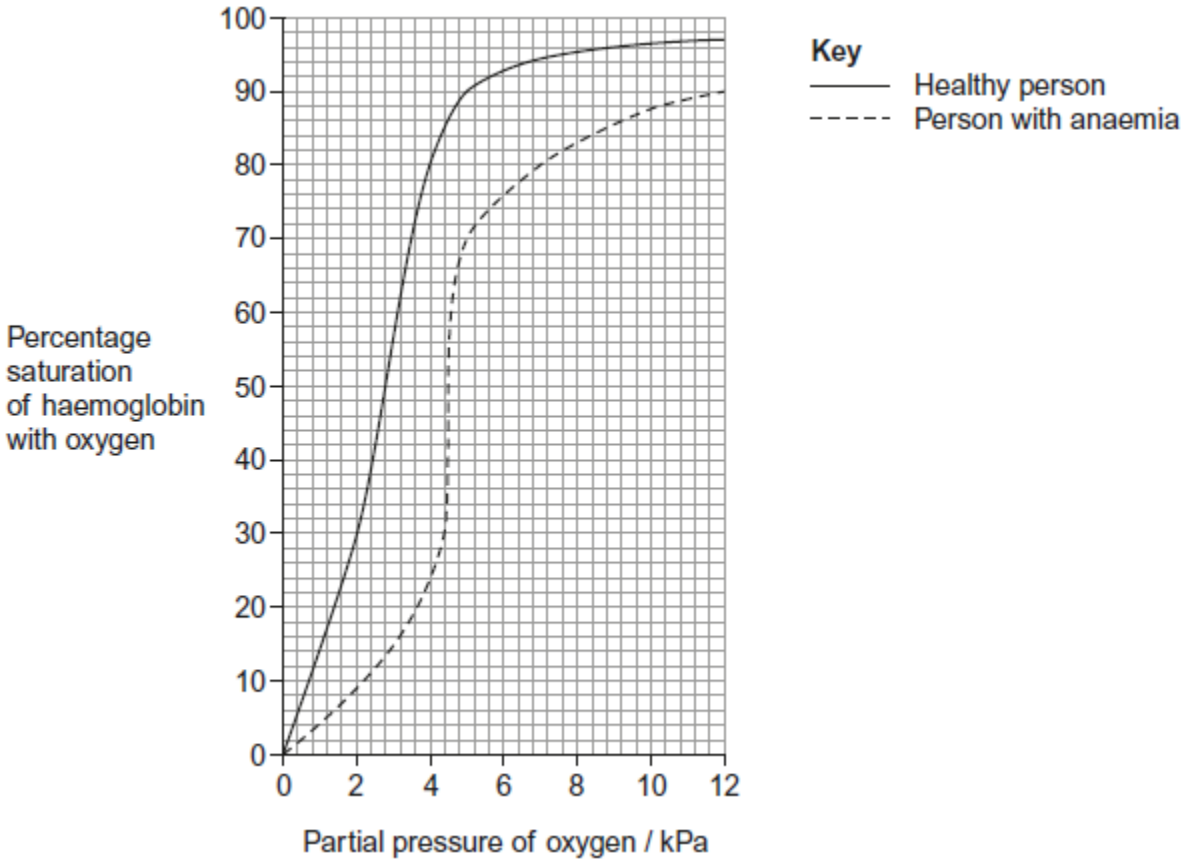
(2)

Anaemia is a condition in which there is a decrease in the concentration of haemoglobin in blood. In some people with anaemia, substances are produced which change the oxygen dissociation curve of haemoglobin.

The graph shows the effect of these substances on the oxygen dissociation curve of haemoglobin.



(d) (i) Use information in the graph to find the difference in the percentage saturation of haemoglobin with oxygen between a healthy person and a person with anaemia at a partial pressure of oxygen of 4 kPa.

