

Haemoglobin

You should be able to use and define the following key terms:

Affinity: an attraction of one thing to another.

Bohr effect: a physiological phenomenon stating that haemoglobin's oxygen binding affinity is inversely related both to acidity and to the concentration of carbon dioxide.

Dissociation: the separation of one molecule from another.

Haemoglobin: globular protein in blood that readily combines with oxygen to transport it around the body. It comprises four polypeptide chains around an iron-containing haem group.

Partial pressure: a measure of the concentration of a substance in a particular area.

Complete the sentences using the words in bold:

affinity average cytoplasm dissociating dissolved evolve first four fourth
high high iron left left low low lungs lungs partial pressure primary
respiring respiring right right second shape small stagnant third
ventilate

Red blood cells contain haemoglobin, enabling them to carry far more oxygen than if it was only _____ in their _____. Haemoglobin is a protein consisting of _____ polypeptide chains, each containing a haem group which includes an _____ ion; this allows each molecule of haemoglobin to transport four molecules of oxygen. The concentration of oxygen in the air or dissolved in a solution can be referred to as the _____ of oxygen (ppO₂). The saturation of haemoglobin depends upon the partial pressure of oxygen where oxygen will bond to haemoglobin where there is a _____ ppO₂ surrounding the molecule and will release the oxygen when there is a _____ ppO₂. This results in oxygen bonding to haemoglobin in blood surrounding the _____ (since high oxygen concentration is being brought in through ventilation) and releasing (_____ with) the oxygen into actively _____ tissues (since there is a low oxygen concentration due to oxygen being used in aerobic respiration).

As each oxygen molecule bonds to haemoglobin the protein changes _____. This means that the haemoglobin molecule has a different _____ for oxygen depending upon how many have bound previously. It works in this way: it is difficult for the _____ oxygen molecule to bond, it is very easy for the _____ and _____ molecules to bond, it is difficult for the _____ molecule to bond. Any one molecule of haemoglobin would therefore produce a dissociation curve with a step-like appearance; however, we normally represent information on the dissociation of oxygen from haemoglobin as an _____ for all molecules which produces a smooth s-shaped curve.

The affinity of haemoglobin is also altered by the partial pressure of carbon dioxide (ppCO₂) surrounding the haemoglobin. Where ppCO₂ is _____ haemoglobin has a higher affinity for oxygen so the dissociation curve shifts _____; where ppCO₂ is _____ haemoglobin has a lower affinity for oxygen so the dissociation curve shifts _____. This allows the haemoglobin to better collect oxygen in the _____,

where CO_2 concentration is low, and unload it at _____ tissues, where CO_2 concentration is high. This is known as the Bohr effect.

The exact affinity of haemoglobin for oxygen will also depend upon the _____ (and therefore the tertiary) structure of the molecule. This has allowed different organisms to _____ different haemoglobins depending on their requirements for oxygen. An organism that lives in an environment with low ppO_2 , such as in _____ water or high altitude, often has haemoglobin with a higher affinity for oxygen (causing the dissociation curve to shift _____) so it can gain all of the oxygen from its environment. An organism that respire rapidly, such as a _____ mammal or active bird, often has haemoglobin with a lower affinity for oxygen (causing the dissociation curve to shift _____) so it can more easily unload oxygen to their tissues, but also meaning it must _____ the lungs more rapidly.

Answer the questions

1. How many oxygen molecules can bind to haemoglobin?

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2. What metal ion is found in haemoglobin?

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3. What is the alternative name for gas 'concentration'?

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4. Is haemoglobin more or less likely to have oxygen bound if the surrounding oxygen concentration is low?

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5. What is the name given to the change in affinity of oxygen to haemoglobin when the surrounding carbon dioxide concentration changes?

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6. What direction does the curve shift if carbon dioxide concentration is high?

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7. What direction does the curve shift in an active mammal?

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8. Does this mean they have a higher or lower affinity for oxygen?

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9. What direction does the curve shift in an organism that lives in an anaerobic bog?

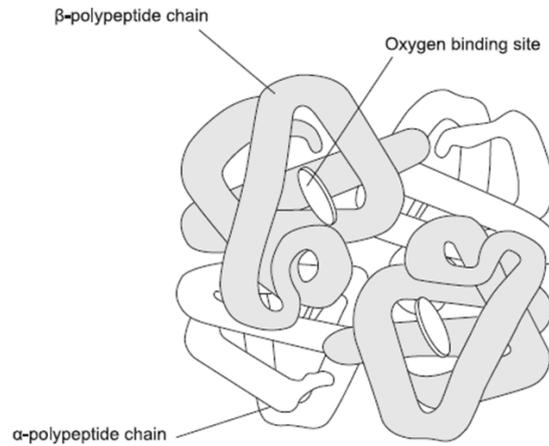
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10. Does this mean they have a higher or lower affinity for oxygen?

