

Molecules, Transport and Health revision notes

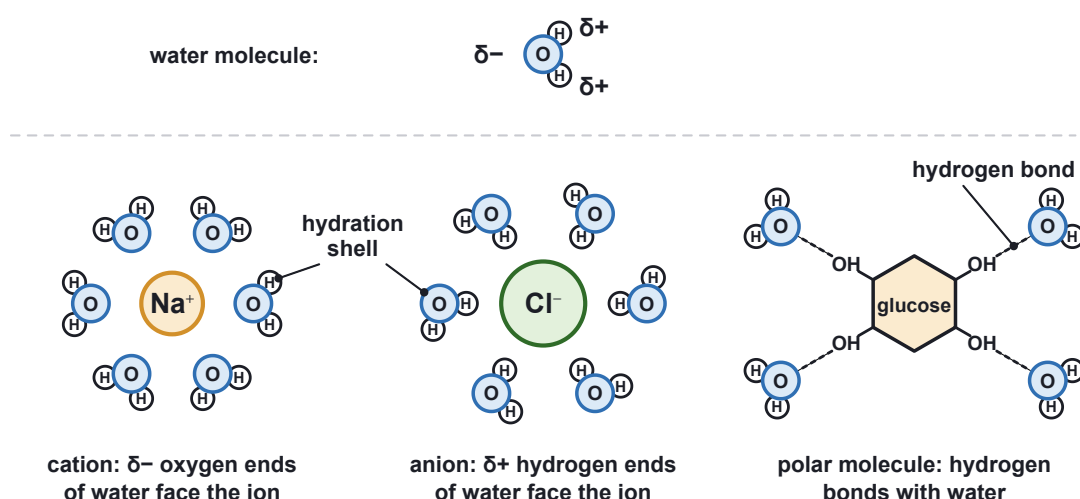
Molecules, Transport and Health is topic 1 of Pearson Edexcel International AS/A Level Biology (XBI11/YBI11) and is examined in Unit 1. It covers water, carbohydrates and lipids, the heart, blood vessels and haemoglobin, the causes of cardiovascular disease, and how health risks are judged and treated, with Core practicals 1 and 2.

For Pearson Edexcel International AS Biology XBI11 and International A Level Biology YBI11. **A Level only** is IA2 content (Units 4 to 6), not needed for the International AS.

1 Water, carbohydrates and lipids Spec 1.1-1.5

Water as a solvent in transport Spec 1.1

A water molecule (H_2O) has one oxygen atom bonded to two hydrogen atoms. Oxygen attracts the shared electrons more strongly than hydrogen does, so the oxygen end carries a small negative charge (δ^-) and each hydrogen end a small positive charge (δ^+). The molecule is overall neutral, but its charge is unevenly spread. This makes water a **dipole**, and a **polar** molecule.



Water is a dipole, so its charged ends surround ions and polar molecules and keep them **dissolved**.

Ions (for example Na^+ , Cl^- , HCO_3^-) and polar molecules (for example glucose, amino acids, urea) are attracted to the oppositely charged ends of water molecules. Water molecules cluster around each solute particle, separate it from its neighbours and keep it dispersed. The result is a **solution**, in which the solute particles move freely and can be carried along by the flow of the liquid.

Examples of dissolved substances transported in solution

Transport system	Substances carried in solution
Blood plasma	Glucose, amino acids, mineral ions, hydrogencarbonate ions, urea, hormones
Xylem sap in plants	Water with dissolved mineral ions
Phloem sap in plants	Sucrose and amino acids
Urine (excretion)	Urea and excess ions in solution

Non-polar molecules such as triglycerides and cholesterol are **hydrophobic**: they are not attracted to water, so they do not dissolve in blood plasma. They have to be carried in other ways (see lipoproteins, in the section on cholesterol, HDL and LDL).

Dipole	A molecule with a slightly positive end and a slightly negative end because its electrons are unevenly shared.
Solvent	A liquid in which other substances (solutes) dissolve to form a solution.

Exam tip: Link the dipole to the dissolving. Say that the charged ends of water molecules are attracted to ions or polar molecules and surround them. 'Water is polar' on its own does not earn the mark.

Monosaccharides, disaccharides and polysaccharides Spec 1.2

Carbohydrates contain carbon, hydrogen and oxygen. They are grouped by the number of sugar units in each molecule.

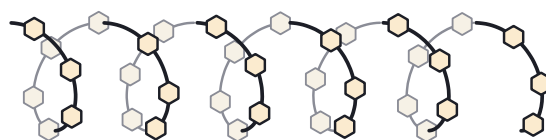
Three groups of carbohydrate			
Group	Size	Examples	Main features
Monosaccharide	One sugar unit (monomer)	Glucose, fructose, galactose (all $C_6H_{12}O_6$)	Small, soluble, sweet; glucose is the main respiratory substrate
Disaccharide	Two monosaccharides joined	Maltose, sucrose, lactose (all $C_{12}H_{22}O_{11}$)	Soluble, sweet; hydrolysed to monosaccharides before use
Polysaccharide	Many monosaccharides joined	Starch (amylose, amylopectin), glycogen	Large, insoluble, not sweet; hydrolysed to glucose when energy is needed

In **α -glucose**, the -OH group on carbon 1 sits below the ring. Starch and glycogen are both made only from α -glucose units. Fructose and galactose are isomers of glucose: they have the same formula but the atoms are arranged differently.

Starch and glycogen

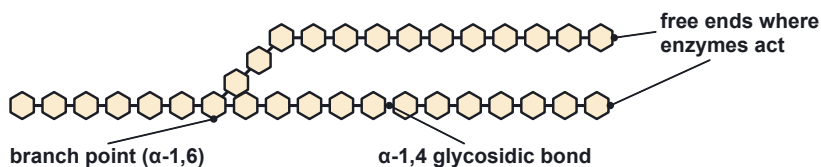
Comparing amylose, amylopectin and glycogen			
Feature	Amylose	Amylopectin	Glycogen
Found in	Plants (part of starch)	Plants (part of starch)	Animals (liver and muscle cells) and fungi
Monomer	α -glucose	α -glucose	α -glucose
Bonds	α -1,4 glycosidic only	α -1,4 and α -1,6 glycosidic	α -1,4 and α -1,6 glycosidic
Branching	Unbranched	Branched (a branch every 20 to 30 units)	Highly branched (a branch every 8 to 12 units)
Shape	Coiled into a helix	Branched, less tightly coiled	Very compact, granular
Role	Energy store	Energy store, hydrolysed quickly from many ends	Energy store, hydrolysed very quickly from many ends

Amylose

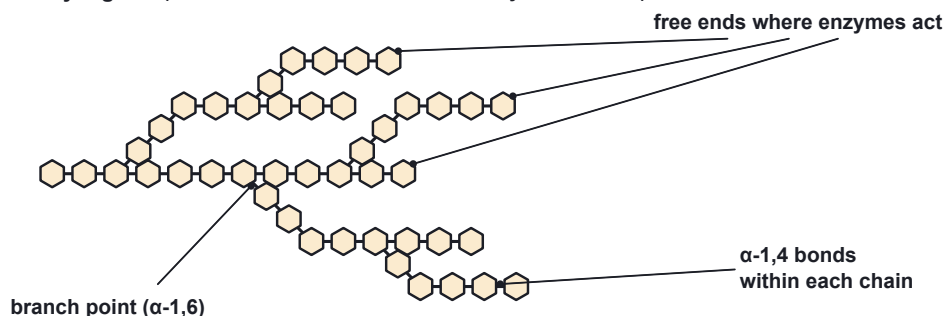


unbranched chain of α -glucose joined by α -1,4 glycosidic bonds, coiled into a helix

Amylopectin (a branch about every 20 to 30 glucose units)



Glycogen (more branched: a branch about every 8 to 12 units)



Amylose is unbranched and helical; amylopectin is branched; glycogen is **more highly branched**, so it has more free ends for enzymes.

How structure relates to role

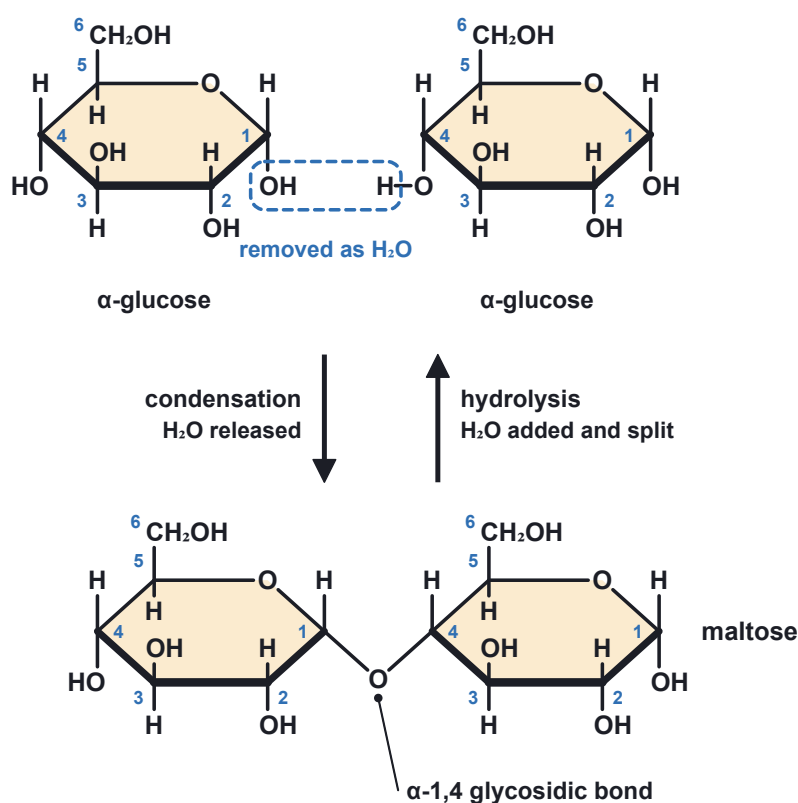
- Monosaccharides and disaccharides are small and soluble, so they are easily transported and glucose is quickly respired to release energy.
- Starch and glycogen are **insoluble** and too large to leave the cell, so they stay put as a store and do not change the water potential of the cell (no osmotic effect).
- The helical shape of amylose and the branching of amylopectin and glycogen make the molecules **compact**, so a large amount of glucose is stored in a small space.
- Branching gives many free ends. Enzymes can hydrolyse glucose from many ends at once, so glucose is released **rapidly**. This suits glycogen in animals, which have a high metabolic rate and need glucose quickly.

