Transport in Animals

- Explain the need for transport systems in multicellular animals in terms of size, level of activity and surface area: volume ratio.
- Explain the meaning of the terms *single circulatory system* and *double circulatory system*.
- Describe the external and internal structure of the mammalian heart.
- Explain the differences in the thickness of the walls of the different chambers of the heart in terms of their functions.
- Describe the cardiac cycle, with reference to the action of the valves in the heart.
- Describe how heart action is coordinated with reference to the sinoatrial node (SAN), the atrioventricular node (AVN) and the Purkyne tissue.
- Interpret and explain electrocardiogram (ECG) traces, with reference to normal and abnormal heart activity.

Transport Systems

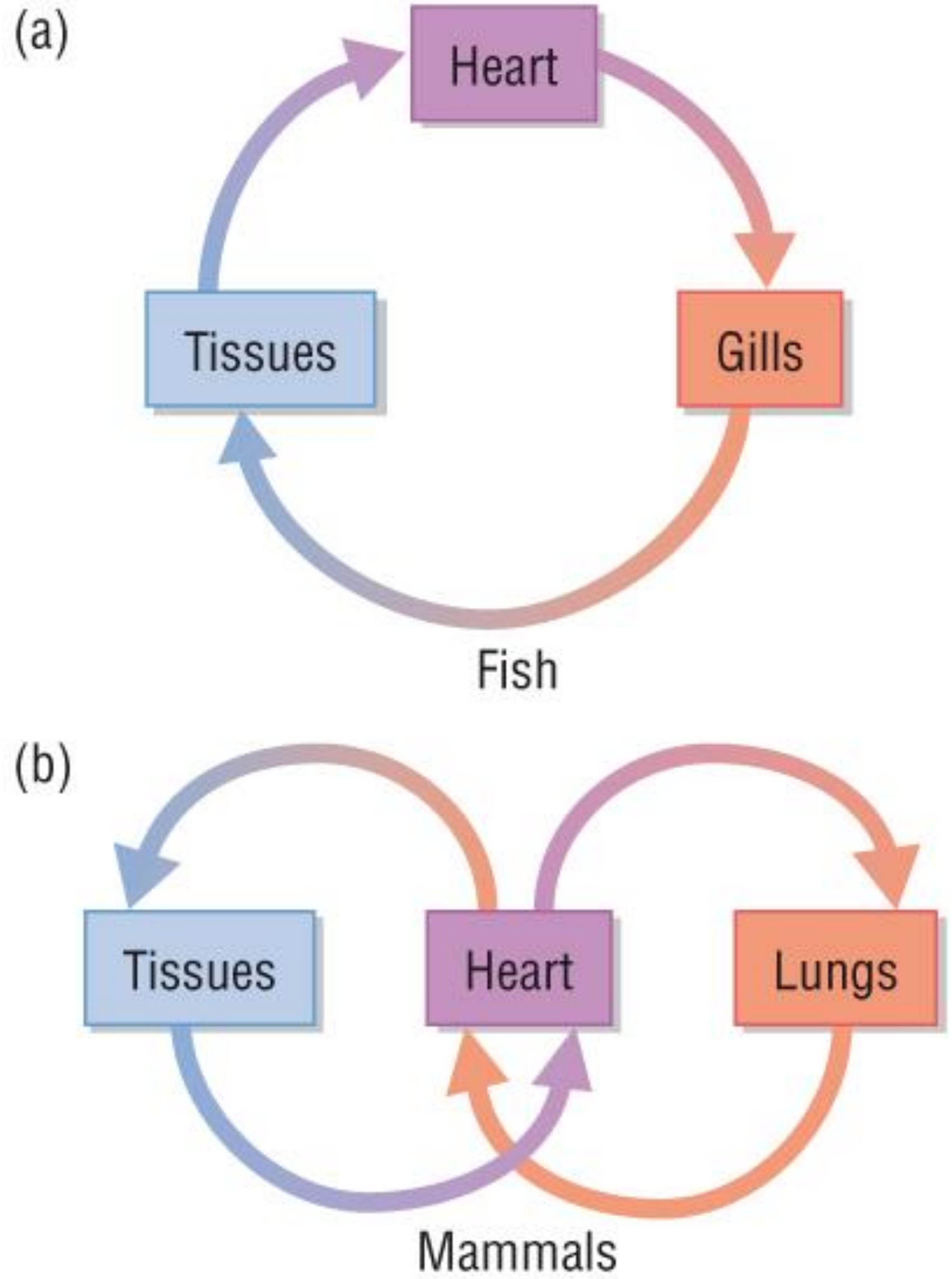
- Small organisms may not need a transport system.
  - Why?

A good transport system has…

- A fluid to carry substances around (blood).
- A pump to keep the fluid moving (heart).
- Exchange surfaces to provide nutrients & remove wastes (lungs, intestines, kidneys).

- Even better if it also has…
  - Tubes to carry the fluid (arteries, veins, capillaries).
  - Two circuits (what??????)

Single or Double Circulation

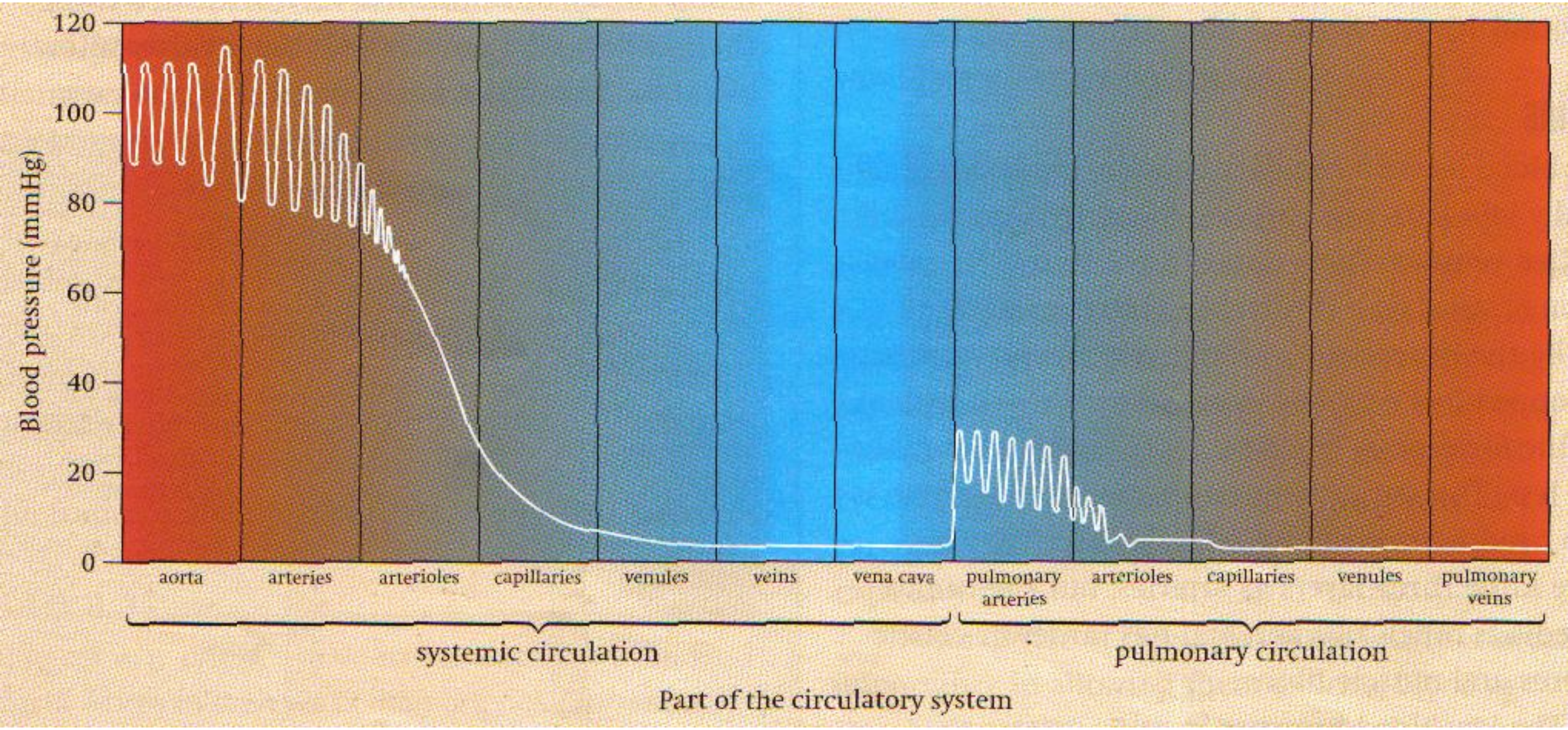


Advantages of Double Circulation

- Single:
  - BP is reduced as blood passes through gill capillaries.
    - Blood flows much slower through tissues.
    - Limits the rate of O_2/nutrient delivery.
- Double:
  - BP is increased again after blood flows through lung capillaries.
    - Blood flows much faster through tissues.
    - Rate of O_2/nutrient delivery is higher.

Double Circulation

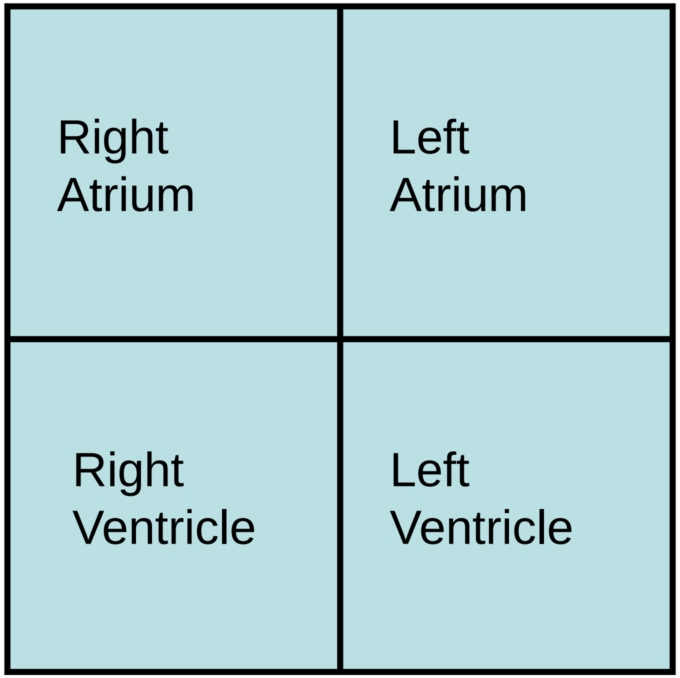
- Blood pressure is boosted to push it through both sets of capillaries (Pulmonary & Systemic).



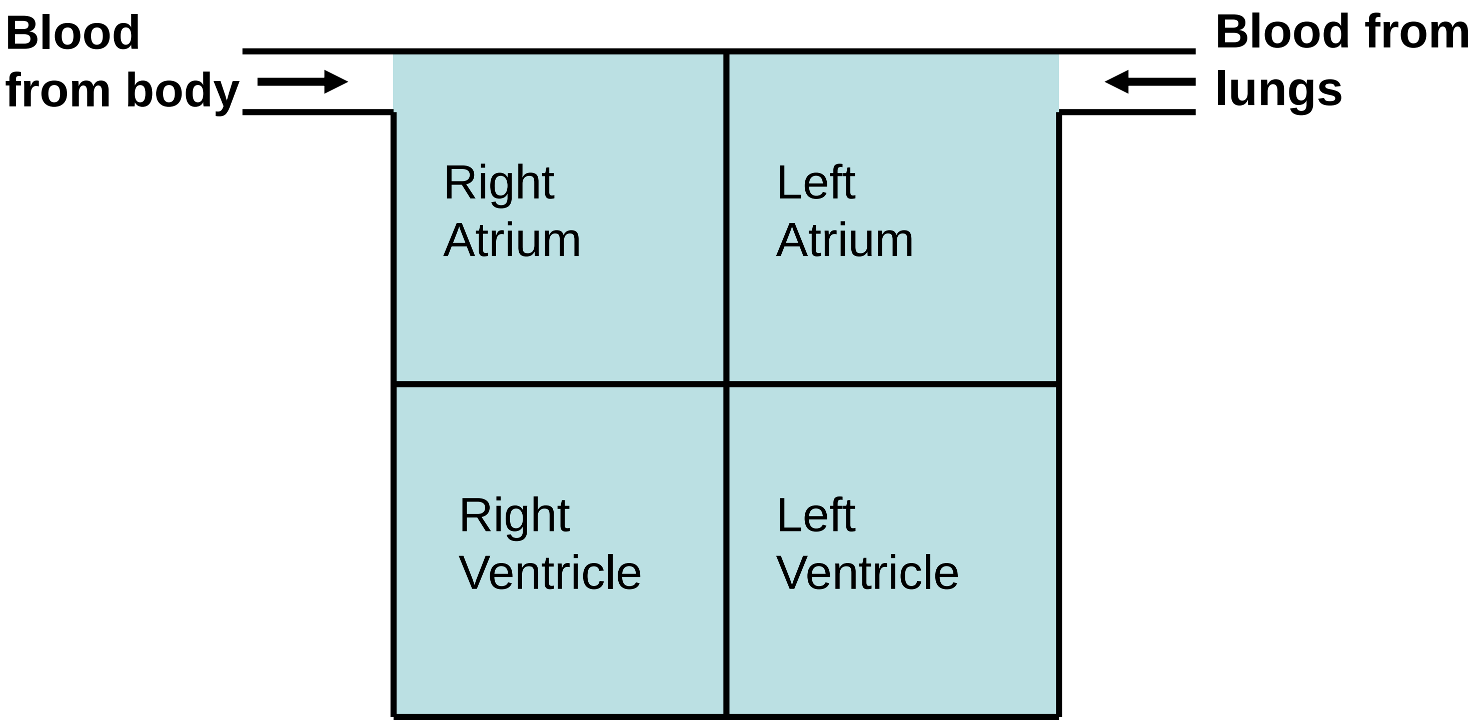
Heart Structure

- 2 separate pumps lying side by side.
  - Left side pumps oxygenated blood from the lungs.
  - Right side pumps deoxygenated blood from the body.
- Each pump has 2 chambers:
  - An Atrium.
  - A Ventricle.

