3.3 Organisms exchange substances with their environment

3.3.1 Surface area to volume ratio

Content:

- The relationship between the size of an organism or structure and its surface area to volume ratio.
- Changes to body shape and the development of systems in larger organisms as adaptations that facilitate exchange as this ratio reduces.
- Students should be able to:
    - Appreciate the relationship between surface area to volume ratio and metabolic rate.

Opportunities for Skills Development:

- Students could use agar blocks containing indicator to determine the effect of surface area to volume ratio and concentration gradient on the diffusion of an acid or alkali.
- Students could be given the dimensions of cells with different shapes from which to calculate the surface area to volume ratios of these cells.

As an organism increase in size, its surface area to volume ratio will decrease. This is because surface area increases by a scale factor of 2, whereas volume increases by a scale factor of 3.

In order to survive, organisms need to exchange materials between their external and internal environment. However, as organisms increase in size, the surface area to volume ratio decreases, so organisms require adaptations to facilitate the exchange of substances. Their increase in size means most cells are too far from exchange surfaces for diffusion to suffice their requirements.

Organisms with higher metabolic rates exchange more materials so require a large surface area to volume ratio.

Certain organisms have adapted for efficient exchange by diffusion by having a flattened shape, thus no cell is far from an exchange surface. Also specialised surfaces with large areas to increase surface area to volume ratio for example lungs in mammals or gills in fish.

Features of specialised exchange surfaces:

- **Large surface area relative to the volume**
- **Very thin (short diffusion pathway)**
- **Selectively permeable**
- **Movement of the environmental medium ie air, to maintain a diffusion gradient**
- **A transport system ie blood, to maintain a diffusion gradient.**

Specialised exchange surfaces will pretty much always be located inside the body of an organism. This is because they are thin and so easily damaged and dehydrated.

3.3.2 Gas exchange

Content

- Adaptations of gas exchange surfaces, shown by gas exchange:
    - Across the body surface of a single-celled organism
    - In the tracheal system of an insect (tracheae, tracheoles and spiracles)
    - Across the gills of fish (gill lamellae and filaments including the counter-current principle)
    - By the leaves of dicotyledonous plants (mesophyll and stomata).
- Structural and functional compromises between the opposing needs for efficient gas exchange and the limitation of water loss shown by terrestrial insects and xerophytic plants
- The gross structure of the human gas exchange system limited to alveoli, bronchioles, bronchi, trachea and lungs
- The essential features of the alveolar epithelium as a surface over which gas exchange takes place
- Ventilation and exchange of gases in the lungs. The mechanism of breathing to include the role of the diaphragm and the antagonistic interaction between the external and internal intercostal muscles in bringing about pressure changes in the thoracic cavity.
- Students should be able to:
    - Interpret information relating to the effects of lung disease on gas exchange and/or ventilation
    - Interpret data relating to the effects of pollution and smoking on the incidence of lung disease
    - Analyse and interpret data associated with specific risk factors and the incidence of lung disease
    - Evaluate the way in which experimental data led to statutory restrictions on the sources of risk factors
    - **Recognise correlations and causal relationships.**

Opportunities for Skills Development

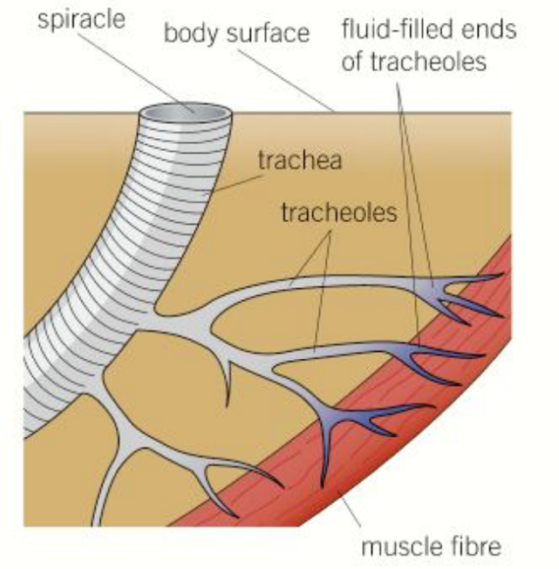
- Students could dissect mammalian lungs, the gas exchange system of a bony fish or of an insect.
- Students could use an optical microscope to:
    - Examine prepared mounts of gas exchange surfaces of a mammal, fish and insect, or temporary mounts of gills
    - Examine vertical sections through a dicotyledonous leaf.
- Students could use three-way taps, manometers and simple respirometers to measure volumes of air involved in gas exchange.
- Students could be given values of pulmonary ventilation rate (PVR) and one other measure, requiring them to change the subject of the equation: PVR = tidal volume x breathing rate

Gas exchange in single-celled organisms:

These organisms are small so have a large surface area to volume ratio, oxygen is absorbed by diffusion across only a cell surface membrane. Carbon dioxide also diffuses out across their body surface, and so without cell walls as you get in living cells, diffusion is enough for efficient uptake of nutrients.

Gas exchange in insects:

Insects have evolved an internal network of tubes called tracheae. The tracheae are supported by strengthened rings to prevent them from collapsing. The tracheae are then divided into smaller dead-end tubes called tracheoles. These tracheoles extend throughout all the body tissues of the insect. In this way, atmospheric air, with the oxygen it contains, is brought directly to the respiring tissues, as there is a short diffusion pathway from a tracheoles to any body cell.



Respiratory gases move in and out of the tracheal system in three ways:

- Along a diffusion gradient. When cells respire, oxygen is used up so its concentration towards the end of the tracheoles falls. This creates a diffusion gradient that causes gaseous oxygen to diffuse from the atmosphere, along the trachea and tracheoles to the cells. Carbon dioxide is produced by cells during respiration. This creates a diffusion gradient in the opposite direction, so carbon dioxide diffuses along the tracheoles and trachea from the cells to the atmosphere. Diffusion in air is more rapid than in water, so respiratory gases are exchanged quickly in this way
- Mass transport. The contraction of muscles in insects can squeeze the trachea enabling mass transport of air in and out, speeding up exchange of respiratory gases
- The ends of the tracheoles are filled with water. During periods of major activity, the muscle cells around the tracheoles respire carrying out some anaerobic respiration. This produces lactate, which is soluble, so lowering the water potential of muscle cells. Water therefore moves in by osmosis (into the cells from the tracheoles), the water in the ends of the tracheoles decreases in volume and in doing so draws air further into them. This means the final diffusion pathway is in gas rather than liquid

phase, so diffusion is more rapid. Thus increasing the rate at which air is moved in the tracheoles but leads to greater water evaporation.

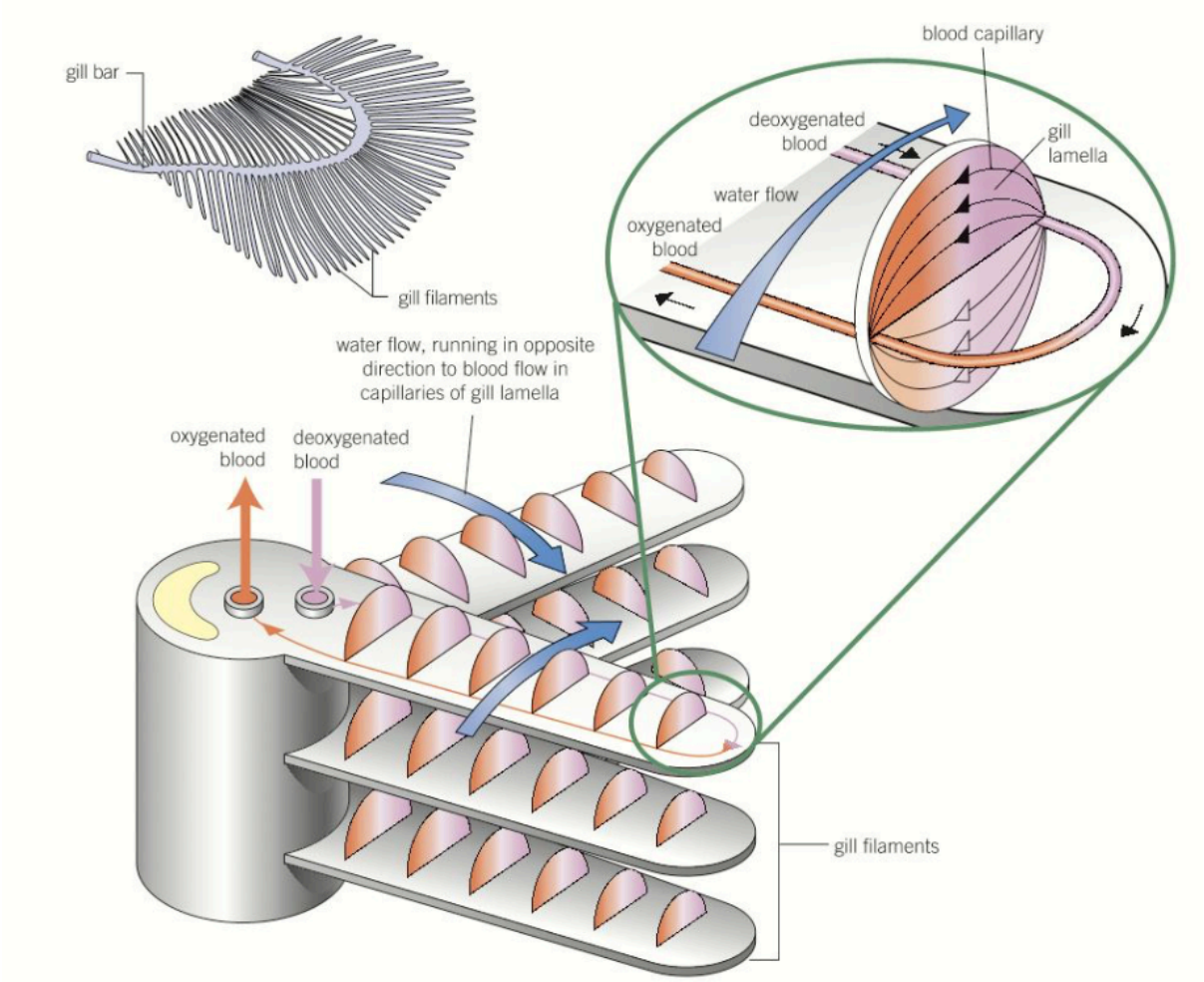
Gases enter and leave the trachea in tiny pores called spiracles on the body surface. These may be opened and closed by a valve. When they open, water vapour can evaporate from the insect. For much of the time insects keep their spiracles close to prevent water loss.

However this system does have limitations, as since the diffusion pathway always needs to be very short, it limits the size of which an insect can attain.

Gas exchange in fish:

Fish have a waterproof and gas-tight outer covering. They also have a relatively large surface area to volume ratio so cannot rely only on diffusion.

The structure of the gills is shown below:



The gills are located within the body of the fish, behind the head. They are made up of gill filaments, and these filaments are stacked up in a pile, like pages in a book. At right angles to the filaments are the gill lamellae, which increase surface area of the gills. Water is taken in through the mouth and forced over the gills and out through an opening on each side of the body.

It is clear from the picture above that the flow of water over the gill lamellae and the flow of blood within them are in opposite directions, known as the **countercurrent flow**. This concept is important in ensuring maximum gas exchange is achieved because it maintains a constant diffusion gradient.

The countercurrent exchange principle: the main idea is that blood and water flow in opposite directions, so blood that is already well loaded with oxygen will meet water, which its maximum concentration of oxygen, so diffusion from the water to the blood takes place. Blood with little oxygen in it meets water which has had most, but not all, of its oxygen removed, so diffusion from water to blood takes place of oxygen.

Gas exchange by the leaves of dicotyledonous plants:

All plant cells require oxygen and produce carbon dioxide during respiration. However some plant cells also carry out photosynthesis, and during photosynthesis plants take in carbon dioxide and produce oxygen. Gases produced in one reaction can be used in the other, so the relative rates of the different gases being exchanged in a plant depend on the balance of the rates of photosynthesis and respiration.

