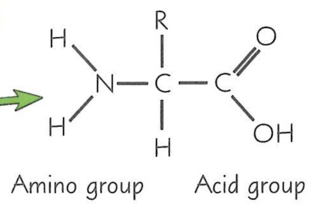
Proteins

Proteins are Made of Amino Acids

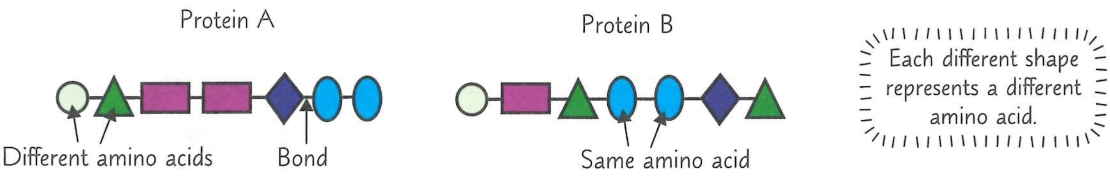
Proteins are composed of long chains of **amino acids**. There are **twenty different** amino acids used in proteins. They all contain carbon, hydrogen, oxygen and nitrogen, and some contain sulfur. All have the **same structure** as the one in the diagram but **R** can be one of twenty different chemical groups.

An amino acid



Proteins are Held Together by Peptide Bonds

1) The amino acids in a protein chain are attached to each other by **strong peptide bonds**.
2) The amino acids can be arranged in any sequence and proteins can be up to **several hundred** amino acids long.
3) The number of different proteins that are possible is almost unimaginable. Consider that there are several thousand ways of arranging a chain of just three amino acids, with each combination forming a different protein. Add one more amino acid to the chain and the number of possibilities leaps into the hundreds of thousands.
4) It's the **order** of the amino acids in a protein that determines its **structure** and it's the structure of a protein that determines **how it works**.

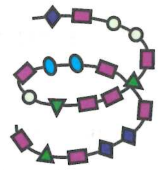


Each Protein has its Own Special Shape

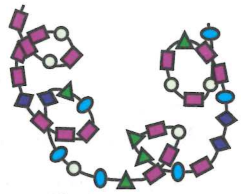
1) The order in which the amino acids are arranged in a protein chain is called the **primary structure**.


Primary structure

2) Some chains **coil up** or **fold** into pleats that are held together by weak forces of chemical attraction called **hydrogen bonds**. The coils and pleats are the **secondary structure** of a protein.


Secondary structure

3) Some proteins (especially enzymes) have a **tertiary structure**. The coiled chain of amino acids is folded into a **ball** that's held together by a mixture of weak chemical bonds (e.g. hydrogen bonds) and stronger bonds (e.g. disulfide bonds).


Tertiary structure

4) If the protein has a roughly spherical shape it's called a **globular protein** (e.g. enzymes are classed as globular proteins).

The name's Bond. Peptide Bond...

PRACTICE QUESTIONS

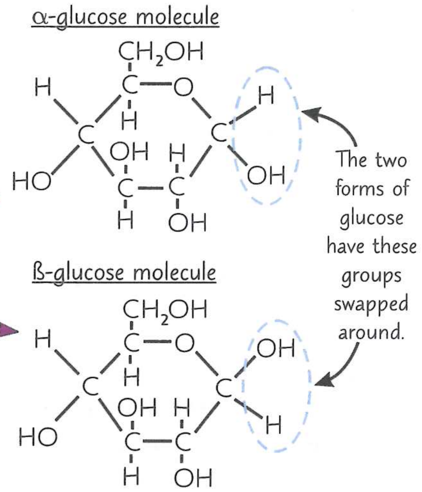
1) What is the primary structure of a protein?
2) What type of bond holds together the secondary structure of a protein?

Carbohydrates

Carbohydrates Contain Three Elements

Carbohydrates contain **carbon**, **hydrogen** and **oxygen**.
There are several types of carbohydrate, e.g. sugars, starch and cellulose.

1) Sugars are **small**, **water-soluble** molecules that taste sweet.
2) They're divided into two groups: **monosaccharides** (pronounced: mono-sack-a-rides) and **disaccharides** (die-sack-a-rides).
3) Monosaccharides are the single units from which all the other carbohydrates are built. **Glucose** and **fructose** are both monosaccharides. Glucose has two forms — **alpha** (α) and **beta** (ß).
4) Disaccharides are formed when **two monosaccharides** are joined together by a chemical reaction. A molecule of **water** is also formed (so it's called a **condensation reaction**).

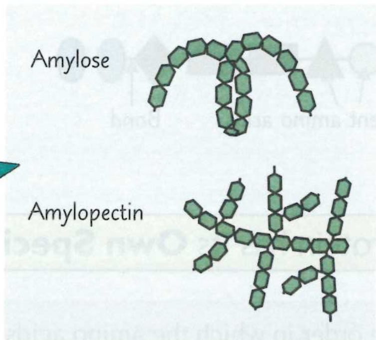


GLUCOSE + GLUCOSE → MALTOSE (a disaccharide) + WATER
GLUCOSE + FRUCTOSE → SUCROSE (a disaccharide) + WATER

Starch is a Polysaccharide

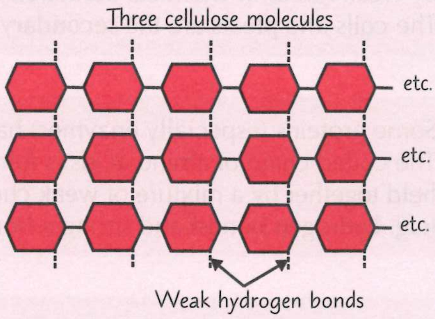
Polysaccharides are **polymers** — large molecules made up of **monomers** (smaller units). The monomers of polysaccharides are **monosaccharides**.

Starch molecules are made up of two different polysaccharides — **amylose** and **amylopectin**, which are polymers of glucose. The insoluble, compact starch molecules are an ideal way of **storing glucose**. Starch is **only** found in plant cells.



Cellulose is Also a Polysaccharide

1) Like starch, cellulose is a polymer of glucose, but the **bonding** between the glucose units is different.
2) As a result, the cellulose molecules are **long** and **straight**.
3) Several cellulose molecules can lie side by side to form **microfibrils**.
4) The molecules are held together by many weak **hydrogen bonds**.
5) Cellulose is only found in plant cells.
6) The microfibrils **strengthen** the plant cell wall.



A poly-sack-a-ride — a bunch of kids on a helter skelter...

PRACTICE QUESTIONS

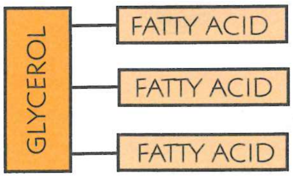
1) Name two monosaccharides.
2) Which disaccharide is composed of two molecules of glucose?
3) Name two polysaccharides.

Lipids

Lipids Contain Carbon, Hydrogen and Oxygen

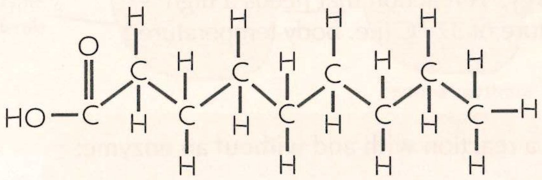
NEW CONTENT

Lipids are **oils** and **fats**. Plant oils and animal fats are mostly made up of a group of lipids called **triglycerides**. A triglyceride consists of a molecule of **glycerol** with **three fatty acids** attached to it.



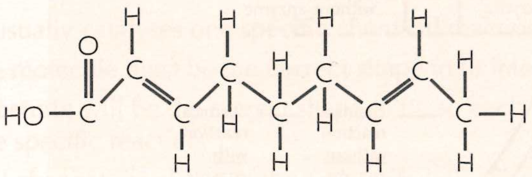
A triglyceride

1) A fatty acid molecule is a long chain of **carbon atoms** with an **acid group** (-COOH) at one end. **Hydrogen atoms** are attached to the carbon atoms.
2) If every carbon atom in the chain is joined by a **single bond**, we say that the fatty acid is **saturated**.



Saturated fatty acid

3) If one or more of the bonds is a **double bond**, it's said to be **unsaturated**. A fatty acid with many double bonds is **polyunsaturated**.



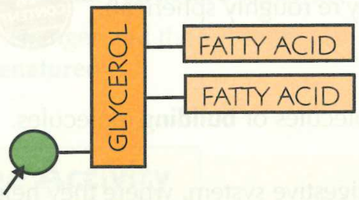
Unsaturated fatty acid

Despite the rain, Polly stayed unsaturated thanks to her umbrella.

Phospholipids are a Special Type of Lipid

NEW CONTENT

1) Phospholipids (pronounced: foss-foe-lip-ids) are like triglycerides, but instead of having three fatty acid chains, they have **two** fatty acid chains and a **phosphate** group.



A phospholipid

2) **Cell membranes** are made from a **double layer** of phospholipids.

PRACTICE QUESTIONS

Acid chain and the phospholipids — sounds like a punk band...

1) Which elements are fatty acids composed of?
2) What's the difference between saturated fatty acids and unsaturated fatty acids?
3) What's the difference between triglycerides and phospholipids?

Enzymes

Enzymes Help to **Speed up Biochemical Reactions**

1) In a living cell, thousands of **biochemical reactions** take place every second. The sum of these reactions is called **metabolism**.
2) A single chain of these reactions is called a **metabolic pathway**. NEW CONTENT
3) Without enzymes, these reactions would take place very **slowly** at normal body temperature.

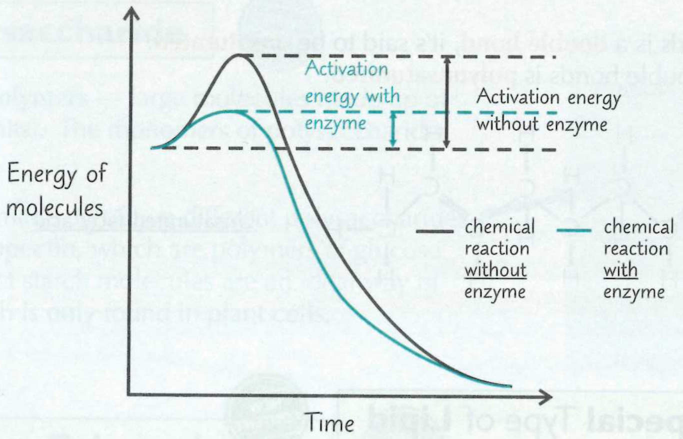
> 1) Enzymes are **biological catalysts**.
> 2) They **increase** the **rate** (speed) of reactions.

How do Enzymes **Act** as **Catalysts**?

NEW CONTENT

1) Even reactions that release energy require an **input of energy** to get them going, e.g. the gas from a Bunsen burner doesn't burn until you provide heat energy from a match.
2) This input energy is called the **activation energy**. A reaction that needs a high activation energy can't start at a low temperature of 37 °C (i.e. body temperature).
3) Enzymes **reduce** the activation energy.