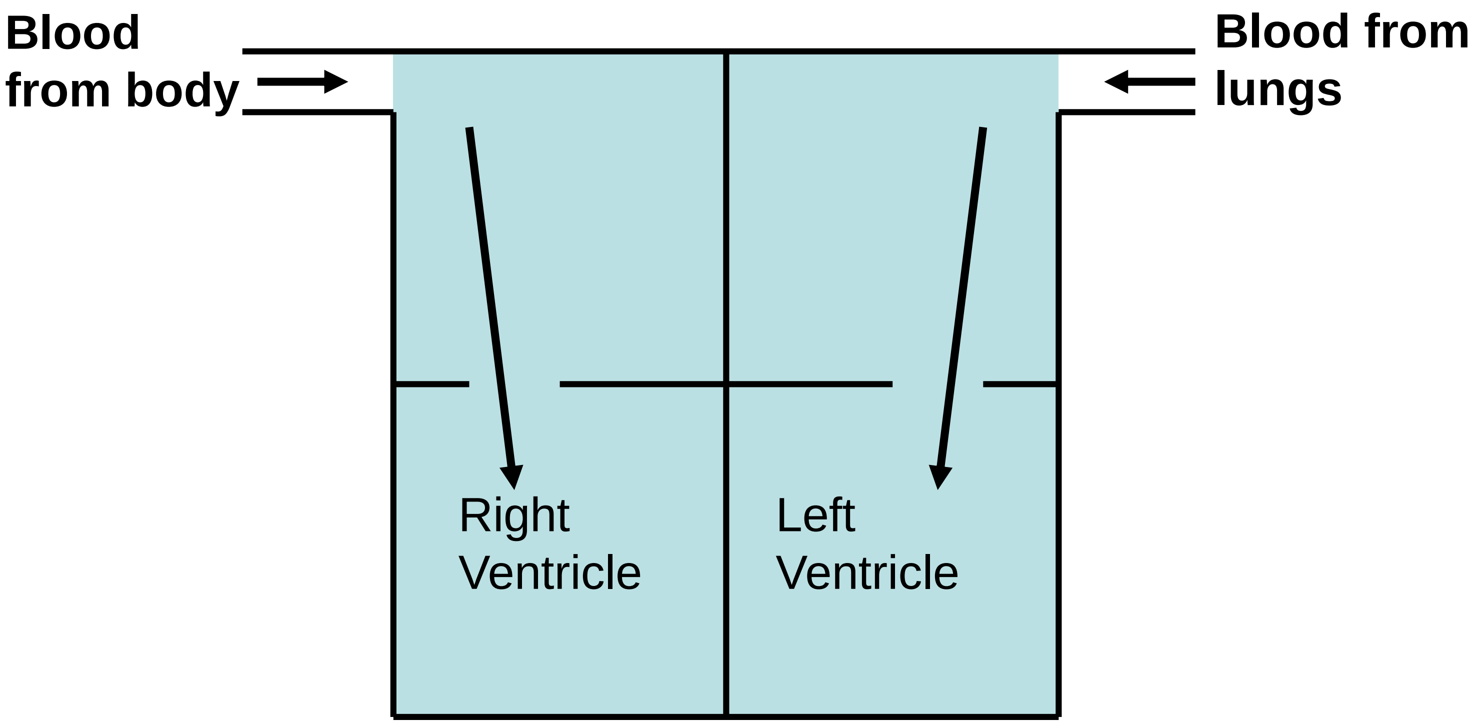
Basic Structure



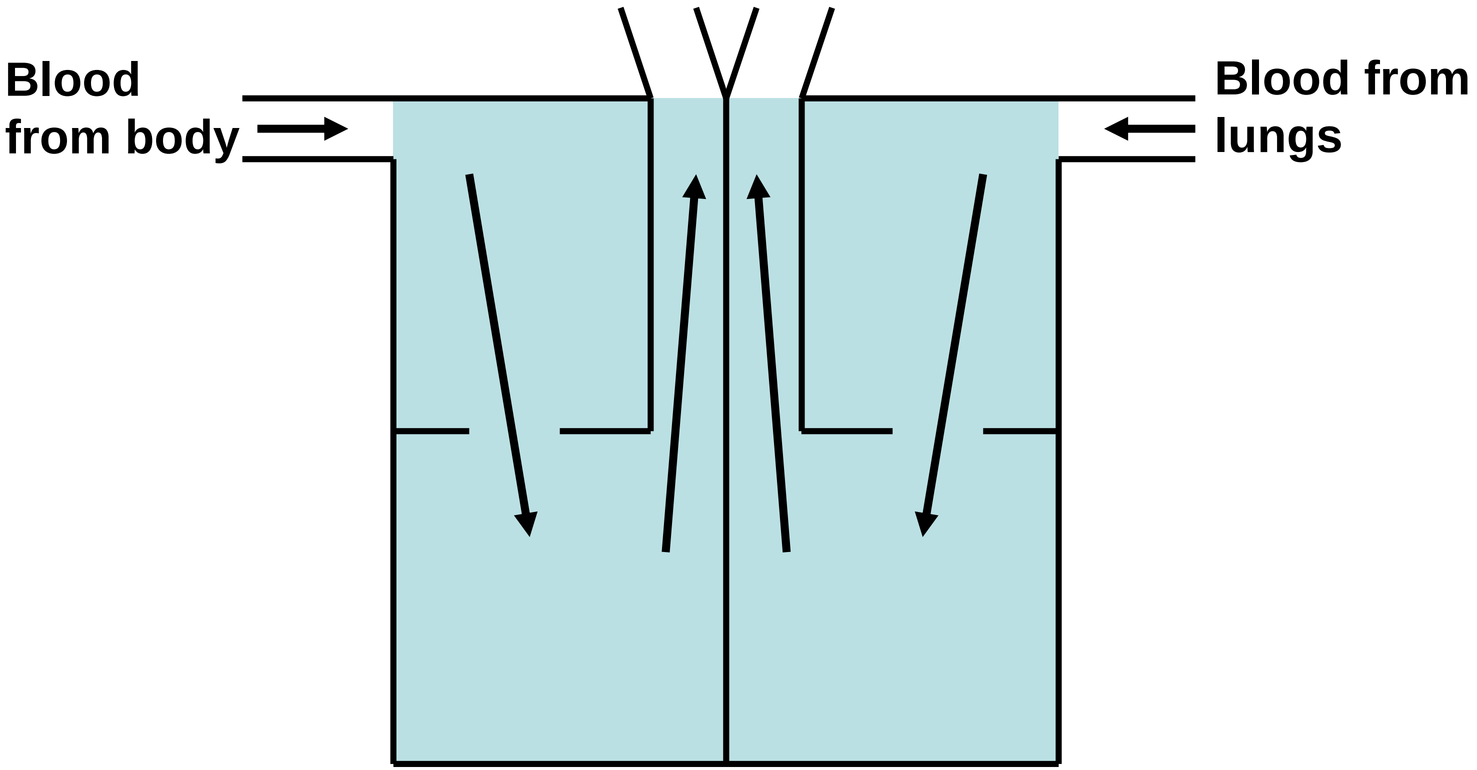
Basic Structure



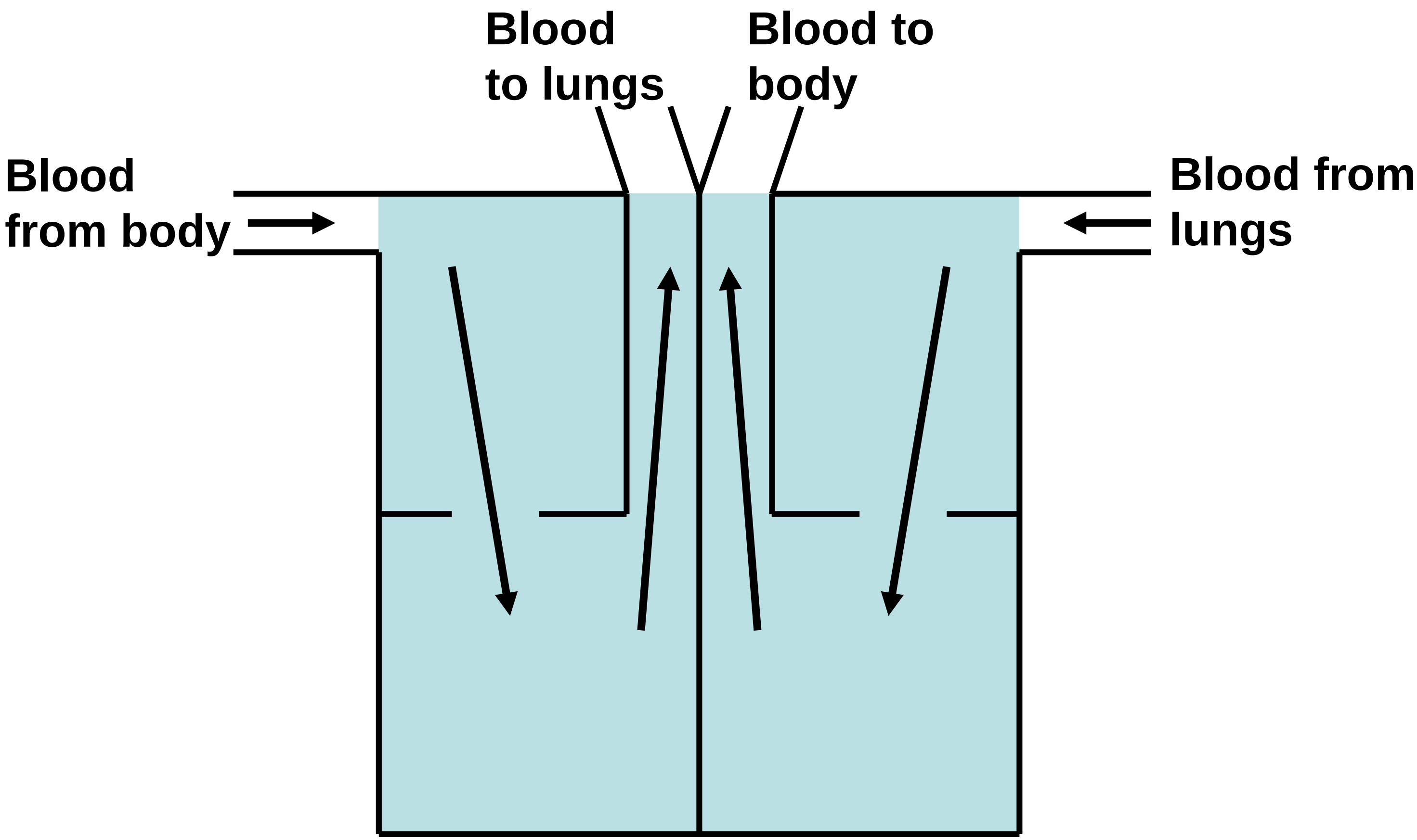
Basic Structure



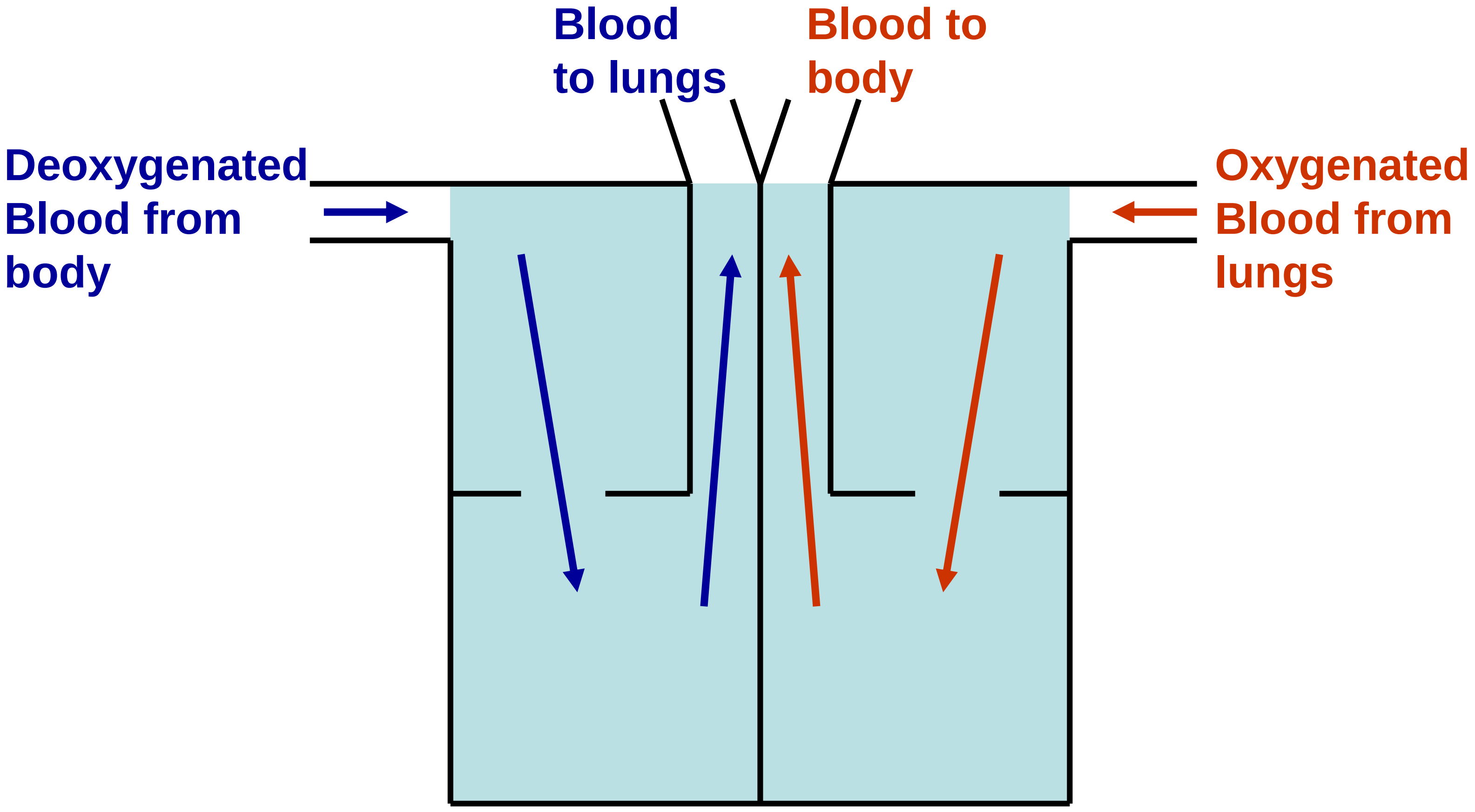
Basic Structure



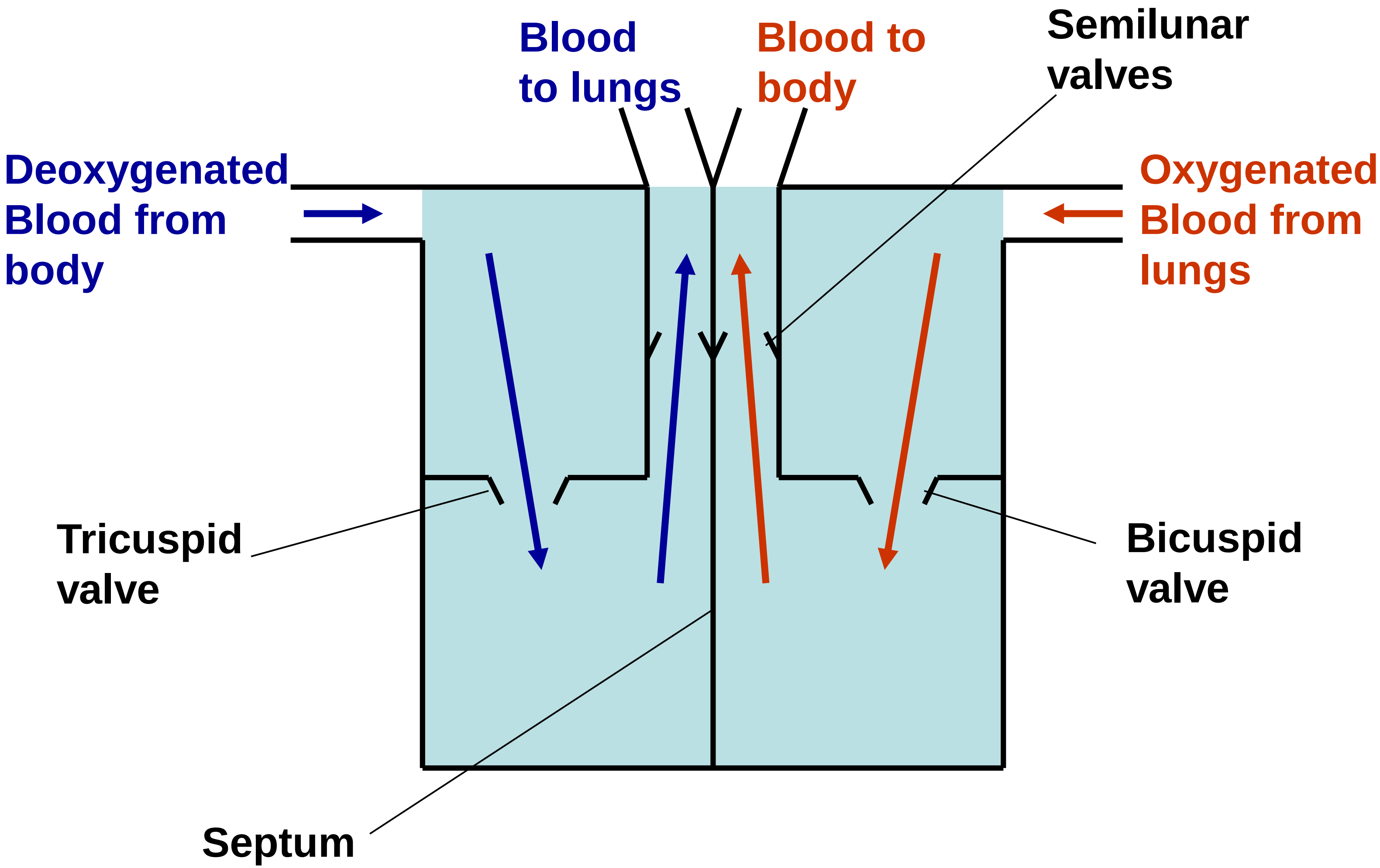
Basic Structure



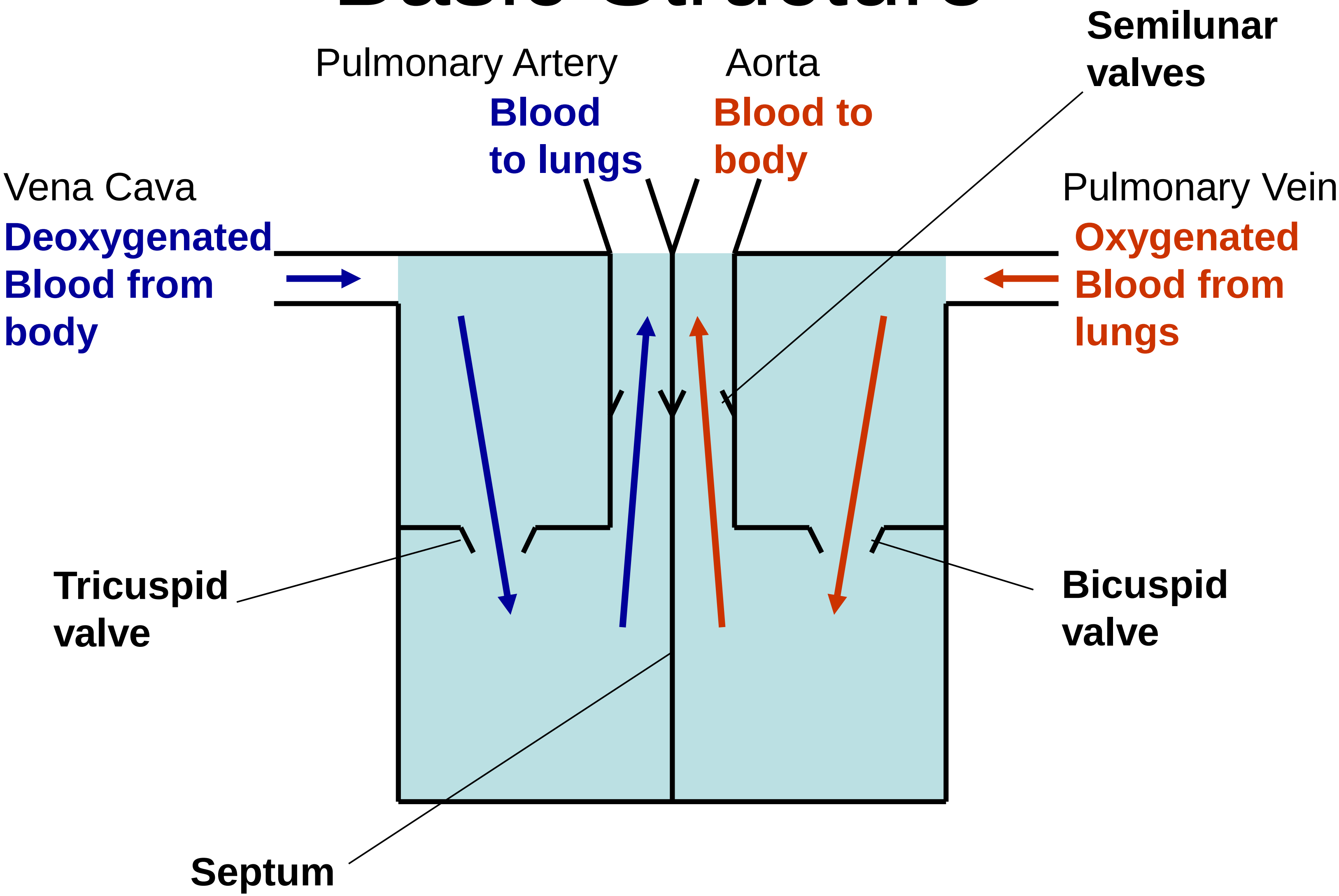
Basic Structure



Basic Structure

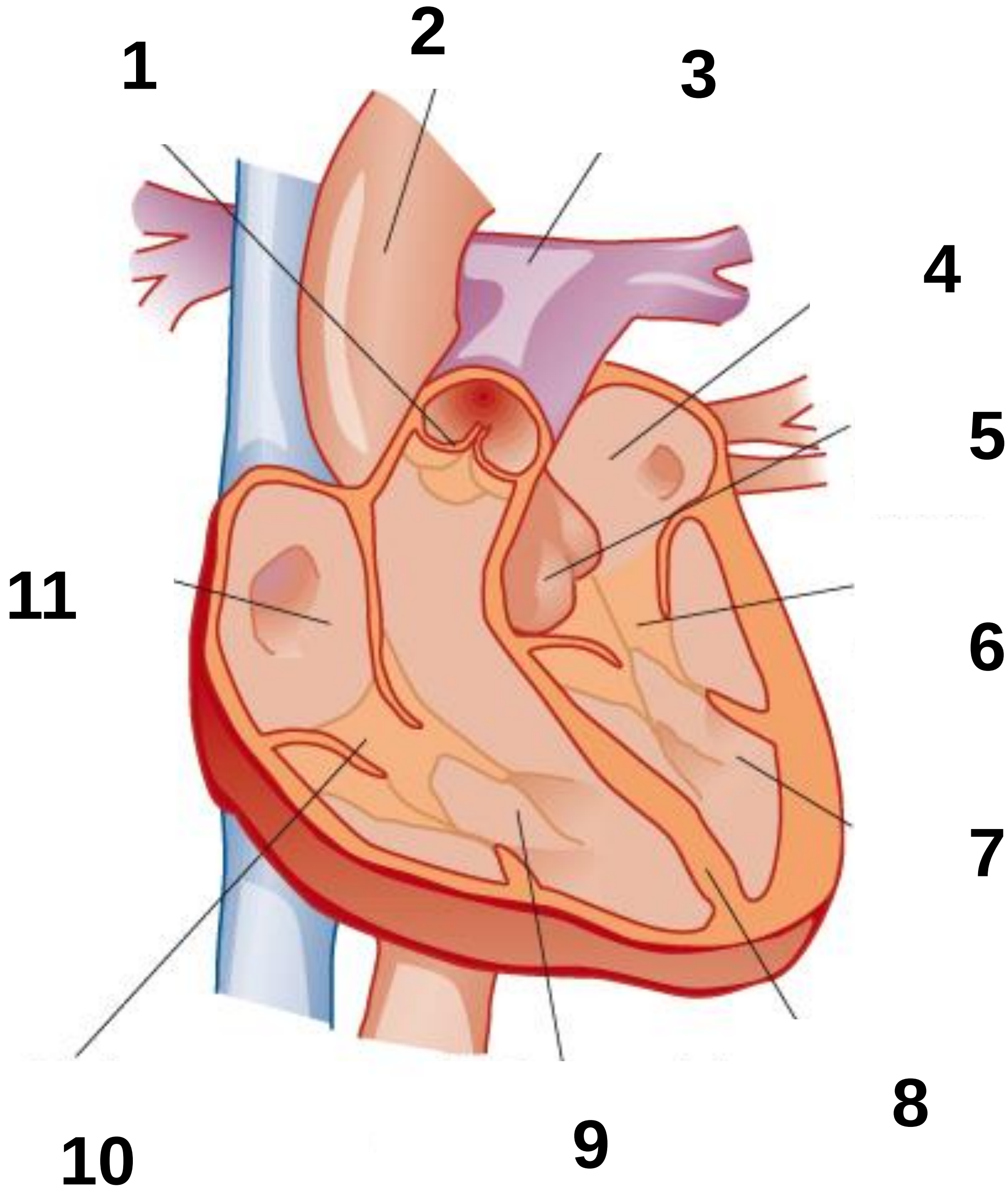


Basic Structure



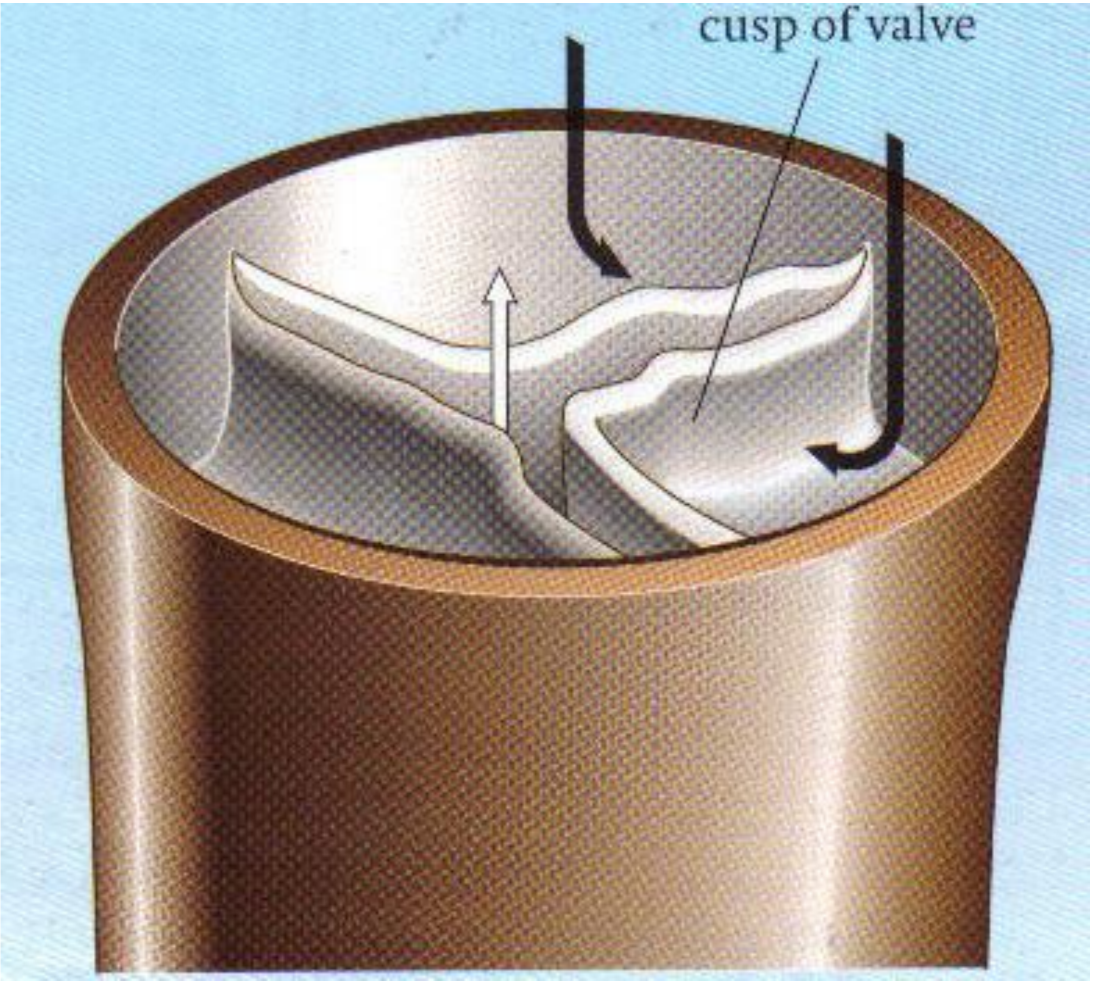
Heart Video

Click here


1
2
3
4
5
6
7
8
9
10
11

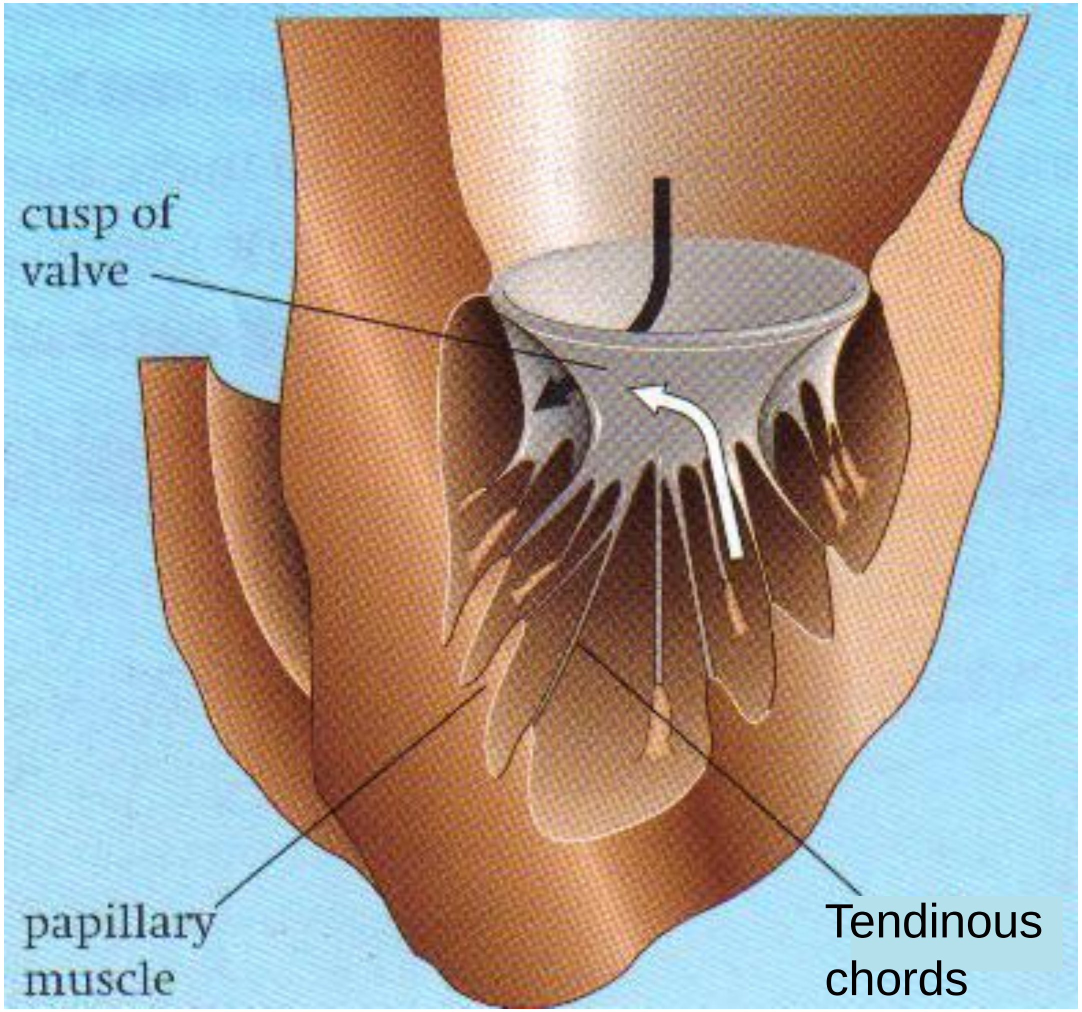
Heart Valves

- Semilunar valves stop blood flowing back into ventricles.



Heart Valves

- Atrioventricular valves (tricuspid & bicuspid) stop blood flowing back into atria.



What is a Coronary?

- The heart muscle uses a lot of oxygen for its own respiration.
- This is supplied by blood vessels called coronary arteries.
- Coronary arteries branch off from the aorta.
- A blockage in these arteries will deprive the heart of oxygen and lead to a heart attack (myocardial infarction).

What Does It Look Like?

- Dissect a heart to find:
  - Coronary Arteries.
  - Right & Left Atria.
  - Right & Left Ventricles.
  - Right & Left Atrioventricular valves.
  - Tendinous chords
  - Semi-lunar valves.
  - Difference in ventricle wall thickness.
  - Septum

How Does Aerobic Exercise Help?

- Increases the amount of cardiac muscle in the heart.
  - So it can pump more blood with each beat.
  - So it can pump blood with greater force.
- This will increase the maximum cardiac output (heart rate x stroke volume).
- This will decrease the resting heart rate.

