CAIE Biology A-level

Topic 8: Transport in mammals

Notes

Circulatory systems can either be open, for instance in insects, or closed, like in fish and mammals where the blood is confined to blood vessels only.

Closed circulatory systems come in two forms;

- a single form which consists of a heart with two chambers, meaning the blood passes through the heart once for every circuit of the body.
- a double form where the heart has four chambers and blood passes through the heart twice for every circuit of the body. Mammals have a closed double circulatory system which consists of the heart, blood vessels and blood.

Important structures and their functions

Blood vessel	Direction of blood flow	Structure of blood vessel	Valves
Arteries	Away from the heart, to the rest of the body	- Thick muscular layer to withstand high blood pressure - Thick elastic tissue for stretch and recoil to smooth blood flow and maintain high blood pressure - Lined with smooth endothelium to reduce friction and ease flow - Narrow lumen	No
Arterioles	Away from the heart, feeds into capillaries	- Thinner muscular walls compared to arteries	No
Capillaries	Between arterioles and venules	- One cell thick for fast exchange of substances by diffusion - Narrow lumen	No
Venules	Towards the heart, branch into veins	- Thinner and smaller than veins, but larger than capillaries	Yes
Veins	Towards the heart	- Thin muscle layer as low blood pressure - Thin elastic layer as no stretch / recoil needed for blood pressure - Wide lumen	Yes

Tissue Fluid

Tissue fluid is a liquid containing dissolved oxygen and nutrients which serves as a means of supplying the tissues with the essential solutes in exchange for waste products such as carbon dioxide. Therefore, it enables exchange of substances between blood and cells.

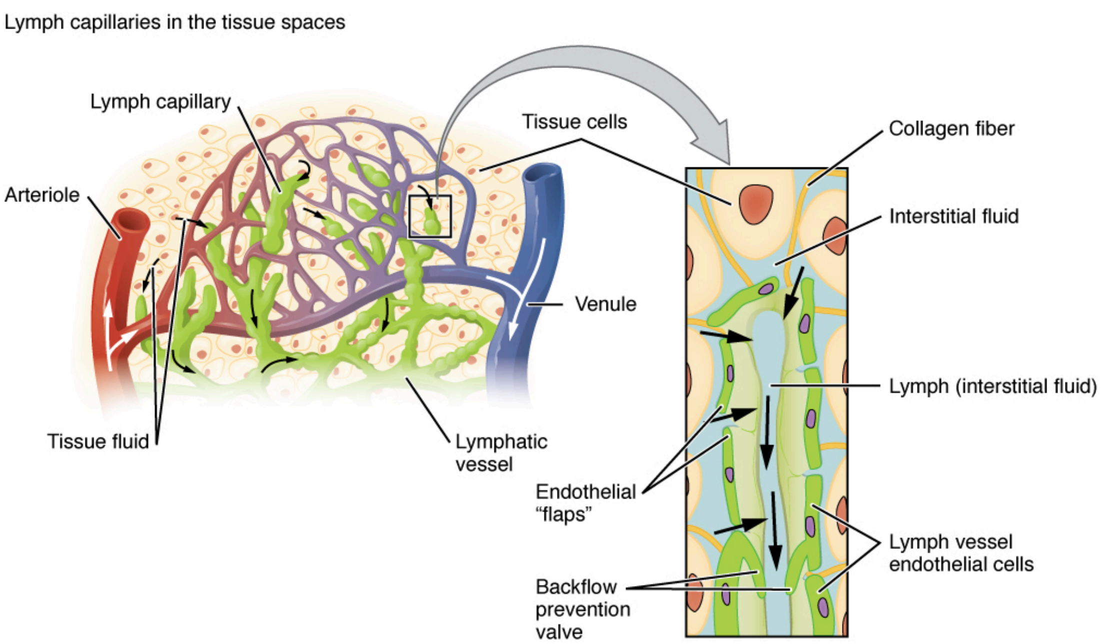
High hydrostatic pressure at the arterial end of capillaries is created as blood is pumped from arteries into arterioles and then capillaries. This pressure forces blood fluid out of the capillaries to form tissue fluid. Only substances small enough to escape through gaps in the capillary wall are components of the tissue fluid – this includes dissolved nutrients and oxygen.

Some tissue fluid returns to the capillaries due to the water potential gradient between blood and tissue fluid. As both tissue fluid and blood contain solutes, they have a negative water potential. However, the water potential of tissue fluid is less negative than that of blood, so water moves back into capillaries by osmosis.