This graph shows the activation energies of a reaction **with** and **without** an enzyme:



Enzymes are **Proteins**

1) All enzymes are **globular proteins** (because they're roughly spherical). NEW CONTENT
2) It's the order of amino acids in an enzyme that determines its **structure**, and so how it works.
3) Enzymes can be involved in **breaking down** molecules or **building** molecules. For example:

> - **Digestive enzymes** are important in the digestive system, where they help to break down food into smaller molecules, e.g. carbohydrases break down carbohydrates.
> - Enzymes involved in **DNA replication** help to build molecules, e.g. DNA polymerase. NEW CONTENT

PRACTICE QUESTIONS

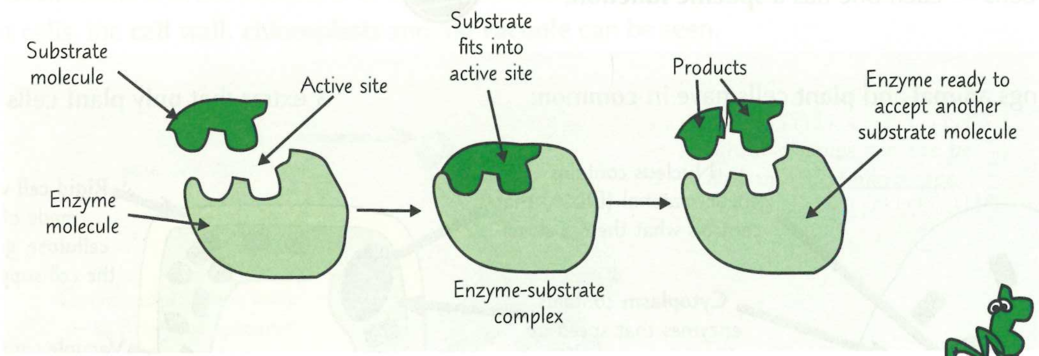
I could really use a catalyst to help me write this gag...

1) What is the function of enzymes?
2) What is activation energy?
3) What do digestive enzymes do?

Enzymes

Enzymes have an **Active Site**

1) A substance that's acted upon by an enzyme is called its **substrate**.
2) The **active site** is a region on the surface of the enzyme molecule where a substrate molecule can attach itself. It's where the catalysed reaction takes place.
3) The shape of the substrate molecule and the shape of the active site are **complementary**, i.e. they fit each other.
4) Almost as soon as the **enzyme-substrate complex** has formed, the products of the reaction are released and the enzyme is ready to accept another substrate molecule.



Enzymes are **Specific**

1) An enzyme usually catalyses one **specific** chemical reaction.
2) The substrate molecule must be the **correct shape** to fit into the active site.
3) **Only one substrate** will be the correct shape to fit, so each enzyme only catalyses one specific reaction.
4) Anything that **changes** the shape of the active site will **affect** how well the enzyme works.

Temperature Affects **Enzyme Activity**

1) As temperature **increases**, enzyme reactions become **faster**, because the molecules have more **energy**.
2) However, at high temperatures the atoms of the enzyme molecule vibrate more rapidly and **break** the weak bonds that hold the **tertiary structure** together.

NEW CONTENT

3) The **shape** of the active site **changes** and the substrate can no longer fit in. The enzyme is said to be **denatured**.

pH also Affects **Enzyme Activity**

1) **Acids** and **alkalis** can denature enzymes.
2) Hydrogen ions (H^+) in acids and hydroxyl ions (OH^-) in alkalis can disrupt the **weak bonds** and change the shape of the active site.

NEW CONTENT

PRACTICE QUESTIONS

Lonely enzyme seeking complementary substrate...

1) Why are enzymes described as 'specific'?
2) Explain why a denatured enzyme will not function.
3) Describe the effect of pH on enzyme activity.

Eukaryotic and Prokaryotic Cells

Organisms can be **Prokaryotes** or **Eukaryotes**

1) **Prokaryotic** organisms are prokaryotic cells (i.e. they're **single-celled** organisms) and **eukaryotic** organisms are made up of eukaryotic cells.

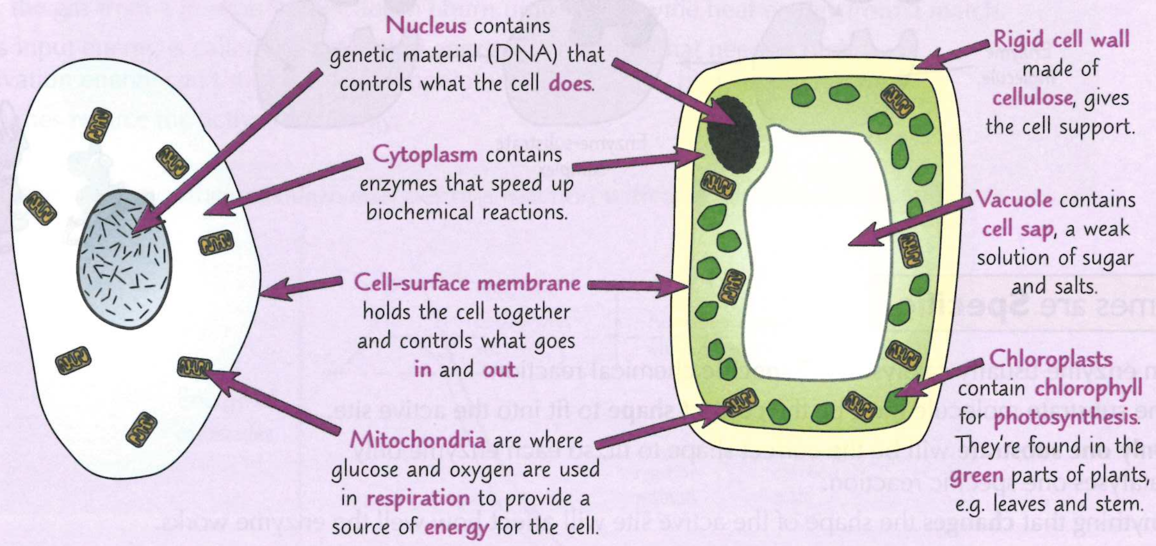
> **Eukaryotic** cells are **complex** and include all **animal** and **plant** cells.
> **Prokaryotic** cells are **smaller** and **simpler**, e.g. **bacteria**.

2) Both types of cells contain **organelles**. Organelles are parts of cells — each one has a **specific function**.

NEW CONTENT

4 things **animal** and **plant** cells have in **common**:

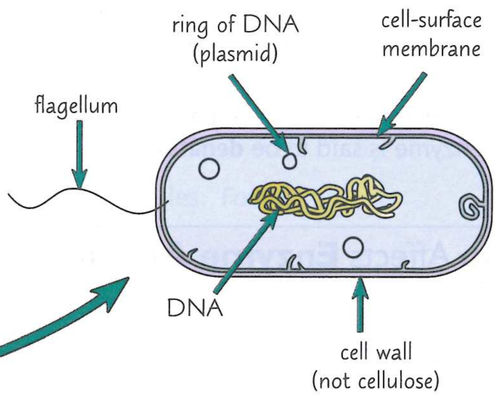
3 extras that **only plant cells** have:



Bacterial Cells are **Prokaryotic**

1) Prokaryotes like bacteria are roughly a **tenth the size** of eukaryotic cells.
2) Prokaryotic cells **don't contain** a nucleus, mitochondria or chloroplasts.
3) As they **don't** have a nucleus, their **DNA floats freely** in the **cytoplasm**. Some prokaryotes also have **rings of DNA** called **plasmids**.
4) Some prokaryotes have a **flagellum**, which **rotates** and allows the cell to **move**.
5) The diagram shows a bacterial cell as seen under an **electron microscope** (see next page).

NEW CONTENT



PRACTICE QUESTIONS

Bacterial cheerleaders — they never stop swirling their flagella...

1) Give an example of a prokaryotic cell.
2) Name four organelles that plant and animal cells both have.
3) What is the function of mitochondria?

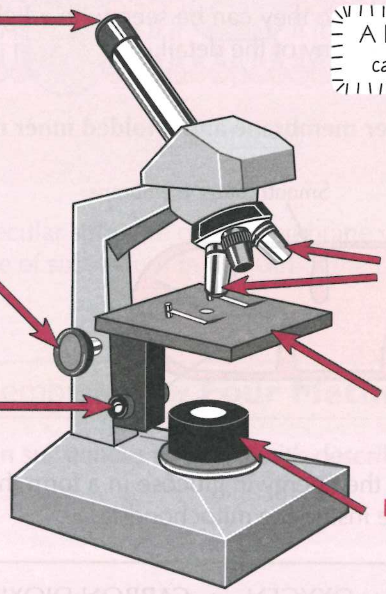
Microscopes

You Can See Cell Structure with a Light Microscope

A **light microscope** can magnify objects up to 1500 times. NEW CONTENT

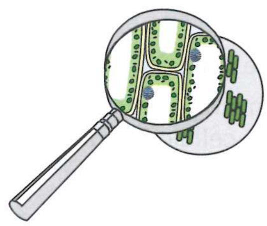
A light microscope allows you to see individual animal and plant cells along with some of the organelles inside them.

1) If the cells have been **stained** you can see the dark-coloured **nucleus** surrounded by lighter-coloured **cytoplasm**.
2) Tiny **mitochondria** and the black line of the **cell membrane** are also visible.
3) In plant cells, the **cell wall**, **chloroplasts** and the **vacuole** can be seen.



Electron Microscopes have a Greater Magnification

1) The detailed **ultrastructure** of cells was revealed in the 1950s, after the **electron microscope** was invented.
2) An electron microscope can **magnify** objects more than 500 000 times. NEW CONTENT
3) This allows you to see **greater detail** than with a light microscope. For example, with an electron microscope, you can see the detailed **structures inside organelles** such as mitochondria and chloroplasts.
4) The image that's recorded is called an **electron micrograph**. NEW CONTENT



PRACTICE QUESTIONS

I put a slide on the stage and then slid straight off the edge...

1) Name three things visible with a light microscope in both animal and plant cells.
2) Which type of microscope must be used to show the detailed ultrastructure of a cell?
3) What is the image recorded by an electron microscope called?

Functions of the Nucleus, Mitochondria and Cell Wall

The **Nucleus** is the **Control Centre** of the Cell

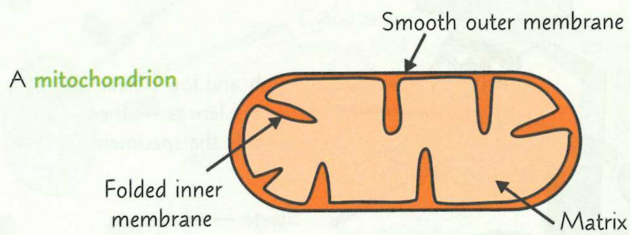
1) It contains **DNA** — the coded information needed for **making proteins**.
2) During **cell division** the chromosomes carrying the long DNA molecules coil up, becoming shorter and thicker and visible with a light microscope.
3) Electron micrographs show that there's a **double membrane** round the nucleus.

DNA stands for deoxyribonucleic acid.

Aerobic Respiration Takes Place in the **Mitochondria**

Mitochondria are about the size of bacteria, so they can be seen with a light microscope, but you need an electron microscope to see any of the detail.

Each mitochondrion has a **smooth outer membrane** and a **folded inner membrane**:



The job of a mitochondrion is to capture the energy in glucose in a form that the cell can use. To do this **aerobic respiration** takes place inside the mitochondria.

Word equation: GLUCOSE + OXYGEN → CARBON DIOXIDE + WATER (+ ENERGY)

The energy released by respiration ends up in molecules of **ATP** (adenosine triphosphate). ATP is used in the cell to provide the energy for **muscle contraction**, **active transport** (called active uptake in some textbooks) and **building large molecules** from small ones, as well as many other processes.

The **Plant Cell Wall Supports** the Cell

1) The plant cell wall is relatively rigid and provides **support** for the cell.
2) It mainly consists of bundles of long, straight **cellulose molecules**. The cellulose molecules lay side by side to form **microfibrils**.

Ralph the raccoon struggled to get out of his plant cell. If only the walls weren't so rigid...

Doctor, doctor my DNA is getting shorter and thicker...*

PRACTICE QUESTIONS

1) Which organelle acts as the control centre of the cell?
2) In which organelle does aerobic respiration occur?
3) Describe the membranes of a mitochondrion.
4) What is the word equation for aerobic respiration?
5) Name the molecule used to provide energy for processes in the cell.
6) Name the molecule that is found in bundles in plant cell walls.

*...that's the least of your worries — you're going to divide soon.