Mini Test

The mammalian heart is made up of **[1]** muscle & is covered by a tough membrane called the **[2].** It contains four chambers: a pair of thin walled ones called **[3]** & a pair of thick muscular ones called **[4].** Between the chambers on the left side are the **[5]** valves, those on the right side are called **[6]** valves. These valves are prevented from turning inside out by **[7]. [8]** blood from the lungs enters the heart via the **[9]** & into the chamber called **[10]. [11]** blood from the body enters the heart via the **[12]** & into the chamber called **[13].** Oxygen is supplied to the heart muscle itself via the **[14]** that branch off from the **[15].** A blockage in these vessels can lead to a **[16].**

Mini Test Answers

1 Cardiac

2 Pericardium

3 Atria

4 Ventricles

5 Bicuspid

6 Tricuspid

7 Tendinous Chords

8 Oxygenated

9 Pulmonary Vein

10 Left Atrium

11 Deoxygenated

12 Vena Cava

13 Right Atrium

14 Coronary Arteries

15 Aorta

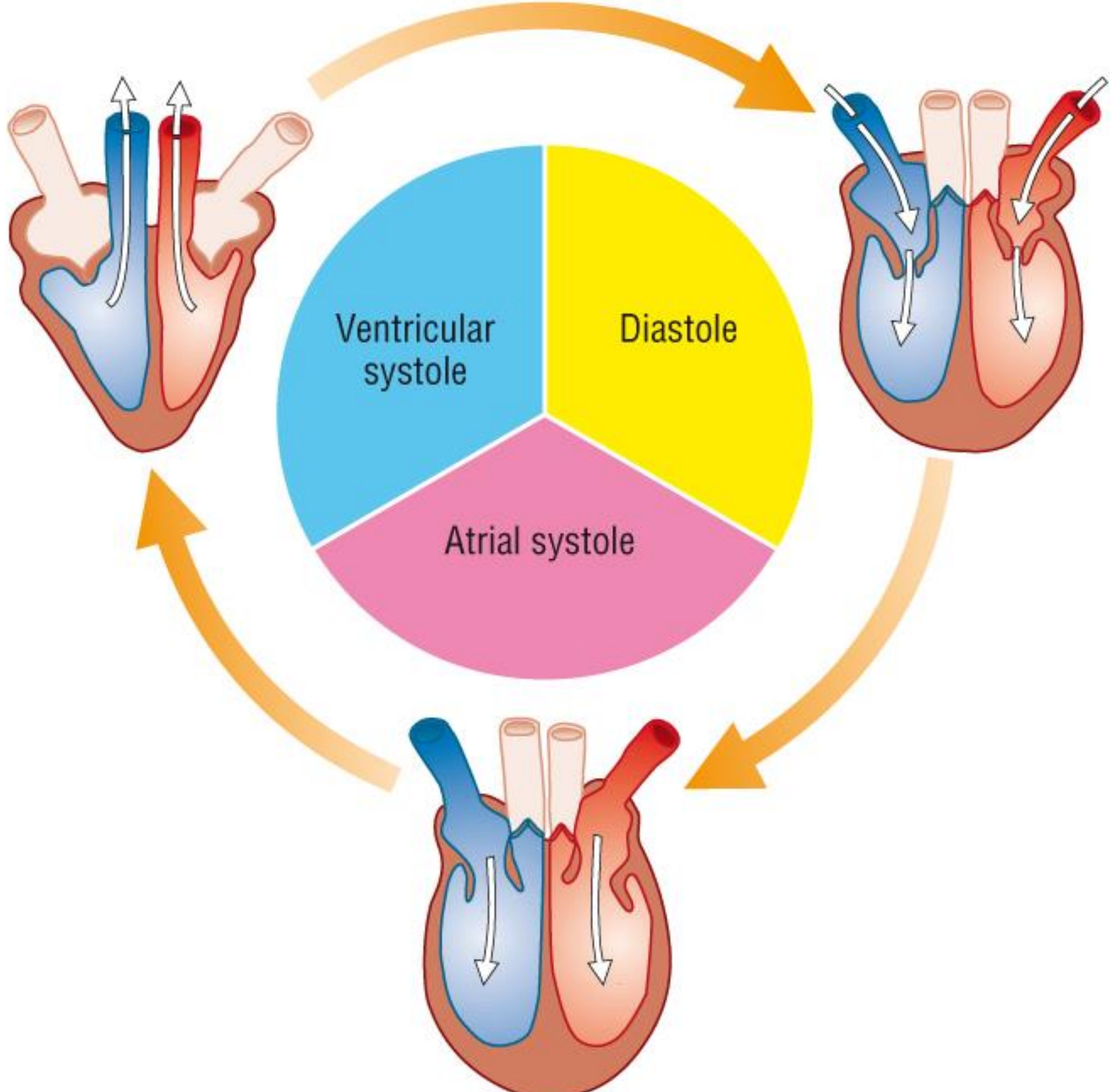
16 Heart Attack/ Cardiac Arrest

The Cardiac Cycle

What is the Cardiac Cycle?

- There are two basic components to the beating heart:
  - Contraction (Systole)
  - Relaxation (Diastole)

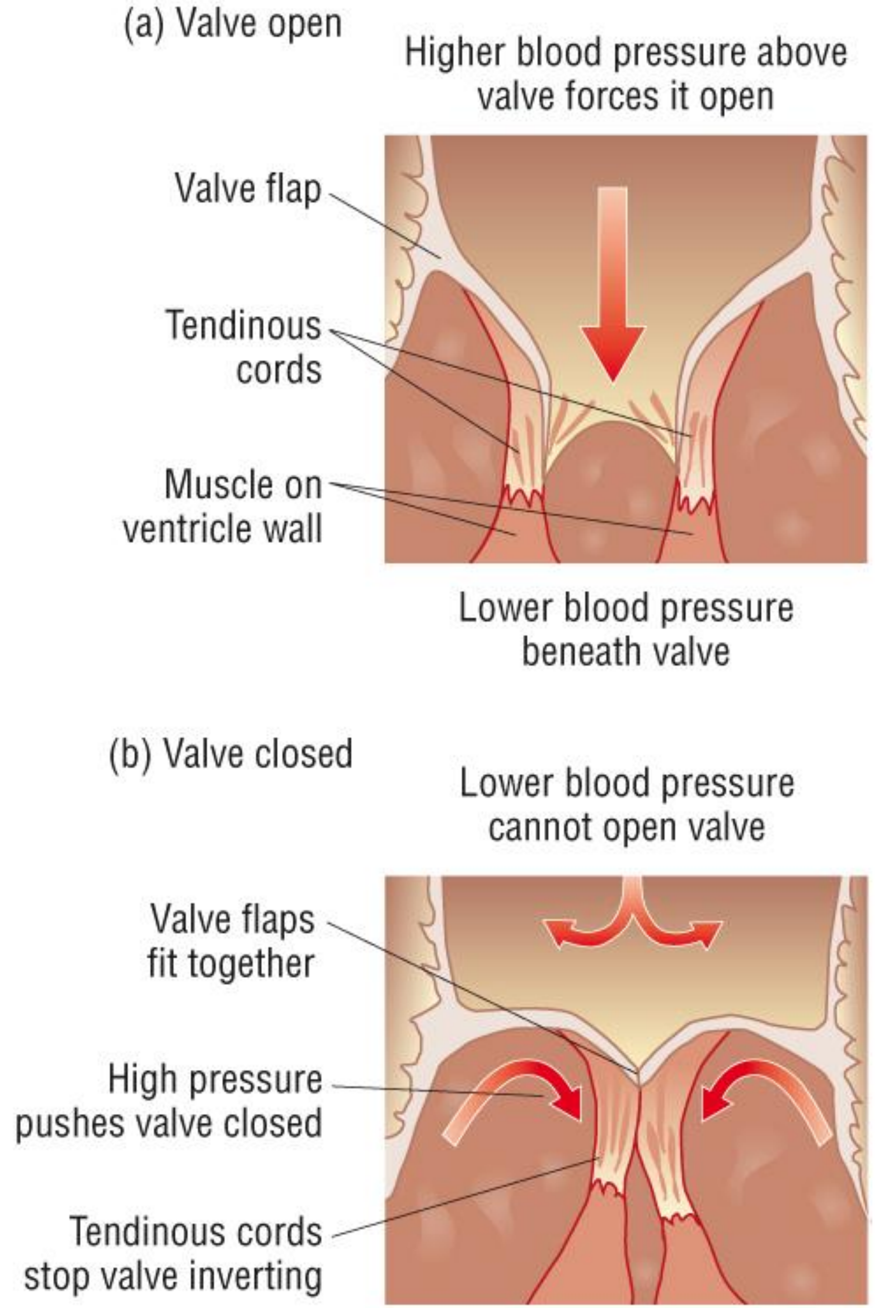
- Each cardiac cycle has three stages:
  - Diastole (atria & ventricles relax)
  - Atrial Systole (atria contract, pushing blood into ventricles)
  - Ventricular Systole (ventricles contract, pushing blood into major arteries).



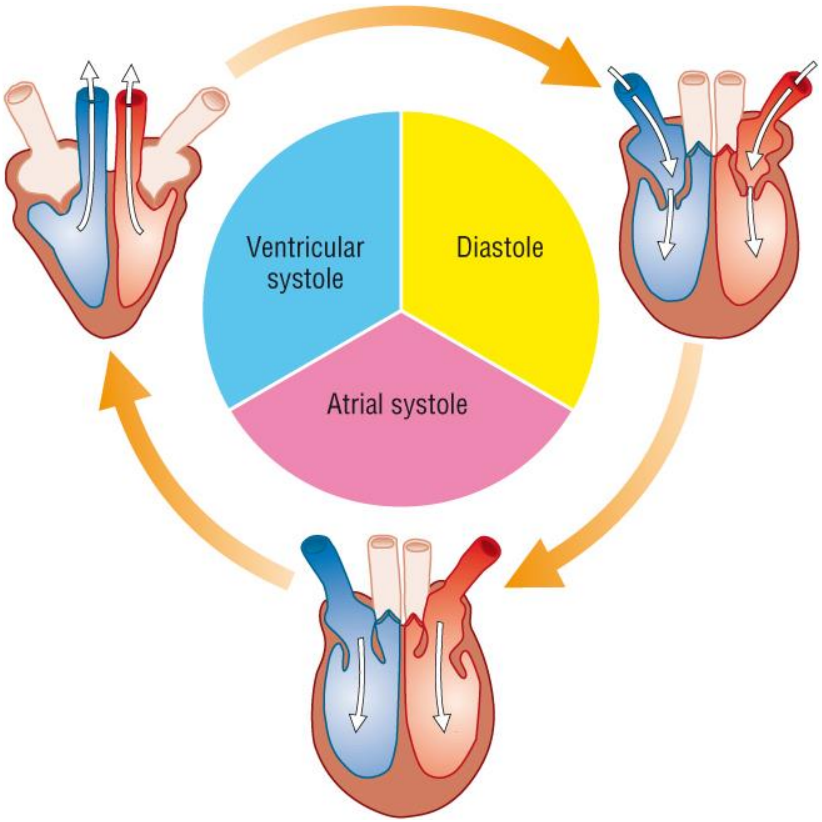
Ventricular systole
Diastole
Atrial systole

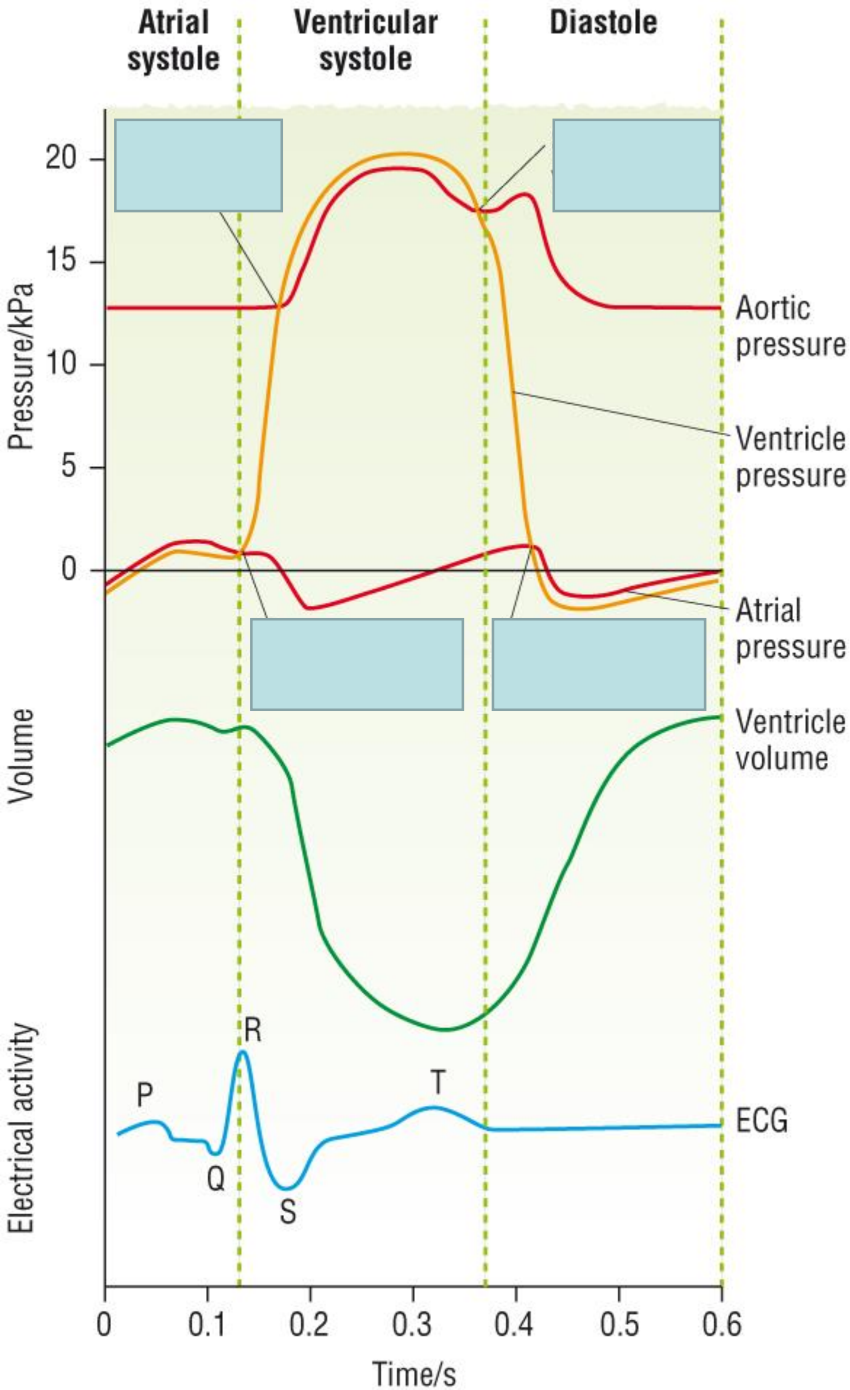
Valves

- Action of the atrioventricular valves.



Interpreting Graphs





How is this controlled?

- Cardiac muscle is myogenic.
  - Contractions are started from the muscle itself rather than from nerve impulses (neurogenic).

- Contractions originate in a region of cells in the right atrium (the sinoatrial node).
- The SA node has a basic rhythm of stimulation that determines the heartbeat.
- The SA node is often called the pacemaker.

A wave of excitation spreads out from the SA node across both atria, causing them to contract.

A layer of non-conductive tissue (the atrioventricular septum) prevents the wave crossing to the ventricles

The wave of excitation is picked up by a second group of cells – the atrioventricular node.

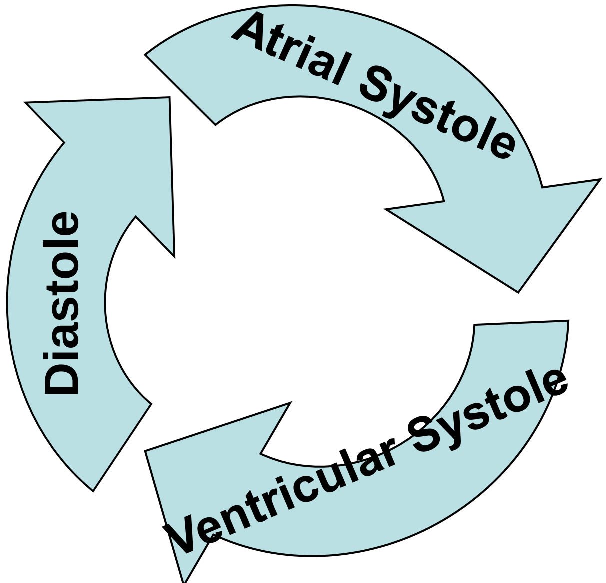
The wave is transmitted down between the ventricles along special muscle fibres called the bundle of His.