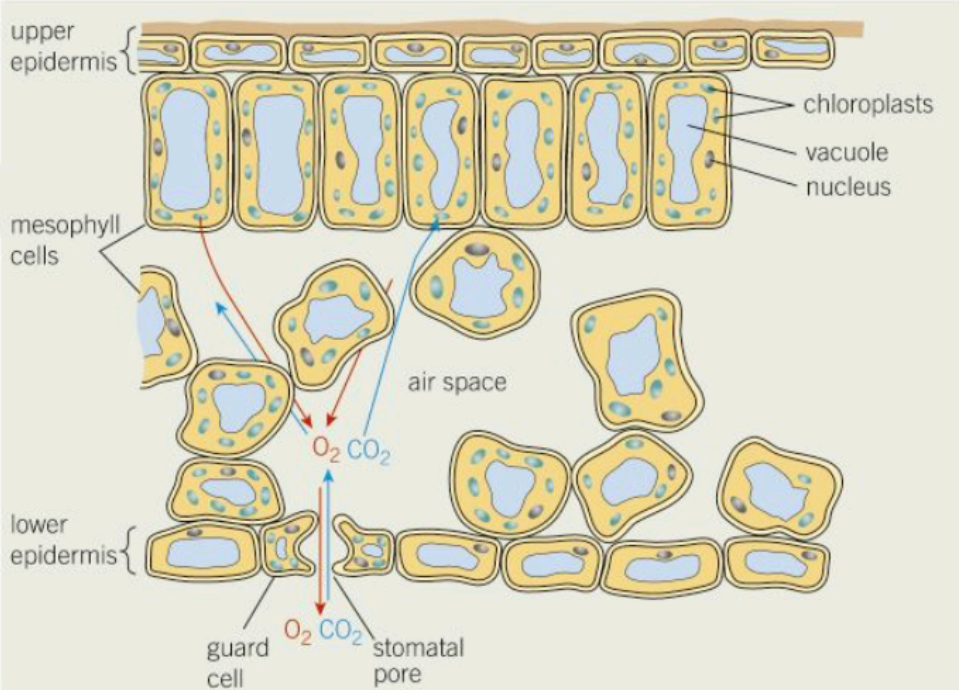
- When photosynthesis is taking place, although some carbon dioxide comes from respiration of cells, most of it is obtained from the external air. In the same way, some oxygen from photosynthesis is used up in respiration but most diffuses out of the plant.
- In the dark, when no photosynthesis occurs, oxygen diffuses into the lead because it is constantly being used by cells during respiration. In the same way, carbon dioxide produced during respiration diffuses out.

Gas exchange in plants in plants is similar to that in insects as no living cell is far from the external air, and so not far from a source of oxygen and carbon dioxide. Also diffusion takes place in air, which makes it more rapid than if it were in water.

Overall, there is a short and fast diffusion pathway. Also the air spaces within the leaf have a very large surface area compared with the volume of living tissue. There is no specific transport system for gases, which simply move in and through the plant by diffusion. However most gaseous exchange occurs in the leaves, which have the following adaptations for rapid diffusion:

- Many small pores, called stomata, and so no cell is far from a stoma and therefore the diffusion pathway is short
- Numerous interconnecting air-spaces that occur throughout the mesophyll so that gases can readily come in contact with mesophyll cells
- Large surface area of mesophyll cells for rapid diffusion

Stomata are small pores controlled by guard cells that occur mainly on the underside of the leaf. Each stoma (singular) is surrounded by a pair of special cells (guard cells), which control the rate of gaseous exchange by opening and closing the stoma. This is important in restricting water loss.



Limiting water loss

The features that make an efficient gas exchange system also increase water loss, so there is a paradox that needs to be resolved in order to limit water loss. This must be done without compromising the efficiency of the gas-exchange system.

Insects are predominantly found on land (terrestrial), thus water easily evaporates from the surfaces of their body which can dehydrate them. Insects have made the following adaptations to reduce water loss:

- Small surface area to volume ratio in order to minimise the area over which water is lost
- Waterproofing coatings over their body surfaces. In the case of insects this covering is a rigid outer skeleton of **chitin** that is covered with a waterproof cuticle
- **Spiracles** are openings at the **tracheae** at the body surface and these can be closed to reduce water loss. Although this conflicts with the need for oxygen and so occurs largely when the insect is at rest.

This means insects cannot use their body surface to diffuse respiratory gases in the way a single-celled organism does. Instead they have an internal network of tubes called tracheae that carry air containing oxygen directly to the tissues.

Plants are unable to have a small surface area to volume ratio as for photosynthesis, they require a large leaf surface area for the capture of light and for the exchange of gases. So in order to reduce water loss, terrestrial plants have a waterproof covering over parts of their leaves called a waxy cuticle. They can also close the stomata using guard cells. Plants that have restricted water supply have also evolved other adaptations to limit water loss through transpiration, these plants are called xerophytes.

Xerophytes are plants adapted to living in areas where water supply is short. Without these adaptations, plants would become desiccated and die.

Plants have the following adaptations in their leaves to limit water loss (as their leaves are the main source of water loss):

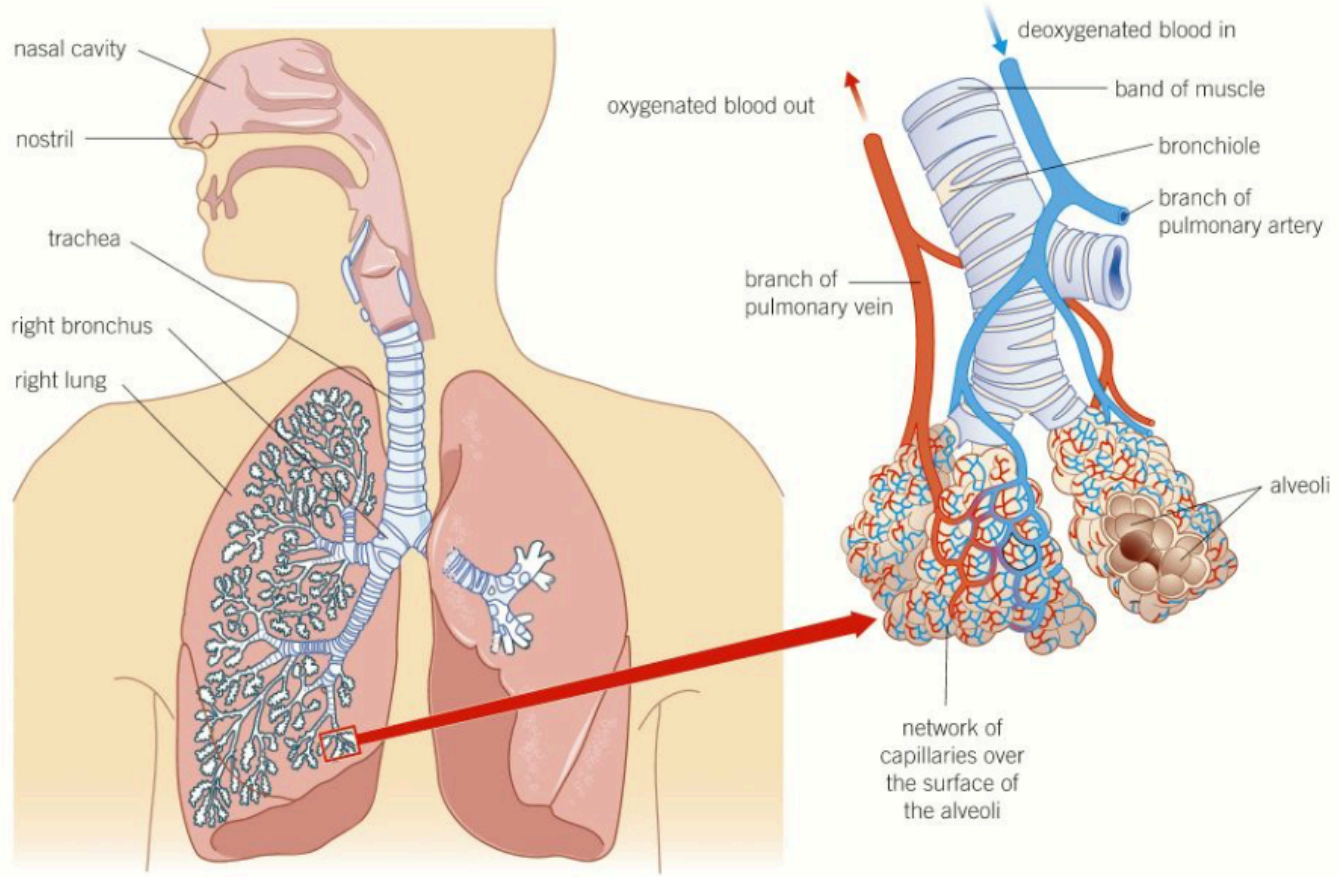
- A thick cuticle, although water can still escape it limits it drastically. Leaves like holly have a very thick cuticle so less water can escape by this means.
- Rolling up of leaves is another adaptation. Since stomata are almost exclusively found on the lower epidermis, the rolling of leaves traps a region of still air within this rolled part. This region becomes saturated with water vapour so has a high water potential. This means there is no water potential gradient so water cannot be lost.
- Hairy leaves are used, especially on the lower epidermis, to trap still moist air next to the leaf surface. The water potential gradient is reduced so less water is lost by evaporation.
- Stomata in **pits** or grooves again trap still, moist air next to the leaf and reduce the water potential gradient.
- A reduced surface area to volume ratio is also sometimes deployed. So for example in the leaves of pine trees, the leaves are thin and needle like to reduce water loss. We know that a reduced surface area to volume ratio decreases rate of diffusion, but it has to be balanced against a sufficient area for photosynthesis to meet the requirements of the plants.

The human gas-exchange system:

All aerobic organisms require a constant supply of oxygen to release energy in the form of ATP during respiration. The carbon dioxide produced in the process needs to be removed as its build up can be harmful to the body.

The volume of oxygen and carbon dioxide that must be removed in mammals is large because they are relatively large organisms with a large volume of living cells, also they maintain a high body temperature which is related to their high metabolic rates and respiratory rates.

Therefore, the lungs have evolved to ensure efficient gas exchange between the air and their blood.



The **lungs** are the site of gas exchange in mammals, and are located inside the body because air is not dense enough to support and protect these delicate structures, and the body as a whole would otherwise lose a great deal of water and dry out.

The lungs are supported and protected by the ribcage. The ribs can be moved by the muscles between them, and the lungs are ventilated by a tidal stream of air, ensuring that the air within them is constantly replenished. The main parts of the gas-exchange system are:

- The lungs, which are shown in the diagram above. They are made up of a series of branched tubules, called bronchioles, which end with tiny air sacs called alveoli
- The trachea is a flexible airway that is supported by rings of cartilage. The cartilage prevents the trachea from collapsing as the air pressure inside falls when breathing in. The tracheal walls are made up of muscle, lines with ciliated epithelium and goblet cells.
- The bronchi are two divisions of the trachea, each going to one lung. They are similar in structure to the trachea, and, like the trachea, also produce mucus to trap dirt particles and have cilia that move the dirt-laden mucus towards the throat. The larger bronchi are supported by cartilage, although the amount of cartilage reduces as the bronchi get smaller
- Bronchioles are a series of branching subdivisions of the bronchi. Their walls are made of muscle lined with epithelial cells. This muscle allows them to constrict so that they can control the flow of air in and out of the alveoli

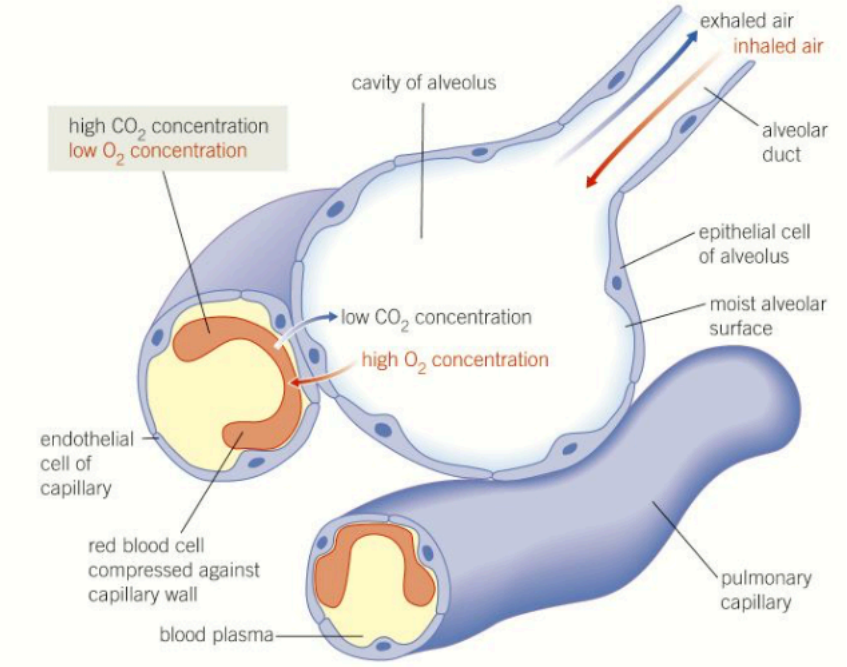
- The alveoli are small air sacs at the end of the bronchioles. Between alveoli are some collagen and elastic fibres. The alveoli are lined with epithelium and the elastic fibres allow the alveoli to stretch as they fill with air when breathing in. They then spring back during breathing out in order to expel the carbon dioxide rich air. The alveolar membrane is a gas exchange surface.