Common mistake: Starch is the plant store and glycogen is the animal store. Do not call glycogen 'animal starch' without saying it is more branched and so releases glucose faster.

Glycosidic bonds: condensation and hydrolysis Spec 1.4

In a **condensation reaction**, an -OH group on one monosaccharide and an -H on another are removed. They form a molecule of water, and the two sugars are joined by a C-O-C link called a **glycosidic bond**. In starch and glycogen the main chain is held together by α -1,4 glycosidic bonds (between carbon 1 of one glucose and carbon 4 of the next). Branches are made by α -1,6 glycosidic bonds.





Condensation forms an **α-1,4 glycosidic bond** and releases water; hydrolysis uses water to break it.

The disaccharides you need to know

Disaccharide	Made from	Found in
Maltose	Glucose + glucose	Germinating seeds; produced when starch is digested
Sucrose	Glucose + fructose	Sugar cane, sugar beet; the main sugar transported in phloem
Lactose	Glucose + galactose	Milk

A polysaccharide is made by repeating condensation many times. A chain of n monosaccharides contains $n - 1$ glycosidic bonds along the main chain, and $n - 1$ molecules of water are released when it forms.

Hydrolysis is the reverse reaction. A molecule of water is added across the glycosidic bond, which breaks it and releases the monosaccharides. In living organisms the reaction is catalysed by enzymes, for example amylase on starch and lactase on lactose.

Exam tip: Name the reaction and the bond, and say what happens to water. Condensation forms a glycosidic bond and releases water. Hydrolysis uses water to break the bond.

Core practical 1: Benedict's reagent and iodine solution Spec 1.3

Core practical: Core practical 1: use a semi-quantitative method with Benedict's reagent to estimate the concentration of reducing sugars, and with iodine solution to estimate the concentration of starch, using colour standards.

Semi-quantitative means the answer is an estimate from comparing colours, not an exact measurement. You make a set of **colour standards** (solutions of known concentration), treat them in exactly the same way as the unknown, and match the unknown to the closest standard. The reducing

sugars you meet are glucose, fructose, galactose, maltose and lactose. Sucrose and starch are not reducing sugars.

Method: reducing sugar with Benedict's reagent

1. Make colour standards from a stock solution of glucose (for example 2.0 % glucose) by dilution with distilled water, to give about five known concentrations plus a water-only blank.
2. Put the same volume of each standard (for example 2 cm³) into a labelled boiling tube. Do the same with the unknown solution.
3. Add the same volume of Benedict's reagent (for example 2 cm³) to every tube.
4. Heat all the tubes together in a water bath at the same temperature (a hot water bath, about 90 °C or above) for the same length of time (for example 3 minutes).
5. Remove the tubes, let any precipitate settle and compare the colours against a white background. Record colours: blue (none), green, yellow, orange, brick-red (highest concentration).
6. Match the unknown to the closest colour standard and state the estimated concentration. Repeat the unknown at least three times.

Method: starch with iodine solution

Prepare standards of starch (for example 0.0 to 1.0 %). Put the same volume of each standard and the unknown in a spotting tile or tube, add the same number of drops of iodine solution (iodine in potassium iodide) and mix. No heating is needed. The colour goes from yellow-brown (no starch) to **blue-black** (high starch). Match the unknown to the closest standard.

Variables in the Benedict's test	
Type	Variable
Independent	Concentration of glucose solution (the standards)
Dependent	Colour of the solution after heating, judged against standards
Controlled	Volume of sample, volume of Benedict's reagent, water bath temperature, heating time, same batch of reagent, same background and lighting for comparing colours

Risks: hot water and hot glassware can scald, so use a water bath, tongs and heat-resistant gloves rather than heating the tubes directly. Benedict's reagent contains copper(II) sulfate and can irritate the eyes, so wear eye protection. Iodine solution stains skin and clothing.

Limitations: judging colour by eye is subjective. It improves reliability to use the same observer, a white background, more standards at smaller concentration steps and repeats. A colorimeter measuring the colour of the filtrate would make the method quantitative.

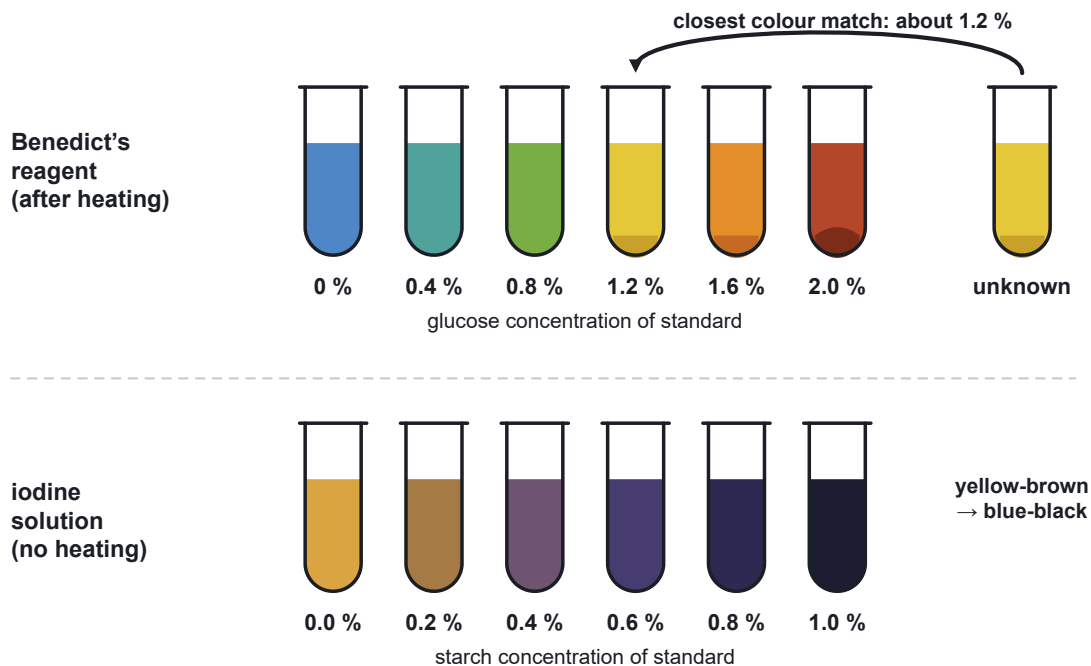
Making a colour standard by dilution

You have a 2.0 % glucose stock solution. Describe how to make 10 cm³ of a 0.4 % standard.

1. Dilution factor = stock concentration ÷ required concentration = 2.0 ÷ 0.4 = 5
2. Volume of stock needed = final volume ÷ dilution factor = 10 ÷ 5 = 2 cm³
3. Volume of distilled water needed = 10 – 2 = 8 cm³

Answer: Mix 2 cm³ of the 2.0 % stock with 8 cm³ of distilled water.

Maths skill: Use concentration × volume to plan dilutions: required volume of stock = (required concentration ÷ stock concentration) × final volume. Always show the working and give units.



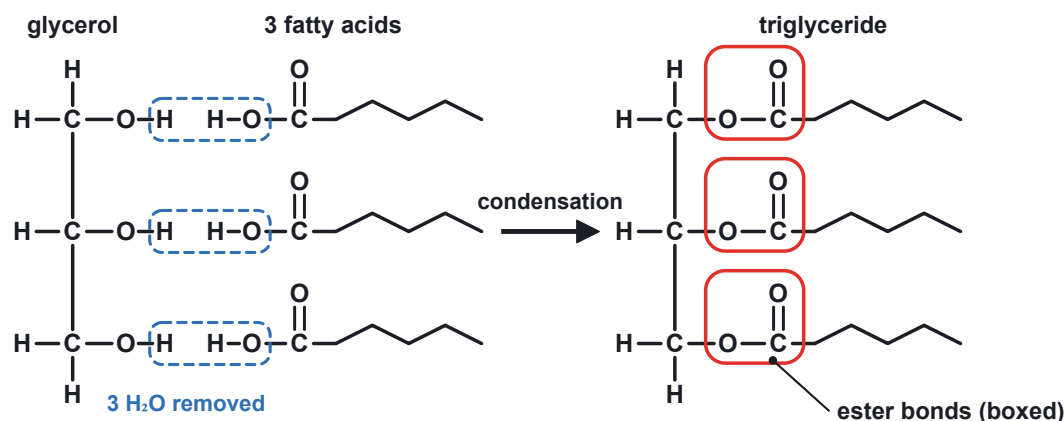
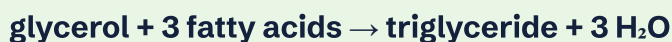
Core practical 1: match the unknown to the **closest colour standard** to estimate its concentration.

Triglycerides and ester bonds Spec 1.5(i)

Lipids contain carbon, hydrogen and oxygen, but far less oxygen than carbohydrates. They are **hydrophobic** and do not dissolve in water. Triglycerides are the most common lipids in the diet and in fat stores.

- **Glycerol** is a small molecule with three carbon atoms, each carrying an -OH (hydroxyl) group.
- A **fatty acid** has a carboxyl group (-COOH) at one end and a long hydrocarbon chain (R) of typically 14 to 20 carbon atoms.