The bundle of His conducts the wave to the base of the ventricles.

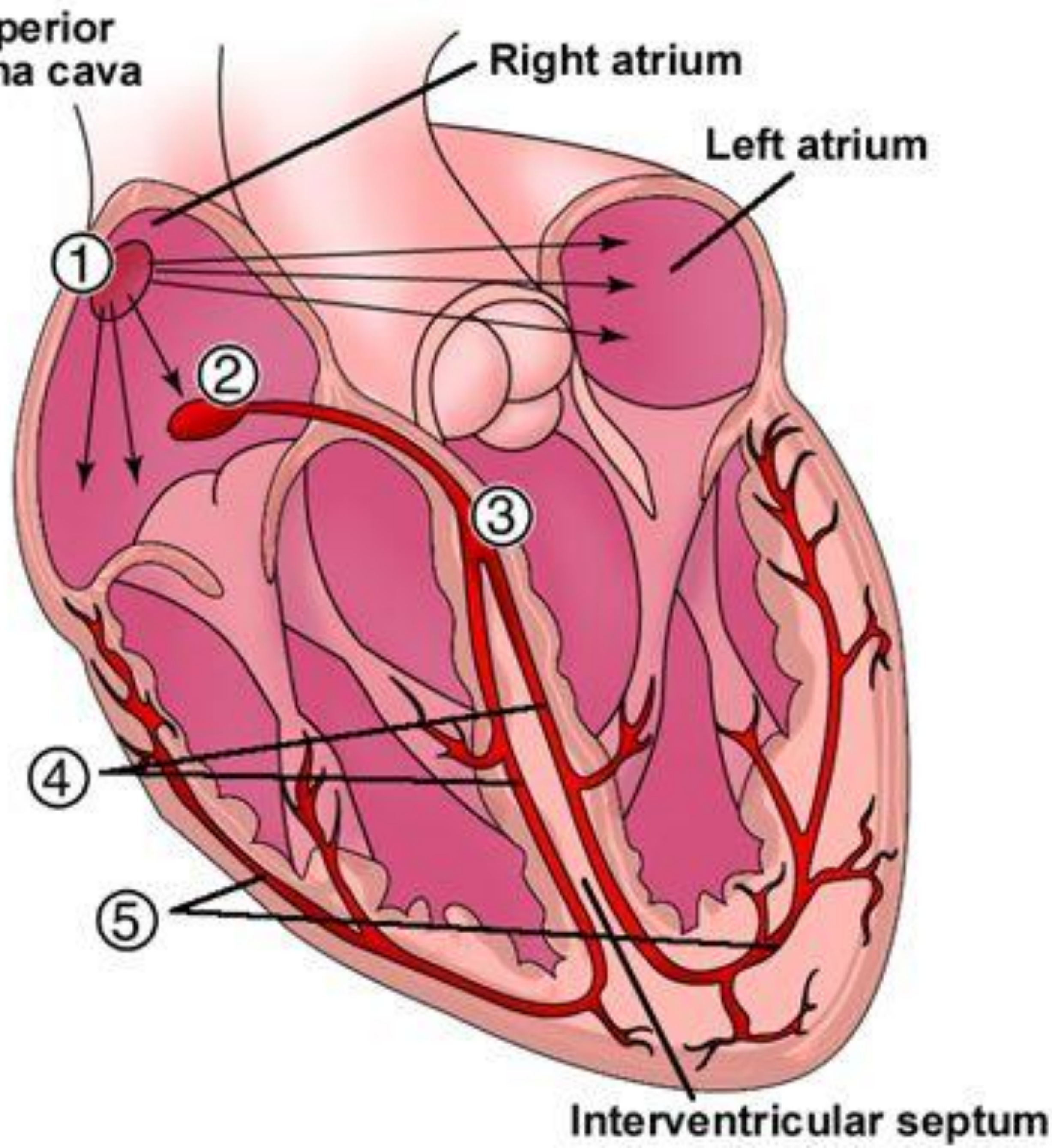
The bundle branches into smaller fibres called Purkyne fibres. The wave travels up through the ventricle walls.

The wave of excitation is released from the Purkyne fibres causing both ventricles to contract from the apex upwards.

All cardiac muscles relax before the cycle starts again.



1. SA Node
2. AV Node
3. Bundle of His
4. Left & right branches of the bundle
5. Bundle branches



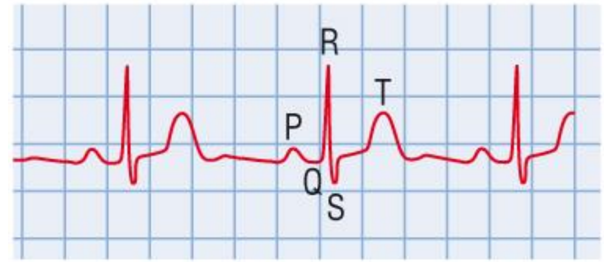
Electrocardiograms (ECGs)

- Some of the electrical activity in the heart spreads through other tissues.
- This can be detected by sensors attached to the skin on the chest.

- A healthy trace has a particular shape.

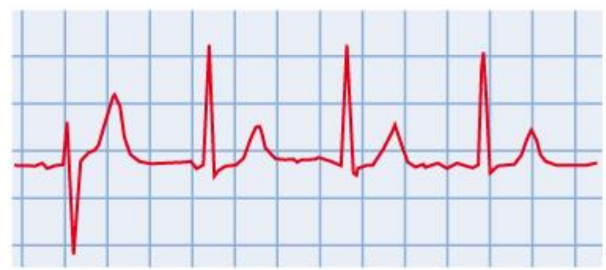
Interpreting the ECG

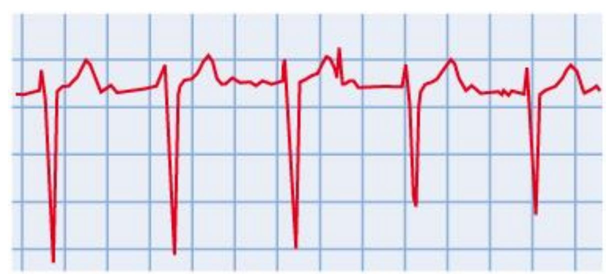
- A healthy trace has shapes labelled as P, Q, R, S & T.
- Wave P shows excitation of atria.
- QRS shows excitation of ventricles.
- T shows diastole.



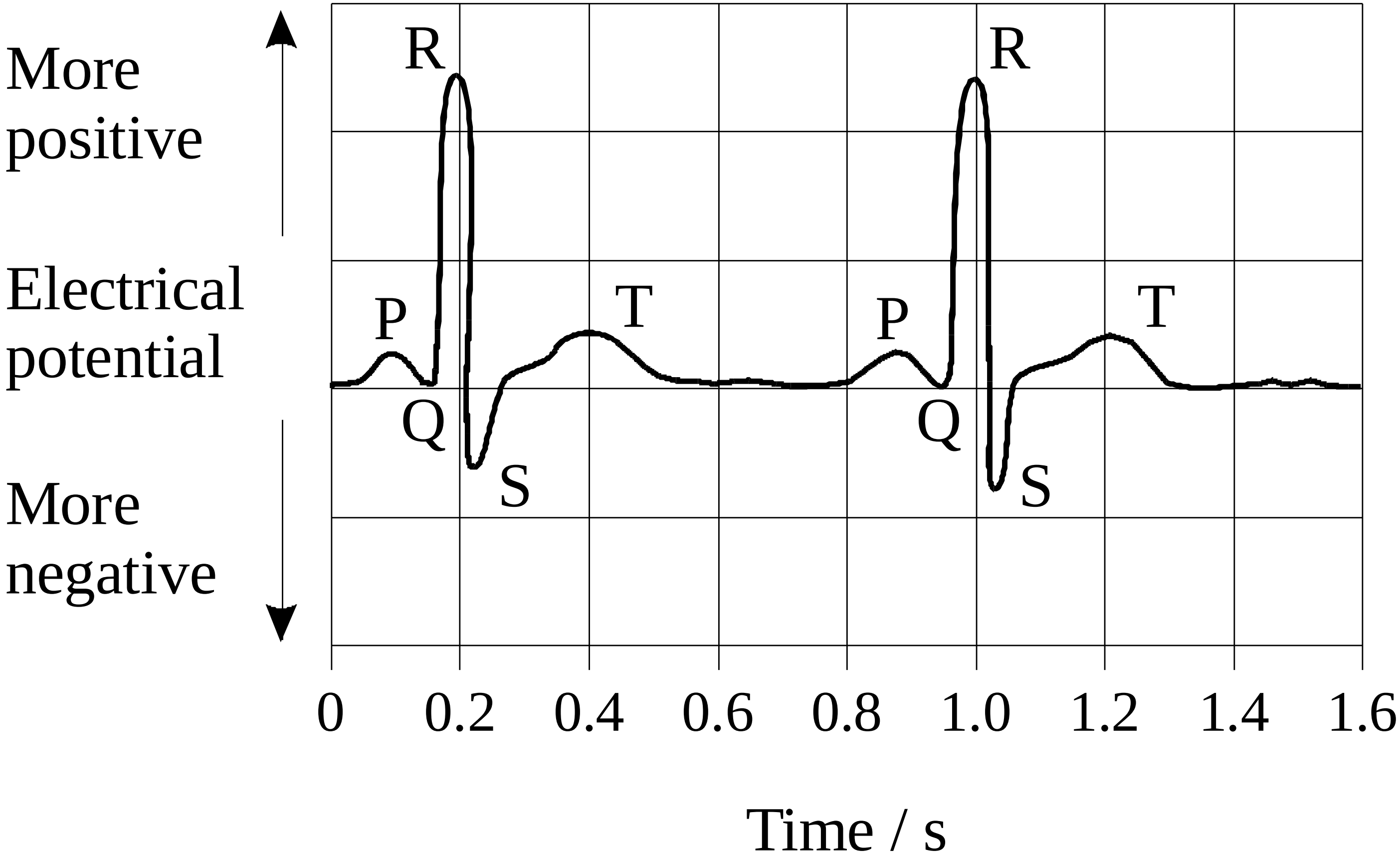
A normal ECG


Elevation of the ST section indicates heart attack


Small and unclear P wave indicates atrial fibrillation


Deep S wave indicates ventricular hypertrophy (increase in muscle thickness)

Calculate the heart rate (show working & units)



ECG traces can show heart abnormalities:

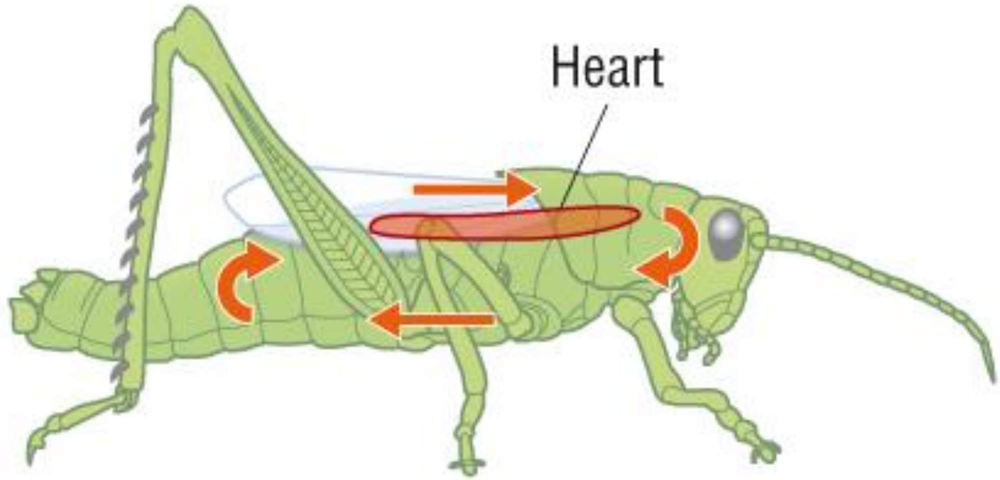
- P.194
- Sketch & summarise the abnormal trace and the disease for:
  - Tachycardia
  - Bradycardia
  - Ectopic heartbeat
  - Atrial fibrillation as example of Arrhythmia

Open v Closed Circulation

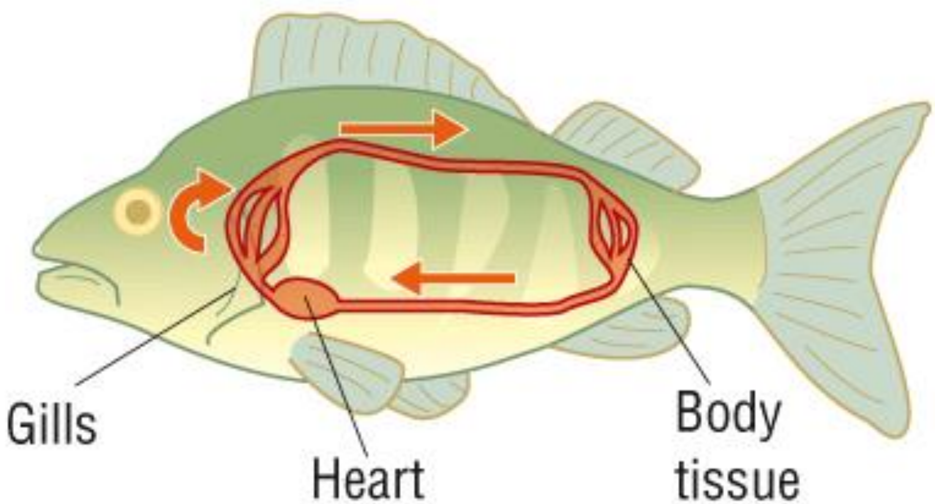
- Some animals have an open circulation system.
  - Blood is not completely held within vessels.
  - Blood circulates through the body cavity.
  - Tissue cells are bathed in blood.

- Eg Insects:

Open circulation of a locust



Closed circulation of a fish



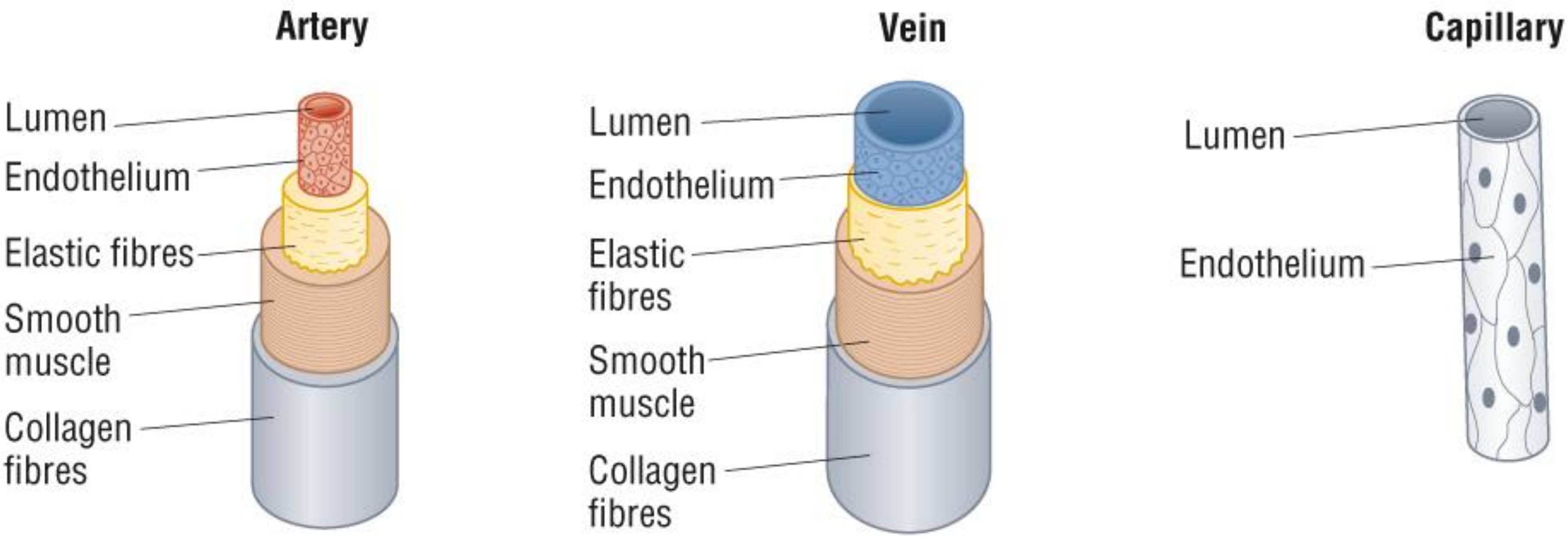
Closed Circulation

- Open systems are OK for small insects.
  - Blood does not have to travel far.
  - Oxygen & Carbon Dioxide do not travel in blood.