Gas exchange over epithelium of alveoli

A diffusion gradient must be maintained to ensure a constant supply of oxygen to the body, so exchange surfaces are kept thin, partially permeable and with a large surface area. To maintain the diffusion gradient, there also has to be movement of both the environmental medium and internal medium (air and blood for example). However, because the alveoli are so thin they can be easily damaged so are located within the organism for protection.

Surrounding the alveoli is a network of pulmonary capillaries, so narrow that red blood cells are flattened against the thin capillary walls in order to squeeze through. These capillary walls are one cell thick. Diffusion of gases between the alveoli and the blood will be very rapid because:

- Red blood cells are slowed as they pass through pulmonary capillaries, allowing more time for diffusion
- The distance between the alveolar air and red blood cells is reduced as the red blood cells are flattened against the capillary walls
- The walls of both alveoli and capillaries are very thin and therefore the distance over which diffusion takes place is very short
- Alveoli and pulmonary capillaries have a very large total surface area
- Breathing movements constantly ventilate the lungs, and the action of the heart constantly circulates blood around the alveoli. Together, these ensure that a steep concentration gradient of the gases to be exchanged is maintained
- Blood flow through the pulmonary capillaries maintains a concentration gradient



To maintain diffusion of gases across the alveolar epithelium, air is constantly moved in and out of the lungs. This process is called breathing (ventilation), as when the air pressure of the atmosphere is greater than that of the lungs, air moves in (inspiration). The opposite is expiration, where air is forced out of the lungs. The pressure changes are brought about by three muscles: the diaphragm (sheet of muscle separating the thorax from the abdomen), the intercostal muscles (they lie between the ribs), and internal/external intercostal muscles. The internal intercostal muscles contraction brings about expiration, and the external contraction brings about inspiration.

Inspiration: breathing in is an **active** process (uses energy).

- The external intercostal (EIC) muscles contract, while the internal intercostal (IIC) muscles relax.
- The ribs are pulled upwards and outwards, increasing volume in the **thorax**
- The diaphragm muscles contract, causing it to flatten, also increasing volume in the thorax
- The increased volume in the thorax results in reduction of pressure in the lungs
- Atmospheric pressure is now greater than pulmonary pressure, and so air is forced into the lungs.

Expiration: breathing out is mainly passive (requires little energy).

- The IIC muscles contract, while the EIC muscles relax
- The ribs move downwards and inwards, decreasing volume in the thorax
- The diaphragm muscles relax and so it is pushed up again by the contents of the abdomen that were compressed during inspiration. The volume of the thorax is therefore further decreased
- The decreased volume of the thorax increases the pressure in the lungs
- The pulmonary pressure is now greater than that of the atmosphere, so air is forced out of the lungs

During normal, quiet breathing, the recoil of elastic tissue in the lungs is the main cause of air being forced out. Only under strenuous conditions such as exercise do the various muscles play a major part.

AQA June 2014 Q4ab

Question:

Describe and explain how the countercurrent system leads to efficient gas exchange across the gills of a fish.

Answer:

1. Water and blood flow in opposite directions;
2. Maintains concentration/diffusion gradient / equilibrium not reached / water always next to blood with a lower concentration of oxygen;
3. **Along whole/length of gill/lamellae;**

Question:

Amoebic gill disease (AGD) is caused by a parasite that lives on the gills of some species of fish. The disease causes the lamellae to become thicker and to fuse together.

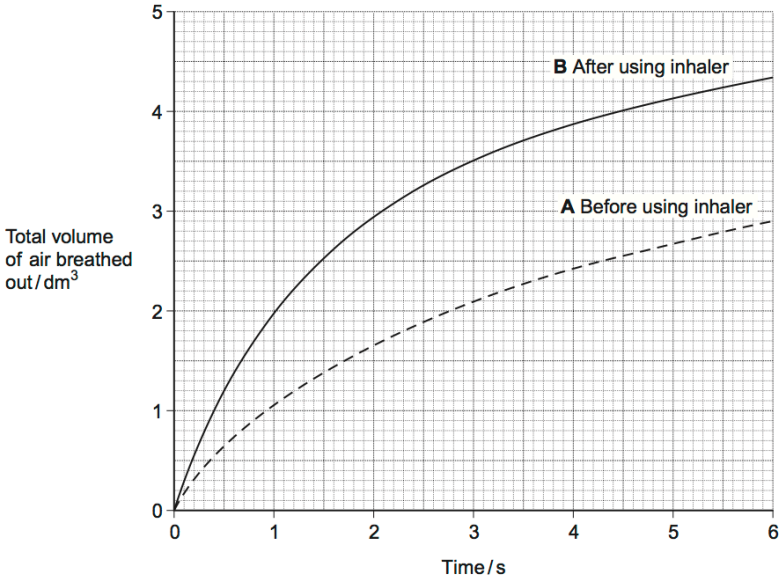
AGD reduces the efficiency of gas exchange in fish. Give **two** reasons why.

Answer:

1. (Thicker lamellae so) greater/longer diffusion distance/pathway;
2. (Lamellae fuse so) reduced surface area;

AQA Jan 2012 Unit 1 Q2b

A person with asthma breathed out as hard as he could. The graph shows the volume of air he breathed out in the first 6 seconds of a breath. Curve **A** shows the volume before he used an inhaler. Curve **B** shows the volume after he used an inhaler.



Question:

The diaphragm helps to bring about the changes shown by the curve **A**. Explain how.

Answer:

1. (Diaphragm/diaphragm muscle) relaxes/relaxed;
2. Domed shape / (diaphragm) moves up;
3. Increases pressure;
4. Decreases volume

Question:

You could use curve **A** to find the total volume of air that this person could breathe out in one complete breath. Describe how

Answer:

1. Extend/extrapolate curve/graph;
2. (Read off where) it flattens/ reaches maximum / peaks;

Question:

The inhaler which the person used contained a substance that dilates bronchioles. Use this information to explain why curve **A** is different from curve **B**

Answer:

1. (Without inhaler) narrower bronchioles / bronchioles not dilated;
2. Muscle (surrounding bronchioles) contracted;
3. Less air able to pass through / more difficult for air to pass through;

3.3.3 Digestion and absorption

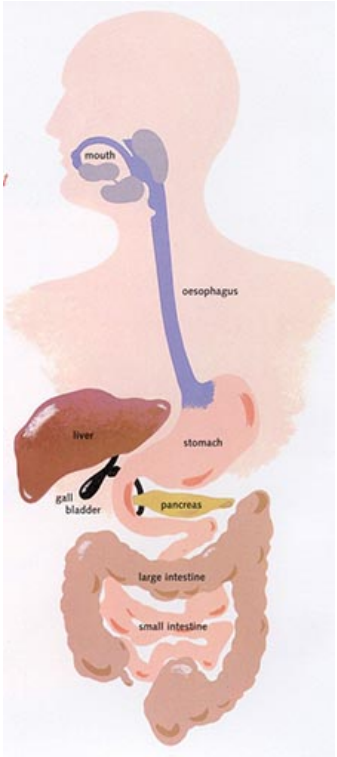
Content

- During digestion, large biological molecules are hydrolysed to smaller molecules that can be absorbed across cell membranes.
- Digestion in mammals of:
  - Carbohydrates by amylases and membrane-bound disaccharidases
  - Lipids by lipase, including the action of bile salts
  - Proteins by endopeptidases, exopeptidases and membrane-bound dipeptidases.
- Mechanisms for the absorption of the products of digestion by cells lining the ileum of mammals, to include:
  - Co-transport mechanisms for the absorption of amino acids and of monosaccharides
  - The role of micelles in the absorption of lipids

During digestion, large biological molecules are hydrolysed to smaller molecules than can be absorbed across cell membranes.

In mammals, carbohydrates are digested by amylases and membrane-bound disaccharidases. Lipids are digested by lipase, including the action of bile salts. Proteins are digested by endopeptidases, exopeptidases and membrane-bound dipeptidases.

The digestive system is responsible for hydrolysing large molecules into smaller molecules, and is an exchange surface through which food substances are absorbed. The main parts of the digestive system are given below:



- The **oesophagus** carries food from the mouth to the stomach
- The stomach is a muscular sac with an inner layer that produces enzymes. Its role is to store and digest food, especially proteins. It has glands that produce enzymes which digest proteins
- The ileum is a long muscular tube (the final part of the small intestine), food is further digested in the ileum by enzymes that are produced by its walls and by glands that pour their secretions into it. The inner walls of the ileum are folded into villi, which gives them a large surface area. The surface area of these villi is further increased by microvilli, on the epithelial cells of each villus.
- The large **intestine absorbs water,** most of the water that is being absorbed is from the secretions of the many digestive glands
- The rectum is the final section of the intestines. The faeces are stored here before periodically being removed by the anus in a process called egestion.
- The salivary glands are situated near the mouth, and they pass their secretion via a duct into the mouth. These secretions contain the enzymes amylase, which hydrolyses starch into maltose.
- The pancreas is a large gland situated below the stomach, it produces a secretion called **pancreatic juice.** This secretion contains proteases to hydrolyse proteins, lipase to hydrolyse lipids, and amylase to hydrolyse starch.

Digestion consists of physical breakdown and chemical breakdown.

Physical breakdown: This involves food being broken down by structures like teeth if the food is quite large. This breakdown results in a larger surface area for the chemical digestion. Food is also churned up by the muscles in the stomach wall and this also physically breaks it up.

Chemical breakdown: Chemical digestion hydrolyses large, insoluble molecules into smaller, soluble ones. It is carried out by enzymes, that all work by hydrolysis. Enzymes are specific and so usually more than one enzyme is required to fully hydrolyse a large molecule. These different types of enzymes include carbohydrases, lipase and proteases.

Carbohydrate digestion: It is important that enzymes are added to the food in the correct sequence, as certain enzymes will hydrolyse large molecules into smaller sections, then other enzymes will split these small sections into monomers.

The enzyme **amylase** is produced in the mouth and the pancreas, amylase hydrolyses the alternate glycosidic bonds of the starch molecule to produce the disaccharide maltose. This maltose is then hydrolysed into two units of alpha glucose by a second enzyme, a disaccharidase called **maltase.**

The process takes place as follows:

- Saliva enters the mouth from the salivary glands and is thoroughly mixed with the food during chewing
- Saliva contains **salivary amylase**. This starts hydrolysing any starch in the food to maltose. It also contains mineral salts that maintain optimum pH conditions for salivary amylase to work (neutral conditions)
- The food is swallowed and then enters the stomach, where the conditions are acidic. This acid **denatures** the amylase and prevents further hydrolysis of starch.
- After a time, the food is passed into the small intestine, where it mixes with the secretion from the pancreas called the **pancreatic juice**
- The pancreatic juice contains **pancreatic amylase** which continues to hydrolyse any remaining starch to maltose. Alkaline salts are produced by the pancreas and intestinal wall to maintain the pH at around neutral
- Muscles in the intestine wall push the food along the ileum. Its epithelial lining produces the disaccharide **maltase**. Maltase is not released into the lumen of the ileum but is part of the cell surface membranes of the epithelial cells that line the ileum. Therefore, it is referred to as a membrane-bound disaccharidase, and hydrolyses maltose into two alpha glucose units.

In addition to the digestion of maltose described above, there are two other disaccharides in the diet that are hydrolysed – sucrose and lactose.

Sucrose if found in many natural foods like fruits, and lactose is found in milk. Each disaccharide is hydrolysed by a membrane-bound disaccharidase.

- **Sucrase** hydrolyses the single glycosidic bond in the sucrose molecule. It produces glucose and fructose

- **Lactase** hydrolyses the single glycosidic bond in the lactose molecule. This hydrolysis produces the two monosaccharides glucose and galactose

Lipid digestion: These are hydrolysed by lipases. These lipases are produced in the pancreas, and hydrolyse the ester bond found in triglycerides to from fatty acids and monogylcerides. A monogylceride is a glycerol molecule with a single fatty acid molecule attached. Lipids are firstly split into tiny droplets called **micelles** by **bile salts** (produced in the liver). This process is called **emulsification** and increases the surface area of lipids so that the action of lipases is speeded up.

Protein digestion: Proteins are large, complex molecules that are hydrolysed by a group of enzymes called **peptidases** (proteases). There are a number of different peptidases:

- **Endopeptidases** hydrolyse the peptide bonds between amino acids in the central region of a protein molecule forming a series of peptide molecules.
- **Exopeptidases** hydrolyse the peptide bonds on the terminal amino acids of the peptide molecules formed by endopeptidases, in this way they progressively release dipeptides and single amino acids
- **Dipeptidases** hydrolyse the bond between the two amino acids of a dipeptide. Dipeptidases are membrane-bound, being part of the cell-surface membrane of the epithelial cells lining the ileum

The **ileum** and the absorption of products of digestion.

The wall of the ileum is folded and possesses finger-like projections, about 1mm long, called villi. They have thin walls lined with epithelial cells, on the other side of which is a rich network of blood capillaries.