In each condensation reaction, the -OH of glycerol and the -OH of the carboxyl group of a fatty acid react. A molecule of water is removed and an **ester bond** (-COO-) forms between them. This happens three times, once at each -OH group of glycerol, so three water molecules are released. The three fatty acids in a triglyceride can be the same or different.



Three condensation reactions release **three water molecules** and form three ester bonds.

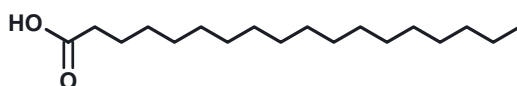
Hydrolysis of the ester bonds (catalysed by lipase) uses three water molecules and releases glycerol and three fatty acids.

Exam tip: The bond is an ester bond, not a glycosidic bond. Quote the numbers: three fatty acids, three ester bonds, three molecules of water.

Saturated and unsaturated lipids Spec 1.5(ii)

Saturated and unsaturated lipids compared		
Feature	Saturated	Unsaturated
C=C double bonds in the hydrocarbon chain	None: every carbon holds the maximum number of hydrogen atoms	One (monounsaturated) or more than one (polyunsaturated)
Shape of the chain	Straight	Bent (kinked) at each double bond
Packing of molecules	Pack closely together	Pack less closely
Melting point	Higher, so usually solid at room temperature	Lower, so usually liquid at room temperature
Typical sources	Butter, lard, animal fats	Olive oil, sunflower oil, oily fish

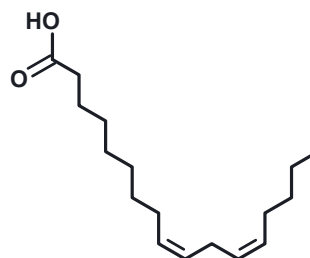
Saturated: no C=C, straight chain



Monounsaturated: one C=C, one bend



Polyunsaturated: two or more C=C, more bends



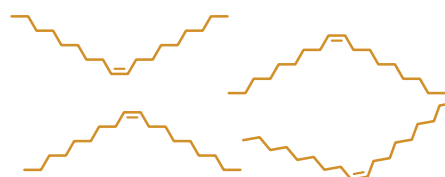
Each chain has 18 carbons; C1 is the carboxyl carbon (–COOH).

Straight chains pack tightly



solid fat (higher melting point)

Bent chains pack loosely



liquid oil (lower melting point)

A C=C double bond puts a kink in the chain, so unsaturated chains pack less closely and melt at a lower temperature.

Because straight chains pack closely, there are more intermolecular attractions between them, so more energy is needed to separate the molecules. This explains why saturated fats have a higher melting point than unsaturated oils.

Health link: diets high in saturated fat tend to raise the concentration of low-density lipoprotein (LDL) cholesterol in the blood, which raises the risk of cardiovascular disease (see the section on dietary risk factors).

Common mistake: Unsaturated means at least one C=C double bond in the hydrocarbon chain. Do not write 'unsaturated fats have no hydrogen' or confuse the term with the number of ester bonds.

Quick check

- 1 . What is a dipole?
- 2 . Name the two types of bond in amylopectin.
- 3 . Which two monosaccharides join to make sucrose?
- 4 . How many water molecules are released when a triglyceride forms?
- 5 . What colour change shows starch with iodine solution?

2 The heart, blood vessels and haemoglobin Spec 1.6-1.9

Why many animals have a heart and circulation Spec 1.6

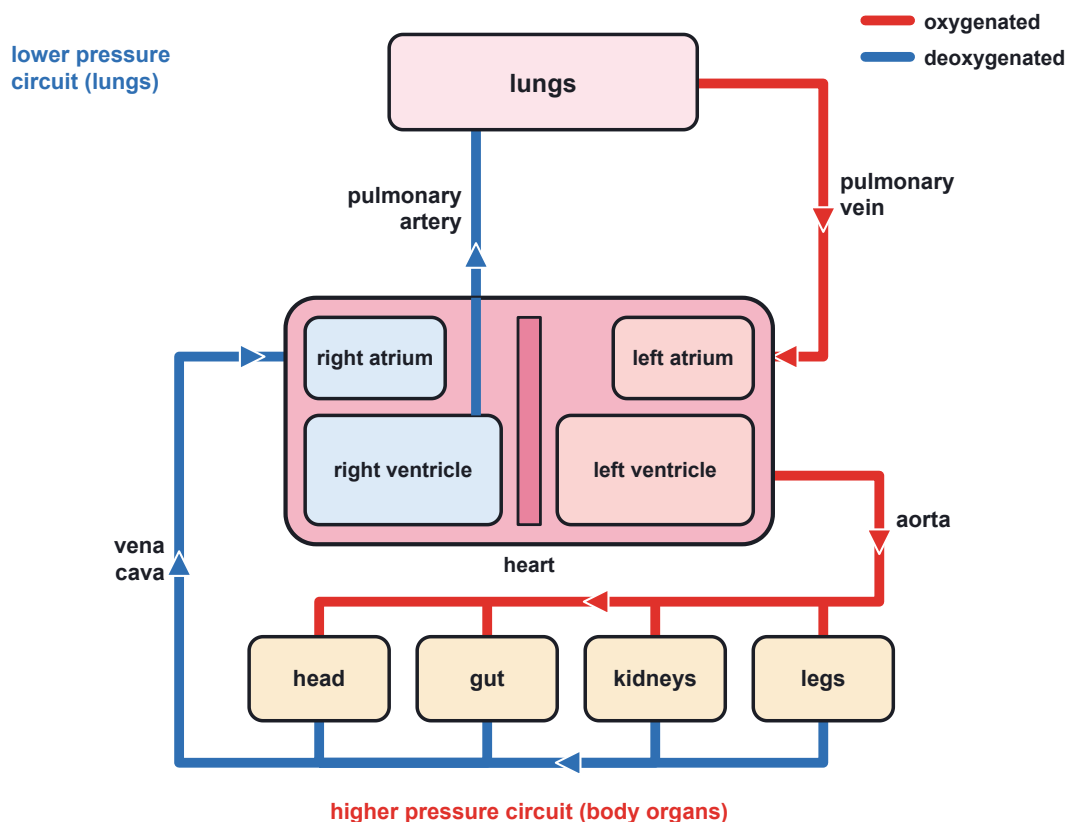
Small organisms, such as single-celled ones, exchange substances by **diffusion** directly across their surface. Their **surface area to volume ratio** is large and the distance from the surface to any part of the cell is tiny, so diffusion is fast enough.

In a large animal this stops working, for three reasons.

- **Surface area to volume ratio falls** as size increases, so the body surface is too small to supply a large volume of cells.
- **Diffusion distances** to cells deep inside the body are long. Diffusion is only fast over very short distances, and the time taken rises sharply as the distance increases.
- A high **metabolic rate** (as in active, warm-blooded animals) means cells use oxygen and glucose, and produce carbon dioxide and wastes, faster than diffusion could move them.

Mass transport solves this problem. A liquid (blood) is moved in bulk, quickly, over long distances through vessels by the pressure generated by a pump (the heart). Blood carries oxygen and nutrients to cells and removes carbon dioxide and wastes. Continually moving blood also keeps concentration gradients steep at the exchange surfaces, which keeps diffusion going.

Mammals have a **closed, double circulation**. Blood stays inside vessels, and passes through the heart twice on each complete circuit: right side of the heart to the lungs, then back to the left side of the heart to be pumped to the rest of the body. Pumping blood to the lungs at lower pressure protects the delicate lung capillaries. Returning it to the heart means the pressure can be raised again before it goes to the body.



Blood passes through the heart **twice** on each complete circuit: once for the lungs and once for the body.

Surface area to volume ratio and size

A cube-shaped organism has sides of 1 cm. Another has sides of 4 cm. Calculate the surface area to volume ratio of each and comment.

1. 1 cm cube: surface area = $6 \times 1^2 = 6 \text{ cm}^2$; volume = $1^3 = 1 \text{ cm}^3$; ratio = 6 : 1

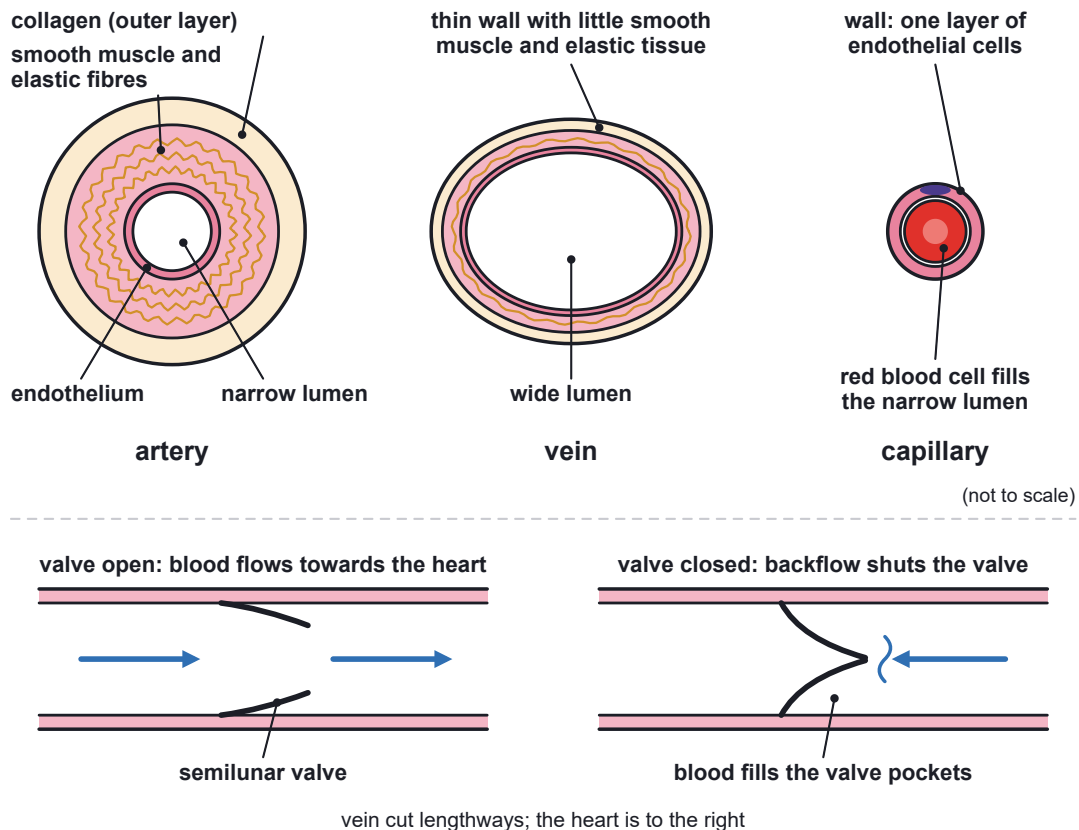
2. 4 cm cube: surface area = $6 \times 4^2 = 96 \text{ cm}^2$; volume = $4^3 = 64 \text{ cm}^3$; ratio = $96 \div 64 = 1.5 : 1$