- Larger organisms need a closed system;
  - Blood speed in a closed system is too slow.
  - Blood is used to transport nutrients, O_2 & CO_2.
  - Active muscles would not receive enough blood.
  - Tissue fluid bathes the cells instead of blood.

Blood Vessels

- Three types:
  - Arteries carry blood away from the heart.
    - Smaller arteries called arterioles.
  - Veins carry blood into the heart.
    - Smaller veins called venules.
  - Capillaries link arteries to veins.



Structure & Function - Arteries

Lumen is small	Adds strength to withstand blood pressure
Thick, muscular wall	Prevents rupturing as artery stretches
Elastic tissue	Maintains high BP.
Smooth muscle	Allows artery to stretch as blood flows through.
Endothelium is folded	Allows constriction of the artery to limit blood flow

Structure & Function - Veins

Lumen is large	No need to stretch & recoil. They do not constrict to reduce flow.
Thin wall	Ensure one way flow. Help blood flow back to the heart.
Contains valves	Eases blood flow

Structure & Function - Capillaries

Lumen is very narrow	Ensures red blood cells are squeezed as they pass through – slows them down.
	Reduces the diffusion distance for Oxygen, Carbon dioxide & nutrients.
Very thin walls (one cell thick)	Allows exchange of materials between blood & tissue fluid.
	Presses red blood cells against walls – shortens diffusion distance.

How is circulation maintained?

- By the heart.
  - A muscular organ that pumps the blood through the vessels.
- By contraction of skeletal muscle.
  - Body movements squeeze veins. Valves ensure blood moves towards the heart.
- By enlargement of the thorax during inspiration.
  - Reduced pressure in the thorax helps to draw venous blood back to the heart.

Blood

- The medium by which materials are transported within the body.
- Consists of:
  - Plasma (the liquid part)
  - Red blood cells
  - White blood cells
  - Platelets

Functions of the Blood

- Two main functions:
  - Transport
    - Transports a wide variety of materials around the body.
  - Defence
    - White blood cells protect the body by engulfing foreign material.
    - White blood cells produce substances to stimulate defensive reactions and provide immunity.

Plasma

- Makes up 55% of blood volume.

- It is 90% water and 10% chemicals.
  - Chemicals are either dissolved or suspended in the plasma.

The Chemicals in Plasma Include:

- **Nutrients** (eg. Glucose, amino acids, vitamins).
- **Waste products** (eg. Urea).
- **Mineral salts** (eg. Calcium, iron).
- **Hormones** (eg. Insulin, adrenaline).
- **Plasma proteins** (eg. Fibrinogen & prothrombin which are involved in clotting).
- **Respiratory gases** (eg. Oxygen, carbon dioxide).

Red Blood Cells - Erythrocytes

- Bi-concave discs (8µm diameter).
- Made in bone marrow of certain bones:
  - Eg. Cranium, sternum, vertebrae, ribs.
- Contain the red pigment haemoglobin
  - Carries oxygen
- Have no nucleus
  - Reduces their lifespan (120 days)
  - More efficient in transporting oxygen
    - Larger surface area : volume ratio
    - More room for haemoglobin

White Blood Cells - Leucocytes

- Many types of Leucocyte.
  - Probably previously known as phagocytes and lymphocytes.
- Made in the thymus gland and marrow of limb bones.
- Protect the body against infection.

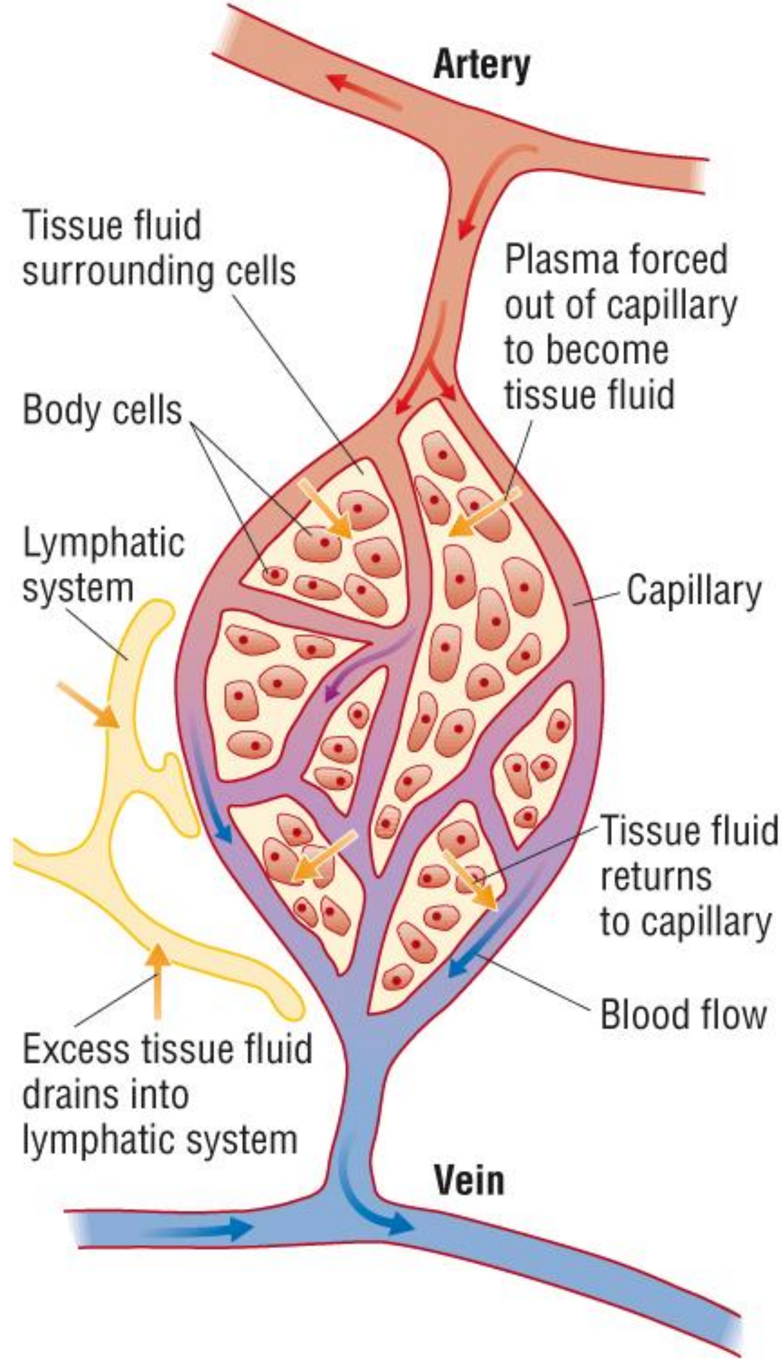
Platelets - Thrombocytes

- These are small fragments of cells.

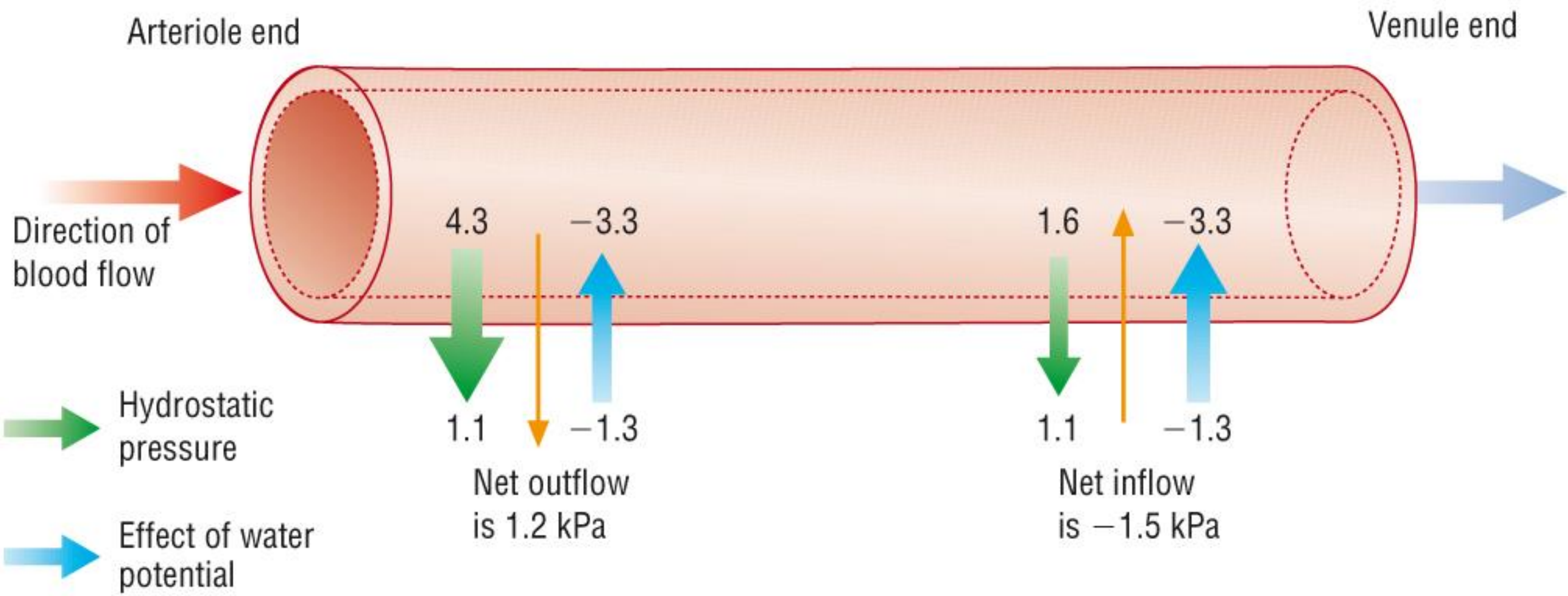
- Have a crucial role in blood clotting.
  - Prevents blood loss when a vessel is ruptured.

Tissue Fluid

- Carries oxygen & nutrients from blood to cells.
- Carries carbon dioxide & other wastes from cells to blood.



How is tissue fluid formed?



(**Oncotic Pressure**)

What is Lymph?

- Lymph is a milky liquid made from three sources:
  - Tissue fluid that has not been reabsorbed at the venous ends of capillaries.
  - Fatty acids & glycerol absorbed into the lacteals in the ileum.
  - Lymphocytes produced in the lymph nodes or that have migrated out of capillaries to fight infection.

What is the Lymphatic System?

- A network of capillaries that merge into larger vessels which run around the body.
- Lymph vessels drain their contents back into the blood stream at two places:
  - The right lymphatic duct
    - Drains lymph from the right side of the head & right arm into the right subclavian vein.
  - The thoracic duct
    - Drains lymph from the rest of the body into the left subclavian vein.

What are Lymph Nodes?

- Points along lymph vessels where lymphocytes are produced & stored.
- These sites filter out any bacteria & other foreign bodies which are engulfed by WBCs.
- This causes the nodes to swell with dead cells.
  - This is the cause of tenderness in the groin, armpits & neck during an infection.

How is Lymph Moved Along the Vessels?

- Lymph is moved along in three ways:
  - – Hydrostatic pressure of tissue fluid leaving the capillaries.
  - – Contraction of skeletal muscles.
    - Lymph vessels are squeezed, pushing lymph out of the way. Valves in the vessels ensure that it flows in the right direction.
  - – Enlargement of the thorax.
    - During inspiration the pressure inside the thorax is reduced which draws lymph into this region.

Activity – Copy & Complete

	Blood	Plasma	Tissue Fluid	Lymph
Location				
How it is Moved				
Direction of flow				
Types of cells inside				

Transport of Oxygen

Even with lungs, blood vessels and a heart to pump blood around the body, transport of oxygen would be inadequate if the gas were simply dissolved in the plasma.

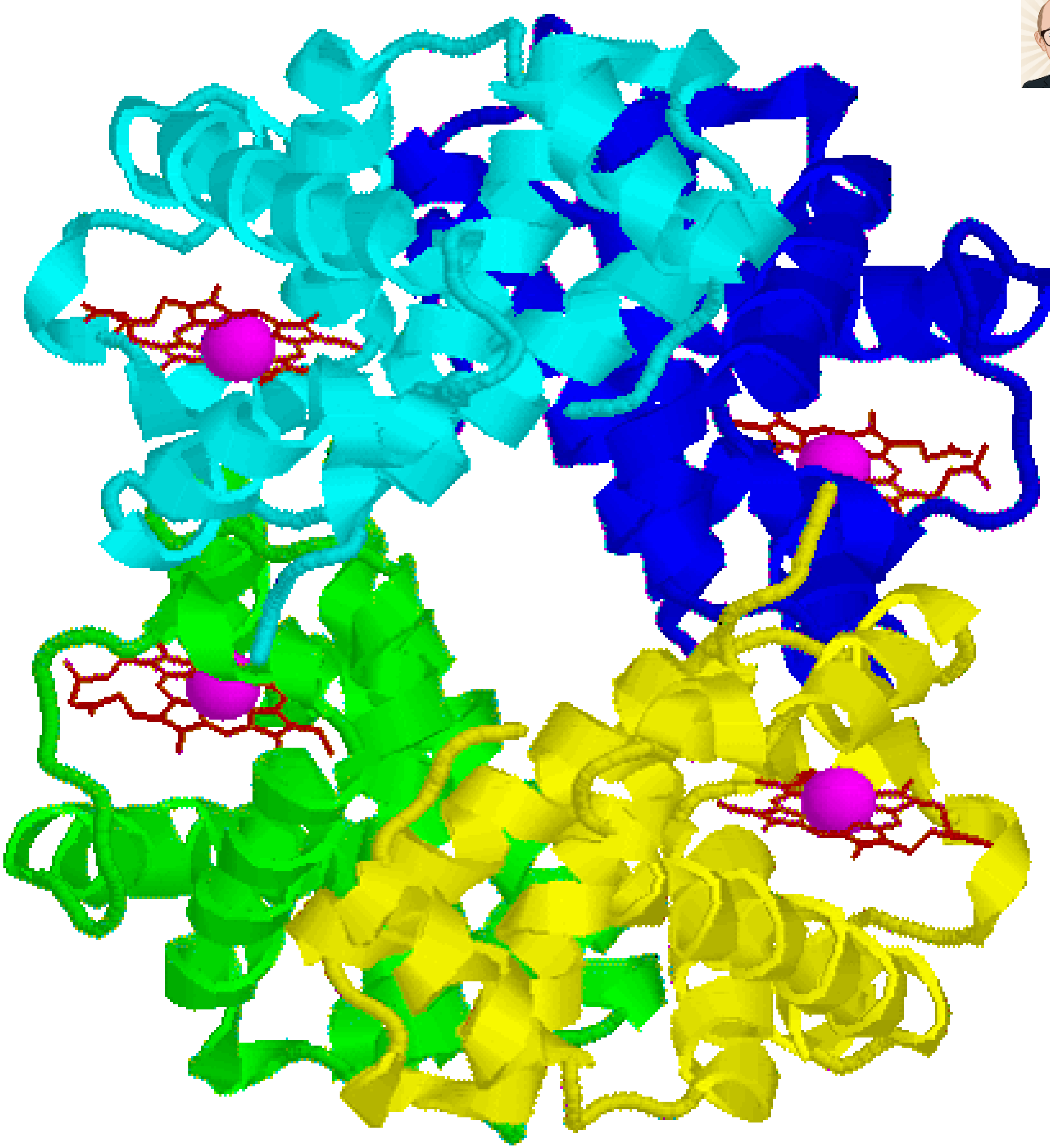
Introduction

- We have evolved specialised molecules capable of carrying large quantities of oxygen.
- These molecules are called respiratory pigments.
- The most well known is haemoglobin.