Villi can be found at the interface between the lumen of the intestines, and the blood and other tissues in the body. Their properties increase efficiency of absorption in the following ways:

- Increase surface area for diffusion
- They are thin walled, thus reducing the distance over which diffusion takes place
- They contain muscle and so are able to move, helping to maintain a diffusion gradient because their movement mixes the contents of the ileum. This ensures that as the products of digestion are absorbed from the food adjacent to the villi, new material rich in the products of digestion replaces it.
- They are well supplied with blood vessels so that blood can carry away absorbed molecules and hence maintain a diffusion gradient
- The epithelial cells lining the villi possess microvilli, which again increase surface area for absorption

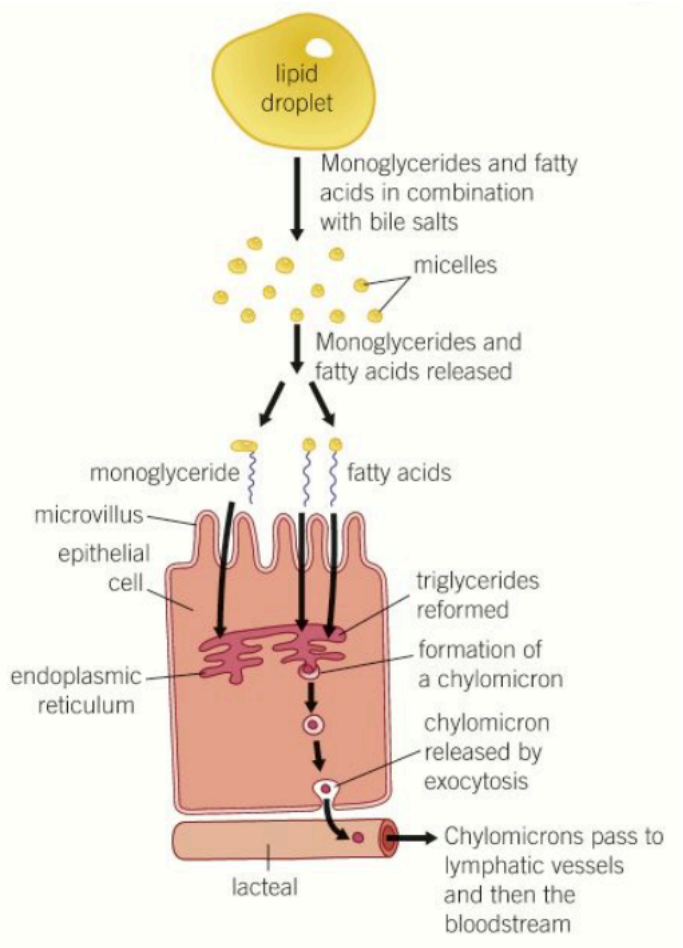
The ileum absorbs **amino acids** and **monosaccharides** in the same way, by diffusion and co-transport.

The absorption of **triglycerides**: monogylcerides and fatty aids remain in association with the bile salts that initially emulsified the lipid droplets. The structures formed are micelles, which are very small structures. Through the movement of material within the lumen of the ileum,

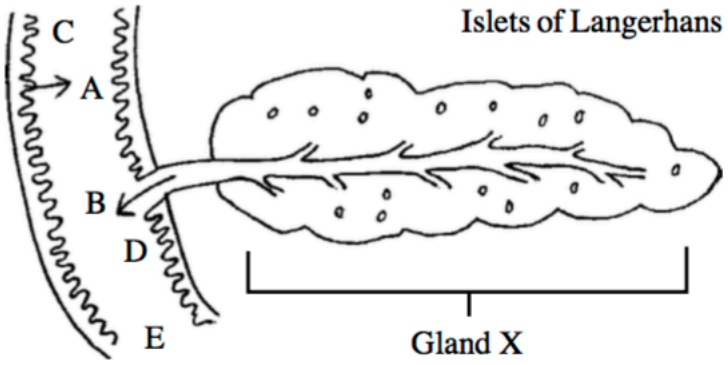
the micelles come into contact with the epithelial cells lining the villi of the ileum. Here, the micelles break down and release monogylcerides and fatty acids. As these are non-polar molecules, they can easily diffuse across the cell-surface membrane into the epithelial cells.

Once inside the epithelial cells, monogylcerides and fatty acids are transported to the endoplasmic reticulum where they are recombined to form triglycerides. Starting in the endoplasmic reticulum, and then continuing in the Golgi apparatus, the triglycerides associate with cholesterol and lipoproteins to form structures called **chylomicrons**. These structures are special particles adapted for the transport of lipids.

Chylomicrons move out of epithelial cells by exocytosis, and enter the lymphatic capillaries called lacteals that are found at the centre of each villus.



2. The diagram below shows part of the human digestive system:



(a) Name gland X as shown on the diagram (1 mark)

(b) Name secretions A and B (2 marks)

(c) These secretions contain enzymes concerned with the digestion of carbohydrates. Name **two** such enzymes present in A and **one** such enzyme present in B. (3 marks)

Answers

Marking points are shown by semicolons

1. pyloric sphyncter;
   chyme;
   duodenum;
   secretin;
   intestinal juice/pancreatic juice;

2. (a) pancreas;

   (b) A = intestinal juice (succus entericus);
   B = pancreatic juice;

   (c) A = Maltase;
   Lactase;
   Sucrase;

   B = Amylase

AQA June 2013 Q6b

Question:

'The concentration of glucose in the blood rises after eating a meal containing carbohydrates.

The rise is slower if the carbohydrate is starch rather than sucrose. Explain why.'

Answer:

1. Starch digested to maltose/by amylase;
2. Maltose digested to glucose/by maltase;
3. Digestion of sucrose is a single step/only one enzyme/sucrase;

AQA June 2013 Q7a

'Read the following passage.

Microfold cells are found in the epithelium of the small intestine. Unlike other epithelial cells in the small intestine, microfold cells do not have adaptations for the absorption of food.

Microfold cells help to protect against pathogens that enter the intestine. They have receptor proteins on their cell-surface membranes that bind to antigens on the surface of pathogens. The microfold cells take up the antigens and transport them to cells of the immune system. Antibodies are then produced which give protection against the pathogen.

Scientists believe that it may be possible to develop vaccines that make use of microfold cells. These vaccines could be swallowed in tablet form.

Use information from the passage and your own knowledge to answer the following questions.'

Question:

Microfold cells do not have adaptations for the absorption of food (lines 2 - 3). Give **two** adaptations that other epithelial cells have for the absorption of food'

Answer:

1. Microvilli; (Accept large surface area)
2. Carrier proteins/co-transport proteins/membrane-bound enzymes;
3. Many mitochondria;

AQA Jan 2013 Unit 1 Q4a

Question:

Cholera bacteria produce toxins which increase secretion of chloride ions into the lumen of the intestine.

Explain why this results in severe diarrhoea (watery faeces).

Answer:

1. Water lost into gut/water moves into gut/ water leaves cells;
2. Low(er) water potential of intestine/gut (lumen);
3. Osmosis/movement down a WP gradient;
4. Less/not enough water (re)absorbed;

AQA Jan 2009 Unit 1 Q7a

Question:

Describe how lipids are digested and absorbed in the ileum.

Answer:

Bile increases SA / Emulsification;

Bile creates alkaline conditions / optimum pH (for lipase)

Lipase produces fatty acids and glycerol;

Diffusion into epithelial cells;

Lipids / Micelles / chylomicrons enter lacteal / lymph capillary;

3.3.4 Mass Transport

3.3.4.1 Mass transport in animals

Content

- The haemoglobins are a group of chemically similar molecules found in many different organisms. Haemoglobin is a protein with a quaternary structure.
- The role of haemoglobin and red blood cells in the transport of oxygen. The loading, transport and unloading of oxygen in relation to the oxyhaemoglobin dissociation curve. The cooperative nature of oxygen binding to show that the change in shape of haemoglobin caused by binding of the first oxygens makes the binding of further oxygens easier. The effects of carbon dioxide concentration on the dissociation of oxyhaemoglobin (the Bohr effect).
- Many animals are adapted to their environment by possessing different types of haemoglobin with different oxygen transport properties.
- The general pattern of blood circulation in a mammal. Names are required only of the coronary arteries and of the blood vessels entering and leaving the heart, lungs and kidneys.
- The gross structure of the human heart. Pressure and volume changes and associated valve movements during the cardiac cycle that maintain a unidirectional flow of blood.
- The structure of arteries, arterioles and veins in relation to their function.
- The structure of capillaries and the importance of capillary beds as exchange surfaces. The formation of tissue fluid and its return to the circulatory system.
- **Students should be able to:**
    - Analyse and interpret data relating to pressure and volume changes during the cardiac cycle
    - Analyse and interpret data associated with specific risk factors and the incidence of cardiovascular disease
    - Evaluate conflicting evidence associated with risk factors affecting cardiovascular disease
    - Recognise correlations and causal relationships.

Haemoglobins are a group of chemically similar molecules found in many different organisms. Haemoglobin is a protein with quaternary structure, and has evolved to become more efficient in loading oxygen under one set of conditions, and unloading under another set of conditions, as well as the general transport of oxygen. It is made of four polypeptide chains where each of these contains a haem group, containing a ferrous ion (iron). These can each combine with a single oxygen molecule.

Loading and unloading oxygen: loading takes place in the lungs, and unloading in tissues (in humans). Haemoglobins with a higher affinity for oxygen will take up oxygen more easily, but release it less easily. The opposite can be said for haemoglobin with a low affinity for oxygen. The combination of haemoglobin and oxygen is called **oxyhaemoglobin**. Moreover, when the first oxygen molecule binds to haemoglobin, it causes a conformational change in the shape of haemoglobin which makes further oxygen binding easier. High concentrations of carbon dioxide cause the dissociation of oxygen, a useful adaptation for when muscles are respiring aerobically rapidly and require large amounts of oxygen. This

effect of carbon dioxide is called the Bohr effect. Essentially haemoglobin need to be adapted for efficient association with oxygen at gas exchange surfaces, and dissociation at tissues requiring it.

Region of body	Oxygen concentration	Carbon dioxide concentration	Affinity of haemoglobin for oxygen	Result
gas exchange surface	high	low	high	oxygen is associated
respiring tissues	low	high	low	oxygen is dissociated

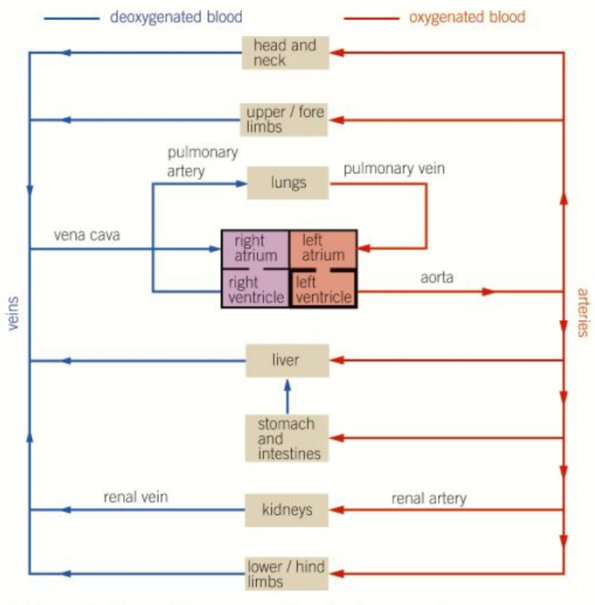
Different animals have different variations of the haemoglobin molecule depending on their oxygen transport properties and requirements. Each species produces a haemoglobin with a slightly different amino acid sequence, so the haemoglobin of these species therefore have a different tertiary and quaternary structure. Thus they have different oxygen binding properties, with some having a higher affinity for oxygen than others.

Transport systems are required in mammals because diffusion alone would be insufficient to absorb nutrients and respiratory gases, and to remove excretory products. Specialised exchange surfaces are required for transfer from cells to exchange surfaces, and exchange surfaces and cells. Surface area to volume ratio and the relative activity of an organism decide whether specialised exchange surfaces are required.

Features of transport systems: They must have a suitable medium to carry materials ie blood, and is usually a water based substance, but can be a gas such as air. They require a form of mass transport in which the transport medium is moved around in bulk over large distances, more rapid than diffusion. A closed system of tubular vessels that contains the transport medium and forms a branching network to distribute it to all parts of the organism. A mechanism for moving the transport medium through vessels, requiring a pressure difference.

Circulatory system in mammals: There is a closed, double circulatory system in which blood is confined to vessels and passes twice through the heart for each complete circuit of the body. This is because the pressure of blood as it comes out of the lungs is low, so blood would not be able to reach the extremities of the body. Blood is returned to the heart and its pressure is boosted before being circulated to the rest of the tissues.

The overview of the structure of the blood circulatory system in mammals is shown below.