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Answer the exam questions

Q1. 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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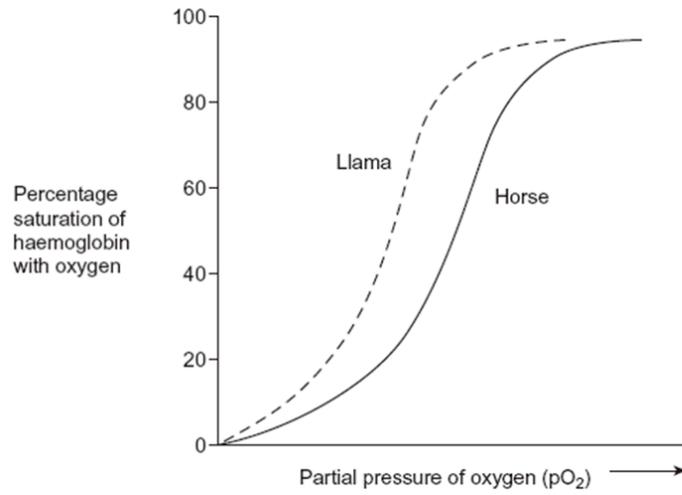
(1)

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

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(1)

(c) 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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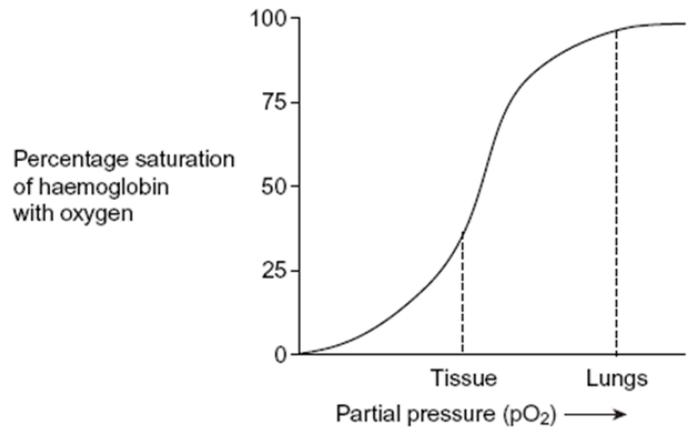
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(3)
(Total 5 marks)

Q2.(a) **Figure 1** shows the oxygen dissociation curve for human haemoglobin.

Figure 1



Use **Figure 1** to describe how haemoglobin loads and unloads oxygen in the body.

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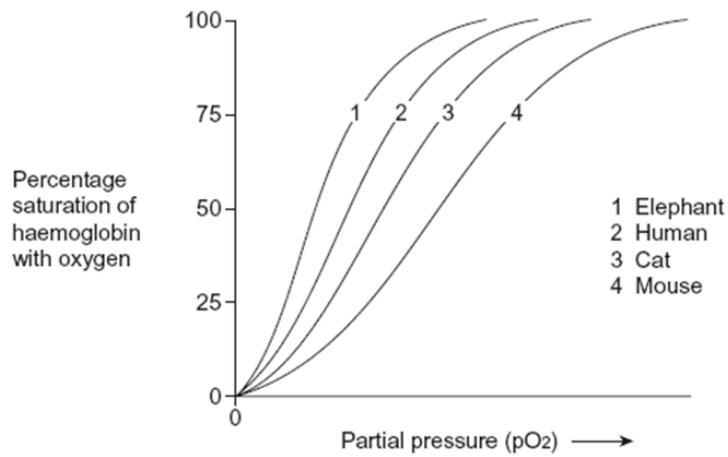
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(b) **Figure 2** shows oxygen dissociation curves from mammals of different size.

Figure 2



(i) Describe the relationship between the size of mammals and the oxygen dissociation curves of their haemoglobins.

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(1)

(ii) Heat from respiration helps mammals to maintain a constant body temperature.

Use this information to explain the relationship between the surface area to volume ratio of mammals and the oxygen dissociation curves of their haemoglobins.