Answer = _____

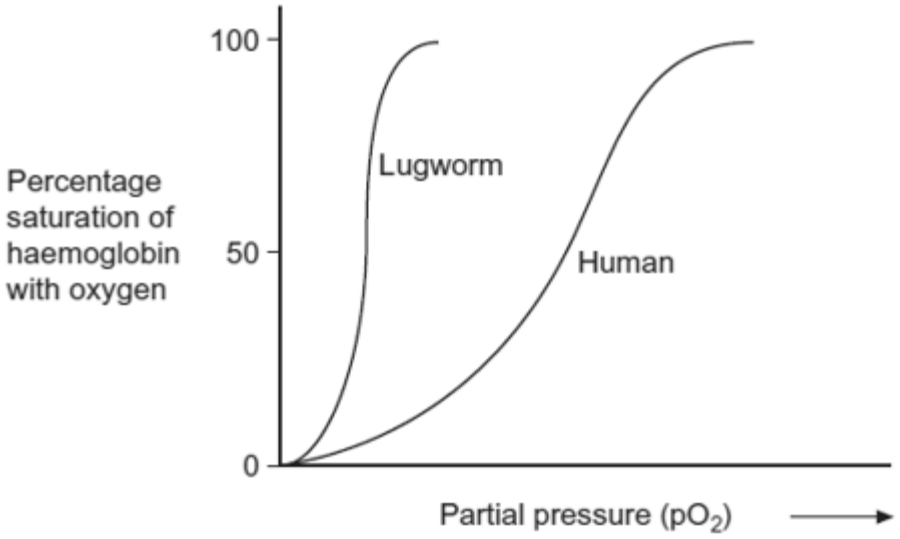
(1)

(ii) Explain the advantage to a person with anaemia of the change shown in the oxygen dissociation curve.

(3)

(Total 8 marks)

7. Lugworms live in mud where the partial pressure of oxygen is low. The graph shows oxygen dissociation curves for a lugworm and for a human.



(a) Explain the advantage to the lugworm of having haemoglobin with a dissociation curve in the position shown.

(2)

(b) In humans, substances move out of the capillaries to form tissue fluid. Describe how this tissue fluid is returned to the circulatory system.

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(3)

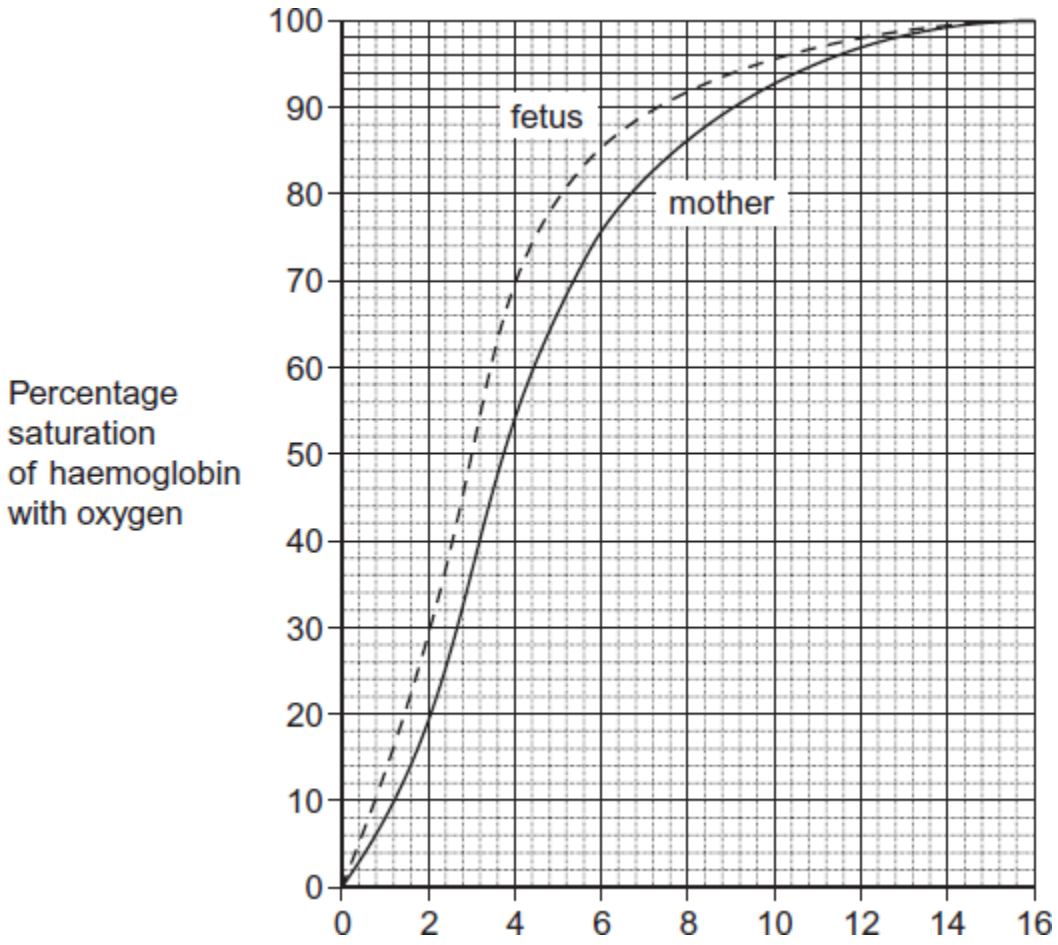
(Total 5 marks)