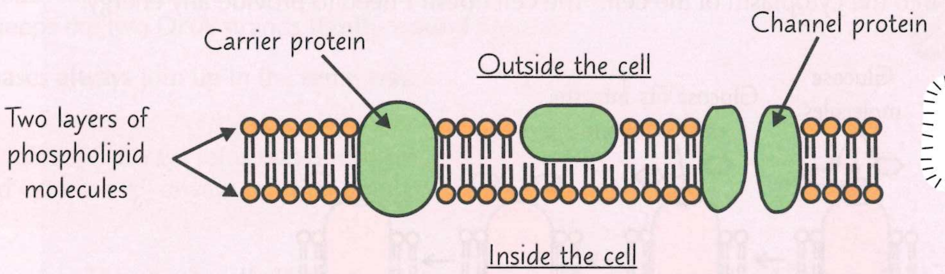
Cell Membranes

Electron Micrographs Show the Structure of the Cell-Surface Membrane

NEW CONTENT

The **cell-surface membrane** is the very thin structure around an individual cell.

1) Electron micrographs show that the cell-surface membrane consists of a double layer of **phospholipid** molecules tightly packed together.
2) Bigger **protein molecules** are embedded in the phospholipid molecules.
3) Some proteins go **all the way through** the membrane and some only go **halfway**.
4) Membranes surrounding the **organelles** inside cells have the **same** structure.



Cell-surface membranes can also be called plasma membranes.

5) Once you're familiar with the molecular structure of the membrane you can explain how the membrane **controls** the passage of substances **in** and **out** of the cell.

Substances **Pass Through** Membranes by **Four Methods**

Since the membrane only allows certain substances through it, it's described as being **partially permeable**.

1. Diffusion

1) The particles of liquids and gases are constantly **moving about**. This movement causes the particles to spread from an area of **higher** concentration to an area of **lower** concentration.
2) Particles will **diffuse** through the cell membrane as long as they are small enough to pass through the very small gaps **between** the phospholipid molecules. Water, oxygen and **carbon dioxide** molecules can do this.
3) The cell **doesn't** need to provide any energy for this process.

The difference in concentration is sometimes called a concentration gradient, e.g. a big difference in concentration is a big concentration gradient.

2. Osmosis

1) **Osmosis** is the diffusion of **water** molecules across a partially permeable membrane from a region of **higher concentration** of water molecules to a region of **lower concentration** of water molecules. The cell **doesn't** need to provide energy.
2) The concentration of water molecules is also referred to as the **water potential**. At AS and A-level, you tend to talk about water moving from a region of **higher water potential** to a region of **lower water potential**.

NEW CONTENT

Cell Membranes

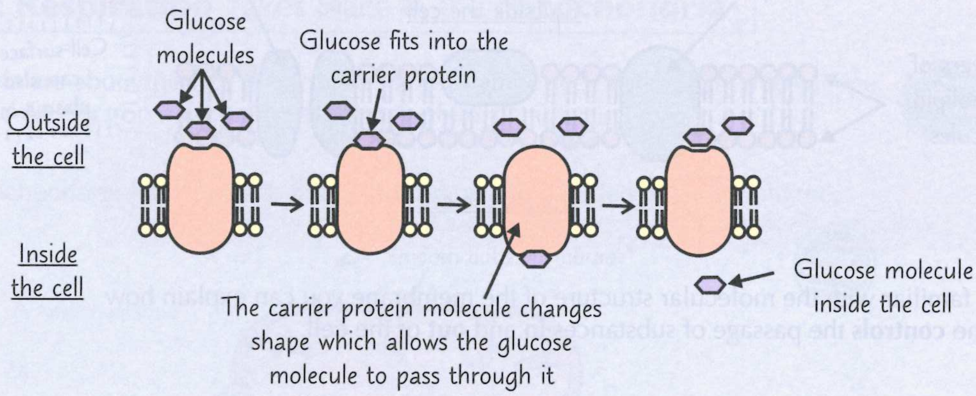
3. Facilitated Diffusion

NEW CONTENT

1) Glucose and many other water-soluble molecules are **too big** to diffuse across the membrane by themselves. They must be helped across by **carrier proteins**.
2) Each substance has its **own specific** carrier protein.

EXAMPLE

A molecule of glucose fits onto the outside end of a **glucose carrier protein**. This causes the protein to **change shape**, allowing the glucose molecule to diffuse through it into the cytoplasm of the cell. The cell **doesn't** need to provide any energy.



3) **Mineral ions** like sodium (Na^+) and potassium (K^+) have electrical charges on them, so they also need help to cross the membrane. Specific **channel proteins** in the membrane allow them to diffuse through.

4. Active Transport (or Active Uptake)

1) When a cell needs to move substances across the membrane from a region of **lower** concentration to a region of **higher** concentration, it must provide **energy**.
2) The substance fits into a **specific carrier protein**, then molecules of **ATP** (see page 8) provide the energy to change the shape of the protein. As it changes shape, the protein **actively transports** the substance across the membrane.
3) These special **carrier proteins** are sometimes called "**pumps**" because they're moving substances **against** a concentration gradient.

NEW CONTENT

NEW CONTENT

PRACTICE QUESTIONS

Active transport — isn't that just riding a bike?

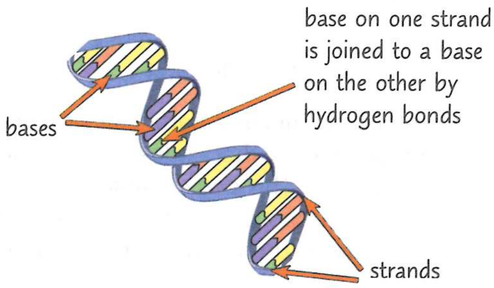
1) Name the two types of molecule that make up the cell membrane.
2) Give four ways substances can cross cell membranes.
3) What do you call the diffusion of water molecules through the cell membrane?
4) Give another term for the concentration of water molecules.
5) Name the two types of protein involved in facilitated diffusion.
6) Why does active transport require ATP?

DNA and Protein Synthesis

DNA is Made Up of **Nucleotides** Containing **Bases**

1) **DNA** is a **double helix** (a double-stranded spiral). Each of the two DNA strands is made up of lots of small molecules called **nucleotides**.
2) Each **nucleotide** contains a part called a **base**. DNA has just **four** different bases.
3) These bases are: **adenine** (A), **cytosine** (C), **guanine** (G) and **thymine** (T).
4) Each base forms **hydrogen bonds** to a base **on the other strand**. This keeps the two DNA strands **tightly wound** together.
5) The bases **always** join up in the **same way**.

A DNA Double Helix



Adenine (A) always joins up with thymine (T), and cytosine (C) always joins up with guanine (G).

These pairs of bases are called **complementary bases**. They join together because they **complement** each other in shape — this is called **complementary base pairing**.

Proteins are Made by **Reading the Code** in **DNA**

1) **DNA** controls the production of **proteins** (**protein synthesis**) in a cell.
2) A **section of DNA** that codes for a particular **protein** is called a **gene**.
3) Proteins are made up of **chains** of **amino acids**. Each different protein has its own particular **number** and **order** of amino acids.
4) This gives each protein a different **shape**, which means each protein can have a different **function**.
5) It's the **order** of the **bases** in a **gene** that decides the order of **amino acids** in a **protein**.
6) Each gene contains a **different sequence** of **bases** — which is what allows it to code for a **unique protein**.

'Codes for' just means 'contains the instructions for'.

The meal was made out of an unidentifiable, unique protein.

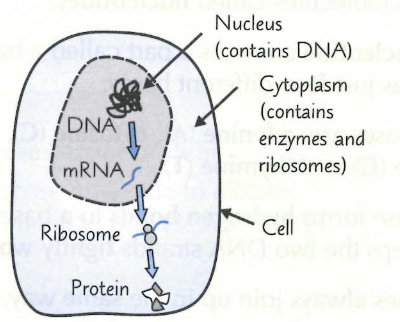
Pro-teen synthesis — supporting youth electronic music-making...

1) What is the name given to the double-stranded structure of DNA?
2) How many different bases are there in DNA?
3) Give the names of the bases in DNA.
4) How do the strands of DNA stay together?
5) What is complementary base pairing?
6) What is a gene?
7) What determines the order of amino acids in a protein?

RNA and Protein Synthesis

RNA is Needed to Make **Proteins**

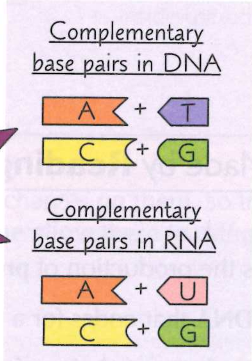
1) DNA molecules (and so genes) are found in the **nucleus** of a cell, but they can't move out of the nucleus because they're very **large**.
2) Protein synthesis happens in the **cytoplasm** at organelles called **ribosomes**.
3) So when a cell **needs** a particular protein, a **copy** of the gene that codes for it is made in the nucleus. This copy is **smaller** than DNA so it can move into the cytoplasm, where it can be used to make the protein.
4) The copy of the gene is made from a molecule called **messenger RNA** (mRNA).



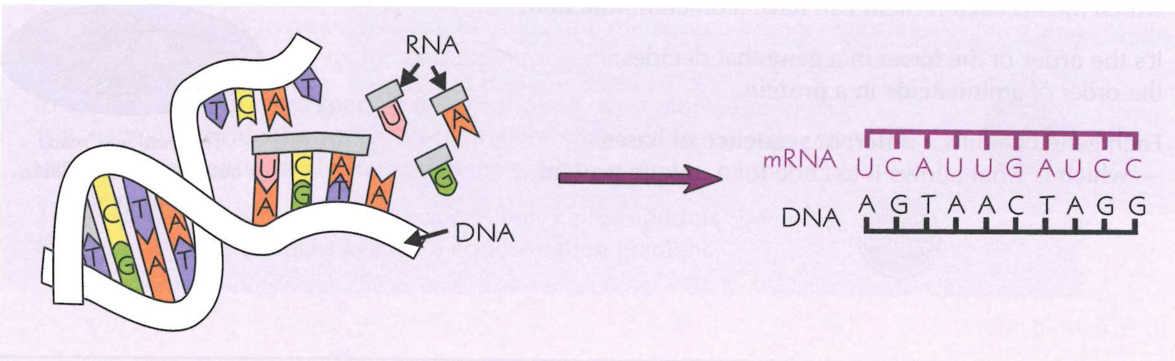
DNA is Used as a **Template** to Make an **mRNA** Molecule

NEW CONTENT

1) The DNA in the gene acts as a **template**.
2) RNA, like DNA, is made up of **nucleotides**, which each have a **base**.
3) The bases on RNA nucleotides line up next to their **complementary** bases on the DNA template.
   - In RNA, there's **no thymine** (T), so the base **uracil** (U) binds to any **adenine** (A) in the DNA instead.
   - Once the bases on the **RNA** nucleotides have **paired up** with the bases on the **DNA** strand, the RNA nucleotides join together to make an **mRNA molecule**.



4) Eventually, a **whole copy** of the gene is made and the **sequence** (order) of **bases** in the mRNA copy is complementary to the sequence of bases in the DNA template.



Complimentary RNA — oh, you do look dashing Mr Ribo Some...

PRACTICE QUESTIONS

1) Why does a copy of a gene need to be made for protein synthesis?
2) What does the 'm' in mRNA stand for?
3) In RNA, which base is complementary to adenine?
4) Give the mRNA sequence that would be complementary to the DNA sequence: ATTGCGCA

Mutations

The Order of Bases Determines the Order of Amino Acids

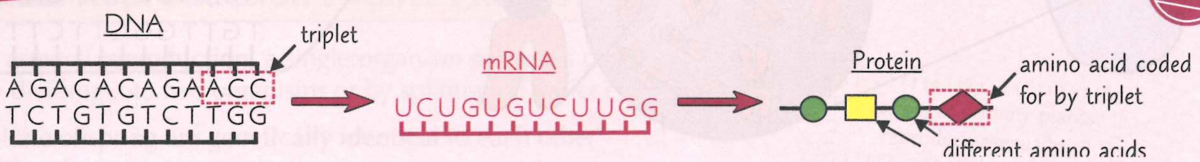
1) **Three** bases in a row (e.g. CGT) codes for **one amino acid** — this is called the **genetic code**.
2) Three bases in a row is known as a **triplet**. **Different amino acids** are coded for by **different triplets**, e.g. TAT = tyrosine, AGT = serine.