The remaining tissue fluid which is not pushed back into the capillaries is carried back via the lymphatic system. The lymphatic system contains lymph fluid, similar in content to tissue fluid. However, lymph fluid contains less oxygen and nutrients than tissue fluid and transports waste products, lipids, and lymphocytes. The lymph system also contains lymph nodes which filter out bacteria and foreign material from the fluid with the help of lymphocytes which destroy the invaders as part of the immune system defences.

Water is the main component of tissue fluid (and blood). The properties of water allow it to be a good transport medium in mammals.

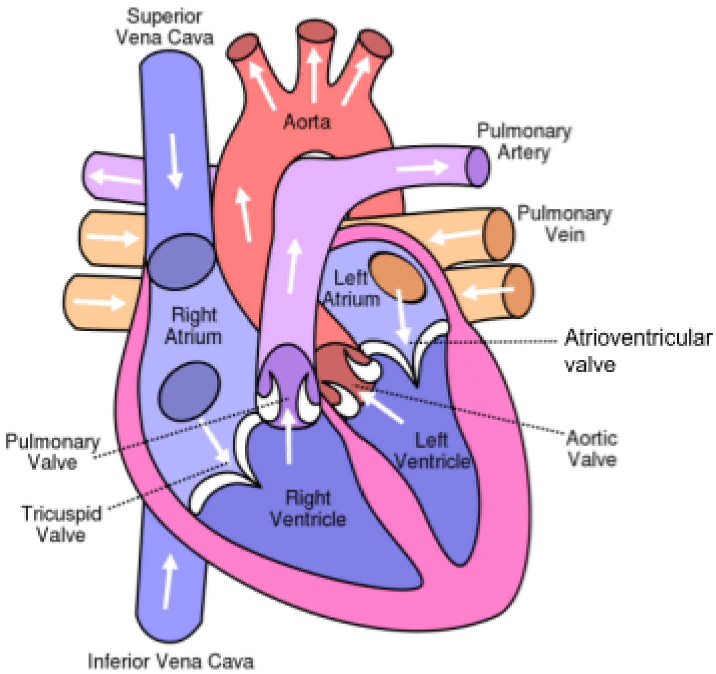
- It can act as a solvent (so it can carry solutes) and has a high specific heat capacity, making it an efficient transport medium.



Mammalian heart and cardiac cycle

The heart's main blood vessels:

1. **Aorta** - connects to left ventricle and carries oxygenated blood to the rest of the body
2. **Pulmonary artery** - connects to the right ventricle and carries deoxygenated blood to the lungs where it is oxygenated.
3. **Pulmonary vein** - connects to the left atrium and carries oxygenated blood from the lungs to the heart.
4. **Vena cava** - connects to right atrium and brings deoxygenated blood back from the tissues



The ventricle pumps blood at high pressure. The ventricle wall is a lot **thicker** than the atria so that it can withstand the high pressure. The left ventricle wall is **thicker** than the right ventricle wall because it pumps blood from the heart to the **rest of the body** - it is important for the blood to be pumped at a high pressure to ensure it reaches all parts of the body.

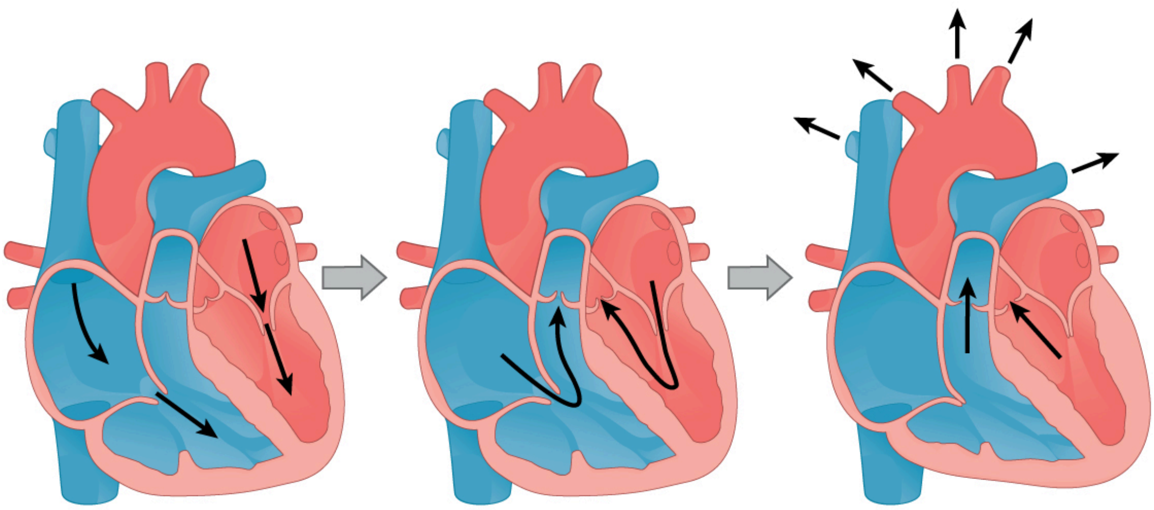
Due to the heart's ability to initiate its own contraction, it is referred to as **myogenic**. In the wall of the right atrium, there is a region of specialised fibres called the **sinoatrial node** which is the **pacemaker** of the heart. It initiates a wave of electrical stimulation which causes the atria to contract at roughly the same time. The ventricles do not start contracting until the atria have finished due to the presence of tissue at the base of the atria which is unable to conduct the wave of excitation. The electrical wave eventually reaches the **atrioventricular node** located between the two atria, which passes on the excitation to the ventricles, down the **bundle of His to the apex** of the heart. The bundle of His branches into the **Purkyne fibres** which carry the wave upwards. This causes the ventricles to contract, forcing blood to be pumped out.