Answer: 6 : 1 and 1.5 : 1. The larger organism has a much smaller surface area to volume ratio, so diffusion across its surface cannot supply all its cells.

Maths skill: Surface area to volume ratio: for a cube of side L , surface area = $6L^2$ and volume = L^3 . Write the ratio as surface area : volume, and give units for the areas and volumes you calculate.

Arteries, veins and capillaries Spec 1.7

Structure and function of blood vessels			
Feature	Artery	Vein	Capillary
Direction of blood flow	Away from the heart	Towards the heart	Between arteries and veins (through tissues)
Blood pressure	High	Low	Falls along the capillary
Wall	Thick, with collagen, smooth muscle and elastic fibres	Thin, with little muscle or elastic tissue	One layer of flattened endothelial cells
Lumen	Narrow	Wide	Very narrow (about the width of a red blood cell)
Valves	None (except at the heart)	Present	None
Main function	Carry blood away from the heart at high pressure	Return blood to the heart	Exchange of substances between blood and cells



Wall thickness and lumen size match the **pressure** in each vessel; valves in veins stop backflow.

Arteries

Blood leaves the heart in a high-pressure surge. The wall of an artery contains **collagen** fibres, which give strength and prevent bursting, and **elastic fibres**, which stretch as the surge passes and then recoil. This elastic recoil evens out the pressure pulse so blood flows smoothly. **Smooth muscle** in the wall can contract to narrow the lumen. The inner lining (endothelium) is smooth, which reduces friction.

Veins

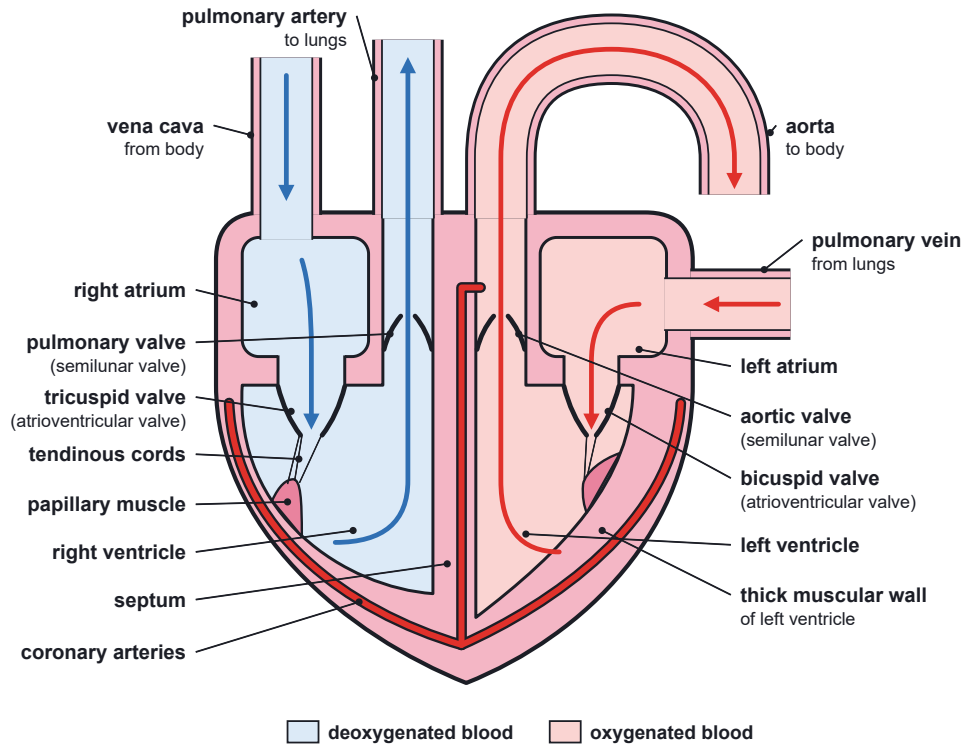
By the time blood reaches the veins its pressure is low, so the walls can be thin, with little muscle or elastic tissue. The wide lumen offers little resistance to flow. **Valves** (semilunar valves) stop blood flowing backwards. Blood is helped towards the heart by contractions of the surrounding skeletal muscles squeezing the veins, and by pressure changes in the chest during breathing.

Capillaries

Capillaries form dense networks close to almost every cell. Their wall is a single layer of flattened endothelial cells, so the **diffusion distance is very short**. Gaps between the cells allow small molecules and fluid to pass. The lumen is so narrow that red blood cells are squeezed through in single file, which brings them close to the wall. Together, the capillaries have a very large total cross-sectional area, so blood flows slowly. This gives time for exchange of oxygen, carbon dioxide, glucose and wastes.

Exam tip: Explain each feature with 'so': thick elastic wall so it withstands high pressure and recoils; one cell thick so a short diffusion distance. A list of features without the reason will not get the mark.

Structure of the mammalian heart Spec 1.8



The left ventricle has the **thickest wall** because it pumps blood to the whole body.

Major blood vessels of the heart

Vessel	Carries blood	From	To
Vena cava	Deoxygenated	Body	Right atrium
Pulmonary artery	Deoxygenated	Right ventricle	Lungs
Pulmonary vein	Oxygenated	Lungs	Left atrium
Aorta	Oxygenated	Left ventricle	Body
Coronary arteries	Oxygenated	Base of the aorta	Heart muscle (cardiac muscle)

- The **atria** have thin walls because they only pump blood a short distance into the ventricles.
- The **ventricles** have thicker, muscular walls to pump blood out of the heart. The **left ventricle** has the thickest wall because it pumps blood to the whole body at high pressure. The right ventricle pumps blood only to the nearby lungs at lower pressure, which protects the lung capillaries.
- The **septum** separates the left and right sides, so oxygenated and deoxygenated blood do not mix.
- Atrioventricular valves** (tricuspid on the right, bicuspid on the left) stop blood flowing back from the ventricles into the atria. They are held in position by **tendinous cords** attached to papillary muscles, so that they are not pushed inside out when the ventricles contract.
- Semilunar valves** at the start of the aorta and pulmonary artery stop blood flowing back from the arteries into the ventricles.
- The **coronary arteries** supply the cardiac muscle with oxygen and glucose. Blockage of a coronary artery causes a heart attack.

Practical: Recommended additional practical (not a core practical): investigate the structure of a mammalian heart by dissection. Cut across the ventricles to compare wall thickness, find the valves and tendinous cords, and identify the vessels. Wear gloves and eye protection, use a sharp scalpel on a dissecting board, cut away from your hand and disinfect surfaces afterwards.

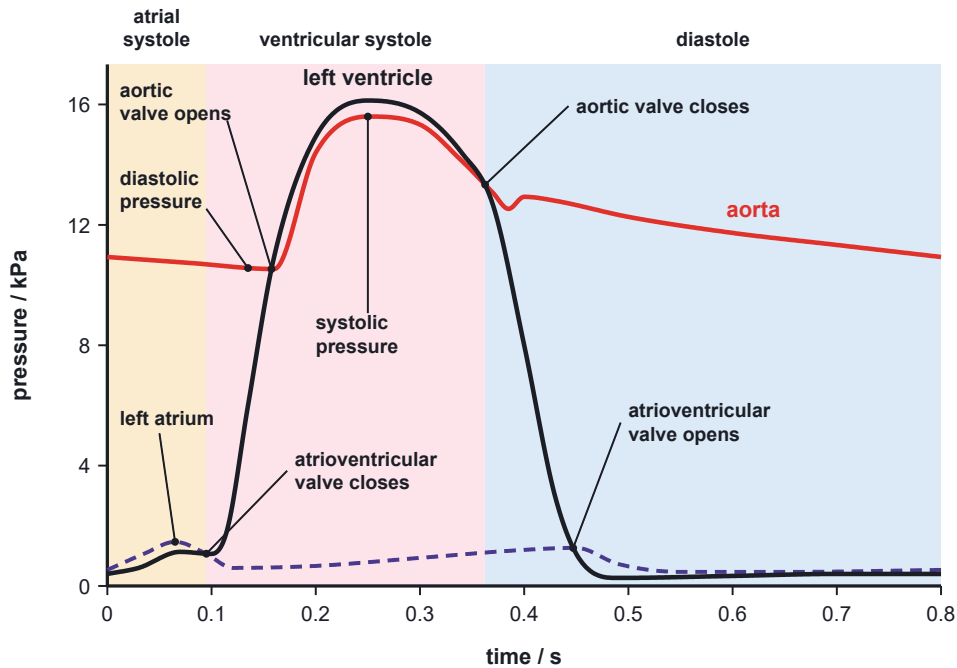
The cardiac cycle Spec 1.8

Systole is contraction. **Diastole** is relaxation. The cycle repeats about 70 times a minute at rest. Valves have no muscle: they open when pressure behind them is higher than in front, and shut when pressure in front is higher.