NEW CONTENT

3) The **order of the bases** (and so triplets) in the DNA of a gene determines the order of bases in its mRNA copy, and that determines the **order of amino acids** in a protein:

EXAMPLE

NEW CONTENT

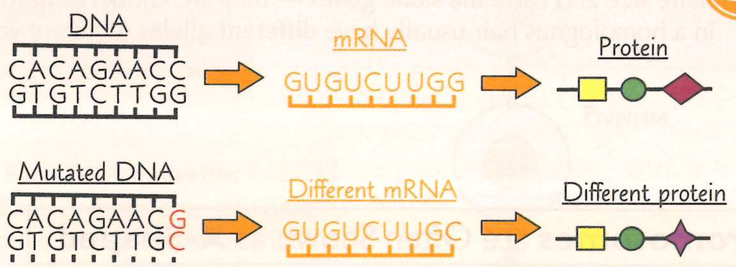


Mutations Change the Order of Bases in DNA

1) **Mutations** are changes to the **base** sequence (order) of DNA.
2) For example, one base can be **substituted** (swapped) for another one. This can cause the base triplet to **change**. E.g. if C is substituted for A, GCT becomes GAT.
3) So mutations can change the **amino acids** in the protein that the gene codes for.
4) A change in the amino acids can cause a **different protein** to be produced.
5) Sometimes the different protein can be **harmful** (see below).

EXAMPLE

NEW CONTENT



Mutations happen **spontaneously** (randomly), but how **frequently** they happen can be increased by **mutagenic agents** — factors that increase mutations, e.g. UV radiation in sunlight.

NEW CONTENT

Mutations can be Harmful

1) Mutations can cause **cancer** because **cell division** is controlled by **proteins**. If mutations occur in the **genes** for these proteins, they can **alter** the proteins so they **no longer work**. This can lead to **uncontrolled cell division**, and the development of a **tumour** (cancer).
2) Mutations also cause **genetic disorders** — mutations that result in **altered** genes and proteins can be **inherited** (passed on from your parents), e.g. cystic fibrosis.

PRACTICE QUESTIONS

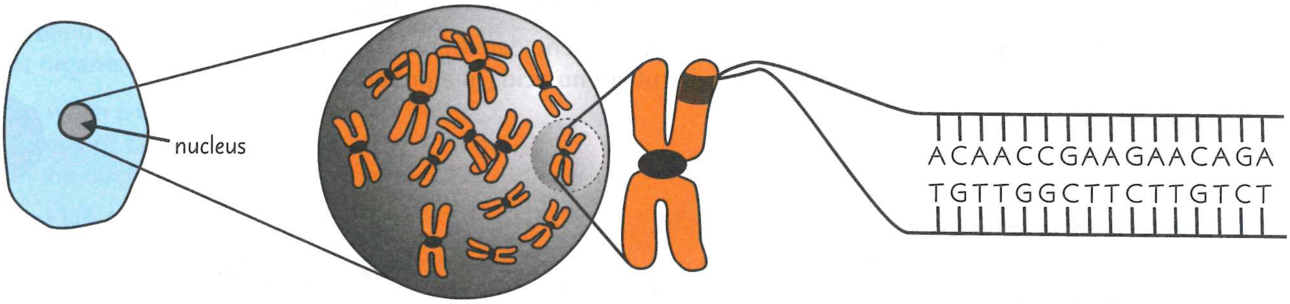
DoNAtello, LeAmino... it's the Teenage Mutant Protein Makers...

1) How many bases code for one amino acid?
2) What are mutations?
3) What do mutagenic agents do?

Chromosomes

DNA is Found in Chromosomes

DNA is found in the **nucleus** of **eukaryotic cells**. It has to be **wound up** into chromosomes to fit in. Each human chromosome contains between a couple of hundred and a few thousand genes.



Human Chromosomes are Found in Pairs

1) Humans have **23 pairs** of chromosomes (46 in total), e.g. two number 1s, two number 2s, two number 3s, etc. One from each pair comes from your mother and one comes from your father.
2) With the exception of the sex chromosomes (X and Y), both chromosomes in a pair are the **same size** and carry the **same genes** — they are known as **homologous pairs**. Chromosomes in a homologous pair usually have **different alleles** (different versions of the genes).

NEW CONTENT

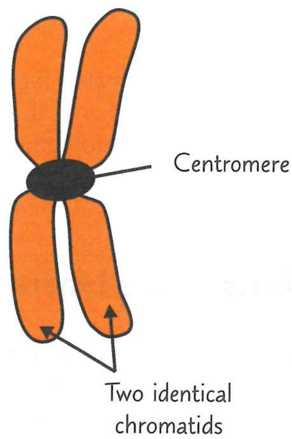
Chromosomes are Often Shown as X-Shaped

In loads of books chromosomes are shown as **X-shaped**.

An X-shaped chromosome is actually **one chromosome** attached to an **identical copy** of itself. Don't get it confused with a homologous pair of chromosomes. They're only X-shaped just after the DNA has been **replicated** (e.g. in cell division).

Each side of the X is referred to as a **chromatid** and the bit in the middle where they're attached is called the **centromere**.

NEW CONTENT



PRACTICE QUESTIONS

Pear chromosomes are found in pairs in pears...

1) Where is most DNA found in a eukaryotic cell?
2) How many homologous pairs of chromosomes do human cells have?
3) Are homologous pairs of chromosomes identical? Explain your answer.
4) What is a chromatid?
5) What is the name of the region where two identical chromatids are joined?

Cell Division — Mitosis

Mitosis is Needed for Growth and Repair

1) If you have damaged tissue, the cells around the damaged area divide by mitosis to replace the damaged cells.
2) Cells also divide by mitosis to produce new tissue for growth.

Jan and Ellen are having a debate about mitosis — it's a divisive topic.

Asexual Reproduction Involves Mitosis

1) In **asexual reproduction**, a single organism produces offspring by dividing into two organisms or by splitting off a piece of itself.
2) All the offspring are **genetically identical** to each other and to the parent.
3) The cells divide by **mitosis** (like most cells).

Bacteria and many plants reproduce asexually.

In Mitosis the DNA Copies Itself, Then the Cell Divides Once

NEW CONTENT

Mitosis is split up into **four** stages: **prophase**, **metaphase**, **anaphase** and **telophase**. **Before** mitosis starts, there's a period called **interphase**.

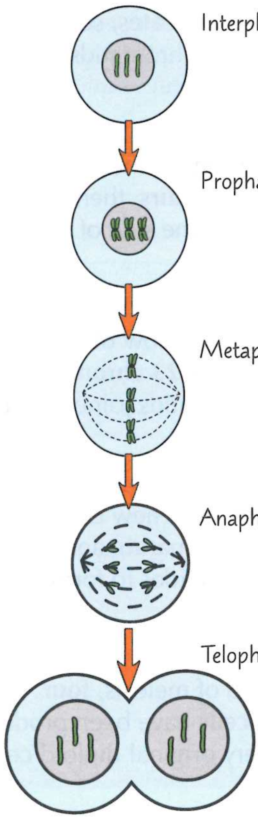
1) **Interphase** — Before the cell starts to divide, every DNA molecule (each chromosome) must **replicate** so that each new cell has a full copy of the DNA. The new molecule remains attached to the original one at the **centromere**.

2) **Prophase** — Mitosis can now begin. Each DNA molecule becomes **supercoiled** and **compact**. Each chromosome can now be seen with a light microscope and appears as two **chromatids** lying side by side, joined by the centromere (i.e. X-shaped).

3) **Metaphase** — The **nuclear membrane** breaks down and the chromosomes **line up** along the **equator** (middle) of the cell.

4) **Anaphase** — The centromeres split and the **chromatids separate** and are dragged to opposite ends of the cell.

5) **Telophase** — A **nuclear membrane** forms around each set of chromatids (exact copies of the original chromosomes) and the **cytoplasm divides**.



Ouch, you stepped on my toe, sis... ba dum tsh

PRACTICE QUESTIONS

1) Give three uses of mitosis.
2) Why is DNA replicated before cell division can occur?
3) Do the homologous pairs separate in mitosis?
4) How many cells are produced when a cell divides by mitosis?

Cell Division — Meiosis

Sexual Reproduction Involves **Meiosis**

1) In **sexual reproduction**, the offspring are genetically different from their parents and from each other. This produces variation in a population.
2) Each parent produces sex cells (**gametes**) containing just **one set** of genetic material. This involves a special kind of cell division, called **meiosis**.
3) During **fertilisation** the nuclei of the gametes join together to form a **zygote**.
4) As they have only one set of genetic material, gametes are described as being **haploid**. The zygote has **two complete sets** of genetic material, and is said to be **diploid**.
5) The zygote grows by simple cell division (**mitosis**) to form the **embryo**.

NEW CONTENT

In **Meiosis**, **DNA Copies Itself** Then the **Cell Divides Twice**

The **only cells** in the human body that divide by meiosis are special cells in the **testes** and **ovaries**.

These cells divide to produce **gametes** (sperm and eggs).

1) The DNA **replicates**, so each of the 46 chromosomes become two chromatids joined by a centromere.

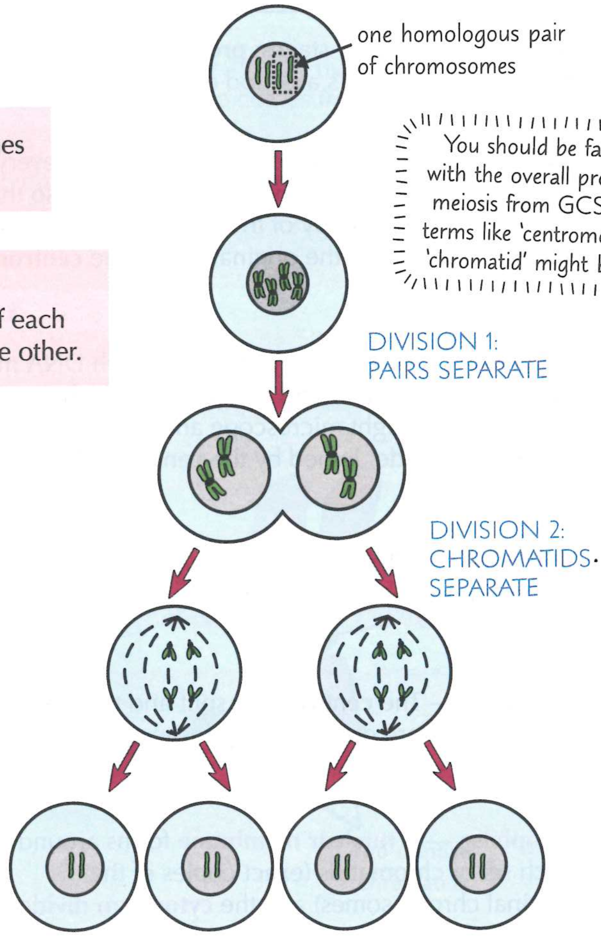
2) The 46 chromosomes sort themselves into the **23 homologous pairs**, then the **pairs separate**. One of each pair goes to one side of the cell and one goes to the other.

3) The cytoplasm now divides. Each of the new cells **contains 23 chromosomes** (consisting of two chromatids joined by a centromere).

4) In both of these new cells the **chromatids separate** and the cytoplasm divides to form two cells.

5) At the end of meiosis, **four haploid cells** have been produced from every original diploid cell.