There are 3 stages of the cardiac cycle:

1) **Cardiac diastole** – during diastole, both the atria and ventricles **relax**. The heart's **elastic recoil** decreases pressure inside the chambers, allowing blood to flow in, while the **semilunar valves** in the aorta and pulmonary arteries **close** to stop blood from flowing **backward**.

2) **Atrial systole** – during atrial systole, the **atria contract** forcing the atrioventricular **valves to open** and blood to flow into the ventricles.

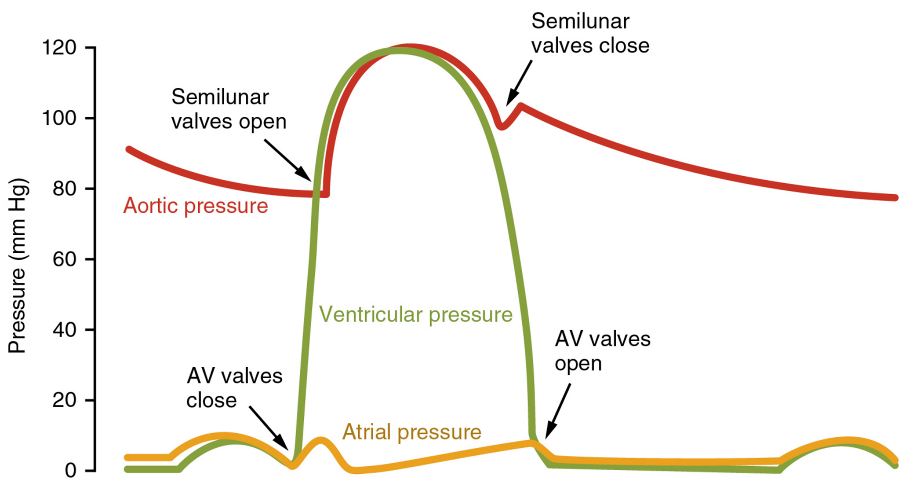
3) **Ventricular systole** – during ventricular systole, **contraction of the ventricles** increases pressure inside them, causing the **atrioventricular valves to close** and the **semilunar valves to open,** so blood is simultaneously forced out of the left ventricle into the **aorta** and out of the right ventricle into the **pulmonary artery.**



(a) Cardiac diastole: all chambers are relaxed, and blood flows into the heart.

(b) Atrial systole, ventricular diastole: atria contract, pushing blood into the ventricles.

(c) Atrial diastole, ventricular systole: after the atria relax, the ventricles contract, pushing blood out of the heart.