1. **Atrial systole**: the atria contract. Atrial pressure is higher than ventricular pressure, so the atrioventricular valves are open and the last of the blood is pushed into the ventricles. The semilunar valves are shut.
2. **Ventricular systole**: the ventricles contract. Ventricular pressure rises above atrial pressure, so the atrioventricular valves shut (the first heart sound). When ventricular pressure exceeds the pressure in the aorta and pulmonary artery, the semilunar valves open and blood is forced out into the arteries.
3. **Cardiac diastole**: the ventricles relax and pressure falls. Arterial pressure is now higher, so the semilunar valves shut (the second heart sound). Blood from the vena cava and pulmonary veins flows into the relaxed atria. When ventricular pressure falls below atrial pressure, the atrioventricular valves open and blood flows into the ventricles.

Summary of the cardiac cycle

Stage	Atria	Ventricles	Atrioventricular valves	Semilunar valves
Atrial systole	Contract	Relaxed, filling	Open	Closed
Ventricular systole	Relaxed, filling	Contract	Closed	Open (once pressure exceeds arterial pressure)
Cardiac diastole	Relaxed, filling	Relaxed, filling	Open	Closed



Each valve opens or closes when the **pressure on one side becomes higher** than on the other.

Length of the cardiac cycle

A person's resting heart rate is 75 beats per minute. Calculate the time for one cardiac cycle.

1. There are 60 seconds in a minute
2. Time for one cycle = $60 \div \text{heart rate} = 60 \div 75$

Answer: 0.8 s

Exam tip: When asked why a valve opens or closes, always compare the pressures on each side of it, and say which is higher. For example: 'ventricular pressure is higher than atrial pressure, so the atrioventricular valve shuts'.

Haemoglobin and the transport of oxygen and carbon dioxide Spec 1.9(i)

Transport of oxygen

Haemoglobin (Hb) is a protein with a quaternary structure: four polypeptide chains, each with a **haem group** containing an Fe^{2+} ion. Each haem group can combine reversibly with one oxygen molecule, so one haemoglobin molecule can carry four O_2 molecules. Haemoglobin is packed inside red blood cells.



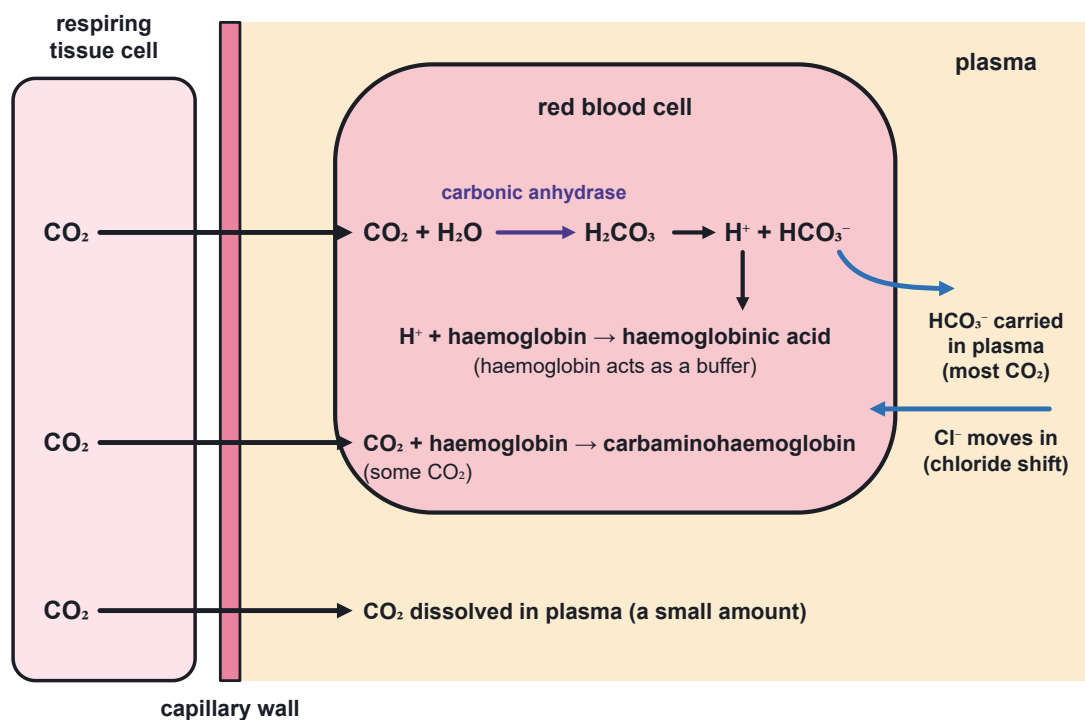
In the lungs the partial pressure of oxygen is high, so oxygen **loads** onto haemoglobin, forming **oxyhaemoglobin**. In respiring tissues the partial pressure of oxygen is low, so oxygen is released (**unloaded**) and diffuses into cells.

Transport of carbon dioxide

How carbon dioxide is carried in blood

Form	Approximate share	Where and how
Hydrogencarbonate ions (HCO_3^-)	Most (about 70 to 85 %)	Formed inside red blood cells and carried in plasma
Carbaminohaemoglobin	About 10 to 20 %	CO_2 binds directly to haemoglobin
Dissolved CO_2	About 5 %	Dissolved in plasma

- CO_2 from respiring tissues diffuses into red blood cells.
- The enzyme **carbonic anhydrase** catalyses $\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3$ (carbonic acid), which dissociates: $\text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^-$.
- HCO_3^- diffuses out of the red blood cell into the plasma. Chloride ions (Cl^-) move in to balance the charge (the chloride shift).
- H^+ ions bind to haemoglobin, forming haemoglobinic acid. Haemoglobin therefore acts as a **buffer**, preventing a large fall in pH in the red blood cell.
- In the lungs the reactions run in reverse and CO_2 diffuses out of the blood into the alveoli.

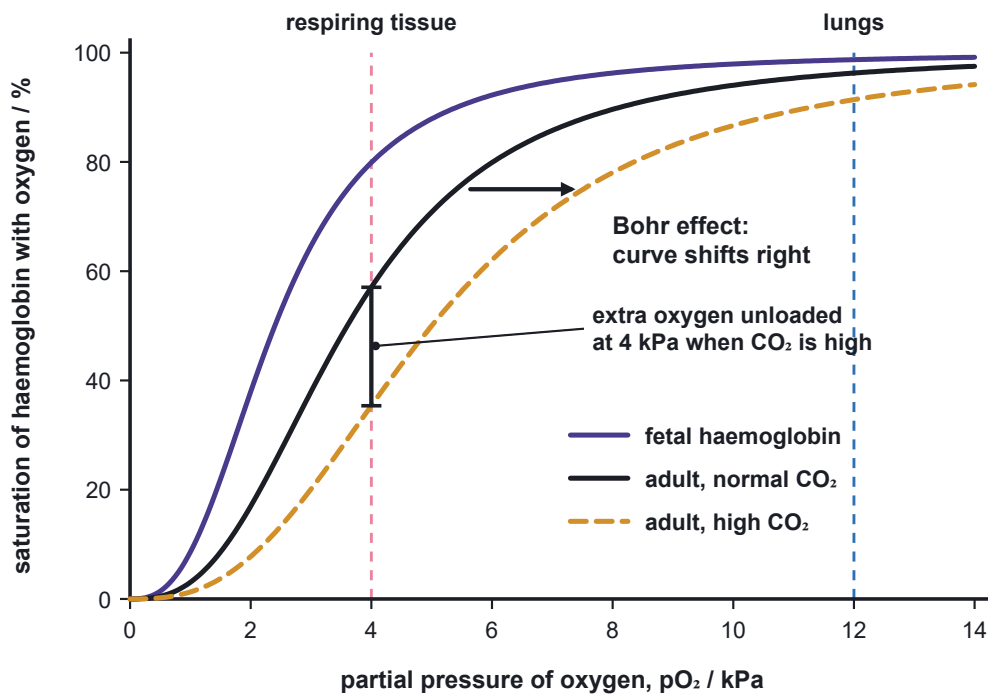


Most carbon dioxide travels as **hydrogencarbonate ions** in the plasma.

Common mistake: Most carbon dioxide is carried as hydrogencarbonate ions in the plasma, not on haemoglobin. Haemoglobin's role in carbon dioxide transport is to combine with H^+ ions (buffering) and to carry some CO_2 directly.

The oxygen dissociation curve, the Bohr effect and fetal haemoglobin Spec 1.9(ii)

The **oxygen dissociation curve** shows the percentage saturation of haemoglobin with oxygen (y-axis) against the partial pressure of oxygen, pO_2 , in kPa (x-axis). The curve is **S-shaped** (sigmoid).



High CO_2 shifts the curve **to the right**, so more oxygen is unloaded; fetal haemoglobin lies to the left.

Why the curve is S-shaped

- At low pO_2 the curve is shallow. The first oxygen molecule is hard to bind because the haem groups are inside the protein.
- Once one oxygen molecule binds, the haemoglobin changes shape slightly, making it easier for the next ones to bind. This **cooperative binding** gives the steep middle section.
- At high pO_2 the curve levels off because haemoglobin is almost saturated: few haem groups are still free, so a further rise in pO_2 adds little more oxygen.

In the lungs (high pO_2) haemoglobin is about 95 % or more saturated. In respiring tissues (low pO_2) it is much less saturated, because it releases oxygen. The steep part of the curve is at the pO_2 of respiring tissues, so a small fall in pO_2 makes a large amount of oxygen unload.