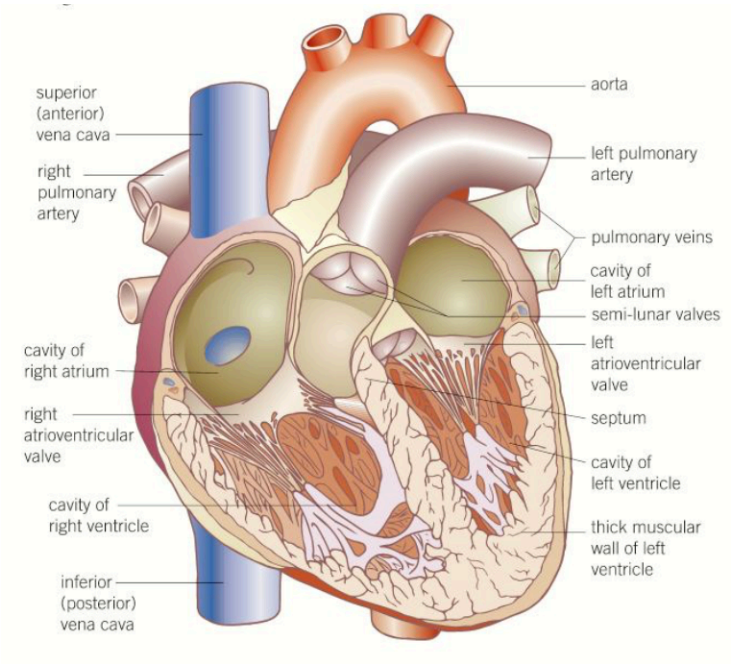
The **heart** is essentially made up of two pumps, one transporting oxygenated blood, one deoxygenated. The atrium is thin walled and elastic, stretching as it collects blood. The ventricle has a much thicker muscular wall as it has to contract strongly to pump blood some distance, either to the lungs or the extremities of the body. The large pressure drop is due to blood passing through tiny capillaries, which increase surface area for exchange of gases, and blood transport would be too slow if blood weren't returned to the heart first. The atria and ventricles contract simultaneously, and are separated by atrioventricular valves, these prevent backflow of blood.

Aorta: connected to the left ventricle carrying oxygenated blood to all parts of the body except the lungs

Vena cava: connected to the right atrium and brings deoxygenated blood back from the tissues of the body.

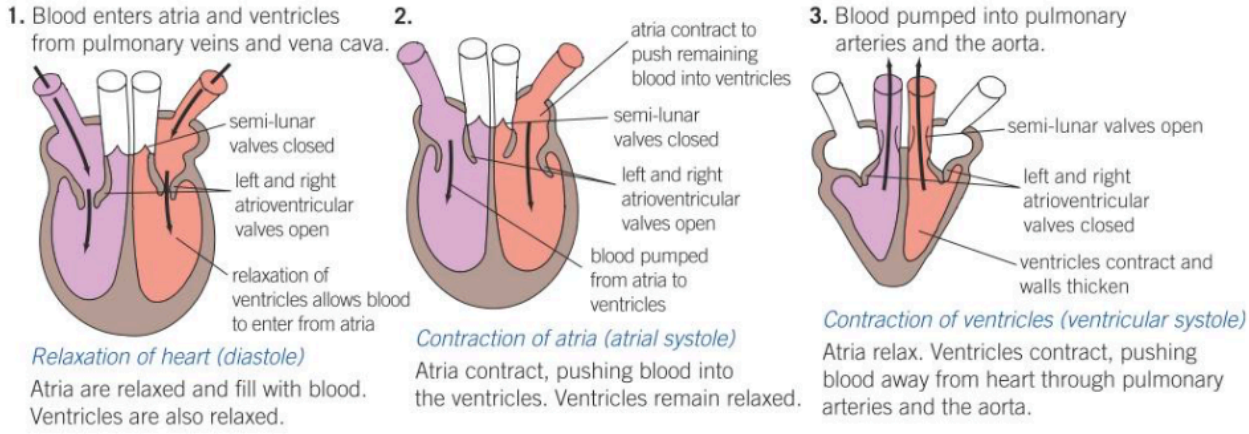
Pulmonary artery: connected to the right ventricle and carries deoxygenated blood to the lungs, where its oxygen is replenished and its carbon dioxide removed. Unusually for the artery, it carries deoxygenated blood.

Pulmonary vein: connected to the left atrium and brings oxygenated blood back from the lungs, and unusually for a vein carries oxygenated blood.



The heart has its own blood vessels called coronary arteries which branch off the aorta shortly after leaving the heart. Blockage of these leads to myocardial infarction, otherwise known as a heart attack, because an area of the heart muscle is deprived of blood and therefore oxygen. The muscle cells cannot respire aerobically so die.

The Cardiac Cycle



There are two main phases to the beating of the heart: contraction, systole, and relaxation, diastole. Contraction occurs separately in the ventricles and the atria and is described in two stages. For some of the time, relaxation takes places simultaneously in all chambers of the heart, and is therefore treated as a single phase in the point below.

Relaxation of the heart (diastole) – blood returns to the atria of the heart through the pulmonary vein (from the lungs) and vena cava (from the body). As the atria fill, the pressure in them rises, and when this pressure exceeds the pressure in the ventricles, the atrioventricular valves open allowing blood to pass into the ventricles. The passage of blood is also aided by gravity.

The walls of the atria and ventricles are all relaxed at this point. The relaxation of the ventricle walls causes them to recoil and reduces the pressure within the ventricle. This causes the pressure to be lower than that in the pulmonary artery and aorta, so the semi-lunar valves in the aorta and the pulmonary artery close, accompanied by the first characteristic 'lub' sound of the heart.

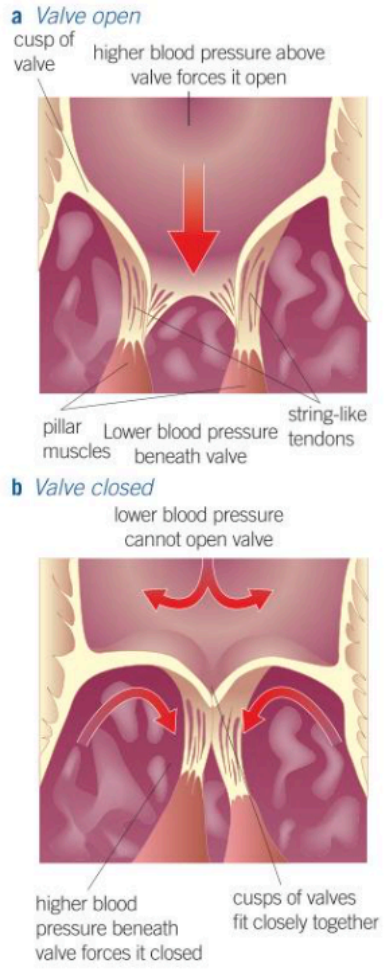
Contraction of the atria (atrial systole) – the contraction of the atrial walls, along with the recoil of the relaxed ventricle walls, forces the remaining blood into the ventricles from the atria. Throughout this stage the muscle of the ventricle walls remains relaxed.

Contraction of the ventricles (ventricular systole) – there is a short gap to allow the ventricles to fill completely, then the walls of the ventricles contract concurrently. This has the effect of increasing the blood pressure within them, and forces shut the atrioventricular valves to prevent backflow of blood into the atria. The second 'dub' sound of these valves closing is a characteristic of the heart beat. Now the atrioventricular valves are closed, the pressure in the ventricles rises further. When the pressure in the ventricles has exceeded that of the pulmonary artery and aorta, blood is forced from each ventricle into these blood vessels. The ventricles have thick muscular walls, however the wall of the left ventricle has more muscle. This is because the left ventricle has to pump blood to the extremities of the body, whereas the right ventricle pumps only to the lungs. This muscle allows a higher pressure to be generated.

Valves – these allow the blood to keep flowing in the correct direction throughout the heart a circulatory system. Valves work alongside the pressure generated by the ventricles to move blood from regions of high pressure to ones of lower pressure. Although when the pressure difference is such that the blood would begin to flow in an undesirable direction, the valves push shut to prevent backflow of blood. Examples of valves in the circulatory system are given below:

- Atrioventricular valves – these appear between the atria and ventricles. They ensure that blood travels to the pulmonary artery and aorta respectively, by ensuring there is no backflow of blood in the atria.
- Semi-lunar valves – these are found in the pulmonary artery and aorta. They prevent backflow of blood into the ventricles.
- Pocket valves – found in veins, ensuring that when veins are pressed down, ie when skeletal muscles contract, blood flows back towards the heart rather than away from it.

The valves all have pretty much the same design, and are made up of a number of flaps of tough, but flexible, fibrous tissue, which are cusp-shaped. Their design is shown below.

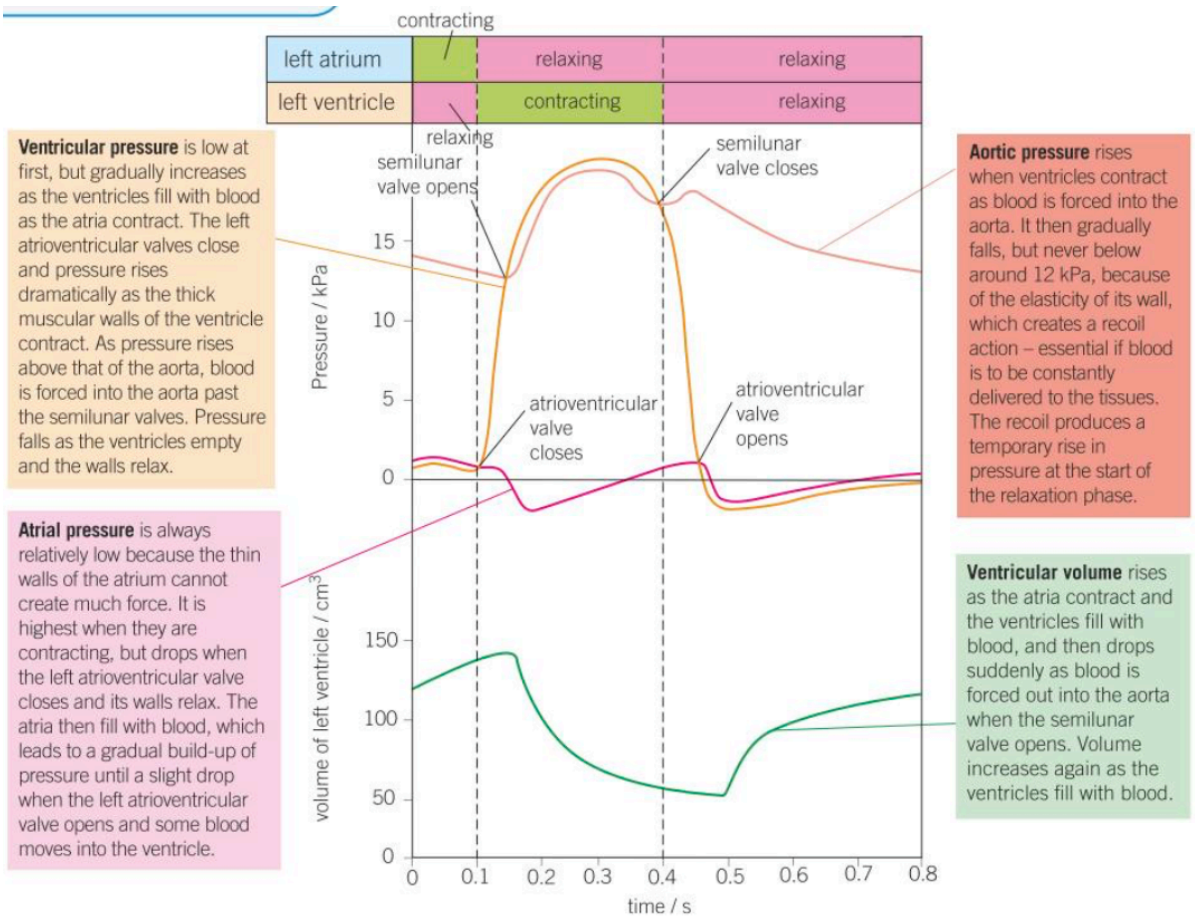


Since the blood system is closed, it allows the pressure within the vessels to be maintained easily.

Cardiac output is the volume of blood pumped by **one** ventricle of the heart, in one minute. It is calculated by multiplying the heart rate by the stroke volume.

Cardiac output = heart rate x stroke volume

The heart rate is the number of beats per unit time, usually per minute. The stroke volume is the volume of blood pumped out for each contraction of the heart.