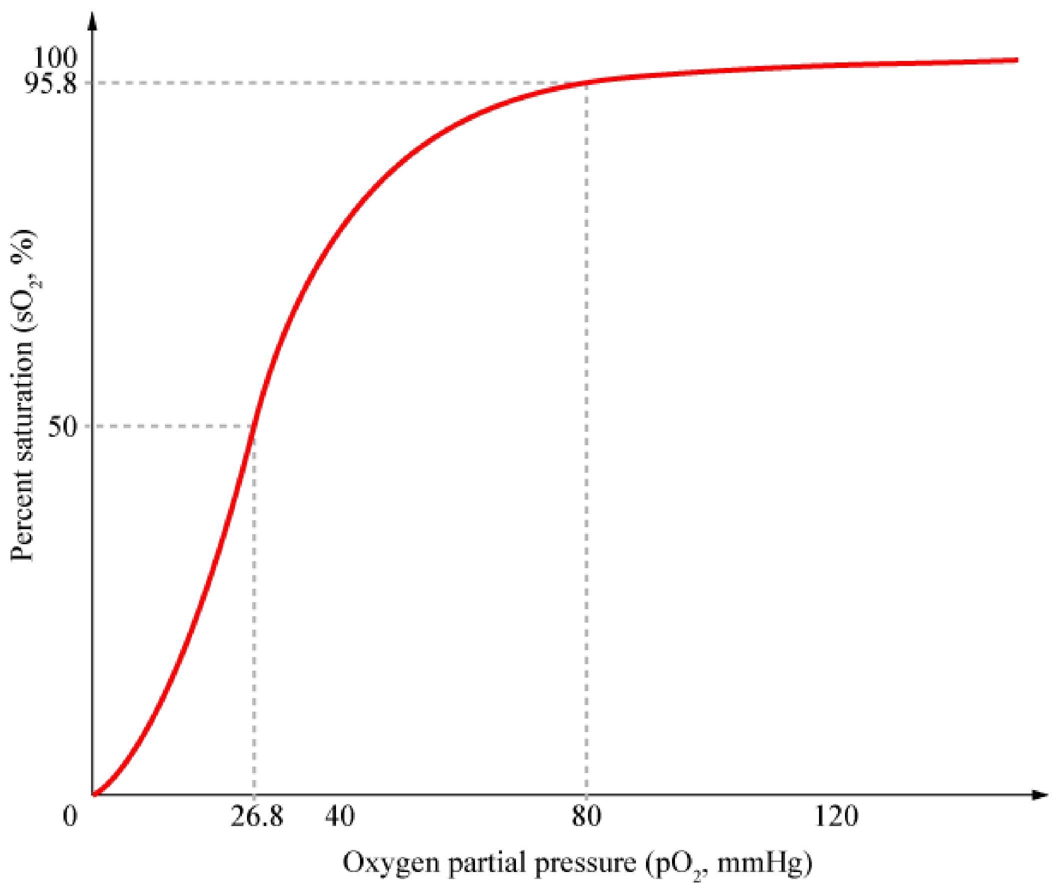


Haemoglobin

Haemoglobin is a **water-soluble globular protein consisting of four polypeptide chains (two alpha and two beta),** each with **a haem group.** The haem group **carries oxygen** in the blood as oxygen binds to the haem (Fe^{2+}) group and is released when required. Each haemoglobin molecule can carry **four** oxygen molecules.

The **affinity of oxygen for haemoglobin** varies depending on the **partial pressure of oxygen** which is a measure of **oxygen concentration**. The greater the concentration of dissolved oxygen, the higher the partial pressure of oxygen. As **partial pressure** increases, the affinity of haemoglobin for oxygen increases, so haemoglobin becomes highly saturated. This occurs in the lungs in the process known as loading. During respiration, oxygen is used up in respiring tissues. This decreases the partial pressure of oxygen, decreasing the affinity of haemoglobin for oxygen. As a result, oxygen is released in respiring tissues where it is needed. After the unloading process, the haemoglobin returns to the lungs where it binds to oxygen again.