8. (a) The table shows three statements about some biological molecules. Complete the table with a tick in each box if the statement is true for haemoglobin, cellulose or starch.

Statement	Haemoglobin	Cellulose	Starch
Has a quaternary structure			
Formed by condensation reactions			
Contains nitrogen			

(3)

The graph shows oxygen dissociation curves for the haemoglobin of a mother and her fetus.



(b) What is the difference in percentage saturation between the haemoglobin of the mother and her fetus at a partial pressure of oxygen (pO_2) of 4 kPa?

(1)

(c) The oxygen dissociation curve of the fetus is to the left of that for its mother. Explain the advantage of this for the fetus.

(2)

(d) After birth, fetal haemoglobin is replaced with adult haemoglobin. Use the graph to suggest the advantage of this to the baby.

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(2)

(e) Hereditary persistence of fetal haemoglobin (HPFH) is a condition in which production of fetal haemoglobin continues into adulthood. Adult haemoglobin is also produced.

People with HPFH do not usually show symptoms. Suggest why.

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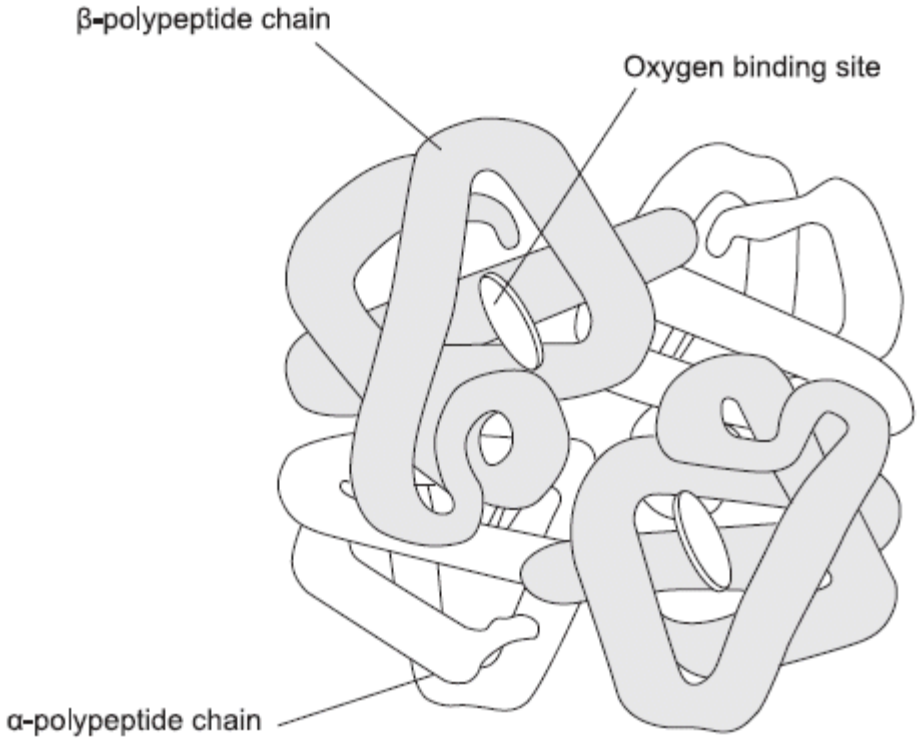
(1)