Haemoglobin is made of 4 separate polypeptides joined together (2 alpha and 2 beta chains).

The red molecule is a Haem group that contains an iron atom (pink) attached.

Oxygen molecules bind to each of the haem groups, so that each haemoglobin molecule can accommodate four O_2 molecules.



Haemoglobin

- A red pigment with a large RMM of 68,000.
- One oxygen molecule can combine with each of its four haem groups to form oxyhaemoglobin.

- Haemoglobin must:
  - Readily pick up oxygen at the lungs.
  - Readily release oxygen at the respiring tissues.

Carbon Monoxide Poisoning

- Hb has a greater affinity for carbon monoxide than for oxygen.
- Once attached to Hb, carbon monoxide stays there permanently.
- This prevents oxygen molecules from binding.

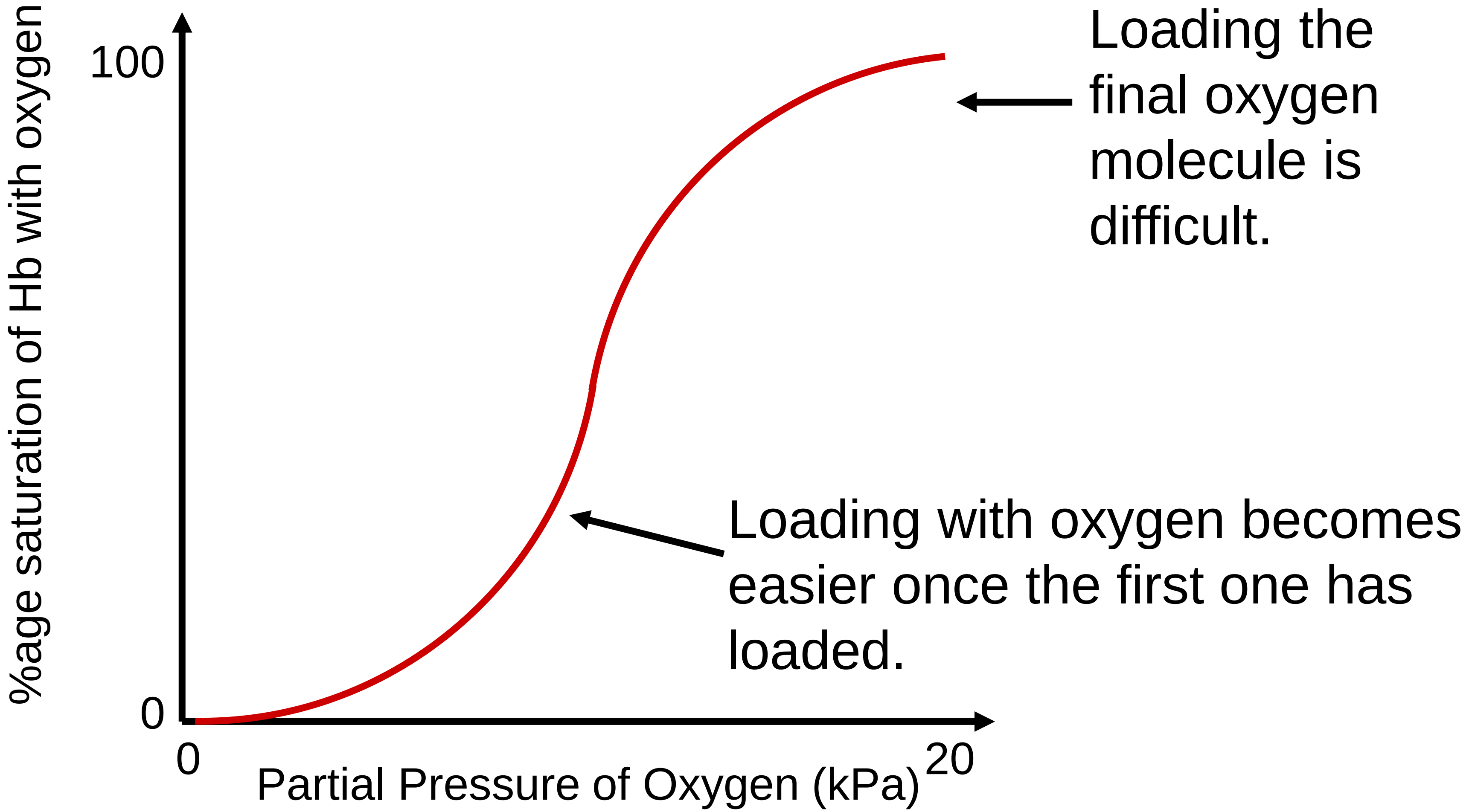
How do we Measure Oxygen Concentration?

- The amount of gas present in a mixture of gases is measured by the pressure it contributes to the total pressure of the gas mixture.
- This is called partial pressure of the gas, or the gas tension.
- Measured in kPa.
- For example:
  - Normal atmospheric pressure is 100kPa. Oxygen makes up 21% of air. So the partial pressure of oxygen (pO_2) is normally 21kPa.

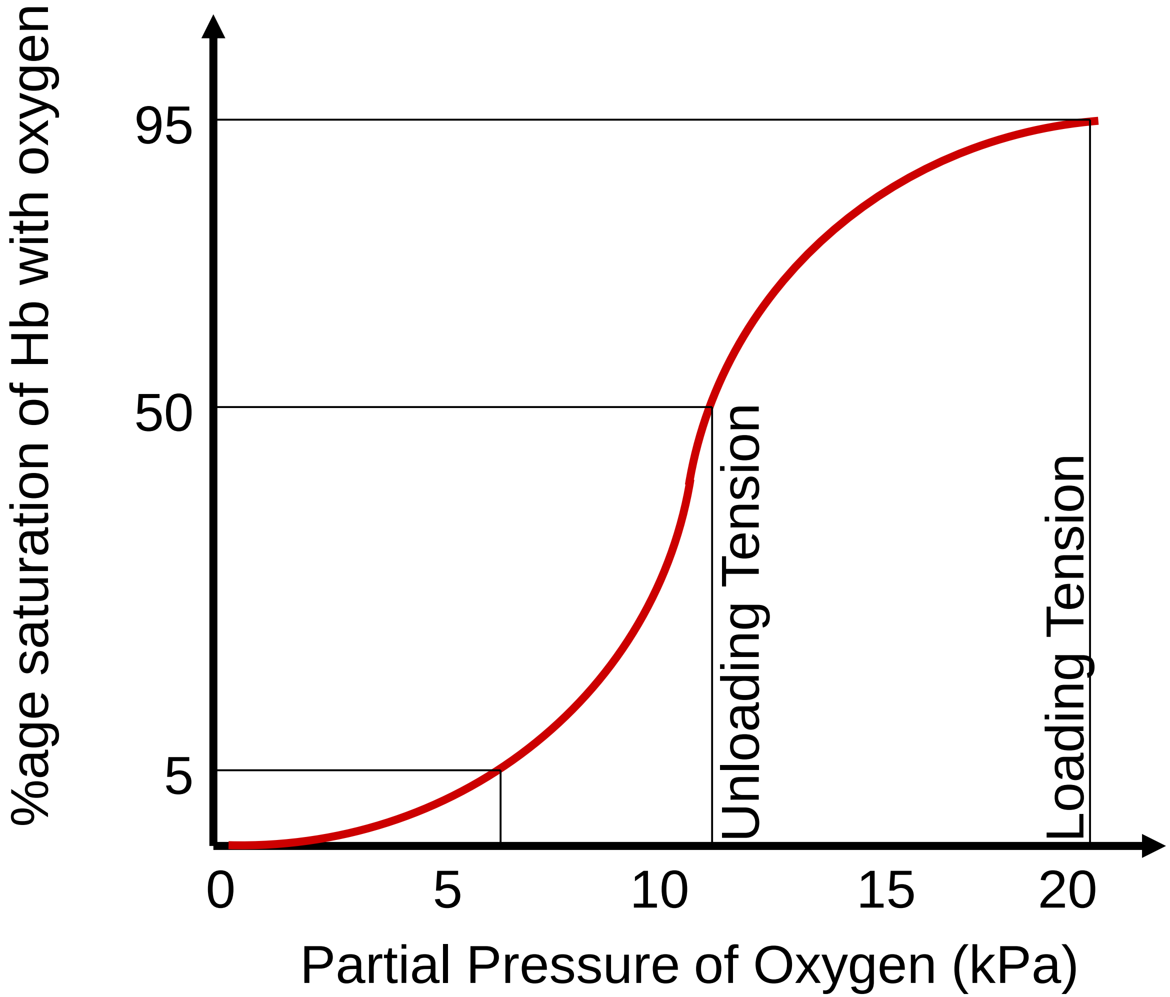
Loading Haemoglobin with Oxygen

- At low pO_2, the four Hb polypeptides are close together.
  - Difficult for the first molecule of O_2 to load.
- Once the first O_2 has loaded, the Hb polypeptides separate slightly.
  - Easier for subsequent O_2 molecules to load.
- Once the Hb is almost saturated, the last O_2 molecule is difficult to load.

Oxygen Dissociation Curve



How Much Oxygen is Carried?



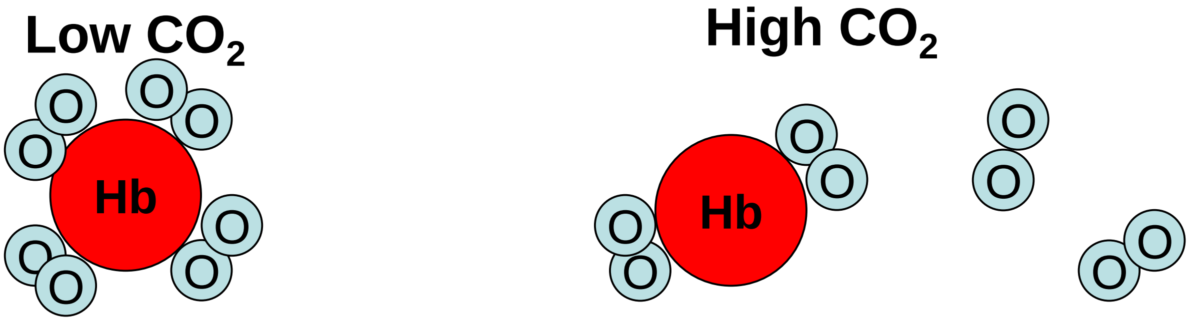
If pO_2 is high (in lungs) then more oxygen is carried by Hb.

In normal atmospheric oxygen the saturation will never be more than 95%

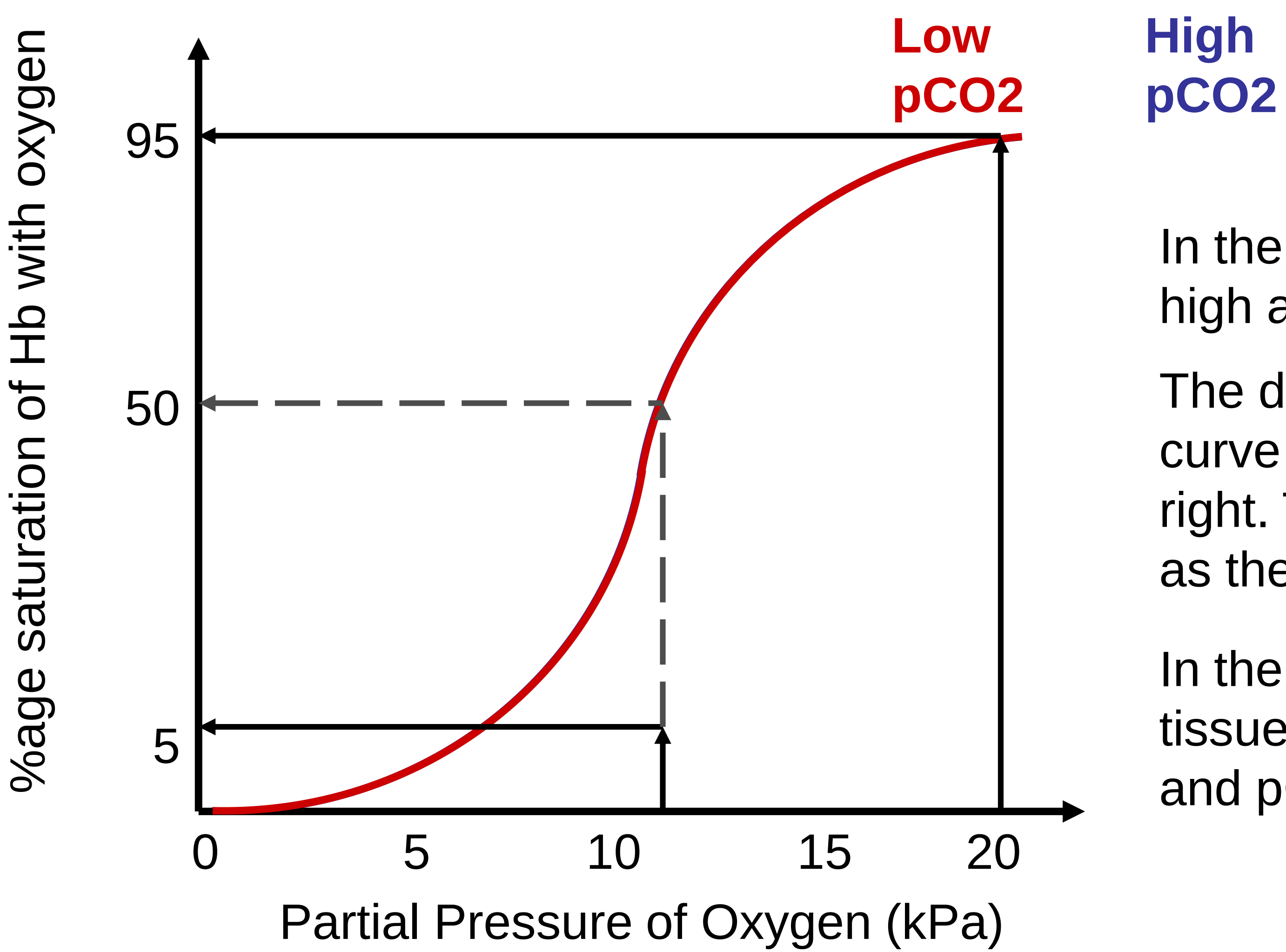
If pO_2 is low (in respiring tissue) then more oxygen is released by Hb.

The Effect of Carbon Dioxide

- The increased acidity from the presence of CO_2 reduces the affinity of haemoglobin for oxygen.



What Effect Does Carbon Dioxide Have?



In the lungs, pO_2 is high and pCO_2 is low.

The dissociation curve is shifted to the right. This is known as the **Bohr Effect**.

In the respiring tissues, pO_2 is low and pCO_2 is high.