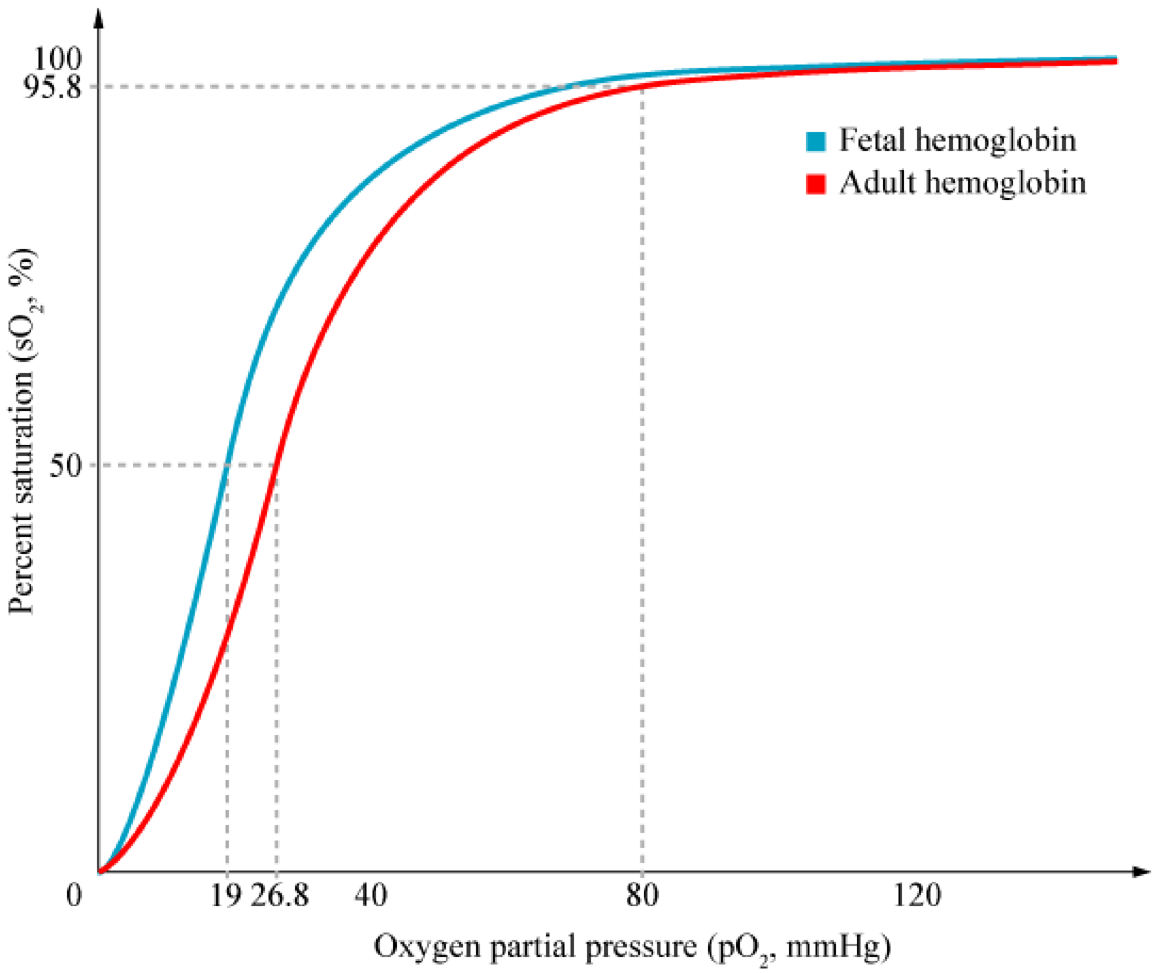
Dissociation curves illustrate the change in haemoglobin saturation as partial pressure changes. The saturation of haemoglobin is affected by its affinity for oxygen. When partial pressure is high, haemoglobin has a high affinity for oxygen and is therefore highly saturated, and vice versa.



Carbonic anhydrase is an enzyme found in the blood. Carbonic anhydrase catalyses the reversible reaction between carbon dioxide and water to form **carbonic acid**. This dissociates into **hydrogen ions** and **hydrogencarbonate ions.** The hydrogen ions bind to haemoglobin forming **haemoglobinic acid**, promoting oxygen release.

Saturation can also affect the affinity of haemoglobin. After the first oxygen molecule binds to a haem group in the haemoglobin, the affinity of haemoglobin for oxygen increases due to a change in shape, thus making it easier for the other oxygen molecules to bind to the rest of the haem groups.

Fetal haemoglobin has a different affinity for oxygen compared to **adult haemoglobin**, as it needs to be better at absorbing oxygen because by the time oxygen reaches the placenta, the oxygen saturation of the blood has decreased. Therefore, fetal haemoglobin must have a **higher affinity for oxygen** in order for the foetus to survive at low partial pressure.



The affinity of haemoglobin for oxygen is also affected by the **partial pressure of carbon dioxide**. Carbon dioxide is released by **respiring cells** as a waste product during respiration. In the presence of carbon dioxide, the affinity of haemoglobin for oxygen decreases, causing oxygen to be released, which is required in respiration. This is known as the **Bohr effect.**

At a **high altitude, red blood cell count increases**. This is because there are fewer oxygen molecules, thus the partial pressure of oxygen decreases. Consequently, more red blood cells are made to produce more haemoglobin for the oxygen to bind to.

Another process that takes place in the red blood cells is the **chloride shift**. This helps maintain the **cell's electrical balance**.

- When blood reaches the lung, the lung tissue has a relatively **low carbon dioxide concentration.**
- **Carbonic anhydrase** catalyses the reaction breaking down carbonic acid into water and carbon dioxide.
- **Hydrogencarbonate** diffuses into the red blood cells and reacts with the **hydrogen ions**. This forms carbonic acid.
- When carbonic acid is broken down by carbonic anhydrase, **free carbon dioxide is released**. This diffuses from the blood into the lungs.
- **Chloride ions** move from the **plasma into the red blood cells,** maintaining electrical balance.