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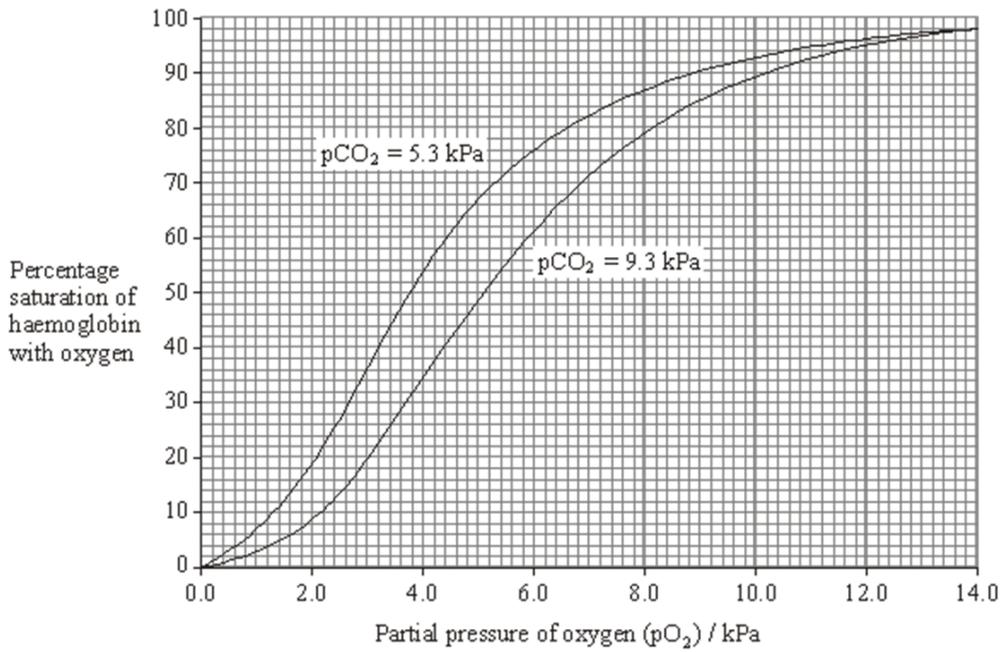
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(4)

Q3. The graph shows the oxyhaemoglobin dissociation curve at two different partial pressures of carbon dioxide ($p\text{CO}_2$).



(a) During vigorous exercise, the blood entering a leg muscle had a $p\text{O}_2$ of 4 kPa and a $p\text{CO}_2$ of 5.3 kPa. The blood leaving the muscle had a $p\text{O}_2$ of 2.8 kPa and a $p\text{CO}_2$ of 9.3 kPa. Each dm^3 of blood leaving the lungs contained 200 cm^3 oxygen and was 98% saturated with oxygen.

Use this information and information from the graph to calculate the volume of oxygen released to the muscle from 1 dm^3 of blood. Show your working.

Answer cm^3 oxygen

(2)

(b) The blood leaving a muscle has a lower pH than the blood entering it. During vigorous exercise, the fall in pH is even greater. Explain what causes this greater fall in pH.

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(3)
(Total 5 marks)

Q4. (a) The table shows some data for a shrew and an elephant.

	Shrew	Elephant
Body mass	10 g	5000 kg
Volume of oxygen taken up per hour	20 cm ³	52.5 dm ³

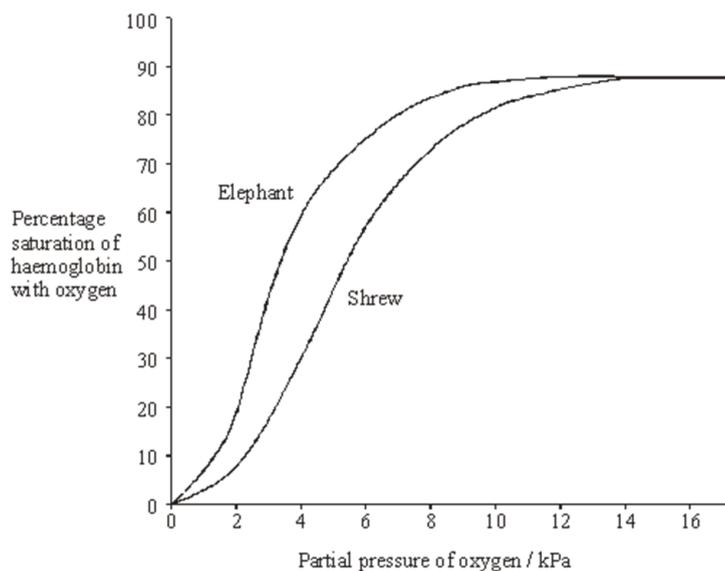
The rate of oxygen uptake for the shrew is 2 cm³g⁻¹h⁻¹. Calculate the volume of oxygen taken up per gram of body tissue per hour in the elephant.

Show your working.

Answer cm³g⁻¹h⁻¹

(2)

(b) The graph shows the oxyhaemoglobin dissociation curves for these mammals.



The tissues of the shrew have a higher rate of oxygen consumption per gram of body tissue than the elephant. There is an advantage to the shrew in having haemoglobin with a dissociation curve in the position shown. Explain this advantage.

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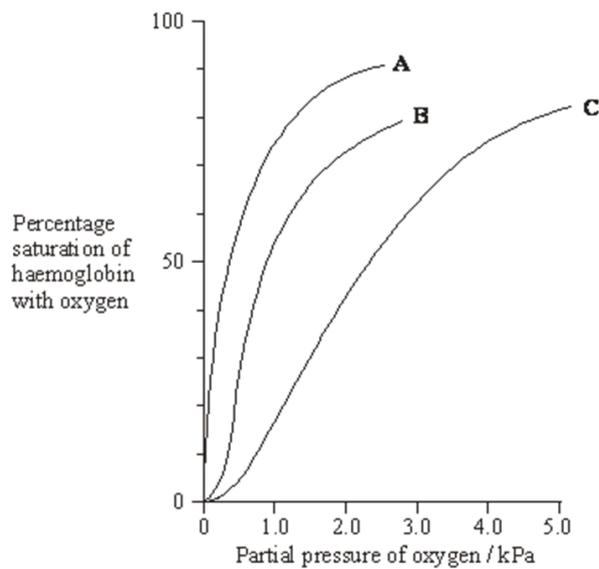
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(3)
(Total 5 marks)

Q5. The graph shows the oxygen haemoglobin dissociation curves for three species of fish.



(a) Species **A** lives in water containing a low partial pressure of oxygen. Species **C** lives in water with a high partial pressure of oxygen. The oxygen haemoglobin dissociation curve for species **A** is to the left of the curve for species **C**. Explain the advantage to species **A** of having haemoglobin with a curve in this position.

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(3)

(b) Species **A** and **B** live in the same place but **B** is more active. Suggest an advantage to **B** of having an oxygen haemoglobin dissociation curve to the right of that for **A**.

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(2)

(Total 5 marks)

Gap fill mark scheme

Dissolved cytoplasm four iron partial pressure high low lungs dissociating respiring shape
affinity first second third fourth average low left high right lungs respiring primary
evolve stagnant left small right ventilate

Questions mark scheme

1. 4
2. Iron
3. Partial pressure
4. Less likely
5. Bohr effect
6. Right
7. Right
8. Lower
9. Left
10. Higher

Exam question mark scheme

M1. (a) More than one polypeptide / chain;

1

(b) Different primary structure / amino acids / different number of polypeptide chains;

1

(c) 1. Low partial pressure of oxygen in lungs;

2. (Llama) haemoglobin able to load more oxygen / (llama) haemoglobin saturated (at low / particular partial pressure of oxygen);

3. Higher affinity for oxygen;

3

[5]

M2.(a) Loading / uptake / association of oxygen at high p_{O_2} ;

In lungs (haemoglobin) is (almost) fully saturated / in lungs haemoglobin has a high affinity for oxygen;

Unloads / releases / dissociates oxygen at low p_{O_2} ;

Unloading linked to higher carbon dioxide concentration;

3 max

(b) (i) Larger the mammal the more to the left / steeper / 'higher' is the curve / the higher the affinity for oxygen;

1

(ii) Smaller mammal has greater surface area to volume ratio;

Smaller mammal / larger SA:Vol ratio more heat lost (per unit body mass);

Smaller mammal / larger SA:Vol ratio has greater rate of respiration / metabolism;

Oxygen required for respiration so (haemoglobin) releases more oxygen / oxygen released more readily / haemoglobin has lower affinity;

4

[8]

M3. (a) Increase in / more carbon dioxide;
Curve moves to the right / depressed;

Q Any reference to haemoglobin increasing affinity for oxygen disqualifies second mark point.

2

(b) (i) More haemoglobin;
So can load / pick up more oxygen (in the lungs);

Q Second mark point must relate to idea of loading oxygen. Answers referring only to transport of oxygen should not be credited this mark.

2

(ii) (Haemoglobin) has lower affinity for oxygen / more oxygen released;
In / to the cells / tissues;

2

[6]

M4. (a) correct answer: 75 - 80 ;; = 2 marks

OR Use of 55 AND 17 saturation / fall = 38; = 1 mark

OR (Fall = γ % +) use of ; = 1 mark

2

(b) (in exercise) - faster respiration rate meaning more CO₂ production;

CO₂ is acidic / forms carbonic acid / lactic acid production;

release of H⁺ ions;

3

[5]

M5. (a) 0.01 / 0.0105;

(allow 1 mark for 52 500 / 5 000 000)

2

(b) (at the tissues at low pp oxygen) the shrew's haemoglobin is less saturated with oxygen / has reduced affinity;

oxyhaemoglobin dissociates more readily / haemoglobin releases oxygen more readily / more oxygen released;

allowing greater demand / respiration rate;

3

[5]

M6. (a) Hb (in A) has greater affinity for O₂;

becomes saturated at low(er) ppO₂ / more saturated at same ppO₂ / unsaturated at very low ppO₂;

able to supply enough O₂ to its tissues;

3

(b) fish B has a greater rate of respiration

(accept more O₂ needed for respiration);
Hb dissociates more readily (than A);
more O₂ supplied;

2 max
[5]