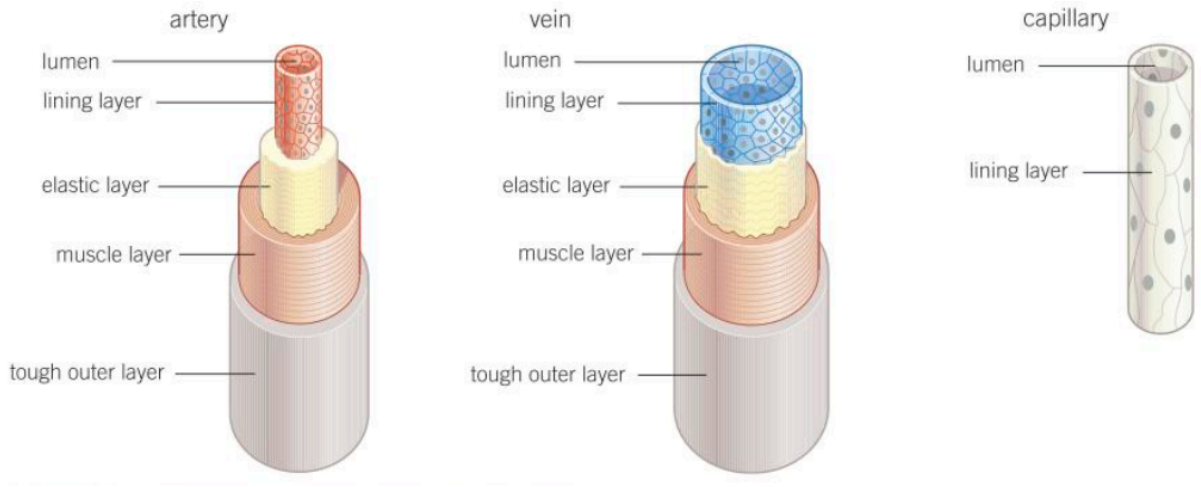
The graph above is quite complex, but remember that pressure and volume are inversely related in this situation, where PV = constant. Thus pressure decreases cause volume increases. Also, blood moves down a pressure gradient, which can also be used to simplify the graph.

We already know that the four blood vessels within the heart are; arteries, arterioles, capillaries and veins. The arteries carry blood away from the heart and into arterioles. Arterioles are smaller arteries that control blood flow from arteries to capillaries. Capillaries are tiny vessels that link arterioles to veins. Veins carry blood from capillaries back to the heart. Also, capillaries are the only vessels to carry out exchange of materials.

They have the same structure in terms of order of layers, except capillaries. This common structure is outlined below:

- Tough fibrous outer layer – resists pressure changes from both within and outside
- Muscle layer – can contract and so control the flow of blood
- Elastic layer – helps the maintain blood pressure by stretching and springing back (recoiling). This layer is not muscle, it will not contract or relax.
- Thin inner lining (endothelium) that is smooth, this reduces friction, and thin the to allow diffusion
- Lumen – that is not actually a layer but the central cavity of the blood vessel through which the blood flows.

The difference between the layers is the relative proportions of each layer. The differences are shown in the diagram below.



Arterioles are very similar to arteries, so are not included in the diagram. Arterioles differ in that they are smaller in diameter than arteries, and have a relatively large muscle layer and lumen. The difference in structure is related to their individual functions.

Artery structure related to its function – the arteries serve the purpose of transporting blood rapidly under high pressure from the heart to the tissues. Their structure is adapted to this function as follows.

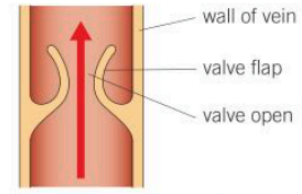
- The muscle layer is thick relative to veins. This means smaller arteries can be constricted and dilated in order to control the volume of blood passing through them.
- The elastic layer is relatively thick compared to veins. This is because it is important pressure in the arteries is kept high if blood is to reach the extremities of the body. The elastic wall is stretched at each beat of the heart (systole). It then springs back when the heart relaxes (diastole) in the same way as a stretched elastic band. This stretch and recoil action helps to maintain high pressure, and smooth pressure surges created by the heart beating.
- The overall thickness of the wall is great. This also resists the vessel bursting under pressure
- There are no valves (except the arteries leaving the heart), as blood is always under high pressure thus tends not to flow backwards.

Arteriole structure related to function – arterioles carry blood, under lower pressure than arteries, from arteries to capillaries. They also control the flow of blood between the two, and their structure is related to the functions given below:

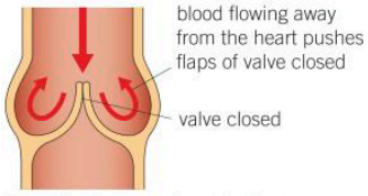
- The muscle layer is relatively thicker than in arteries. The contraction of this muscle layer allows constriction of the lumen of the arteriole, to restrict the flow of blood and so control its movement into the capillaries that supply the tissues with blood
- The elastic layer is relatively thinner than in arteries because pressure in the vessel is lower.

Vein structure related to function – These vessels transport blood slowly, under low pressure, from the capillaries in tissues to the heart. Their structure is related to this function as follows:

- The muscle layer is relatively thin compared to arteries because veins carry blood away from tissues, so their constriction and dilation cannot control the flow of blood to the tissues
- The elastic layer is relatively thin compared to arteries because the low pressure of blood within the veins will not cause them to burst and pressure is too low to create a recoil action.
- The overall thickness of the wall is small because there is no need for a thick wall as the pressure within the veins is too low to create any risk of bursting. It also allows them to be flattened easily, aiding the flow of blood within them
- There are valves at intervals throughout to ensure that blood does not flow backwards. This backflow of blood would occur because of an insufficient pressure gradient in the correct direction. When body muscles contract, veins are compressed, pressurising the blood within them. The valves ensure that this pressure directs the blood in one direction only: towards the heart.



Blood flowing towards the heart passes easily through the valves.



Blood flowing away from the heart pushes valves closed and so blood is prevented from flowing any further in this direction.

Capillary structure related to function – the function of capillaries is to exchange metabolic materials like oxygen, carbon dioxide, glucose, between the blood and the cells of the body. The flow of blood in capillaries is much slower, allowing time for exchange of materials.

- Their walls consist mostly of the lining layer – making them extremely thin, so the distance over which diffusion takes place is short. This allows for rapid diffusion of materials between the blood and cells
- They are numerous and highly branched to provide a large surface area for exchange
- They have a very small diameter compared with the other vessels. Thus they permeate tissues, so no cell is far from a capillary, also ensuring a short diffusion pathway.
- Their lumen is very narrow, with a diameter the same as that of red blood cells. This brings the aforementioned red blood cells even closer to the cells to which they supply oxygen.
- There are spaces between the lining (endothelial) cells, allowing white blood cells to escape in order to deal with infections within tissues.

The diagram below shows a 'capillary bed', whose formation results from a network of capillaries between arterioles and venules. (Venules are very small veins that collect blood from the capillaries to return to the heart). These 'beds' serve as exchange sites between the blood and tissue fluid (interstitial fluid). The capillaries cannot serve each individual cell directly, thus the final part of the journey is completed by said **tissue fluid (interstitial fluid).**

Tissue fluid is a watery liquid that contains glucose, amino acids, fatty acids, ions in solution and oxygen. Tissue fluid supplies all of these substances to tissues, and the subsequent cells. In return, it receives carbon dioxide and other waste materials from the tissues. Tissue fluid bathes all of the cells of the body, it is their immediate environment, where they live. Tissue fluid is formed from blood plasma. The composition of blood plasma is controlled by various homeostatic systems. As a result, tissue fluid provides a mostly constant environment for the cells it surrounds.

Formation of tissue fluid – blood pumped by the heart passes along arteries, then the narrower arterioles and, finally, the even narrower capillaries. Pumping by the heart creates **hydrostatic pressure** at the arterial end of the capillaries. This hydrostatic pressure causes tissue fluid to move out of the blood plasma. The outward pressure is, however, opposed by two other forces:

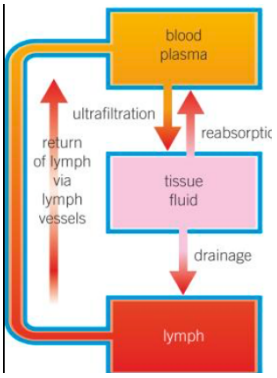
- Hydrostatic pressure of the tissue fluid outside the capillaries, which resists outward movement of liquid
- The lower water potential of the blood, due to the plasma proteins, causing water to move back into the blood within the capillaries.

However, the combined effect of all these forces creates an overall pressure that pushed tissue fluid out of the capillaries at the arterial end. This pressure is only enough to force small molecules out of the capillaries, leaving all cells and proteins in the blood (they are also too large to cross the membranes). This type of filtration under pressure is called ultrafiltration.

Return of tissue fluid – once tissue has been exchanged the metabolic materials with the cells it bathes, it is returned to the circulatory system. Most tissue fluid returns to the blood plasma directly via capillaries, however some is returned via the **lymphatic system**.

This system begins in the tissues, initially resembling capillaries. They gradually merge into larger vessels that form a network throughout the body. These larger vessels drain their contents back into the bloodstream via two ducts that join veins close to the heart.

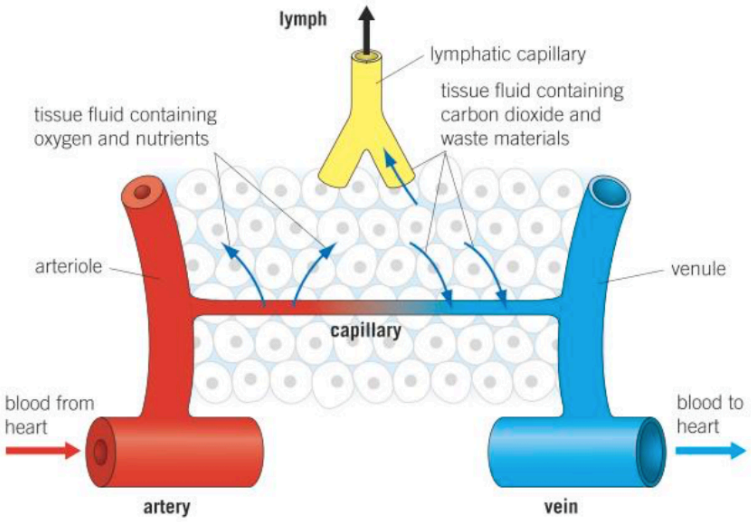
The diagram to the right shows the passage of the contents of the lymphatic system. The contents are not moved by the heart, instead by hydrostatic pressure of the tissue fluid leaving the capillaries. Also by contraction of body muscles, that squeeze lymph vessels. Also, valves in these lymph vessels prevent backflow of the fluid.



The return via the capillaries is summarised below:

- The loss of the tissue fluid from the capillaries reduces the hydrostatic pressure inside them
- As a result, by the time the blood has reached the venous end of the capillary network its hydrostatic pressure is usually lower than that of the tissue fluid outside it
- Therefore, tissue fluid is force back into the capillaries by the higher hydrostatic pressure outside them
- In addition, the plasma has lost water and still contains proteins, therefore it has a lower water potential than the tissue fluid, forming a gradient down which the fluid, water, can move (by osmosis).

The tissue fluid however, has now lost a lot of its oxygen and nutrients as they have diffused into the cells. It has however, gained carbon dioxide and waste materials in return.



Past paper question related to tissue fluid:

AQA June 2012 Unit 2 Q8c

'Describe how tissue fluid is formed and how it is returned to the circulatory system'

- Formation:

1. High blood / hydrostatic pressure / pressure filtration;
2. Forces water / fluid out;
3. Large proteins remain in capillary;

Return:

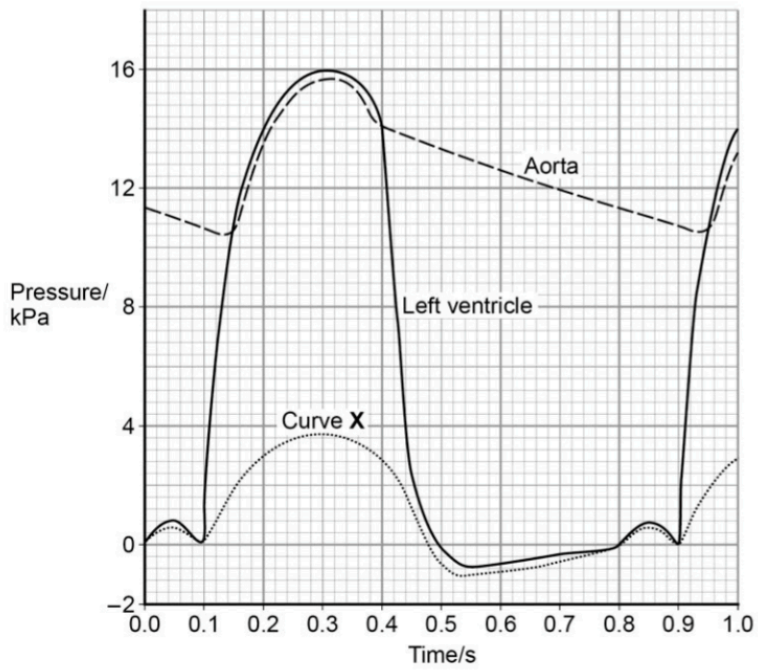
1. Low water potential in capillary / blood;
2. Due to (plasma) proteins;
3. Water enters capillary / blood;
4. (By) osmosis;
5. Correct reference to **lymph**;

AQA International 2018 Specimen

Question:

Figure 3 shows changes in pressure in the aorta and different parts of the heart during a period of one second

Figure 3



At what time do the semilunar valves close?