NEW CONTENT



You should be familiar with the overall process of meiosis from GCSE, but terms like 'centromere' and 'chromatid' might be new.

Nope... I can't think of any more bad cell division puns, sorry...

PRACTICE QUESTIONS

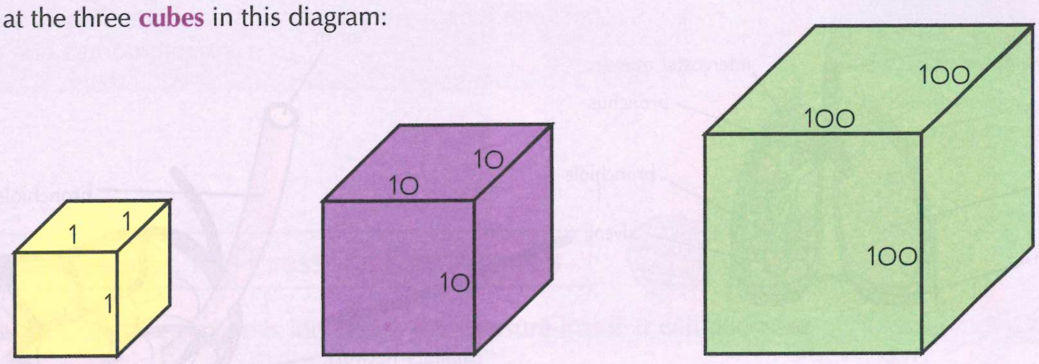
1) Are gametes haploid or diploid?
2) Where in the human body does meiosis occur?
3) How many cell divisions are there in meiosis?
4) How many cells are produced when a cell divides by meiosis?

Size and Surface Area to Volume Ratio

Small Objects have Relatively **Large Surface Areas**

1) Have you ever wondered **why** there are no large single-celled organisms, or why big animals are made up of **millions** of tiny cells instead of a few large ones?
2) The main reason relates to the changes in the **surface area to volume ratio** of an object as it increases in size.

Look at the three **cubes** in this diagram:



Surface area = 6 cm^2	Surface area = 600 cm^2	Surface area = 60,000 cm^2
Volume = 1 cm^3	Volume = 1000 cm^3	Volume = 1,000,000 cm^3
Surface area : Volume 6 : 1	Surface area : Volume 0.6 : 1	Surface area : Volume 0.06 : 1

The **smallest cube** has the **biggest** surface area to volume ratio...

...and the **biggest cube** has the **smallest** surface area to volume ratio.

Surface Area is Important for **Exchange**

1) Cells or organisms need to **exchange materials** and **heat** with their environment.
2) **More** chemical reactions happen every second in organisms with a **larger volume** than in ones with smaller volumes.
3) Therefore **more** oxygen, nutrients, waste products and heat need to be exchanged across the membrane of cells of larger organisms.
4) With increasing volume this becomes an **ever-increasing problem**.

PRACTICE QUESTIONS

My surface area just keeps growing...

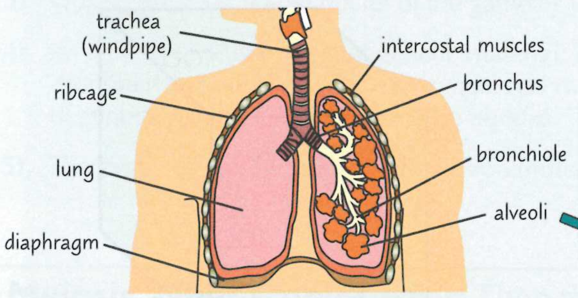
1) Which has the bigger surface area to volume ratio, a small organism or a large organism?
2) An animal has a surface area of 7.5 cm^2 and a volume of 1 cm^3. What is its surface area to volume ratio?
3) Which animal has the greatest surface area to volume ratio — Animal A (9.8 : 1), Animal B (0.98 : 1)?
4) Give three materials that need to be exchanged across the membranes of organisms' cells.

Structure of the Thorax

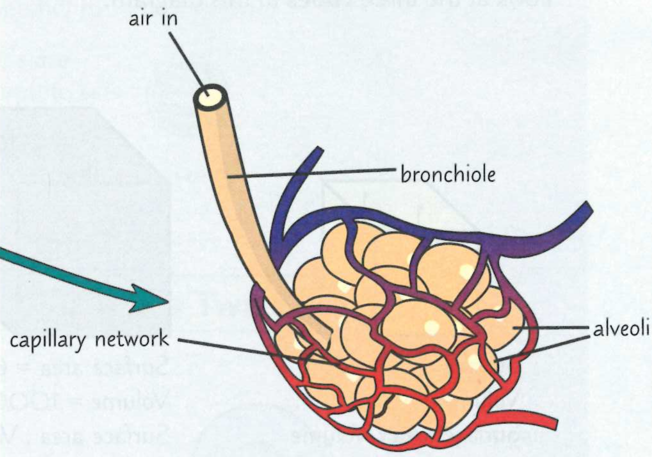
Lungs have a Very **Large Gas Exchange Surface**

Large, active animals, like mammals, have evolved complex **blood systems** and **lungs** to provide a **large surface area** for the efficient diffusion of oxygen and carbon dioxide.

Here's a diagram of the **human gas exchange system**:



Inside the lungs, **gas exchange** takes place in millions of tiny air sacs, called **alveoli**.



Alveoli have **Adaptations** that **Increase** the **Diffusion Rate**

1) The walls of the alveoli consist of a **single layer** of thin, flattened, epithelial cells. Diffusion happens **faster** when molecules only have to travel **short** distances.
2) Diffusion is faster when there's a **bigger difference** in concentration between two regions. The blood flowing through the rich network of capillaries around the alveoli **carries away** the oxygen that has diffused through the alveolar walls.
3) This ensures that there's always a **higher concentration of oxygen** inside the alveoli than in the blood. The reverse is true for **carbon dioxide**.
4) The alveolar walls are **fully permeable** to dissolved gases. Oxygen and carbon dioxide can pass easily through the cell membranes of the epithelial cells.

PRACTICE QUESTIONS

I like my ralveoli filled with spinach and ricotta...

1) Why have large mammals evolved complex blood systems and lungs?
2) In which part of the lungs does gas exchange take place?
3) Describe the shape of the cells that make up the walls of the alveoli and explain how their shape suits their function.
4) What type of cell are the alveoli walls made of?
5) a) Why does oxygen diffuse from inside the alveoli into the blood?
   b) Name another gas that can pass easily through the walls of the alveoli.

Breathing In and Breathing Out

Why do We Need to **Breathe**?

Ventilation (breathing) ensures that air with a **high concentration of oxygen** is taken into the lungs, and air with a **high concentration of carbon dioxide** is removed from the lungs.

This maintains high **concentration gradients** between air (inside your alveoli) and blood, **increasing** the rate of diffusion of oxygen and carbon dioxide.

In Brian's opinion, breathing was over-rated.

If Volume **Increases**, Air Pressure **Decreases**

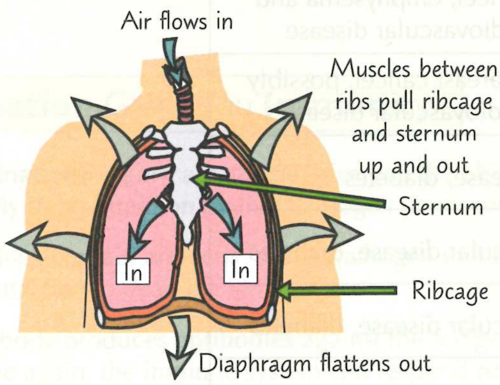
NEW CONTENT

If the **volume** of an enclosed space is **increased**, the **pressure** inside it will **decrease**.

1) The lungs are suspended in the **airtight thorax**.
2) Increasing the volume of the thorax decreases the air pressure in the lungs to below atmospheric pressure. Air flows **into** the lungs, inflating them until the pressure in the alveoli equals that of the atmosphere.
3) Decreasing the volume of the thorax increases the pressure in the lungs and air **flows out** until the pressure in the alveoli drops to atmospheric pressure.

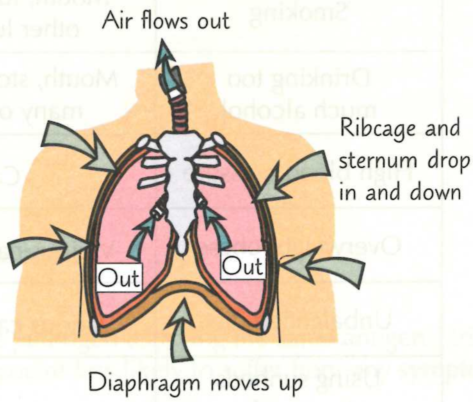
Breathing In

1) **Intercostal muscles** and **diaphragm** (a muscular sheet) **contract**.
2) Thorax volume **increases**.
3) This decreases the pressure, so air **flows in**.



Breathing Out

1) **Intercostal muscles** and **diaphragm relax**.
2) Thorax volume **decreases**.
3) This increases the pressure, so air flows **out**.



PRACTICE QUESTIONS

And breathe...

1) Describe the relationship between volume and pressure in an enclosed space.
2) Does the volume of the thorax increase or decrease when you breathe out?
3) Which two sets of muscles contract when we breathe in?

Disease

Disease can be Caused by Many Things

1) **Pathogens** — these are organisms that can cause disease, e.g. bacteria and viruses. **Infectious diseases** are caused by pathogens and can be passed from organism to organism, e.g. TB, malaria and HIV.

2) **Genetic defects** — some diseases are caused by **mutations** in a person's genes, e.g. cystic fibrosis is caused by a mutation in a gene for a protein.

3) **Lifestyle** — certain lifestyles **increase the risk** of getting some diseases, e.g. smokers are more likely to get lung cancer.

Risk Factors Increase the Chance of Developing a Disease

1) A risk factor is something that **increases the chances** of something bad happening. For example, smoking is a risk factor for heart disease — if you smoke you're **more likely** to get heart disease.
2) Risk factors **don't always** lead to disease though. For example, using sunbeds is a risk factor for skin cancer — if you use sunbeds you increase your risk of skin cancer, but you won't necessarily get the disease.
3) Some risk factors are **unavoidable** because they're **inherited**, e.g. certain versions of genes increase your risk of getting breast cancer.
4) Some risk factors are **avoidable** because they're associated with your **lifestyle**. For example, a diet high in salt is a risk factor for high blood pressure — if you change your lifestyle to reduce your salt intake you reduce the risk.

Here's a table showing some common **lifestyle** risk factors and the diseases they're associated with:

Risk factor	Diseases
Smoking	Mouth, lung and throat cancer, emphysema and other lung diseases, cardiovascular disease
Drinking too much alcohol	Mouth, stomach, liver and breast cancer, possibly many other cancers, cardiovascular disease
High blood pressure	Cardiovascular disease, diabetes
Overweight/obese	Various cancers, cardiovascular disease, diabetes
Unbalanced diet	Various cancers, cardiovascular disease, diabetes
Using sunbeds too much	Skin cancer

PRACTICE QUESTIONS

Taking your Nan's fashion advice — a risk factor for embarrassment...

1) What are pathogens?
2) Give an example of an infectious disease.
3) What is a risk factor?
4) List two diseases that smoking is a risk factor for.

Immunity

Phagocytes Engulf **Pathogens**

There are lots of different types of white blood cells.

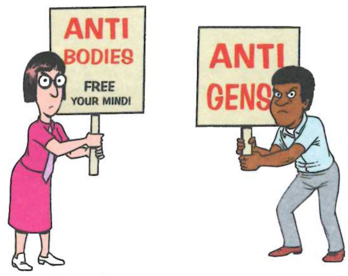
1) If a pathogen gets into the body it's detected by a type of white blood cell called a **phagocyte**.
2) It's actually the **molecules** on the **surface** of the pathogen that the phagocytes detect. These molecules are called **antigens**.
3) Human cells have antigens on their surface too, but phagocytes can tell the difference between '**self**' (your own) and '**foreign**' antigens.
4) Phagocytes **engulf** pathogens that are carrying foreign antigens and destroy them.