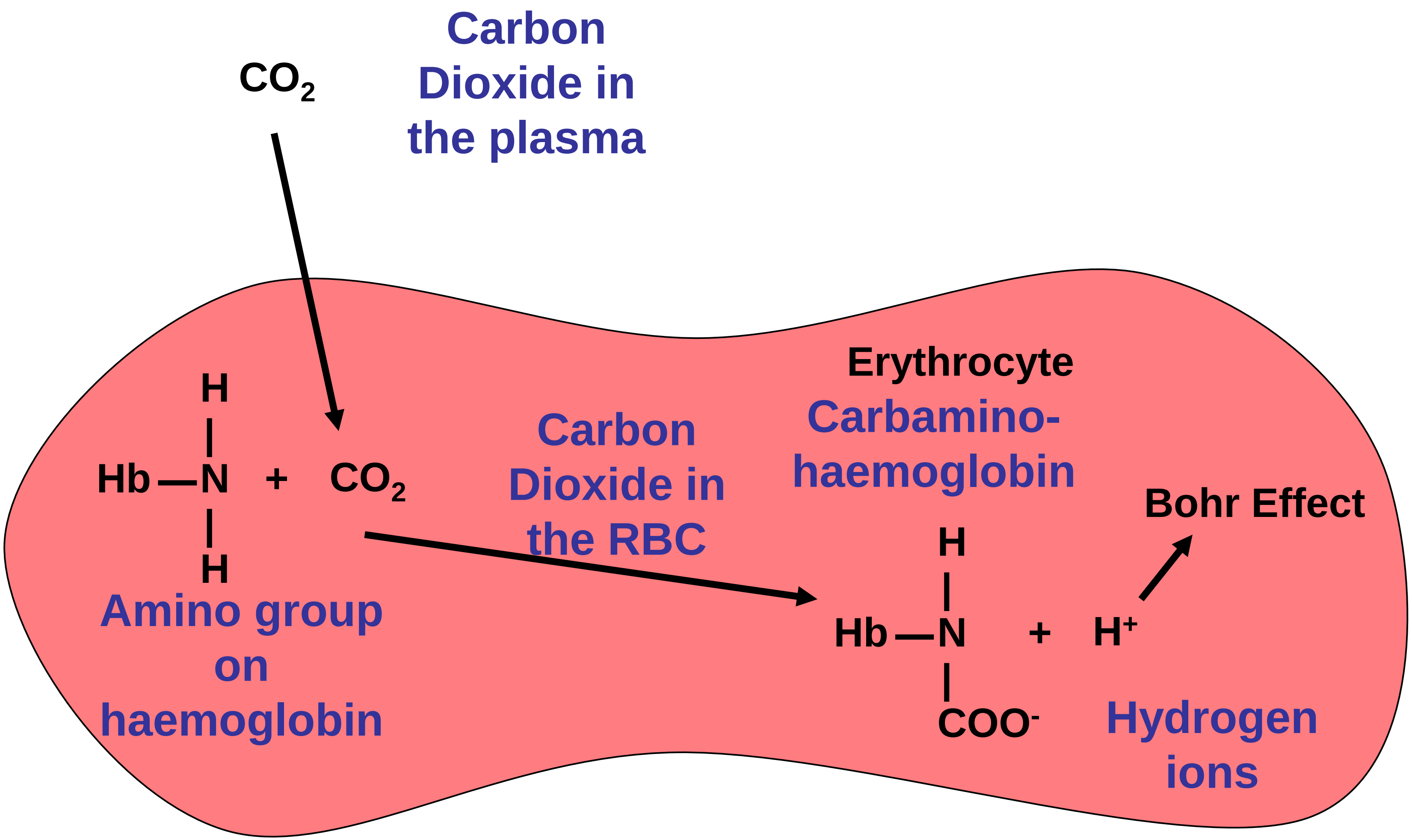
The Bohr Effect

- Named after Christian Bohr in 1904.
- It is the result of increased acidity due to dissolved carbon dioxide.
  - Hydrogen ions lower the pH.
  - Hydrogen ions reduce the affinity of Hb for oxygen.
- Other acids (eg. Lactic acid have the same effect).

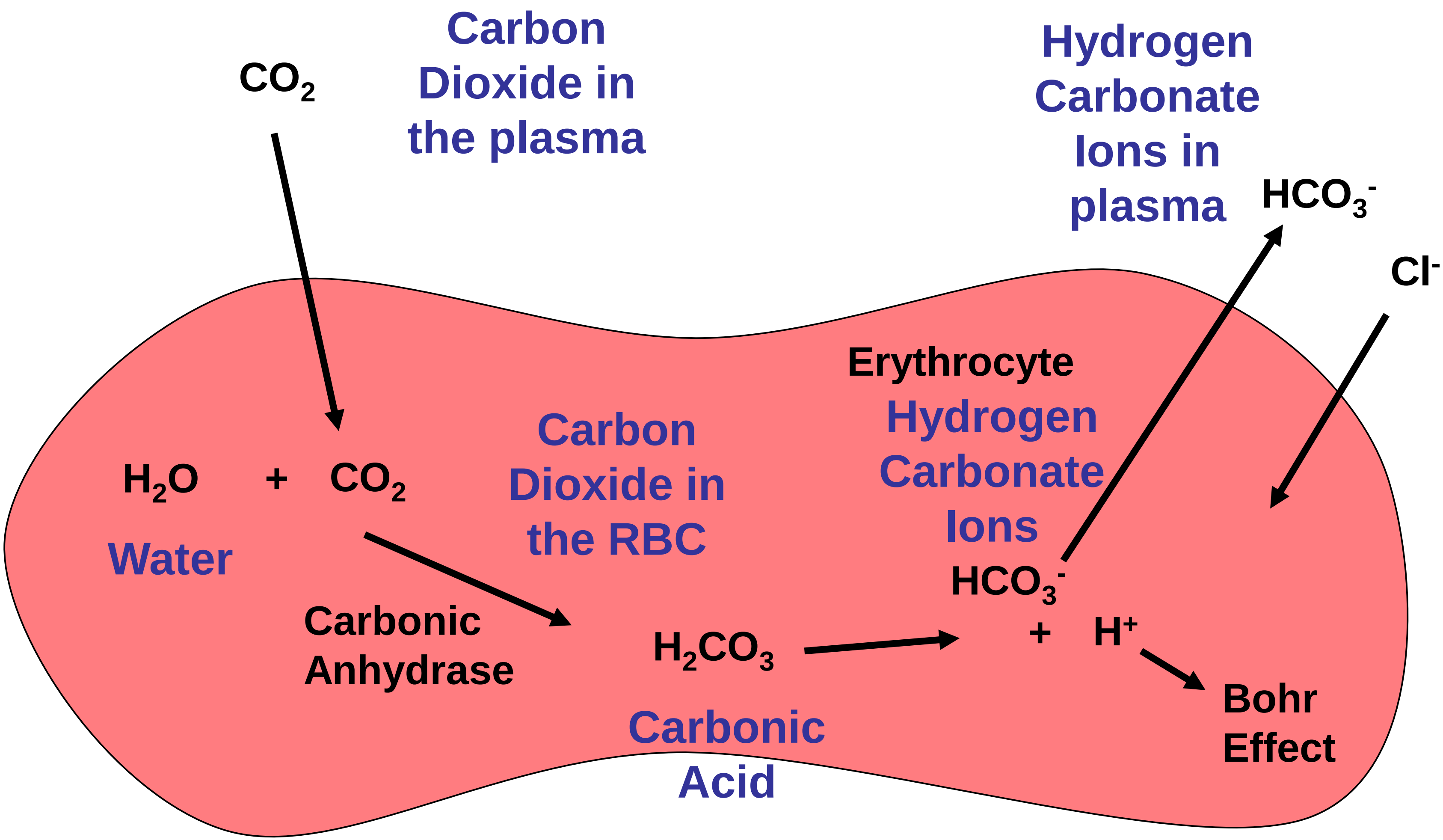
How is CO_2 Transported?

- Carbon dioxide is carried from the tissues in three ways:
  - In solution in the blood plasma.
    - Only 5% of CO_2 is carried this way.
  - In combination with haemoglobin.
    - Only 10% of CO_2 is carried this way.
  - As hydrogen carbonate ions in the blood plasma.
    - Most of the CO_2 is carried this way.

In Combination with Haemoglobin



As Hydrogen Carbonate Ions



Hydrogen Ions & the Bohr Effect

- The hydrogen ions produced from the dissociation of Carbaminohaemoglobin & Hydrogen Carbonate ions bind to haemoglobin to form haemoglobinic acid.

$$H^{+} \quad + \quad Hb\text{-}O_{8} \longrightarrow H\text{-}Hb \quad + \quad 4O_{2}$$

- This causes haemoglobin to release its oxygen.

Hb Changes its affinity for oxygen under different conditions.

Region of the body	Oxygen tension	Carbon dioxide tension	Affinity of Hb for oxygen	Result
Gas exchange surface	High	Low	High	Oxygen is absorbed
Respiring tissues	Low	High	Low	Oxygen is released

What about other respiratory pigments?

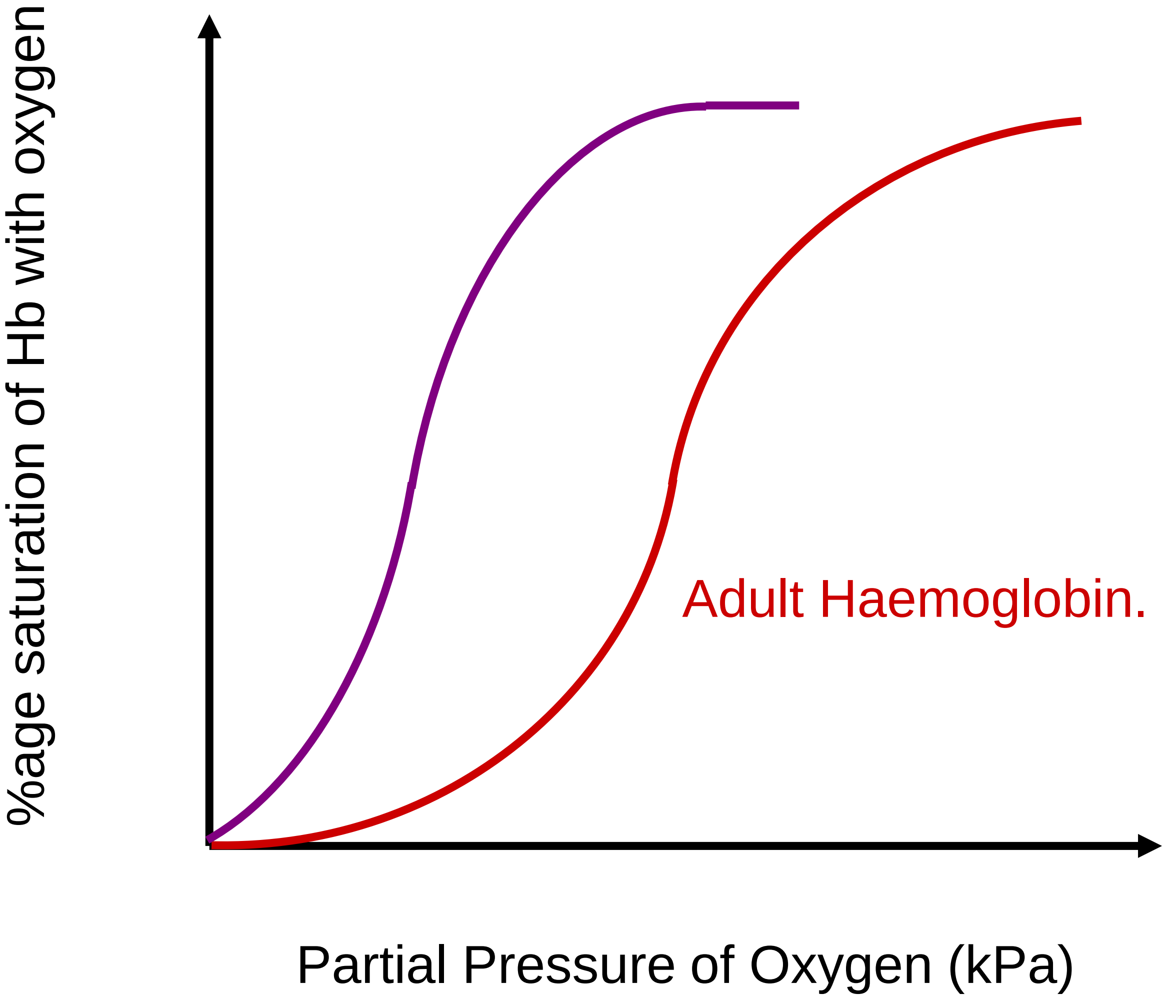
- Haemoglobin exists in different forms.
  - Adult haemoglobin
  - Foetal haemoglobin

- Myoglobin is found in muscles of vertebrates.
  - Concerned with storage rather than transport of oxygen.

Foetal Haemoglobin

- If mother & foetus had the same haemoglobin, there would be no reason for oxygen to pass from one to the other.
- Foetal RBCs are produced in the liver and foetal Hb has a higher affinity for oxygen than adult Hb.
- Once born, RBCs are produced in the bone marrow with adult Hb.

Foetal v Adult Haemoglobin



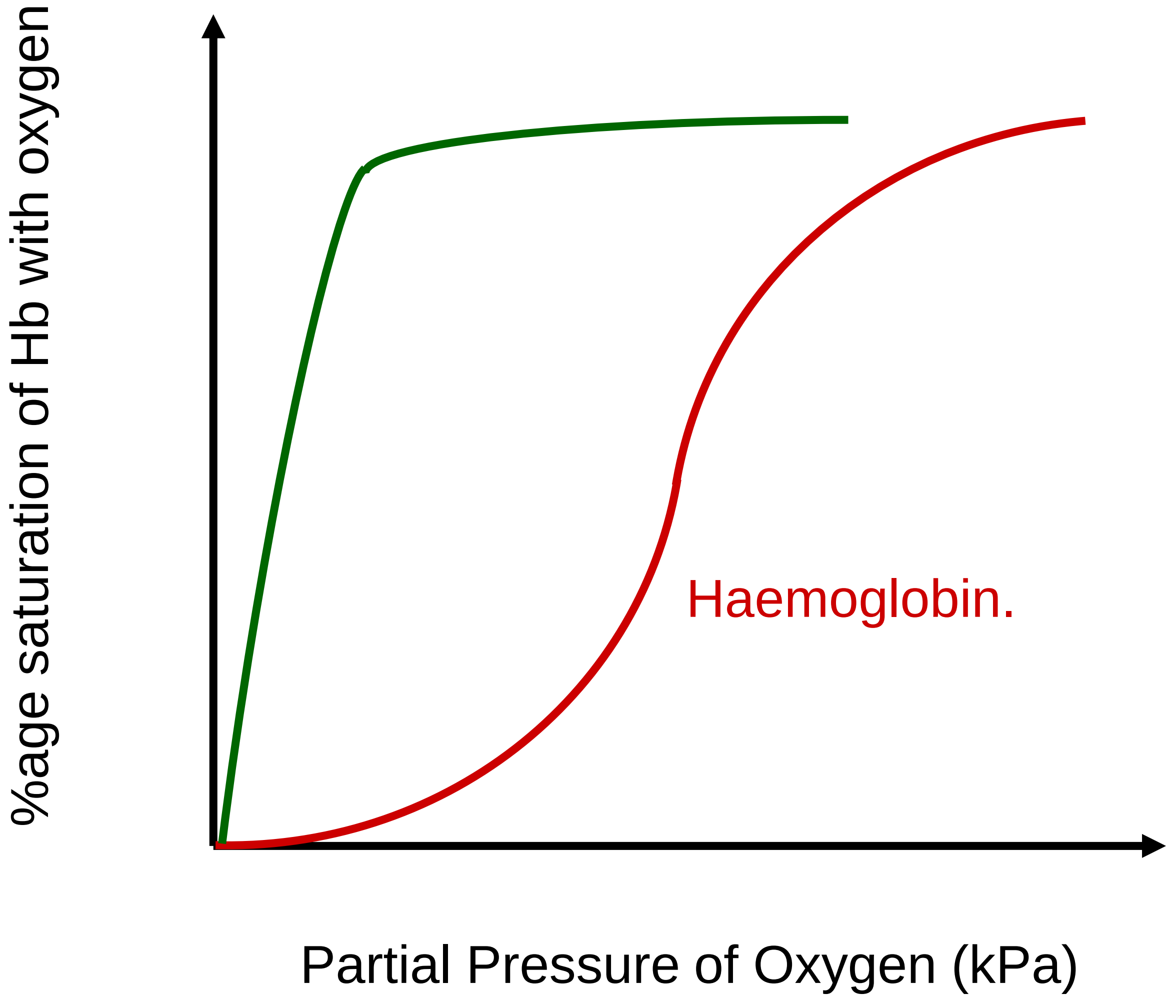
Foetal Hb has a higher affinity for oxygen.

Oxygen can be obtained from mother's Hb in the placenta.

Myoglobin

- Provides an emergency supply of oxygen to muscles when demand exceeds supply.
- Myoglobin has a higher affinity for oxygen than haemoglobin.
  - Ensures that oxygen is taken from haemoglobin first.
  - Ensures that oxygen taken from myoglobin is rapidly replaced once exercise has stopped.

Myoglobin v Haemoglobin



Myoglobin has a higher affinity for oxygen.

It acts as an oxygen store in the muscles.