Answer:

0.4s (Recall that the semi-lunar valve opens when pressure in (left) ventricle surpasses pressure in aorta/pulmonary artery and forces blood through)

Question:

Use **figure 3** to calculate the heart rate in beats per minute. Show your working.

Answer:

60/0.8 = 75bpm (Time between ventricle starting to fill = 0.8s; shown by the initial increase in pressure in the ventricle, to when it begins to fill again, after one complete cycle of diastole and systole).

Question:

What does curve **X** represent? Explain your answer.

Answer

- Right ventricle;
- Same pattern / description (as left ventricle) but lower (pressure)

(Recall that the ventricles contract from the apex upwards simultaneously (via SAN, AVN, down the Bundle of His to Purkyne Fibres). Since both curves peak at the same time, it must be the right ventricle. Recall also, that the left ventricle has thicker muscular walls. This means it can contract with more force and push blood under higher pressure relative to the right ventricle, in order for blood to reach the extremities of the body)

Question:

Doctors measured the thickness of the walls of three blood vessels connected to the heart in a large group of people. Their results are given in the table.

Name of vessel	Mean wall thickness /mm ± standard deviation
Aorta	5.7 ± 1.2
Pulmonary artery	1.0 ± 0.2
Pulmonary vein	0.5 ± 0.2

Explain the difference in thickness between the pulmonary artery and the pulmonary

Answer:

High pressure / smoothes out blood flow / artery wall
contains more collagen / muscle / elastic (fibres) / connective tissue;

Accept converse for pulmonary vein Incorrect function of artery disqualifies mark

Question:

The thickness of the aorta wall changes during each cardiac cycle. Explain what causes the change.

Answer:

(Aorta wall) stretches;

1. Allow expand
2. Because ventricle / heart contracts / systole / pressure increases;
3. (Aorta wall) recoils;
4. Allow spring back
5. Because ventricle relaxes / heart relaxes / diastole / pressure falls;
6. Maintain smooth flow / pressure;

AQA June 2012 Unit 1 Q8a

Question:

a) The heart controls and coordinates the regular contraction of the atria and ventricles. Describe how.

Answer:

- SAN → AVN → bundle of His /Purkyne fibres;
- Impulses / electrical activity (over atria);
- Atria contract;
- Non-conducting tissue (between atria and ventricles);
- Delay (at AVN) ensures atria empty/ ventricles fill before ventricles contract;
- Ventricles contract from apex upwards

AQA June 2012 Unit 2 Q8c

Question:

'Describe how tissue fluid is formed and how it is returned to the circulatory system'

Answer:

- Formation:

4. High blood / hydrostatic pressure / pressure filtration;
5. Forces water / fluid out;
6. Large proteins remain in capillary;

Return:

6. Low water potential in capillary / blood;
7. Due to (plasma) proteins;
8. Water enters capillary / blood;
9. (By) osmosis;
10. Correct reference to lymph;

AQA June 2013 Unit 1 Q8ab

Question:

'Describe how a heartbeat is initiated and coordinated'

Answer:

1. SAN sends wave of electrical activity / impulses (across atria) causing atrial contraction;
2. Non-conducting tissue prevents immediate contraction of ventricles/prevents impulses reaching the ventricles;
3. AVN delays (impulse) whilst blood leaves atria/ventricles fill;
4. (AVN) sends wave of electrical activity / impulses down Bundle of His;
5. Causing ventricles to contract from base up;

Question:

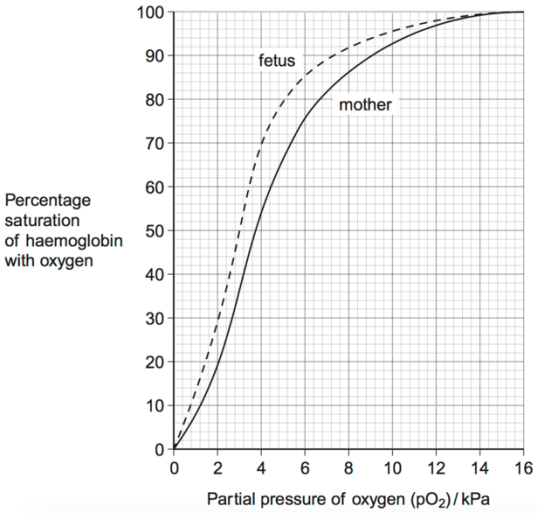
'Explain how the heart muscle and the heart valves maintain a one-way flow of blood from the left atrium to the aorta.

Answer:

1. Atrium has higher pressure than ventricle (due to filling/contraction);
2. Atrioventricular valve opens;
3. Ventricle has higher pressure than atrium (due to filling/contraction);
4. Atrioventricular valve closes;
5. Ventricle has higher pressure than aorta;
6. Semilunar valve opens;
7. Higher pressure in aorta than ventricle (as heart relaxes);
8. Semilunar valve closes;
9. (Muscle/atrial/ventricular) contraction causes increase in pressure;

AQA June 2013 Unit 2 Q6cde

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



Question:

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

Answer:

1. Higher affinity / loads more oxygen;
2. At low/same/high partial pressure/;
3. Oxygen moves from mother/to fetus

Question:

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

Answer:

1. Low affinity / oxygen dissociates;
2. (Oxygen) to respiring tissues/muscles/cells;

Question:

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.

Answer:

Enough adult Hb produced / enough oxygen released / idea that curves/affinities/Hb are similar / more red blood cells produced

AQA Jan 2013 Unit 1 Q7c

Question:

The pulse felt in the artery in the wrist can be recorded and used to measure heart rate.

Suggest why the pulse felt can be used to measure heart rate.

Answer:

1. Caused by pressure/surge of blood;
2. From (one) contraction/beat of (left) ventricle/heart;

AQA Jan 2013 Unit 2 Q2c

Question:

Kwashiorkor is a disease caused by a lack of protein in the blood. This leads to a swollen abdomen due to a build up of tissue fluid.

Explain why a lack of protein in the blood causes a build up of tissue fluid.

Answer:

1. Water potential (in capillary) not as low/is higher/less negative / water potential gradient is reduced;
2. Less/no water removed (into capillary);
3. By osmosis (into capillary);

AQA Jan 2012 Unit 2 Q9a

Question:

Explain how oxygen is loaded, transported and unloaded in the blood.

Answer:

1. Haemoglobin carries oxygen / has a high affinity for oxygen / oxyhaemoglobin;
2. In red blood cells;
3. Loading/uptake/association in lungs;
4. at high p.O^2;
5. Unloads/ dissociates / releases to respiring cells/tissues;
6. at low p.O^2;
7. Unloading linked to higher carbon dioxide (concentration)

3.3.4.2 Mass transport in plants

Content

- Xylem as the tissue that transports water in the stem and leaves of plants. The cohesion-tension theory of water transport in the xylem.
- Phloem as the tissue that transports organic substances in plants. The mass flow hypothesis for the mechanism of translocation in plants. The use of tracers and ringing experiments to investigate transport in plants.
- **Students should be able to:**
- Recognise correlations and causal relationships
- Interpret evidence from tracer and ringing experiments and to evaluate the evidence for and against the mass flow hypothesis.

Xylem is the tissue that transports water in the stem and leaves of plants. On the other hand, phloem is the tissue that transports organic substances in plants.

The atmosphere is usually less humid than the air spaces next to the stomata. As a result, there is a water potential gradient from the air spaces through the stomata to the air. Provided the stomata are open, water vapour molecules diffuse out of the air spaces into the surrounding air. Water lost by diffusion from the air spaces is replaced by water evaporating from the cells walls of the surrounding mesophyll cells, so by changing the size of the stomatal pores, plants can control their rate of transpiration.

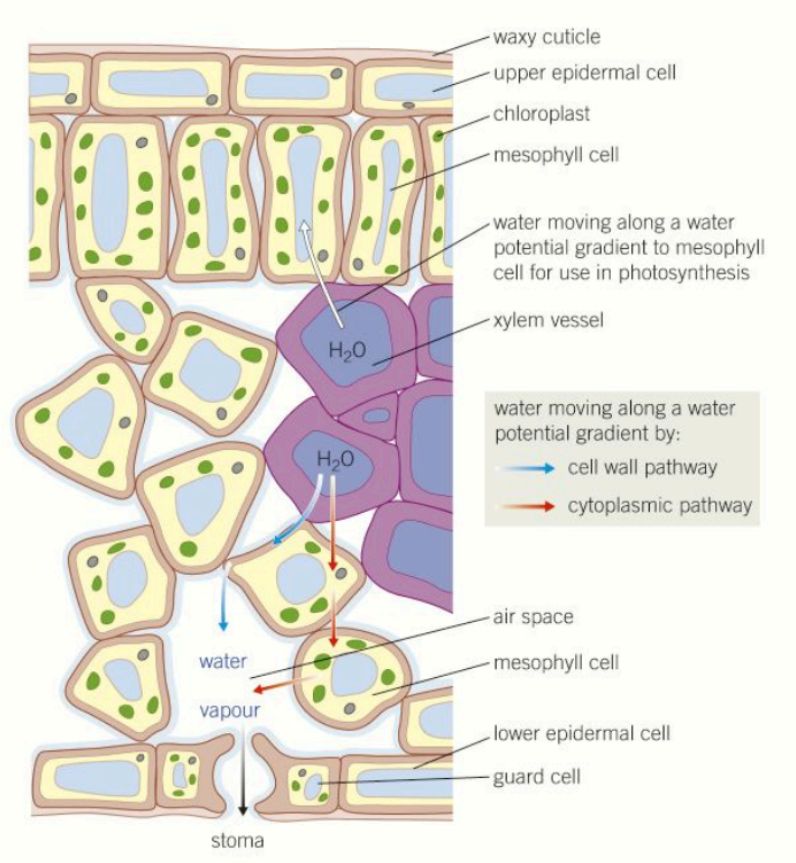
Water is lost from mesophyll cells by evaporation from their cell walls to the air spaces of the leaf. This water is then replaced by water reaching the mesophyll cells from the xylem either via cell walls or via the cytoplasm. In the case of the cytoplasmic route, it is as follows:

- Mesophyll cells lose water to the air spaces by evaporation, due to the heat supplied by the sun
- These cells now have a lower water potential and so water enters by osmosis from neighboring cells
- The loss of water from these neighboring cells lowers their water potential
- They, in turn, take in water from their neighbours by osmosis.

In this way, a water potential gradient is established that pulls water from the xylem, across the leaf mesophyll, and finally out into the atmosphere.

Water moves up the stem in the xylem, and the main reason for this is **cohesion-tension.**

- Water evaporates from mesophyll cells due to the heat from the sun, leading to transpiration
- Water molecules form hydrogen bonds between one another and hence tend to stick together, known as cohesion
- Water forms a continuous, unbroken column across the mesophyll cells and down the xylem

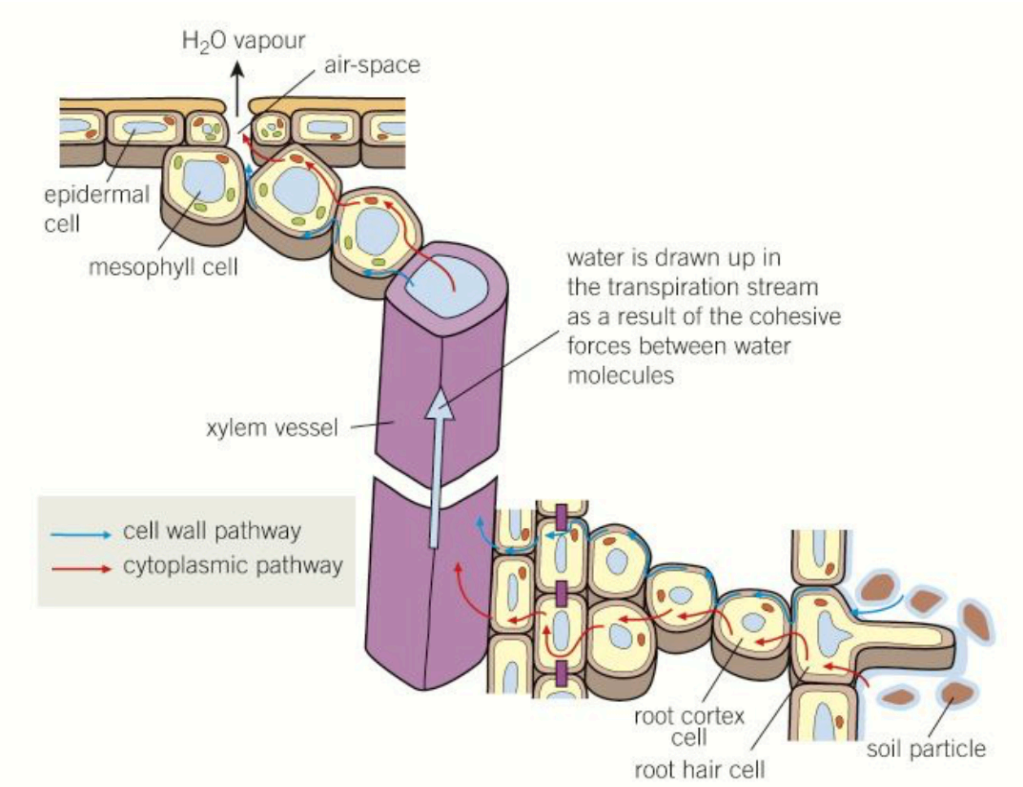


- As water evaporates from the mesophyll cells in the leaf into the air spaces beneath the stomata, more molecules of water are drawn up behind it as a results of this cohesion
- A column of water is therefore pulled up the xylem as a result of transpiration, called a transpiration pull
- Transpiration pull puts the xylem under tension, so there is a negative pressure within the xylem, hence the name cohesion-tension theory.