NEW CONTENT

White Blood Cells Produce **Antibodies**

1) Some white blood cells produce **antibodies** that **bind to** antigens.
2) The ones that produce antibodies are called **B-cells** (they're sometimes called B-lymphocytes — pronounced: lim-fo-sites).
3) When the antibody binds to the antigen it brings about the **death** of the pathogen carrying it.

NEW CONTENT



Another Type of **White Blood Cell** is Involved

NEW CONTENT

1) **T-cells** (or T-lymphocytes) are a type of white blood cell that are involved in **communication** between phagocytes and B-cells.
2) When a phagocyte has engulfed a pathogen it signals to the T-cell that it's found something. The T-cell then **activates** the B-cells to produce antibodies.

Vaccination Gives You **Immunity**

1) **Vaccinations** against a pathogen give you the ability to **respond rapidly** to an **infection** by that pathogen (immunity).
2) Vaccines **contain antigens** from a pathogen in a form that can't harm you, e.g. attached to dead bacteria.
3) Your body produces **antibodies** against the antigens so, if the same pathogen (carrying the same antigens) tries to invade again, the immune system can respond **really quickly** and you're less likely to suffer from any **symptoms**.
4) Vaccines don't stop the pathogen getting **into** the body — they just **get rid of it** really quickly when it does.

PRACTICE QUESTIONS

I seem to be immune to learning all this Biology...

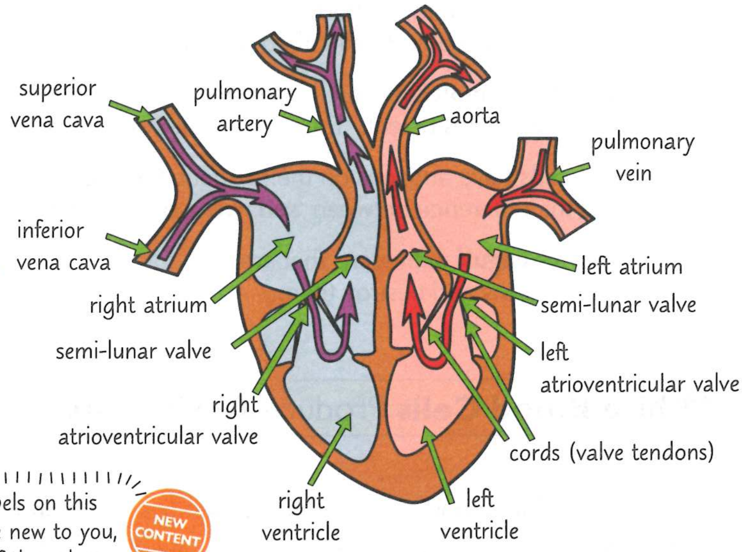
1) What do phagocytes detect?
2) What kind of white blood cells produce antibodies?
3) What is the role of T-cells?
4) What do vaccines contain?

The Circulatory System

Large Animals Need a **Circulatory System**

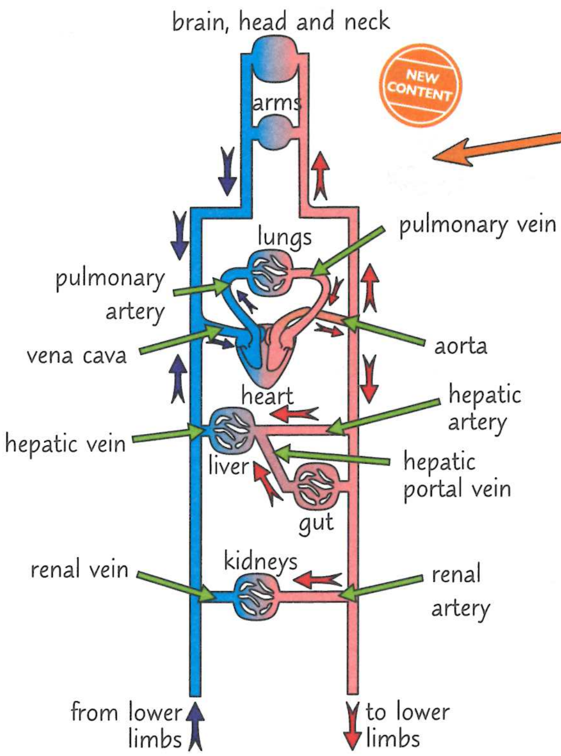
1) Diffusion is only efficient over **short distances**, so any animal bigger than a simple worm needs a system that will bring glucose and oxygen into close contact with individual cells.
2) In humans, the **heart** pumps blood around the body through **blood vessels**.
3) The heart has four chambers — two **atria** and two **ventricles**.

The **heart**



Some of the labels on this diagram might be new to you, e.g. the names of the valves.

NEW CONTENT



3) The blood vessels carry blood around the **entire body** and go to **every organ** before returning the blood to the heart.
4) There are **three** main types of blood vessel:
   - **Arteries** carry blood **away** from the heart.
   - **Veins** carry blood **to** the heart.
   - **Capillaries** are where the exchange between the blood and the cells takes place.
5) As the blood flows through the **tissues**, dissolved substances such as glucose, oxygen and carbon dioxide are **exchanged** between the blood and the cells.

The main artery in the human body is the aorta. It carries oxygenated blood from the heart to the rest of the body.

PRACTICE QUESTIONS

A circulatory system — going round and round the M25...

1) Name the organ that pumps blood around the body.
2) Name the four chambers of the heart.
3) Name the three main types of blood vessel.
4) In which type of blood vessel are substances exchanged between the blood and the cells?

The Heart

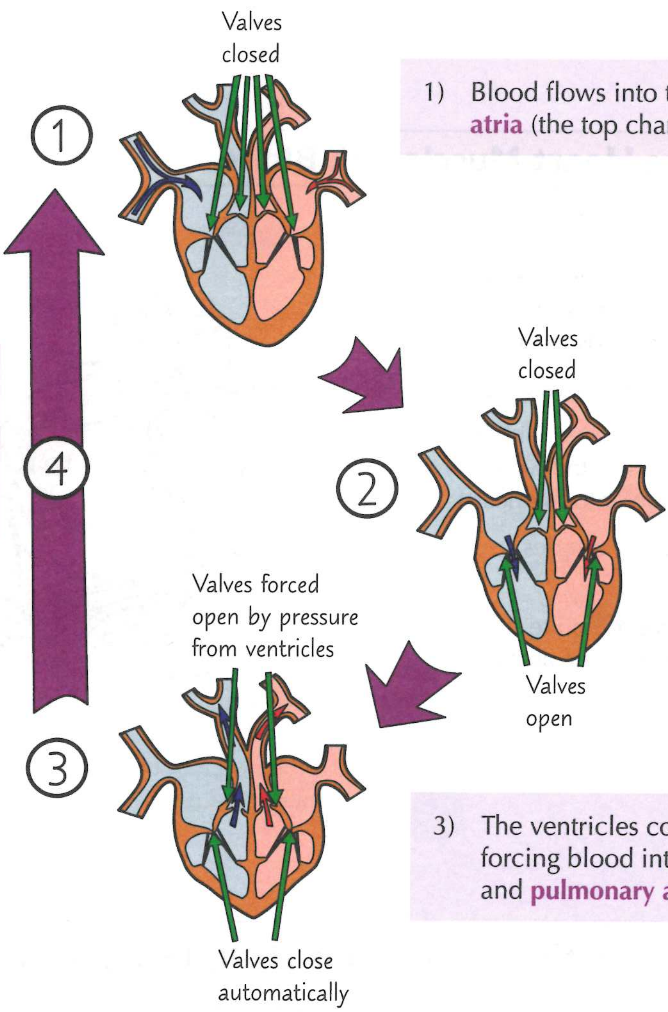
The **Heart** Acts Like **Two Separate Pumps**

1) The **right side** of the heart sends blood to the **lungs** and the **left side** pumps blood around the rest of the **body**.
2) Blood always flows from a region of **higher pressure** to a region of **lower pressure**.
3) **Valves** in the heart prevent the blood from flowing backwards.
4) **No energy** is required to make the valves work — it's the **blood pressing** on the valves that makes them **open and close**.

The **Heart Contracts** via the **Cardiac Cycle**

The **cardiac cycle** is the sequence of events that occurs during **one heartbeat**.

NEW CONTENT



1) Blood flows into the two **atria** (the top chambers).

2) The atria contract to push the blood into the **ventricles** (the lower chambers).

3) The ventricles contract, forcing blood into the **aorta** and **pulmonary artery**.

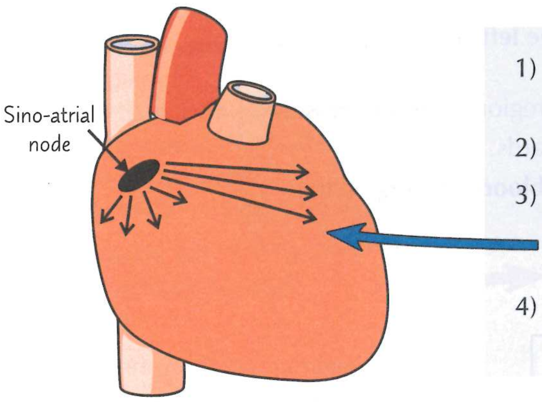
4) The blood flows down the arteries and **leaves the heart**. The whole cycle then starts again.

The **ventricles** are much more **powerful** than the atria and, when they contract, the **heart valves** pop shut automatically to prevent **backflow** into the atria. The ventricle walls are **thicker** because they need to push the blood further (e.g. the **left ventricle** has to push blood all the way round the body).

As soon as the ventricles relax, the valves at the top of the heart **pop shut** to prevent backflow of blood (back into the ventricles) as the blood in the arteries is now under **a fair bit of pressure**.

The Heart

The Heart has its Own Pacemaker

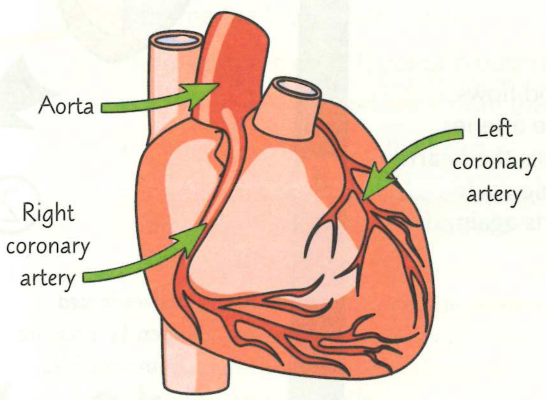


NEW CONTENT

1) **Most muscles** require **nerve impulses** from the central nervous system to make them **contract**.
2) The heart **produces** its own **electrical impulses**.
3) A group of specialised cells called the **sino-atrial node**, in the wall of the right atrium, sends out **regular impulses**.
4) These spread across the atria, making them **contract**.

Arteries Supply The Heart Muscle with Blood

1) Heart muscle, like all tissue, needs **oxygen** and **glucose** so it can respire and release the energy it needs to function.
2) It gets these things from the **blood**.
3) The heart muscle is supplied with blood by the **coronary arteries** (the word coronary is used to refer to the heart).
4) The two main coronary arteries come off the **aorta**.
5) The coronary arteries are quite **thin** (especially compared to the aorta).