The Bohr effect

Respiring tissues release CO_2 . CO_2 forms carbonic acid, which dissociates to release H^+ ions, so a higher partial pressure of CO_2 lowers the pH. Haemoglobin changes shape, its **affinity** for oxygen falls, and the curve shifts to the **right**. This is the **Bohr effect**. At a given pO_2 the haemoglobin is then less saturated, so **more oxygen is unloaded** where it is needed most, in active tissues. In the lungs, where CO_2 is removed, the affinity rises again and oxygen loads easily.

Fetal haemoglobin

Fetal haemoglobin has a **higher affinity** for oxygen than adult haemoglobin at all partial pressures. Its curve lies to the **left** of the adult curve. In the placenta the pO_2 is low, so the mother's haemoglobin unloads oxygen, and the fetal haemoglobin, which is still highly saturated at this low pO_2 , loads it. Oxygen is therefore transferred from mother to fetus.

Percentage saturation of haemoglobin (typical rounded values for practice)

pO ₂ / kPa	Adult Hb (%)	Fetal Hb (%)
2	17	33
4	57	76
6	80	90
8	90	95
10	94	97
12	96	98

Exam tip: 'Shift to the right' means lower affinity, so more oxygen is released at the same pO₂. Describe a shift in terms of percentage saturation at a stated pO₂, and use values from the graph if one is given.

Quick check

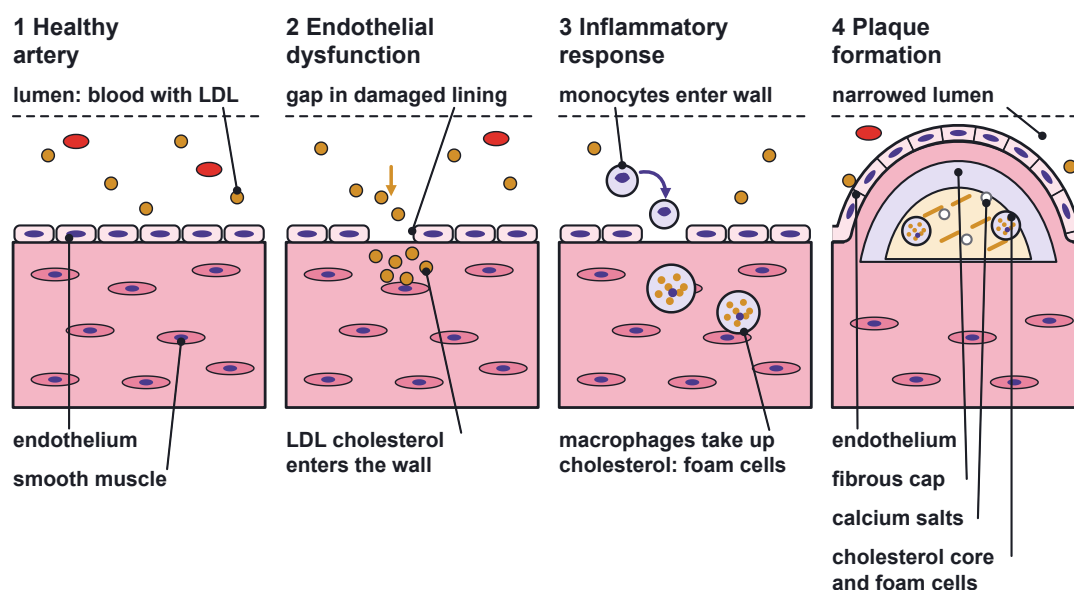
1. Why does a large animal need a circulatory system?
2. Why is the left ventricle wall thicker than the right?
3. What are the three stages of the cardiac cycle?
4. How many oxygen molecules can one haemoglobin molecule carry?
5. What happens to the oxygen dissociation curve when CO₂ concentration increases?

3 Cardiovascular disease and its causes Spec 1.10-1.14

Atherosclerosis Spec 1.10

Cardiovascular disease (CVD) is the name for diseases of the heart and blood vessels, including coronary heart disease, strokes and high blood pressure. The most common underlying process is **atherosclerosis**.

1. **Endothelial dysfunction**: the endothelium (inner lining of the artery) is damaged, for example by high blood pressure, chemicals in tobacco smoke or high blood glucose. The damaged lining becomes more permeable, and LDL cholesterol from the blood enters the artery wall.
2. **Inflammatory response**: the damaged tissue attracts white blood cells (monocytes). They enter the wall, become macrophages and take up the cholesterol, forming foam cells. They release chemicals that attract more white blood cells.
3. **Plaque formation**: foam cells, cholesterol, dead cells, and smooth muscle cells that have moved into the area build up as an **atheroma** (plaque). Fibres and calcium salts are deposited, forming a hardened cap over the plaque.
4. The plaque makes the lumen narrower and the artery wall less elastic. Blood flow is reduced and **blood pressure rises**.
5. Raised blood pressure damages the endothelium further, so the process speeds up (a positive feedback).



Atherosclerosis: **endothelial dysfunction**, inflammatory response, then a plaque (atheroma) forms inside the artery wall and narrows the lumen.

Reduced blood flow means less oxygen reaches the tissue supplied by the artery. In a coronary artery this can cause chest pain (angina). A plaque can also rupture, exposing the artery wall to the blood and triggering blood clotting (see the next section).

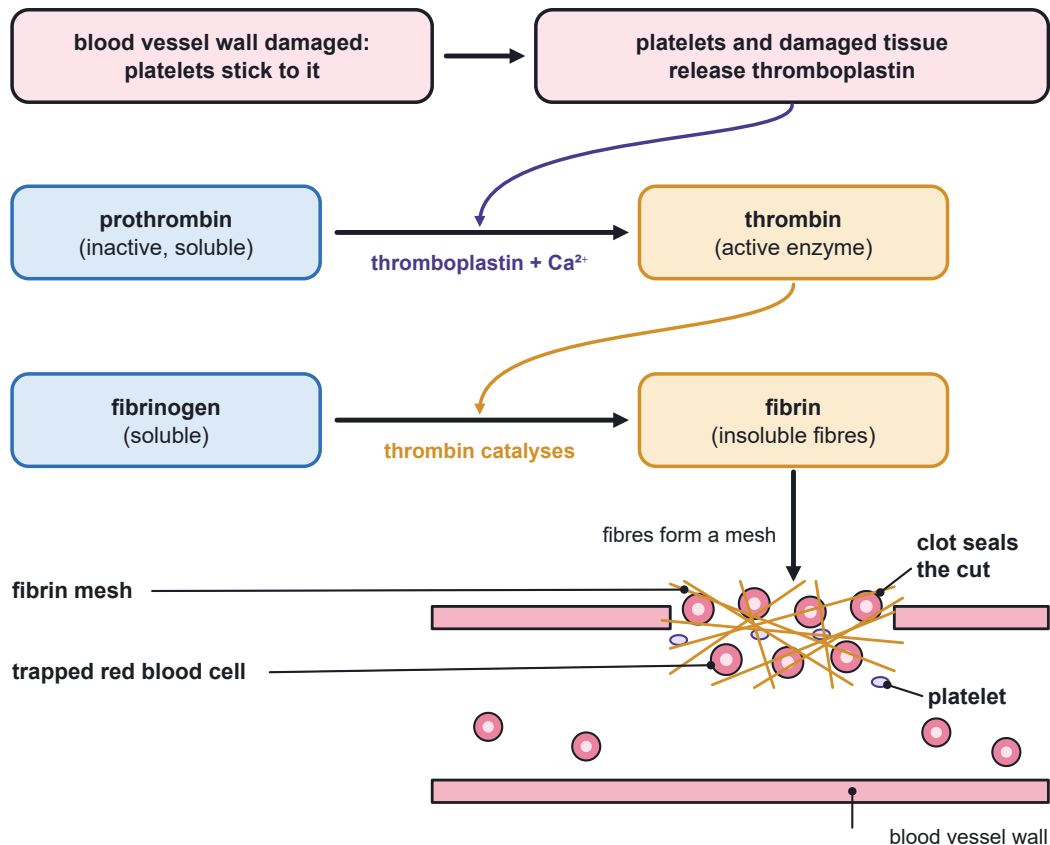
Exam tip: Learn the four named stages in order: endothelial dysfunction, inflammatory response, plaque formation, raised blood pressure. Say that raised blood pressure both results from and causes more damage.

Blood clotting and cardiovascular disease Spec 1.11

When a blood vessel is damaged, platelets stick to the damaged surface and release chemicals. Platelets and the damaged tissue release **thromboplastin** (a clotting factor). This starts a cascade of

reactions.

1. Thromboplastin (with calcium ions) catalyses the conversion of the inactive plasma protein **prothrombin** to the enzyme **thrombin**.
2. Thrombin catalyses the conversion of soluble **fibrinogen** to insoluble **fibrin**.
3. Fibrin forms long fibres that make a mesh. The mesh traps red blood cells and platelets, forming a **clot** that seals the damage and stops blood loss.



The clotting cascade: **prothrombin** → **thrombin**, then **fibrinogen** → **fibrin**, which forms the clot.

Role in cardiovascular disease

- A plaque can rupture and expose the artery wall. Clotting is triggered and a **thrombus** forms on the plaque, blocking a narrowed artery.
- If the blocked artery is a **coronary artery**, the cardiac muscle supplied is starved of oxygen and glucose, cannot respire aerobically and dies. This is a **myocardial infarction** (heart attack).
- If the blocked artery supplies the brain, the result is a **stroke**.
- A clot can also break away and travel in the blood (an embolus) until it lodges in a narrower vessel.

Common mistake: Fibrinogen is soluble and fibrin is insoluble, and thrombin is an enzyme made from inactive prothrombin. Do not swap these pairs, and keep the order: thromboplastin, prothrombin to thrombin, fibrinogen to fibrin.