This transpiration is so strong it can raise water 100m or higher to the tallest trees. Evidence supporting the cohesion-tension theory is:

- The change in diameter of tree trunks according to the rate of transpiration. During the day, when transpiration is at its greatest, there is more tension (negative pressure) in the xylem. This pulls the walls of the xylem vessels inwards and causes the trunk to shrink in diameter, but at night when transpiration is at its lowest, less tension in xylem causes diameter of the trunk to increase
- If a xylem vessel is broken and air enters it, the tree can no longer draw up water. This is because the continuous column of water is broken so water molecules no longer stick to each other
- When a xylem vessel breaks, water does not leak out, as would be the case if it were under pressure. Instead air is drawn in, consistent with the idea of negative pressure.

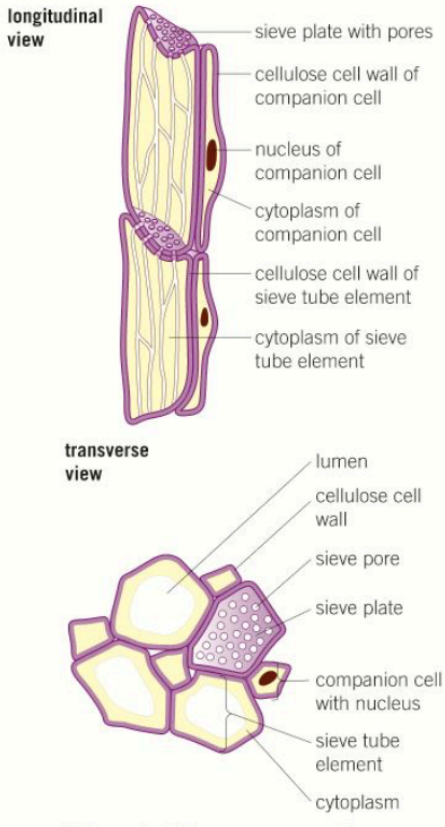
Transpiration pull is a passive process and therefore does not require metabolic energy to take place. The xylem vessels are dead so cannot actively move water, but form a continuous, unbroken tube from root to leaves, essential to the cohesion-tension theory of water flow up the stem. Energy is nevertheless needed to drive the process of transpiration, in the form of heat that evaporates water from the leaves from the sun.



Phloem is the tissue responsible for transporting organic substances in flowering plants. Examples of these organic substances are sucrose and amino acids, also inorganic ions like potassium, chloride, phosphate and magnesium ions.

The process by which organic molecules and some mineral ions are transported from one part of a plant to another is called translocation. Phloem is made up of sieve tube elements, which are long thin structures arranged end to end. Associated with the sieve tube elements are companion cells.

Sugars are produced in photosynthesis, and then the plant transports these sugars from sites of production (sources) to places where they will be directly used or stored (sink). Translocation can occur both upwards and downwards.



The mechanism of translocation – the rate of movement in the phloem is far too fast to be diffusion, and the mass flow theory is the current favoured mechanism of this process.

1. Transfer of sucrose into sieve elements from photosynthesising tissue

- Sucrose is manufactured from the products of photosynthesis in cells with chloroplasts
- The sucrose diffuses down a concentration gradient by facilitated diffusion from the photosynthesising cells into companion cells
- Hydrogen ions are actively transported from companion cells into the spaces within cell walls using ATP
- These hydrogen ions then diffuse down a concentration gradient through carrier proteins into the sieve tube elements
- Sucrose molecules are transported along with hydrogen ions in a process called co-transport. Therefore, the protein carriers are co-transport proteins.

2. Mass flow of sucrose through sieve tube elements – mass flow is the bulk movement of a substance through a given area in a specified time

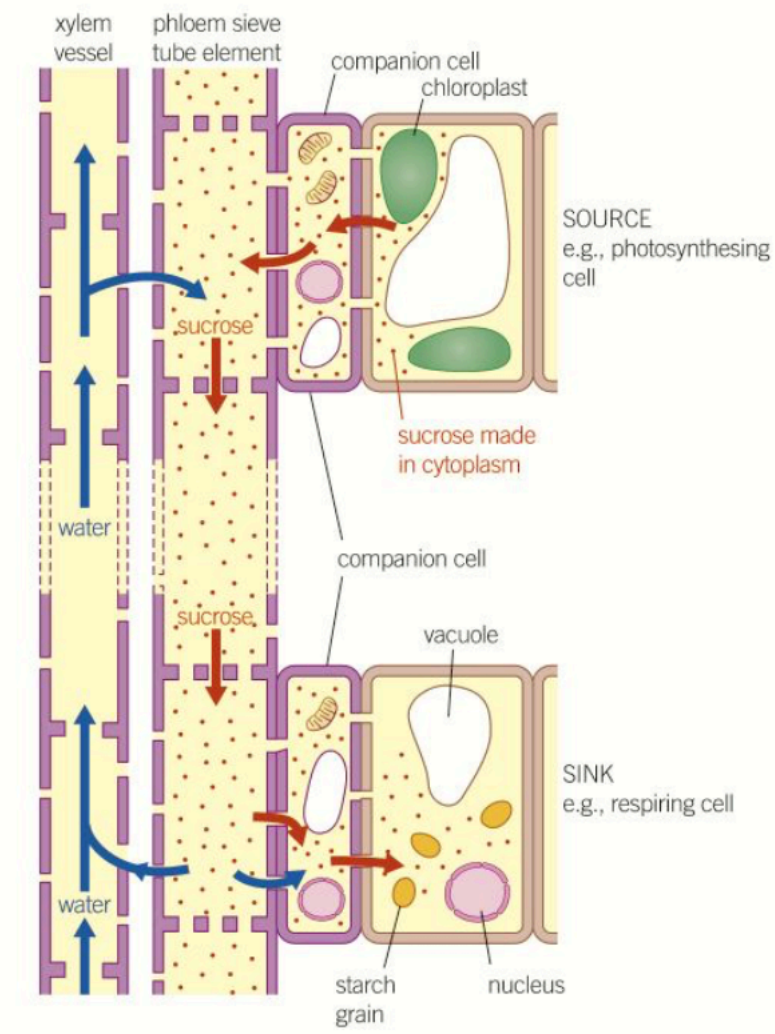
- The sucrose produced by photosynthesising cells (source) is actively transported into the sieve tubes as described above
- This causes the sieve tubes to have a lower water potential
- As the xylem has a much higher water potential, water moves from the xylem into the sieve tubes by osmosis, creating a high hydrostatic pressure.
- At respiring cells (sink), sucrose is either used up during respiration or converted to starch for storage
- These cells therefore have a low sucrose content, and so sucrose is actively transported into them from the sieve tubes, lowering their water potential
- Due to this lowered water potential, water also moves into these respiring cells, from the sieve tubes by osmosis
- The hydrostatic pressure of the sieve tubes in this region is therefore lowered
- As a result of water entering the sieve tube elements at the source and leaving at the sink, there is a high hydrostatic pressure at the source and a low one at the sink
- There is therefore a mass flow of sucrose solution down this hydrostatic gradient in the sieve tubes

Despite mass flow being a passive process, is occurs as a result of the active transport of sugars. Therefore the process as a whole is active, hence it is affected by temperature and metabolic poisons.

Evidence supporting the mass flow hypothesis	Evidence questioning the mass flow hypothesis
• there is a pressure within sieve tubes, as shown by sap being released when they are cut. • the concentration of sucrose is higher in leaves (source) than in roots (sink). • downward flow in the phloem occurs in daylight, but ceases when leaves are shaded, or at night. • increases in sucrose levels in the leaf are followed by similar increases in sucrose levels in the phloem a little later. • metabolic poisons and/or lack of oxygen inhibit translocation of sucrose in the phloem. • companion cells possess many mitochondria and readily produce ATP.	• the function of the sieve plates is unclear, as they would seem to hinder mass flow (it has been suggested that they may have a structural function, helping to prevent the tubes from bursting under pressure). • not all solutes move at the same speed – they should do so if movement is by mass flow. • sucrose is delivered at more or less the same rate to all regions, rather than going more quickly to the ones with the lowest sucrose concentration, which the mass flow theory would suggest.

3. Transfer of sucrose from the sieve tube elements into storage or other sink cells

- The sucrose is actively transported by companion cells, out of the sieve tubes and into sink cells



Investigating transport in plants to check that water is carried in the xylem and sugar and amino acids in the phloem.

Ringing experiments – Woody stems have an outer protective layer of bark on the inside, which is a layer of phloem that extends all round the stem. Inside the phloem layer is xylem.

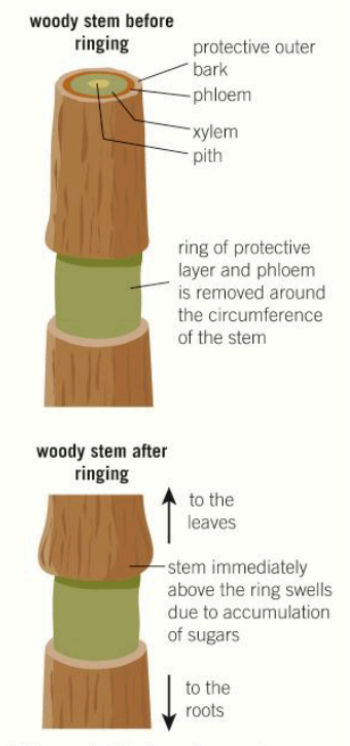
The diagram below shows how a section of the outer layer of the stem and phloem is removed. After a period of time, the region of the stem immediately above the missing ring of tissue swells, and samples of liquid that accumulates in this area is rich in sugars and other dissolved substances. Also, some non-photosynthetic tissues in the region below the ring are found to wither and die, while those above continue to grow.

These observations have led to suggest that removing the phloem around the stem has led to:

- The sugars of the phloem accumulating above the ring, leading to swelling in this region

- The interruption of flow of sugars to the region below the ring and death of tissues in this region

The conclusion from this type of experiment is that phloem is the tissue responsible for translocation in plants. The ring of tissue removed does not extend into the xylem, so its continuity had not been broken. If xylem transported sugars then you would not see the results



Tracer experiments – Radioactive isotopes are useful for tracing the movement of substances in plants. For example, growing plants in an atmosphere containing $^{14}CO_2$ will incorporate the ^{14}C isotope into sugars during photosynthesis. These radioactive sugars can then be traced as they move throughout the plant.

An example method involves taking thin cross sections of the plant stem and placing them on a piece of X-ray film. The film becomes blackened where it has been exposed to the radiation produced by the radioactive isotope. The blackened regions are found to correspond to where the phloem tissue is in the stem. As the other tissues do not blacken the film, it follows that they do not carry sugars and that phloem alone is responsible for their translocation.

Other evidence that phloem transports organic molecules is given below:

- When phloem is cut, a solution of organic molecules flow out
- Plants provided with radioactive CO_2 can be shown to have radioactively labelled carbon in phloem after a short time
- Aphids are a type of insect that feed on plants, they have needle-like mouthparts which penetrate the phloem. They can therefore be used to extract the contents of the

sieve tubes, and these contents show daily variations in the sucrose content of leaves that are mirrored a little later by identical changes in the sucrose content of the phloem.

- The removal of a ring of phloem from around the whole circumference of a stem leads to the accumulation of sugars above the ring, and their disappearance from below it.

AQA Specimen A2 Paper 1 Q9.1

'Describe the mass flow hypothesis for the mechanism of translocation in plants.'

- In source/leaf sugars actively transported into phloem;
- By companion cells;
- Lowers water potential of sieve cell/tube and water enters by osmosis;
- Increase in pressure causes mass movement (towards sink/root);
- Sugars used/converted in root for respiration for storage;