PRACTICE QUESTIONS

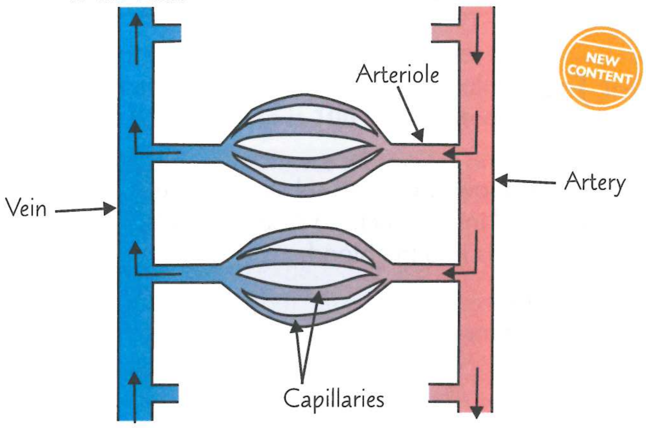
Aorta get on with learning this stuff, I suppose...

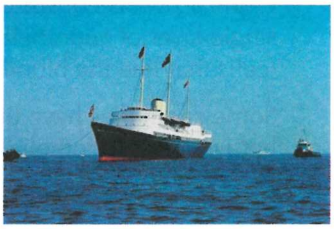
1) Does the right-hand side of the heart pump blood to the body or to the lungs?
2) What is the function of the heart valves?
3) Do heart valves require energy to open and close?
4) Where does the blood go after leaving the atria?
5) Why are the walls of the ventricles thicker than the walls of the atria?
6) The sino-atrial node is sometimes called the heart's natural pacemaker. What is its function?
7) Why does heart muscle require a blood supply?
8) Name the blood vessels that supply the heart muscle with blood.

Blood Vessels

Blood Vessels Include Arteries, Arterioles, Capillaries and Veins

1) **Arteries** carry blood away from the heart.
2) They subdivide into smaller vessels called **arterioles**.
3) Arterioles subdivide into microscopic vessels called **capillaries**.
4) Capillaries join up to form **veins**.
5) Veins **return** blood to the **heart**.



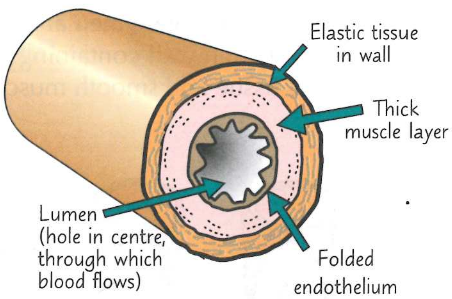


No, not that type of vessel.

Arteries are Elastic

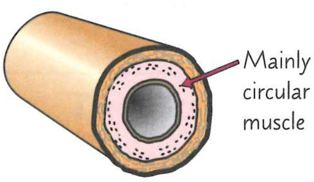
1) Arteries have a **thick wall** compared to the diameter of the lumen. There's an outer layer of **fibrous tissue**, then a thick layer of **elastic tissue** and **smooth muscle**, then a very thin inner layer of folded **endothelial tissue**.
2) When the ventricles contract, blood enters the arteries at **high pressure**. This **stretches** the folded endothelium and elastic walls. When the ventricles relax, it's the elastic recoil of the artery wall (when the wall shrinks back to its original size) that keeps the blood pressure up. Important organs, like the kidneys, wouldn't be able to function if the blood pressure dropped too far between heartbeats.

An Artery



Arterioles can Contract

An Arteriole



1) Arterioles are **narrower** than arteries and they have a higher proportion of **smooth muscle fibres** and a lower proportion of **elastic tissue**.
2) When the circular muscle fibres of an arteriole contract, the diameter of the lumen is reduced, so **less blood flows** through that vessel. This means that arterioles can **control** the amount of blood flowing to a particular organ.

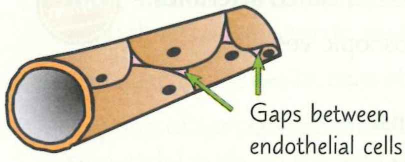
Blood Vessels

Capillaries can Only be Seen With a Microscope

Capillary walls consist of a single layer of endothelial cells (cells that line the blood vessels).

Some capillaries have tiny gaps between the endothelial cells.

A Capillary



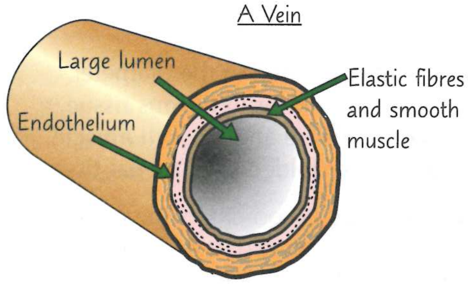
Capillaries are Well Suited to Their Job

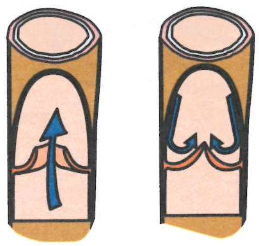
1) The very thin walls and the gaps between the cells allow water and substances like glucose and oxygen to diffuse quickly from the blood into the cells. Waste products, such as carbon dioxide and urea, diffuse from the cells into the blood.
2) Organs contain thousands of capillaries, so altogether there's a huge surface area for the exchange of substances.
3) Blood flows quite slowly through capillaries. This allows more time for diffusion to occur.

Veins Have Valves

1) A vein has a **large lumen** and a relatively thin wall containing some elastic tissue and smooth muscle.

A Vein





2) Veins also have **valves** that prevent the blood flowing backwards.
3) When the **leg muscles** contract they bulge and press on the walls of the veins, pushing the blood up the veins. When the muscles relax, the valves close. This action helps the blood **return** to the heart.

NEW CONTENT

PRACTICE QUESTIONS

I hate to be vein, but my doctor says I have excellent circulation...

1) What is the role of arteries in the circulatory system?
2) Explain the importance of the elastic tissue in the walls of arteries.
3) Describe how arterioles can control the amount of blood flowing to an organ.
4) Capillaries have very thin walls, which sometimes have gaps in them. Explain how these characteristics make capillaries suited to their job.
5) What structure do veins contain, that other blood vessels don't have?
6) Explain how leg muscles help return blood to the heart.

Blood

Haemoglobin Carries Oxygen

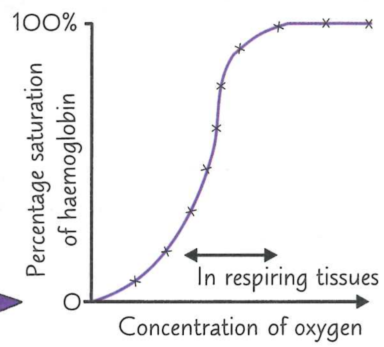
1) The blood's main function is to **transport** materials to and from cells.
2) So the blood can do this, red blood cells are packed with **haemoglobin**, a protein that contains iron and can **carry oxygen**.
3) When oxygen combines with haemoglobin it forms **oxyhaemoglobin**.

Haemoglobin has Special Properties

NEW CONTENT

1) When there's a lot of oxygen present, one molecule of haemoglobin can combine with **four** molecules of oxygen — the haemoglobin is **100% saturated**.
2) When less oxygen is present, fewer molecules of oxygen combine and the haemoglobin is **less than** 100% saturated.

It would be reasonable to expect that a graph of '% saturation of haemoglobin' against 'concentration of oxygen' would be a straight line (i.e. that the two would be proportional). However, when experiments are carried out and the results plotted, the line of best fit is **S-shaped**.

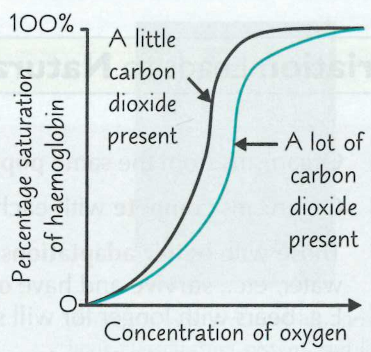


3) Haemoglobin has special properties that allow it to become fully saturated with oxygen in the capillaries around the **alveoli** of the lungs, where there's a **high concentration** of **oxygen**.
4) Then when it reaches respiring tissue, where there's **less oxygen**, it can give up almost all of its oxygen immediately — so the rate of respiration in the tissues isn't slowed down because of an oxygen shortage.

Carbon Dioxide Changes the Properties of Haemoglobin

NEW CONTENT

1) Respiring tissues produce **carbon dioxide**.
2) If there's not a lot of carbon dioxide present, the haemoglobin is **less efficient** at **releasing** oxygen.
3) But, when there's a lot of carbon dioxide present, the haemoglobin becomes **more efficient** at **releasing** oxygen (i.e. it can release more oxygen molecules in areas of fairly high oxygen demand).
4) This is good because it means that **rapidly respiring tissues**, e.g. contracting leg muscles and brain cells, get **more oxygen**.
5) This effect of carbon dioxide concentration on the oxygen-binding properties of haemoglobin is known as the **Bohr effect**.



The Bore effect — caused by reading this page...

PRACTICE QUESTIONS

1) Name the substance picked up by the blood in the lungs.
2) How many molecules of oxygen are bound to a haemoglobin molecule when it's fully saturated?
3) Which gas affects the oxygen-binding properties of haemoglobin?
4) Under what circumstances does a tissue require the most oxygen?

Variation and Evolution

We all Vary

1) All organisms are **different** from each other, e.g. giraffes are loads different from zebras, which are different from lions and tigers and bears...
2) Organisms of the **same species** also show **some variation**, e.g. humans show variation in height, weight, favourite colour of shoe polish...
3) Organisms of the **same species** are similar because they all have the **same genes** but they vary because they have **different versions** of those genes (called **alleles**). E.g. humans all have a gene for blood type, but they can have A, B or O alleles.

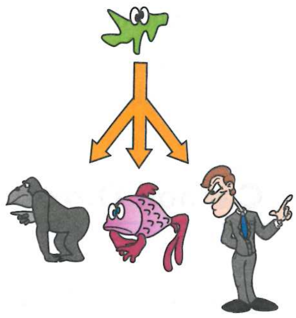
The environment also causes organisms of the same species to vary.

Variation Means Some Organisms are Better Adapted

1) An adaptation is a **characteristic** that helps an organism to **survive** and **reproduce**, e.g. polar bears have **thick**, **white fur** to stay warm and camouflaged in the snow.
2) **Characteristics vary** in a population so some organisms are **better adapted** for certain conditions than others, e.g. polar bears with thicker fur are better adapted to survive in a cold environment than polar bears with thinner fur. The slightly different adaptations you get **within species** (e.g. slightly thicker fur on one polar bear compared to another) are coded for by **different alleles**.

Evolution Happens Over Time

1) Evolution is the **gradual change** in the **characteristics** of a population from one generation to the next. The theory of evolution is that all organisms evolved from **simple life forms** over **millions of years**.
2) There's **more than one** mechanism by which evolution occurs — one is **natural selection**.



Variation Leads to Natural Selection

1) Organisms from the **same population** all **vary** (e.g. different length of fur).
2) Organisms **compete** with each other for food, shelter, water, etc.
3) Those with **better adaptations** (caused by different **alleles**) are more likely to find food, shelter, water, etc., **survive** and have **offspring**. So they **pass on** the alleles for their better adaptations. E.g. bears with longer fur will stay warmer and be more likely to survive, and so have kids with longer fur.
4) Over time, the **number** of organisms with the better adaptations (alleles) **increases**.
5) The **whole population** of organisms **evolves** to have the better adaptations (alleles).

Bah, evolution takes ages. I want wings NOW...

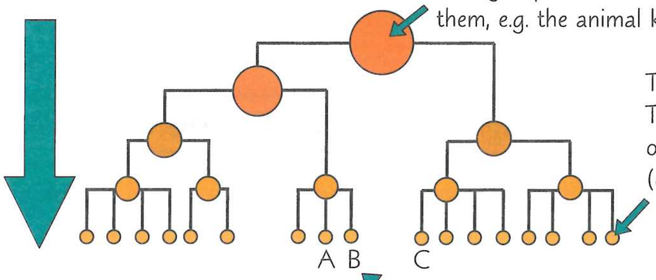
1) What is an allele?
2) What is an adaptation?
3) Briefly describe natural selection.