Risk factors for cardiovascular disease Spec 1.12

A **risk factor** is something that is linked to an increased probability of developing a disease. It does not mean that a person will definitely get the disease, and a person with no risk factors can still develop it.

How risk factors increase the risk of CVD

Risk factor	How it increases risk
Genetics	Inherited gene variants can affect blood cholesterol (for example high LDL), blood pressure and clotting, so a family history of CVD raises risk
Diet	High saturated fat raises LDL cholesterol; high salt raises blood pressure; both promote atherosclerosis
Age	Risk rises with age: endothelial damage and plaque build up over many years, and arteries lose elasticity
Gender	Men are at higher risk, and at a younger age, than women; the risk for women rises after the menopause
High blood pressure	Damages the endothelium, so LDL enters the wall and plaques form faster; it also strains the heart
Smoking	Carbon monoxide binds to haemoglobin and reduces oxygen transport; nicotine raises heart rate and blood pressure; chemicals damage the endothelium; platelets become stickier, so clots form more easily
Inactivity	Associated with raised blood pressure, higher LDL and lower HDL, and with obesity

Risk factors combine. A smoker who also has high blood pressure and a diet high in saturated fat has a much greater risk than the effect of any one factor alone, because each adds to the damage to the artery wall.

Exam tip: Write 'increases the risk of' rather than 'causes', and give the mechanism: damage to endothelium, raised LDL, raised blood pressure or more likely clotting.

Dietary antioxidants and the risk of CVD Spec 1.13

Free radicals are very reactive molecules, formed in normal metabolism and by factors such as tobacco smoke. They damage cell membranes and other molecules. In artery walls they damage endothelial cells and **oxidise LDL cholesterol**. Macrophages take up oxidised LDL more readily, forming foam cells, so oxidation speeds up the formation of atheroma.

Antioxidants are substances that neutralise free radicals, by donating electrons to them. Dietary antioxidants include vitamin C, vitamin E and carotenoids. They are found in fruit, vegetables, nuts and seeds. A higher intake of antioxidants is expected to reduce LDL oxidation and endothelial damage, and so reduce the risk of CVD.

The evidence

- Studies of populations show that people who eat more fruit and vegetables have a lower incidence of CVD.
- But this may be due to other differences (such as less saturated fat, more fibre or more exercise), so it does not show that antioxidants are the cause.
- Trials giving people antioxidant supplements have mostly found little or no benefit. A diet of whole foods may work through the combination of nutrients, not a single antioxidant.

Exam tip: A good answer to 'discuss the link' states the mechanism (neutralise free radicals, less oxidised LDL, less foam cell formation) and then comments on the conflicting evidence.

Core practical 2: vitamin C content of food and drink Spec 1.14

Core practical: Core practical 2: investigate the vitamin C content of food and drink.

DCPIP (dichlorophenolindophenol) is a blue dye. Vitamin C (ascorbic acid) is a reducing agent: it reduces DCPIP to a colourless compound. The more vitamin C a solution contains, the less of it is needed to decolourise the same volume of DCPIP.

1. Make standard solutions of ascorbic acid of known concentration (for example 1.0 mg cm^{-3} and dilutions of it).
2. Place a fixed volume of DCPIP solution (for example 1 cm^3) in a test tube or small beaker.
3. Add the first standard drop by drop from a graduated pipette or burette, shaking the tube after each drop, until the blue colour just disappears. Record the volume added.
4. Repeat with each standard and plot a calibration curve of volume needed against concentration (or use the standard which decolourises 1 cm^3 DCPIP to find its equivalent).
5. Extract juice from a solid food by crushing it in water and filtering, then treat the unknown in exactly the same way. Repeat each measurement at least three times and calculate a mean.
6. Use the volume needed and the calibration to find the vitamin C concentration of the unknown.

Variables in the DCPIP method

Type	Variable
Independent	Type of food or drink, or its treatment (for example fresh or boiled)
Dependent	Volume of sample needed to decolourise DCPIP, which gives the vitamin C concentration
Controlled	Volume and concentration of DCPIP, temperature, rate of adding drops, same measuring equipment, fresh solutions each time, time between preparing and testing

Risks: DCPIP can stain and irritate skin and eyes, so wear eye protection and gloves and wipe spillages. Do not eat or drink any food used in the laboratory.

Limitations: vitamin C is destroyed by heat, light and air (oxidation), so keep solutions cool and fresh and test promptly. Other reducing substances in a food may also decolourise DCPIP. The end point is judged by eye, which is more difficult in coloured juices, so dilute the juice or use a paler food, and use the same observer.

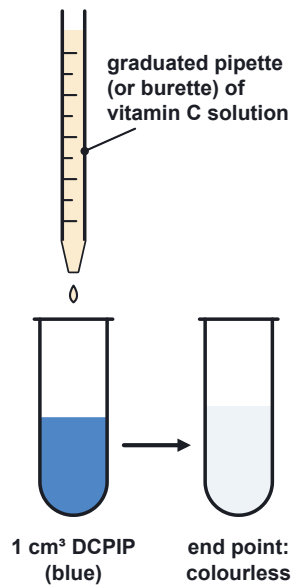
Calculating vitamin C concentration

It takes 0.8 cm^3 of a 1.0 mg cm^{-3} ascorbic acid standard to decolourise 1 cm^3 of DCPIP. It takes 1.6 cm^3 of fruit juice to decolourise 1 cm^3 of the same DCPIP. Calculate the vitamin C concentration of the juice, and the percentage change if boiling the juice raises the volume needed to 2.0 cm^3 .

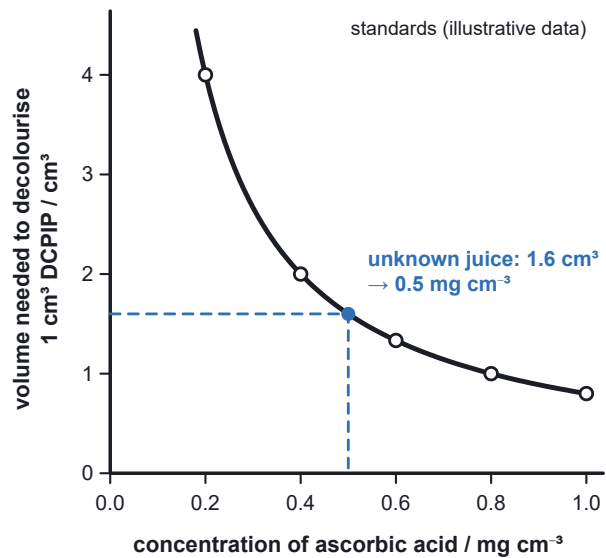
1. Mass of vitamin C that decolourises 1 cm^3 DCPIP = $0.8 \text{ cm}^3 \times 1.0 \text{ mg cm}^{-3} = 0.8 \text{ mg}$
2. Concentration of juice = $0.8 \text{ mg} \div 1.6 \text{ cm}^3 = 0.5 \text{ mg cm}^{-3}$
3. Boiled juice = $0.8 \text{ mg} \div 2.0 \text{ cm}^3 = 0.4 \text{ mg cm}^{-3}$
4. Percentage change = $(0.4 - 0.5) \div 0.5 \times 100 = -20 \%$

Answer: 0.5 mg cm^{-3} ; boiling reduced the concentration by 20 %.

Maths skill: Percentage change = $(\text{new value} - \text{original value}) \div \text{original value} \times 100$. A negative answer is a decrease. Show the working and include units for concentrations.



add drop by drop, shaking each time



Core practical 2: the **less juice needed** to decolourise DCPIP, the more vitamin C it contains.

Quick check

1. Name the four stages in the course of events leading to atherosclerosis.
2. What does thrombin do?
3. Give two ways smoking raises the risk of CVD.
4. How do antioxidants reduce the risk of CVD?
5. In Core practical 2, what colour change shows vitamin C?

4 Health risks, evidence and treatment Spec 1.15-1.20

Analysing data on illness and mortality Spec 1.15

Health data are usually given as **rates** so that populations of different sizes can be compared.

- **Incidence**: the number of new cases of an illness in a population in a stated time, often per 100 000 people per year.
- **Prevalence**: the total number of people with the illness at a given time, often per 100 000 people.
- **Mortality rate**: the number of deaths from a cause in a stated time, per 100 000 people (or per 1000).

Calculating a mortality rate

In one year 1500 people died from coronary heart disease in a town of 600 000 people. Calculate the mortality rate per 100 000 people.

1. Rate per 100 000 = (number of deaths ÷ population) × 100 000

2. = (1500 ÷ 600 000) × 100 000

Answer: 250 deaths per 100 000 people per year

To interpret data, describe the trend with figures from the table or graph, calculate percentage changes, and compare groups. Percentage change = (new value – original value) ÷ original value × 100.

Correlation and causation

A **correlation** is a relationship between two variables, often shown on a scatter diagram: as one rises the other rises (positive) or falls (negative). A correlation does not show that one variable **causes** the other. A third variable (a confounding variable) may be responsible for both, or the link may be due to chance.

Evidence for a causal relationship is stronger when there is a plausible biological mechanism, the effect increases with the dose of the factor, the link is found repeatedly in different studies, and intervention (removing the factor) reduces the disease.

Conflicting evidence

Studies on the same risk may reach different conclusions because they differ in sample size, the people studied, the length of the study, how data were collected and which other variables were controlled. When evidence conflicts, compare the quality of the studies and look at the overall weight of evidence.

Maths skill: Give rates with units (per 100 000 per year), and when calculating a percentage change always divide by the original value.

Exam tip: When asked why data do not prove causation, name a possible confounding variable (for example, other lifestyle differences between groups) rather than just writing 'correlation is not causation'.

Evaluating the design of studies Spec 1.16

Valid	The data measure what the study claims to measure, with other variables controlled.
Reliable	The results are consistent, and similar results would be obtained if the study were repeated.

