Paper 1 AS Biology Notes

3.1 Biological Molecules

3.1.1 Monomers and Polymers

Content

- The variety of life, both past and present, is extensive, but the biochemical basis of life is similar for all living things.
- Monomers are the smaller units from which larger molecules are made.
- Polymers are molecules made from a large number of monomers joined together.
- Monosaccharides, amino acids and nucleotides are examples of monomers.
- A condensation reaction joins two molecules together with the formation of a chemical bond and involves the elimination of a molecule of water.
- A hydrolysis reaction breaks a chemical bond between two molecules and involves the use of a water molecule.

Clearly there is huge variety in life, from ants to whales, however biochemically they are actually very similar. Four main elements oxygen, carbon, hydrogen, and nitrogen make up the majority of pretty much every organism. From proteins to carbohydrates, these elements are fundamental to life.

A **monomer** is simply a smaller unit from which larger molecules are made from. For example, if you were to look at proteins, they are made up of much smaller monomers called amino acids. These monomers join together to make **polymers**, which are just a large number of monomers joined together. Other examples of monomers are monosaccharides (monomers of carbohydrates) or nucleotides (building blocks of nucleic acids like DNA).

A **condensation reaction** is the basis for the synthesis of all the important biological macromolecules (carbohydrates, proteins, lipids, nucleic acids) from their simpler sub-units.

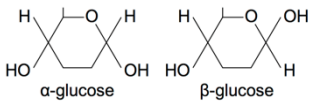
It joins two molecules together and forms a chemical bond, removing a molecule of water in the process, hence ‘condensation’. So essentially a molecule of H_2O is removed in a condensation reaction.

Contrary to a condensation reaction, a **hydrolysis** reaction involves the addition of one water molecule. