Haemoglobin and Oxygen Transport

A Level

Haemoglobin is the main protein responsible for oxygen transport in animals.

The structure of a haemoglobin protein consists of four polypeptide chains, each attached to a haem molecule. The iron ion at the centre of each haem molecule can bind to one oxygen molecule, meaning that each haemoglobin protein can carry up to four oxygen molecules.

Part A The need for haemoglobin

How does haemoglobin maximise the uptake of oxygen by the red blood cells in the lungs? Select all that apply.

- [ ] Haemoglobin is an enzyme that catalyses a reaction between oxygen and glucose in aerobic respiration. Because oxygen is used up during this reaction, a steep diffusion gradient between the air and the blood in the lungs is maintained.
- [ ] Oxygen that is bound to haemoglobin no longer contributes to the diffusion gradient, which ensures that the steep diffusion gradient between the air and the plasma in the lungs is maintained.
- [ ] Haemoglobin is a membrane transport protein that actively transports oxygen from the plasma into the red blood cells, ensuring that the red blood cells have a high oxygen concentration.
- [ ] Oxygen is not very soluble in plasma.
- [ ] Oxygen cannot diffuse from the air in the lungs into the plasma - haemoglobin is required to make this possible.

Part B Loading & unloading

For haemoglobin to effectively transport oxygen it needs to rapidly load (bind to) oxygen in the lungs and rapidly unload (release) oxygen in the body tissues.

Which of the following statements explain how haemoglobin is able to do both of these things effectively? Select all that apply.

- [ ] Haemoglobin has a low affinity for oxygen at low oxygen partial pressures.
- [ ] Haemoglobin has a high affinity for oxygen at high oxygen partial pressures.
- [ ] Each oxygen molecule that binds to haemoglobin causes a change in the shape of the protein, which makes it **easier** for the next oxygen molecule to bind.
- [ ] Each oxygen molecule that binds to haemoglobin causes a change in the shape of the protein, which makes it **harder** for the next oxygen molecule to bind.
- [ ] Carbon dioxide **increases** the affinity of haemoglobin for oxygen.
- [ ] Carbon dioxide **decreases** the affinity of haemoglobin for oxygen.

Part C The Bohr effect

Drag the items below into the correct order on the right to explain how high carbon dioxide partial pressures affect the oxygen affinity of haemoglobin (i.e. the Bohr effect).

Note that not all of the items below are part of the correct sequence of events, and so you should not use all of the items below.

Available items

- haemoglobin changes shape and has an **increased** affinity for oxygen
- haemoglobin changes shape and has a **reduced** affinity for oxygen
- carbon dioxide dissolves in plasma to form **carbonic acid**
- carbon dioxide dissolves in plasma to form **carbon hydroxide**
- H^+ ions bind to haemoglobin
- OH^- ions bind to haemoglobin
- the pH of the blood **increases**
- the pH of the blood **decreases**

Created for isaacphysics.org by Lewis Thomson

Oxygen Dissociation Curves: Globins

A Level

C C C

Globins are globular proteins that contain one or more haem groups and are involved in binding and/or transporting oxygen.

Two important globins in humans are haemoglobin (Hb, found in red blood cells) and myoglobin (Mb, found in muscle cells). There are two forms of haemoglobin: adult haemoglobin (HbA, the main form of haemoglobin in adults) and foetal haemoglobin (HbF, the main form of haemoglobin in foetuses).

The oxygen dissociation curves of these three globins are shown below (unlabelled) in **Figure 1**.

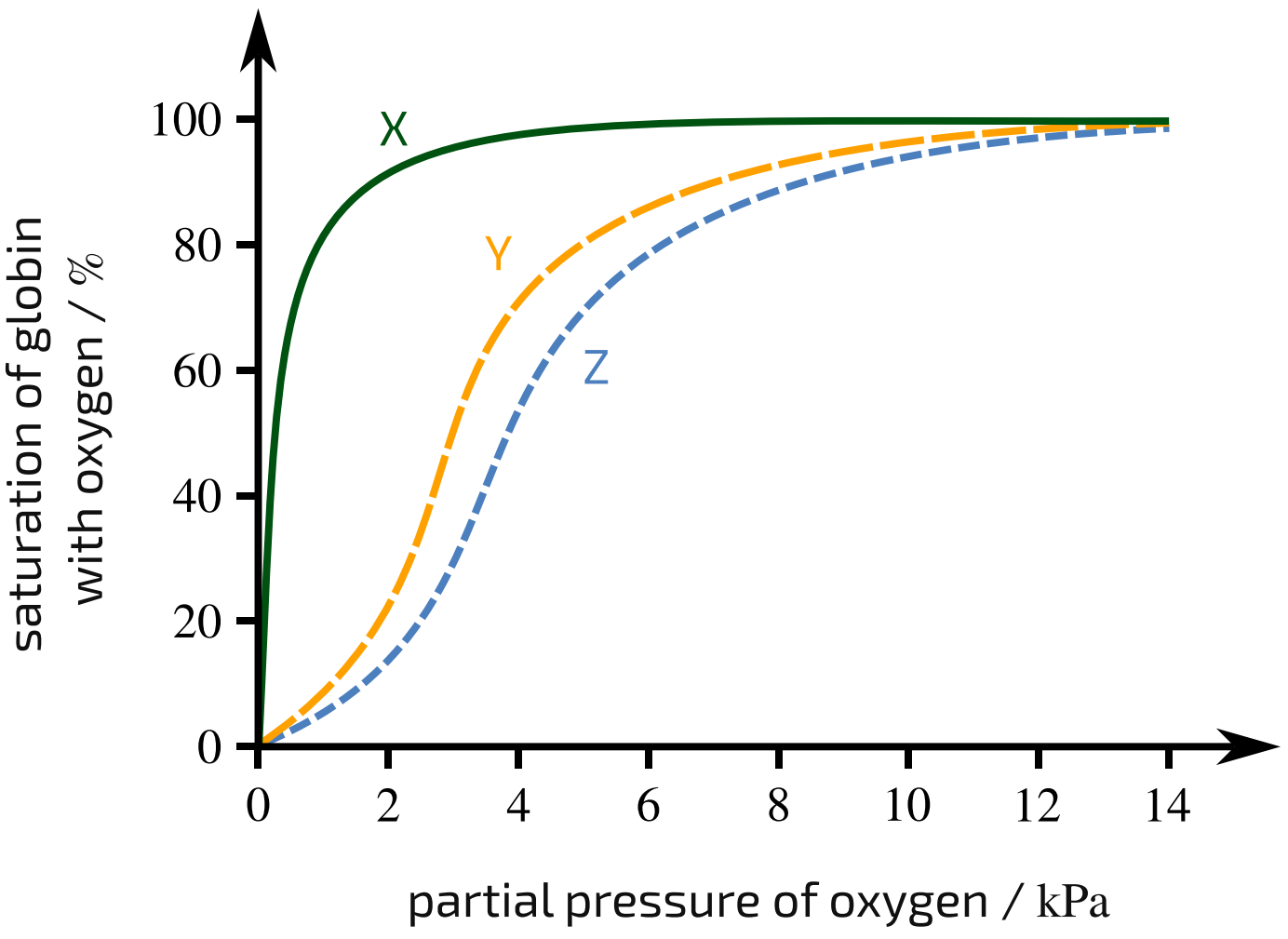


Figure 1: Oxygen dissociation curves for three globins.

Part A Identify the globin

Use the information below to match the globin to the curve in **Figure 1**.

- Myoglobin only releases oxygen when partial pressures are very low.
- Foetal haemoglobin has a higher affinity for oxygen than adult haemoglobin.

	Globin
X	
Y	
Z	

Items:

adult haemoglobin (HbA) **foetal haemoglobin (HbF)** **myoglobin (Mb)**

Part B Oxygen transfer and globin functions

Based on **Figure 1**, which of the following statements are correct? Select all that apply.

- [ ] As blood flows through respiring skeletal muscle tissue, oxygen will be **released from haemoglobin** and will **bind to myoglobin**.
- [ ] As blood flows through respiring skeletal muscle tissue, oxygen will be **released from myoglobin** and will **bind to haemoglobin**.
- [ ] Myoglobin acts as an oxygen store in muscle cells, allowing muscles to keep aerobically respiring for longer than they otherwise would.
- [ ] As blood flows through the placenta, oxygen will be **released from adult haemoglobin** and will **bind to foetal haemoglobin**.
- [ ] As blood flows through the placenta, oxygen will be **released from foetal haemoglobin** and will **bind to adult haemoglobin**.
- [ ] Foetal haemoglobin acts as an oxygen store in the placenta, allowing the placenta to keep aerobically respiring for longer than it otherwise would.

Part C Myoglobin vs haemoglobin

Myoglobin consists of a single polypeptide (bound to a single haem group), whereas haemoglobin consists of four polypeptides (each bound to a haem group).

Which of the following statements explain the difference in shape between the myoglobin dissociation curve and the haemoglobin dissociation curves? Select all that apply.

- [ ] In haemoglobin, cooperative binding means that the binding of one oxygen molecule makes it easier for the next oxygen molecule to bind.
- [ ] Each myoglobin molecule can only bind to one oxygen molecule.
- [ ] In haemoglobin, it is not possible for all four haem groups to be bound to oxygen molecules at the same time, and so a haemoglobin molecule cannot be fully saturated.
- [ ] Both myoglobin and haemoglobin can bind to four oxygen molecules each, but myoglobin binds to the four oxygen molecules instantaneously, whereas haemoglobin binds to the four oxygen molecules sequentially.
- [ ] Haemoglobin binds to oxygen **reversibly**, whereas myoglobin binds oxygen **irreversibly**.

Adapted with permission from CIE A Level Biology, November 2003, Paper 1, Question 23

Gameboard:

STEM SMART Biology Week 20 - Circulatory Systems 2

Oxygen Dissociation Curves: Llamas vs Camels

A Level

C C C

The oxygen saturation of red blood cells is the percentage of haemoglobin binding sites in red blood cells with oxygen bound to them.

Camels and llamas have evolved from the same ancestor. Camels live at low altitude and llamas live at high altitude.

The graph below shows the effect of oxygen partial pressure on the oxygen saturation of red blood cells in camels and llamas.

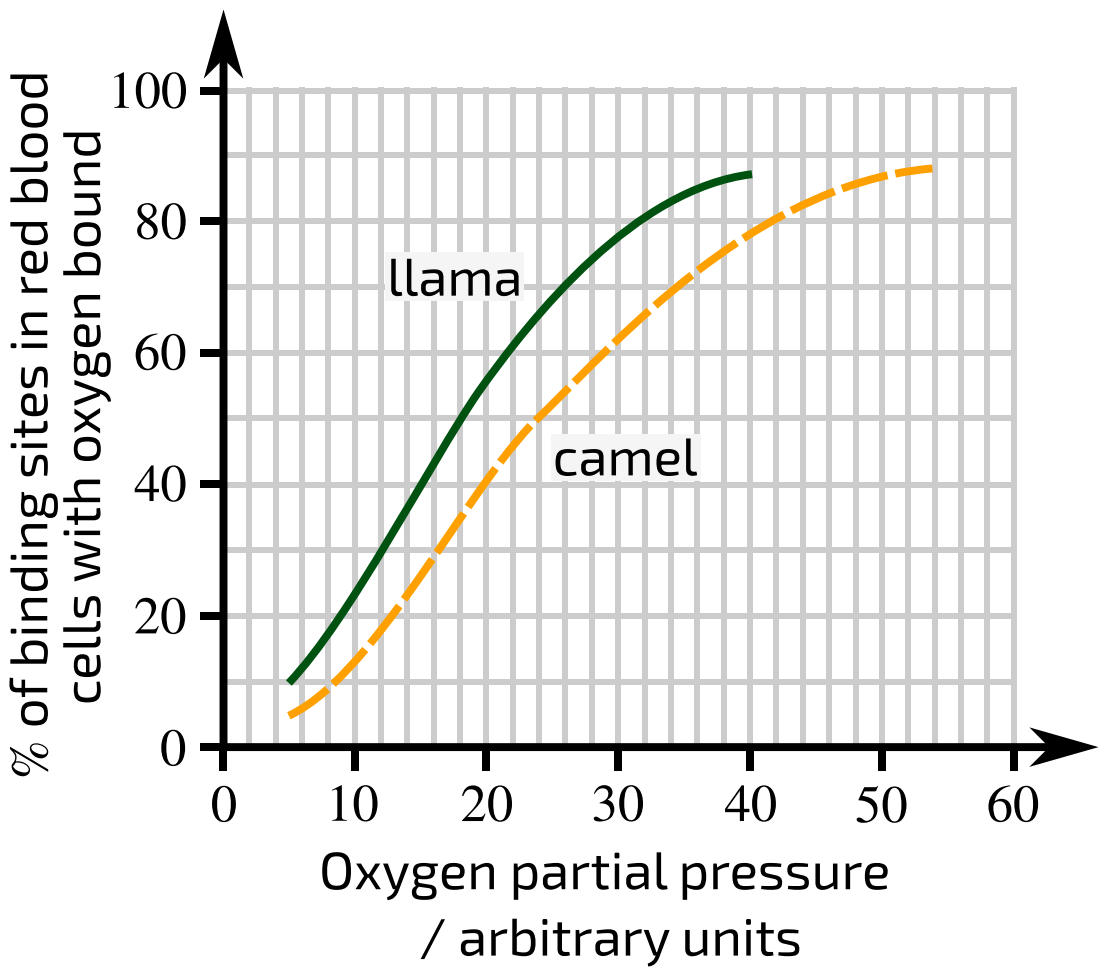


Figure 1: Oxygen dissociation curves of llama haemoglobin and camel haemoglobin.

Part A Saturation points

At what oxygen partial pressure will llama red blood cells be 50% saturated?

At what oxygen partial pressure will camel red blood cells be 50% saturated?

Part B Saturation statements

Which of the following statements are correct? Select all that apply.

- [ ] The different oxygen binding properties evolved because of mutations caused by different oxygen partial pressures.
- [ ] The different oxygen binding properties in llamas may have evolved because the **low** oxygen partial pressures at high altitudes acted as a selective pressure.
- [ ] The different oxygen binding properties in llamas may have evolved because the **high** oxygen partial pressures at high altitudes acted as a selective pressure.
- [ ] 50% oxygen saturation of llama red blood cells occurs at $\frac{3}{4}$ of the oxygen partial pressure required for 50% oxygen saturation of camel red blood cells.
- [ ] For oxygen partial pressures between 5 and 40 arbitrary units, the oxygen saturation of camel red blood cells is higher than that of llama red blood cells.
- [ ] To reach the same levels of oxygen saturation, the oxygen partial pressure must be higher for camel red blood cells than for llama red blood cells.

Part C Pros and cons

The sigmoid (S shape) nature of haemoglobin oxygen dissociation curves means that within intermediate oxygen partial pressures, haemoglobin is very sensitive to changes in oxygen partial pressure and will work efficiently (i.e. it will easily release oxygen when it is in tissues with a low oxygen partial pressure, and will easily absorb oxygen when it is in tissues with a high oxygen partial pressure). However, at extreme partial pressures (very high or very low), it does not work efficiently.

Which of the following statements are correct? Select all that apply.

- [ ] In a **high** altitude environment, a **camel's** red blood cells would be **less efficient** at absorbing and releasing oxygen than a llama's red blood cells.
- [ ] In a **high** altitude environment, a **llama's** red blood cells would be **less efficient** at absorbing and releasing oxygen than a camel's red blood cells.
- [ ] In a **low** altitude environment, a **camel's** red blood cells would be **less efficient** at absorbing and releasing oxygen than a llama's red blood cells.
- [ ] In a **low** altitude environment, a **llama's** red blood cells would be **less efficient** at absorbing and releasing oxygen than a camel's red blood cells.

Adapted with permission from NSAA 2021 Section 2 Q49

Gameboard:

STEM SMART Biology Week 20 - Circulatory Systems 2

Blood Vessel Structure and Function

A Level

Blood vessels are the structures through which blood travels around the body. There are different types of blood vessels, each with a different structure and function.

Three types of blood vessels are shown below in **Figure 1**.

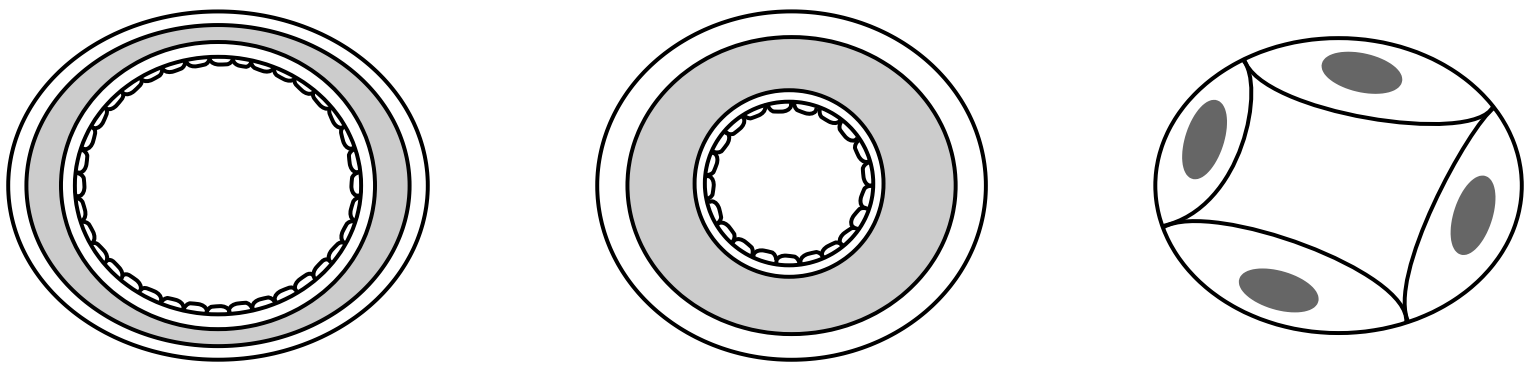


Figure 1: Cross sections of three types of blood vessels, not drawn to the same scale.

Part A Blood vessel functions

Based on **Figure 1**, match the blood vessel and its function to each letter in the table below.

	Vessel	Function
X		
Y		
Z		

Items:

artery **capillary** **vein**

the site of exchange of gases, nutrients and waste products between the blood and other tissues of the body

transports blood from the heart to the other organs and tissues of the body

transports blood from the other organs and tissues of the body to the heart

Part B Arteries

Which of the following statements about **arteries** are correct? Select all that apply.

- [ ] Arteries have a relatively thick wall (compared to veins), which helps them withstand the high pressure as blood is pumped out of the heart.
- [ ] In smaller arteries and arterioles, the smooth muscle layer can contract to **increase** blood flow to the target tissue.
- [ ] In smaller arteries and arterioles, the smooth muscle layer can contract to **reduce** blood flow to the target tissue.
- [ ] In mammals, all arteries carry oxygenated (oxygen-rich) blood to their target organs.
- [ ] Arteries contain valves to prevent backflow.

Part C Veins

Which of the following statements about **veins** are correct? Select all that apply.

- [ ] Veins have a relatively wide lumen compared to arteries.
- [ ] In smaller veins and venules, the smooth muscle layer can contract to **reduce** blood flow to the target tissue.
- [ ] Veins do not contain an elastic layer or a smooth muscle layer.
- [ ] Veins contain valves to prevent backflow.

Part D Capillaries

Which of the following statements about **capillaries** are correct? Select all that apply.

- [ ] The wall of a capillary consists solely of a single layer of endothelial cells. There is no smooth muscle layer and no elastic layer.
- [ ] Capillaries are the only blood vessels that contain an endothelial layer.
- [ ] Red blood cells leave the capillary and enter the surrounding tissue to deliver oxygen to the cells.
- [ ] Water and other small molecules can move between the capillary and the surrounding tissue.

Part E Blood flow

Drag the items below into the correct order on the right to show how blood moves in and out of a tissue/organ.

Available items

- venule
- capillary
- vein
- artery
- arteriole

Created for isaacphysics.org by Lewis Thomson

Gameboard:
STEM SMART Biology Week 20 - Circulatory Systems 2

Capillary Pressures and Interstitial Fluid

A Level

C C C

Figure 1 below shows a capillary (**c**) surrounded by interstitial fluid (**i**). Hydrostatic pressures (**P**) and oncotic pressures (π) are shown. All values are given in mmHg.

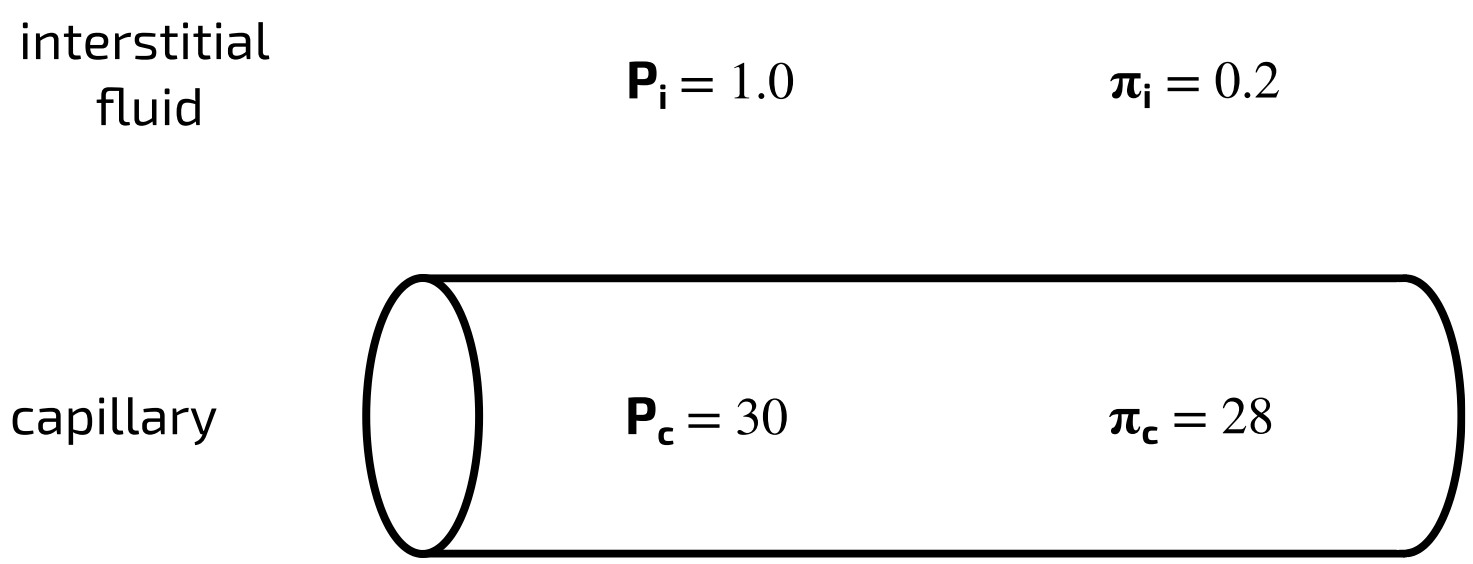


Figure 1: Hydrostatic and oncotic pressures in a blood capillary and in the surrounding interstitial fluid.

The net movement of fluid between the capillary and interstitial tissue is determined by the net driving force (NDF):

$$\mathrm{NDF} = (\mathbf{P_c} - \mathbf{P_i}) - (\boldsymbol{\pi}_\mathbf{c} - \boldsymbol{\pi}_\mathbf{i})$$

When NDF > 0, fluid leaves the capillary.

When NDF < 0, fluid enters the capillary.

Part A Calculate the NDF

Calculate the net driving force (NDF) for the capillary shown in **Figure 1**.

Which of the following processes will occur? Select all that apply.

- [ ] fluid will enter the capillary
- [ ] fluid will leave the capillary
- [ ] interstitial fluid will be produced
- [ ] interstitial fluid will be lost

Part B Pressure equilibrium

Assuming the other values remain the same (as in **Figure 1**), what value for the capillary hydrostatic pressure would result in no net fluid movement between the capillary and the interstitial fluid?

Adapted with permission from OCR A Level Biology B, June 2017, Fundamentals of Biology, Question 18

Gameboard:

STEM SMART Biology Week 20 - Circulatory Systems 2

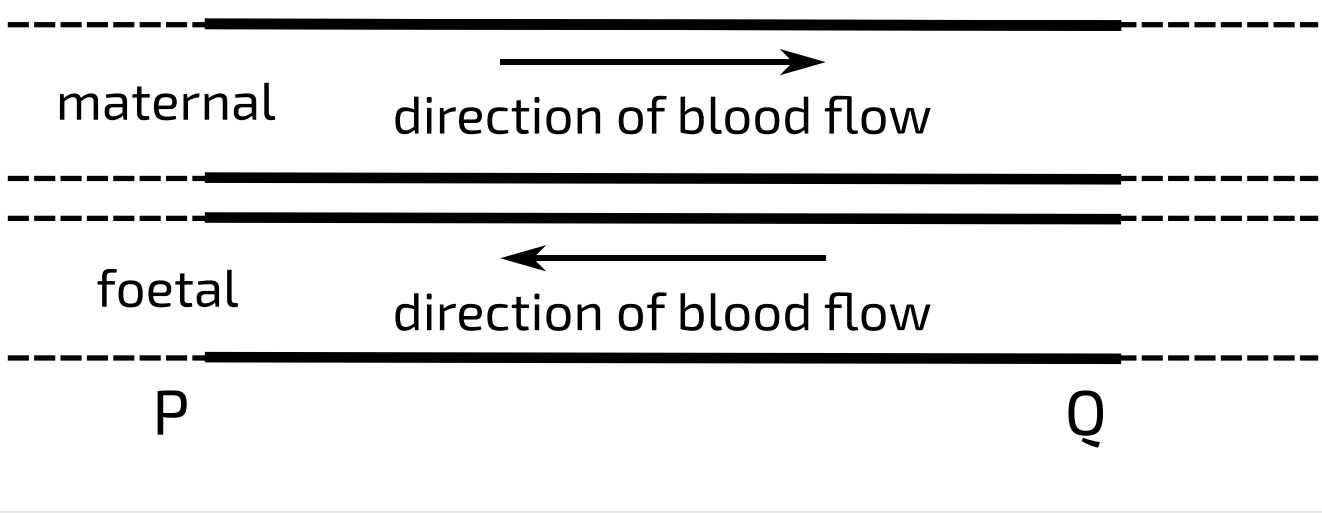
Placental Circulation

A Level

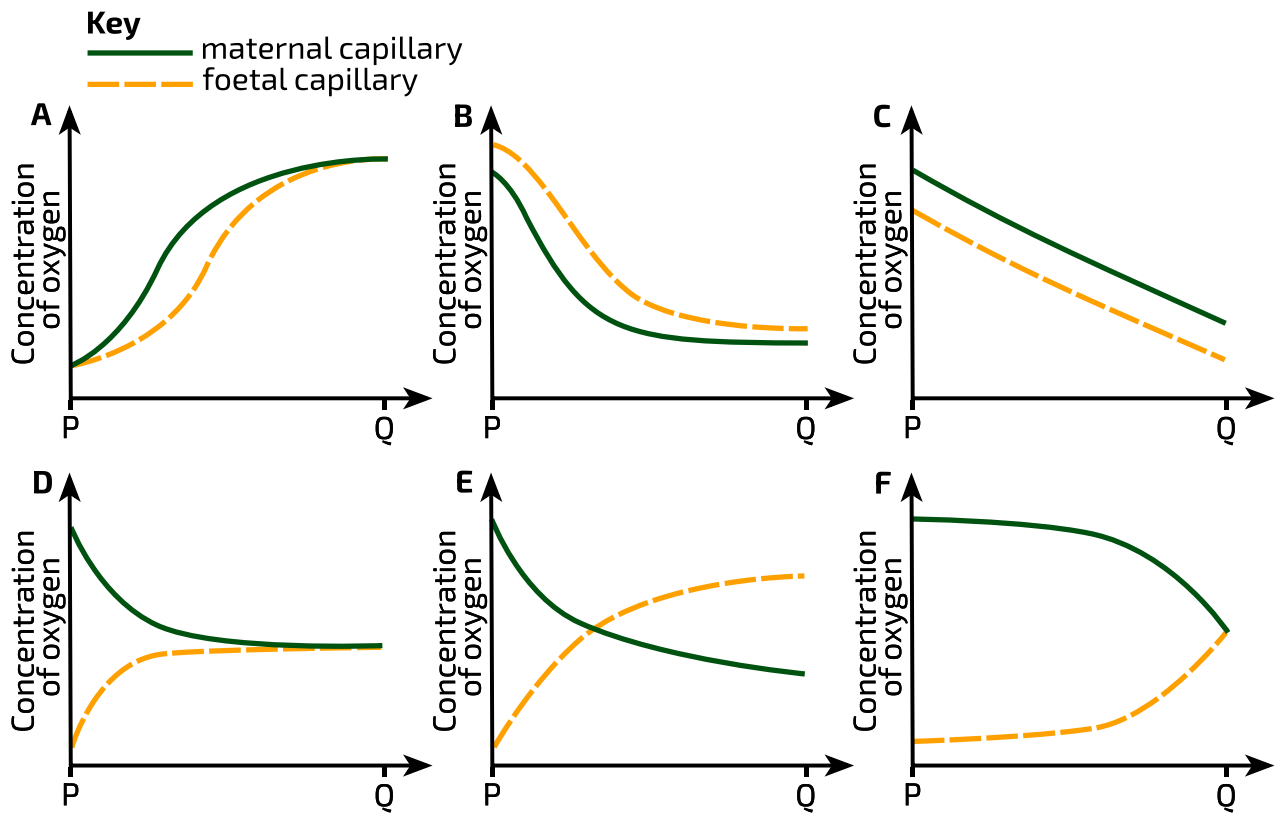
C C C

The placenta is an organ that develops during pregnancy. One function of the placenta is to allow the exchange of gases between the mother and the developing foetus.

The diagram below represents the maternal and foetal blood flow between **P** and **Q** in a section of the placenta of a healthy small mammal. The concentration of oxygen in both maternal and foetal blood was measured at regular distances along this section.



Part A Which graph?



Which graph illustrates the concentration of oxygen in both maternal and foetal blood between P and Q?

- A
- B
- C
- D
- E
- F

Which graph would illustrate the concentration of oxygen in both maternal and foetal blood if the two flowed in the same direction (from P to Q)?

- A
- B
- C
- D
- E
- F

Part B Opposite directions

What is the name of this type of system, in which two substances flow in opposite directions to maximise efficiency of exchange?

What other animals use this type of system to maximise blood oxygen uptake?

Part C Circulation statements

How does this type of system benefit the foetus?

Select all that apply.

- [ ] Because the two bloodstreams are flowing in opposite directions, they slow each other down when they mix, which allows more time for oxygen to diffuse from the maternal blood into the foetal blood.
- [ ] Because the two bloodstreams are flowing in opposite directions, they slow each other down when they mix, which allows more time for carbon dioxide to diffuse from the foetal blood into the maternal blood.
- [ ] A diffusion gradient of carbon dioxide is maintained over a longer distance, which means that the foetus gets rid of more carbon dioxide than if the foetal blood flowed in the same direction as the maternal blood.
- [ ] Diffusion of carbon dioxide would not occur if foetal blood flowed in the same direction as maternal blood. This system ensures that diffusion of carbon dioxide from the foetus to the mother does occur.
- [ ] Diffusion of oxygen would not occur if foetal blood flowed in the same direction as maternal blood. This system ensures that diffusion of oxygen from the mother to the foetus does occur.
- [ ] More red blood cells are able to cross from foetal blood into maternal blood.
- [ ] More red blood cells are able to cross from maternal blood into foetal blood.
- [ ] A diffusion gradient of oxygen is maintained over a longer distance, which means that the foetus receives more oxygen than if the foetal blood flowed in the same direction as the maternal blood.

Adapted with permission from NSAA 2020 Section 1 Q76