Questions to ask when evaluating a study

Feature	What makes it better	Why
Sample selection	People who represent the whole population (age, gender, lifestyle), chosen at random	Avoids bias, so the findings can be applied to the population; volunteers may be unusually health-conscious
Sample size	Large	Reduces the effect of chance and of anomalous individuals; the results are more reliable
Control of variables	Groups matched for age, gender and other factors, with a control group	Reduces the effect of confounding variables, so any difference is more likely to be due to the factor
Data collection	Objective, measured values (blood pressure, cholesterol)	Self-reported diet and exercise rely on memory and honesty
Duration	Long enough for the disease to develop; follow people over time	CVD takes years to develop

In a **cohort study** a large group is followed over time and the rate of disease is compared between people with and without a factor. In a **case-control study** people with the disease are compared with matched people without it. Both can show a link but cannot prove a cause.

Exam tip: Do not just write 'bigger sample'. Say why: a larger sample reduces the effect of chance and anomalies, so the data are more reliable. Link bias in selection to validity.

Perception of risk Spec 1.17

The **actual risk** is the measured probability of harm, found from data. The **perceived risk** is what people think the risk is. The two often differ.

- **Overestimating**: risks that are dramatic, rare and widely reported, or outside a person's control (for example air travel).
- **Underestimating**: risks from everyday lifestyle choices whose harm builds up slowly, such as a diet high in saturated fat, little exercise and smoking. People feel healthy now, and the harm is years away.
- Reasons include media coverage, the experience of friends and family (a relative who smoked and lived to 90), the pleasure or convenience of the behaviour, believing the risk applies to others, and difficulty understanding statistics (for example confusing a large relative increase with a large absolute risk).

These differences matter because people who underestimate the risk of heart disease from diet and inactivity are less likely to change their behaviour. Health education aims to present the evidence clearly so perceived risk is closer to actual risk.

Exam tip: Use the wording 'overestimate' and 'underestimate' with a named lifestyle risk, and give a reason such as media coverage or the delay before harm appears.

Blood cholesterol, HDL and LDL Spec 1.18(i)

Cholesterol is needed to make cell membranes and some hormones, but it is hydrophobic and cannot dissolve in plasma. It is carried in blood inside **lipoproteins**: particles with a surface of phospholipid and protein around a core of cholesterol and triglyceride.

LDL and HDL		
	LDL (low-density lipoprotein)	HDL (high-density lipoprotein)
Carries cholesterol	From the liver to the body tissues	From the tissues back to the liver
Effect on arteries	Excess LDL is taken into the artery wall and contributes to plaque formation	Removes excess cholesterol from the artery wall, so protective
Effect on CVD risk	Higher level = higher risk	Higher level = lower risk

Doctors look at total cholesterol, LDL and HDL, and often the ratio of total cholesterol to HDL. The lower the ratio, the lower the risk. Typical UK guidance suggests a total cholesterol below about 5 mmol dm^{-3} and LDL below about 3 mmol dm^{-3} (you are not expected to learn these values). A diet high in saturated fat tends to raise LDL.

Exam tip: When analysing data, compare people using LDL and the total:HDL ratio, quote the values, and say a high LDL level with a low HDL level means the highest risk.

Evidence linking cholesterol and CVD Spec 1.18(ii)

- **Correlation** in large population studies: groups with higher total and LDL cholesterol have more cardiovascular disease.
- **Genetic evidence**: people with inherited conditions that cause very high LDL cholesterol develop atherosclerosis and CVD at a young age.
- **Mechanism**: LDL cholesterol is found in plaques; oxidised LDL is taken up by macrophages to form foam cells.
- **Intervention trials**: lowering LDL cholesterol with statins and diet reduces the number of heart attacks and strokes.
- Laboratory studies: animals fed high-cholesterol diets develop atherosclerosis.

Not every piece of evidence is consistent. Some people with normal cholesterol develop CVD and some people with high cholesterol do not, because CVD has many risk factors. Studies of drugs that raise HDL have not always shown reduced CVD. Overall the weight of evidence from several different kinds of study supports a causal role for high LDL.

Exam tip: Strong answers use more than one type of evidence (population, genetic, mechanism, intervention) and mention that CVD is multifactorial, which is why correlation alone is not proof.

Using scientific knowledge to reduce the risk of CHD Spec 1.19

Lifestyle changes and why they reduce risk

Change	Scientific reason
Eat less saturated fat	Lowers LDL cholesterol, so less atheroma forms
Eat less salt	Lowers blood pressure, so less endothelial damage
Eat more fruit, vegetables and fibre	Antioxidants and fibre; helps control weight and cholesterol
Take regular exercise	Lowers blood pressure, raises HDL, helps control body mass
Stop smoking (or never start)	Removes carbon monoxide, nicotine and chemicals that damage the endothelium and raise clotting
Keep to a healthy body mass	Obesity is linked to high blood pressure and raised LDL

Obesity indicators

body mass index (BMI) = mass (kg) ÷ height² (m²)

waist-to-hip ratio = waist circumference ÷ hip circumference

A BMI under 18.5 is classed as underweight, 18.5 to 24.9 as healthy, 25 to 29.9 as overweight and 30 or over as obese. BMI is simple to calculate but does not distinguish muscle from fat, so a muscular person can have a high BMI without being unhealthily fat. Waist-to-hip ratio shows fat distribution: a high ratio means more fat stored around the abdomen, which is linked to a higher risk of CVD (commonly used thresholds for higher risk are above 0.90 in men and above 0.85 in women).

Calculating BMI and waist-to-hip ratio

A man has a mass of 80 kg and a height of 1.75 m. His waist is 92 cm and his hips are 102 cm. Calculate his BMI and waist-to-hip ratio.

1. $\text{BMI} = 80 \div 1.75^2 = 80 \div 3.0625 = 26.1$ (to 3 s.f.)
2. $\text{Waist-to-hip ratio} = 92 \div 102 = 0.90$ (to 2 d.p.)

Answer: BMI 26.1 kg m⁻² (overweight); waist-to-hip ratio 0.90

Maths skill: Square the height before dividing in BMI, and use the same units for waist and hip. BMI is expressed in kg m⁻² and waist-to-hip ratio has no units.

Treatments for cardiovascular disease Spec 1.20

Drug treatments for CVD			
Drug	How it works	Benefits	Risks
Antihypertensives (for example beta blockers, ACE inhibitors, calcium channel blockers, diuretics)	Lower blood pressure, by relaxing artery walls, slowing the heart or reducing blood volume	Less damage to the endothelium and less strain on the heart; lower risk of stroke and heart attack	Dizziness or fainting if blood pressure falls too far, tiredness, and other side effects specific to the drug type
Statins	Reduce the liver's production of cholesterol (by inhibiting an enzyme), so the liver removes more LDL from the blood	Lower blood LDL; slow atheroma formation; lower risk of heart attack and stroke	Muscle pain, digestive upset, rarely liver damage
Anticoagulants (for example warfarin, heparin)	Interfere with the clotting cascade, so less fibrin is made	Reduce the risk of clots forming, for example after a previous clot or in people at risk	Bleeding and bruising, which can be serious; dose needs monitoring
Platelet inhibitors (for example aspirin)	Stop platelets sticking together and to damaged vessel walls	Reduce the risk of clots in arteries, so lower risk of heart attack and stroke	Bleeding, and irritation or ulcers in the stomach

These drugs treat risk factors or reduce the effects; they do not cure atherosclerosis. Treatment is chosen by weighing the likely benefit against the risk of side effects for the individual, and is used together with lifestyle changes. Anticoagulants and platelet inhibitors act at different points: anticoagulants affect the clotting cascade, whereas platelet inhibitors stop platelets aggregating.

Exam tip: For 'evaluate' or 'discuss' questions on drugs, give at least one benefit and one risk for each drug named, and conclude with who is most likely to benefit.

Quick check

1. How do you calculate a mortality rate per 100 000?
2. What is the difference between valid and reliable data?
3. What does LDL do?
4. Give the formula for BMI.
5. How do statins reduce the risk of CVD?

Quick check answers

Water, carbohydrates and lipids

1. A molecule with a slightly positive end and a slightly negative end because its electrons are shared unevenly.
2. α -1,4 glycosidic bonds (main chain) and α -1,6 glycosidic bonds (branch points).
3. Glucose and fructose.
4. Three, one for each ester bond formed.
5. Yellow-brown to blue-black.

The heart, blood vessels and haemoglobin

1. Its surface area to volume ratio is small and diffusion distances are long, so diffusion alone is too slow to supply all cells.
2. It pumps blood to the whole body at high pressure, whereas the right ventricle only pumps to the lungs.
3. Atrial systole, ventricular systole and cardiac diastole.
4. Four, one on each haem group.
5. It shifts to the right (Bohr effect), so haemoglobin releases more oxygen.

Cardiovascular disease and its causes

1. Endothelial dysfunction, inflammatory response, plaque formation and raised blood pressure.
2. It is an enzyme that catalyses the conversion of soluble fibrinogen to insoluble fibrin.
3. Any two of: carbon monoxide reduces oxygen carried by haemoglobin; nicotine raises heart rate and blood pressure; chemicals damage the endothelium; platelets are stickier.
4. They neutralise free radicals, so less LDL is oxidised and there is less endothelial damage and foam cell formation.
5. Blue DCPIP turns colourless.

Health risks, evidence and treatment

1. $(\text{Number of deaths} \div \text{population}) \times 100\,000$.
2. Valid data measure what the study claims to measure; reliable data are consistent and repeatable.
3. It carries cholesterol from the liver to the body tissues; high levels raise the risk of CVD.
4. $\text{Mass in kg} \div (\text{height in m})^2$.
5. They lower blood LDL cholesterol by reducing cholesterol production in the liver.