(Total 9 marks)

9. The diagram shows a molecule of haemoglobin.



(a) What is the evidence from the diagram that haemoglobin has a quaternary structure?

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(1)

(b) (i) A gene codes for the α-polypeptide chain. There are 423 bases in this gene that code for amino acids. How many amino acids are there in the α-polypeptide chain?

(1)

(ii) The total number of bases in the DNA of the α-polypeptide gene is more than 423.

Give **two** reasons why there are more than 423 bases.

1. _____

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2. _____

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(2)

(c) The haemoglobin in one organism may have a different chemical structure from the haemoglobin in another organism. Describe how.

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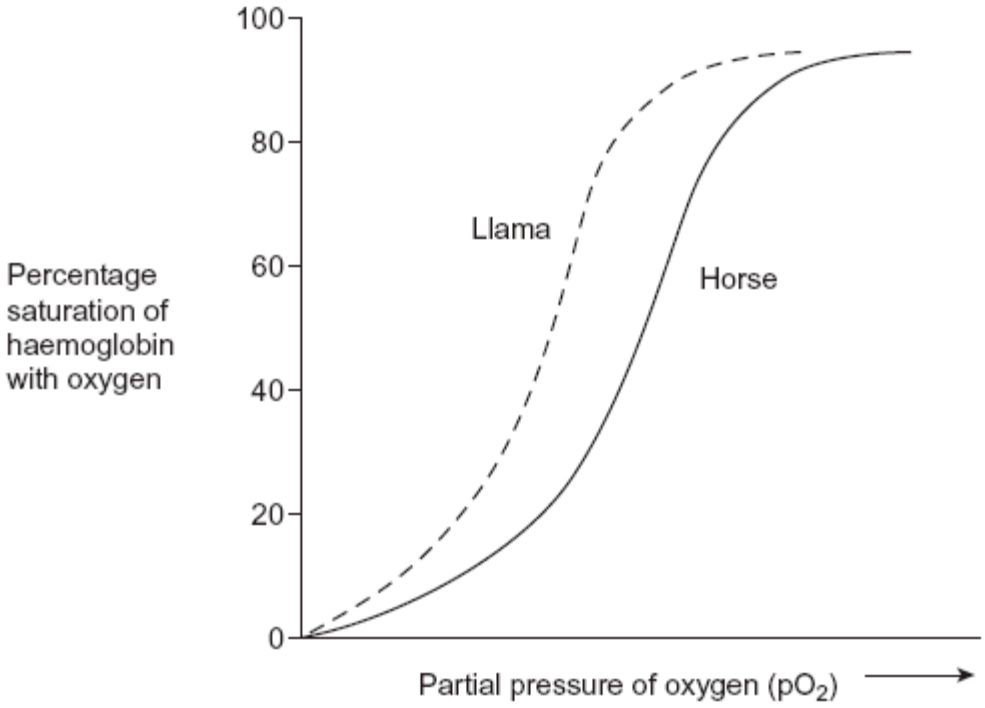
(1)

(d) The graph shows oxygen dissociation curves for horse haemoglobin and for llama haemoglobin. Horses are adapted to live at sea level and llamas are adapted to live in high mountains.



Use the graph to explain why llamas are better adapted to live in high mountains than horses.

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(3)

(Total 8 marks)