Classification

Classification Means Sorting Organisms into Groups

1) Classification also involves **naming organisms**.
2) It makes it **easier** for scientists to **study** organisms without getting **confused**, because every type of organism has a different name, e.g. *Homo sapiens* (humans) or *Ursus maritimus* (polar bears).
3) Organisms are arranged into different groups depending on their **similarities** and **differences**, e.g. all animals are grouped together, and all plants are grouped together in a separate group because they're different to animals.
4) Organisms are placed in groups in **classification hierarchies** (pronounced: hire-arc-ees) — the biggest groups (e.g. animals, plants) are **split** into **smaller groups** (e.g. animals with a backbone in one group and animals without a backbone in another). These groups are **split again** into more smaller groups, and so on.

NEW CONTENT



A **species** is a group of organisms that **look similar** and can reproduce to give **fertile offspring** (their children can also reproduce).

Classification Systems are Based on Lots of Things

1) **Older** classification systems grouped organisms based only on how they look, e.g. four limbs, six eyes, bum chin...
2) **Newer systems** use looks and lots of other things:
   - **DNA** — how similar and different the base sequence is (e.g. ATTTAC vs. ATTTAT).
   - **Other molecules** — e.g. proteins and enzymes.
   - **Early development** — how they grow from an embryo to a baby.

NEW CONTENT

Tony was very proud of his current book classification system, and liked to show it off on video calls.

PRACTICE QUESTIONS

Access denied: this pun data is classified...

1) What does classification involve?
2) What is a species?
3) List four things newer classification systems use to group organisms.

Xylem and Phloem

Xylem Tissue Transports Water and Minerals from Roots

Water from the soil **enters** the roots by **osmosis**. Then it travels through the root to the **xylem** — this is the tissue that **transports water** through the plant and up to the leaves.
Water can travel through the roots in **two** ways:

The **symplast system**:

- Some water moves through the root via the **cytoplasm** of the root cells. The water has to cross the **cell membrane**, which regulates the passage of the water and dissolved minerals.

NEW CONTENT

The **apoplast system**:

- The water moves through the **cell walls** and the **spaces between the cells**.
- There are **no membranes** to regulate the passage.

NEW CONTENT

Water Travels Up the Plant Through the Xylem Tissue

The cells that make up the tubes (vessels) of **xylem tissue** are dead, waterproof and hollow. This means water can **move** through them easily.

Water is **pulled up** through the xylem tissue by a combination of factors: **cohesion**, **tension** and **adhesion**:

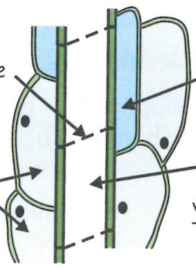
NEW CONTENT

1) Water **evaporates** from inside the leaf leaving a higher concentration of solutes.
2) Water from the nearest xylem vessel enters by **osmosis**.
3) Water molecules stick together because of weak hydrogen bonds between them — this is called **cohesion**.
4) As water molecules leave the xylem vessel they **pull up** further molecules, so the whole column of water is pulled up.
5) Evaporation pulls the water column upwards and gravity pulls it down, so the water column is under **tension**.
6) The **adhesion** of water molecules to the sides of the xylem vessels stops the column breaking.

Phloem Transports Organic Compounds

Sugars and other organic compounds are **transported** through plants in **phloem tissue**.
Phloem tissue is also arranged in **tubes** so the solutions of sugar, etc. can **move** through them easily.

1) The movement of carbohydrates and other organic compounds in plants is known as **translocation**.
2) It occurs in the **sieve tubes** of the **phloem tissue**. NEW CONTENT
3) **Companion cells** next to the sieve tubes are believed to **actively transport** sugar into the sieve tubes, and then water follows by **osmosis**. NEW CONTENT



Vertical section of phloem tissue

PRACTICE QUESTIONS

Relax, sit back, and just go with the phloem...

1) In the symplast system, which part of the cell does water move through?
2) Why is the column of water in the xylem under tension?
3) What substances are transported in the phloem tissue?

Planning an Experiment

A Good Experiment Gives Repeatable and Valid Results

1) **Repeatable** means that if the same person repeats the experiment using the same methods and equipment, they will get the same results. Good results are also **reproducible** — if someone different does the experiment, or a slightly different method or piece of equipment is used, the results will still be the same.
2) **Valid** results **answer the original question**. To get valid results you need to **control all the variables** to make sure you're only testing the thing you want to.

To Get Good Results You Need to Design Your Experiment Well

Here are some of the things you need to consider when thinking about **experimental design**:

1) **Only one variable should be changed.**
   Variables are **quantities** that have the **potential to change**, e.g. pH. In an experiment you usually **change one variable** and **measure its effect** on another variable.
   - The variable that you **change** is called the **independent variable**.
   - The variable that you **measure** is called the **dependent variable**.
2) **All the other variables should be controlled.**
   When you're investigating a variable you need to keep everything else that could affect it **constant**. This means you can be sure that **only** your **independent** variable is **affecting** the thing you're measuring (the dependent variable).
3) **Negative controls should be used.**
   Negative controls are used to **check** that only the independent variable is affecting the dependent variable. Negative controls **aren't expected** to have **any effect** on the experiment.
4) **Repeat the experiment at least three times.**
   Doing **repeats** and getting **similar results** each time shows that your data is **repeatable**. This makes it more likely that your results could be **reproduced** by another scientist in an independent experiment. Doing repeats also makes it easier to spot any **anomalous results** — unexpected results that don't fit in with the rest.

EXAMPLE

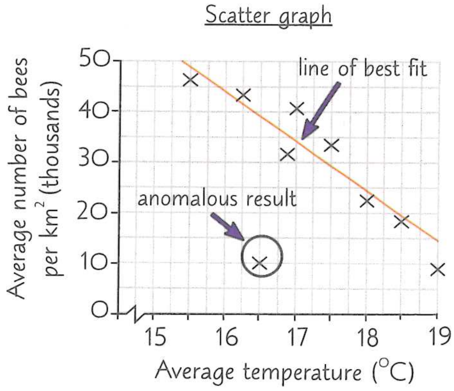
Investigating the effect of temperature on enzyme activity.

1) Temperature is the **independent** variable.
2) Enzyme activity is the **dependent** variable.
3) pH, volume, substrate concentration and enzyme concentration should all stay the **same**.
4) The experiment should be **repeated** at least three times at each temperature used.
5) A **negative control**, containing everything used except the enzyme, should be measured at each temperature. No enzyme activity should be seen with these controls.

Graphs

You Can Use **Scatter Graphs** to **Present** Your **Data**

1) When you want to show how **two variables** are **related** (or **correlated**, see next page) you can use a **scatter graph**.
2) Make sure that:
   - The **dependent variable** goes on the ***y*-axis** (the vertical axis) and the **independent** on the ***x*-axis** (the horizontal axis).
   - You always **label** the **axes**, include the quantity and **units**, and choose a **sensible scale**.
3) When you draw a **line** (or curve) **of best fit** on a **scatter graph**, draw the line through or as near to as many points as possible, **ignoring** any **anomalous** results.

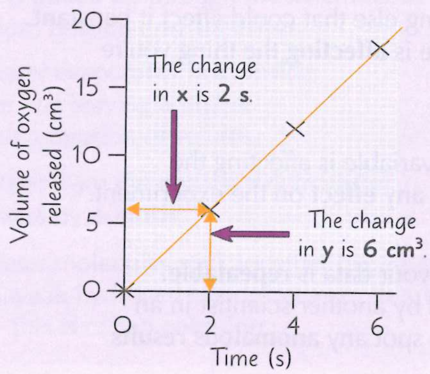


Find the **Rate** By Finding the **Gradient**

Rate is a measure of how much something is **changing over time**. Calculating a rate can be useful when **analysing** your data, e.g. you might want to find the **rate of a reaction**. Rates are easy to work out from a **graph**.

For a **linear** graph you can calculate the **rate** by finding the **gradient of the line**:

EXAMPLE



$$\text{gradient} = \frac{\text{change in } y}{\text{change in } x}$$

So in this **example**:

$$\textbf{rate} = \frac{6\ \text{cm}^3}{2\ \text{s}} = \mathbf{3\ cm^3\ s^{-1}}$$

$cm^3\ s^{-1}$ means the same as cm^3/s (centimetres cubed per second)

For a **curved** (non-linear) graph you can find the **rate** by drawing a **tangent**:

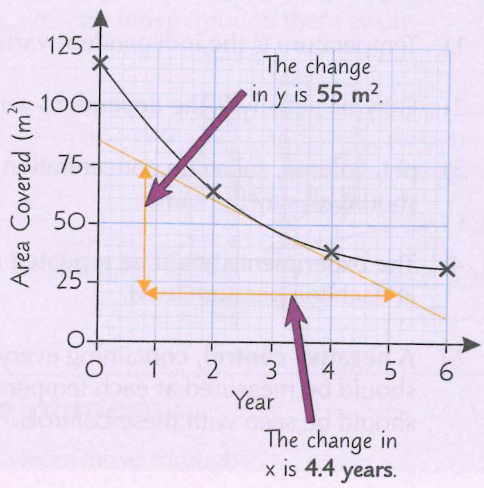
EXAMPLE

1) Position a ruler on the graph at the **point** where you want to know the **rate**.
2) **Angle** the **ruler** so there is **equal space** between the **ruler** and the **curve** on **either** side of the point.
3) **Draw** a **line** along the ruler to make the tangent.

Extend the line right across the graph — it'll help to make your gradient calculation easier as you'll have more points to choose from.

4) **Calculate** the **gradient** of the **tangent** to find the **rate**:

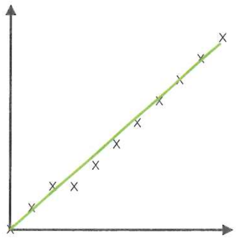
gradient = 55 m² ÷ 4.4 years = **12.5 m² year⁻¹**

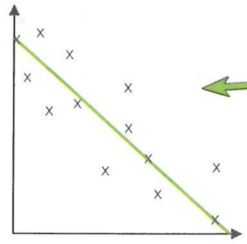


Correlation and Cause

Lines of Best Fit Are Used to **Show Trends**

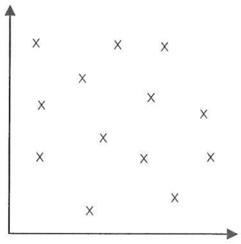
The line of best fit on this graph shows that as one variable **increases**, the other variable **also increases**. This is called a **positive correlation**. The data points are all quite close to the line of best fit, so you can say the correlation is **strong**. If they were more spread out, the correlation would be **weaker**.





Variables can also be **negatively correlated** — this means one variable **increases** as the other one **decreases**. Look at the way the line of best fit **slopes** to work out what sort of correlation your graph shows.

Sometimes the graph won't show any clear trend and you won't be able to draw a line of best fit. In this case, you say there's **no correlation** between the variables.



Correlation Doesn't Always Mean **Cause**

1) Be careful what you **conclude** from an experiment — just because two variables are correlated, it doesn't necessarily mean that a change in one **causes** a change in the other.
2) In lab-based experiments, you can say that a change in the independent variable causes the dependent variable to change — the increase in temperature **causes** an increase in the rate of the reaction. You can say this because everything else has **stayed the same** — nothing else could be causing the change.
3) Outside a lab, it can be much harder:

EXAMPLE

Kate measured the level of **air pollution** and the incidence of **TB**, to see whether the two are related. Her results show a **positive correlation** between the variables — where the level of pollution is **highest**, the incidence of TB is also **highest**.

From Kate's results, you **can't** say that air pollution causes TB. Neither can you say that TB causes air pollution.

It could be either way round... or one change might not cause the other at all — **you just can't tell.**

There was a correlation between how much work Priya did and her grades, but she refused to believe that one caused the other.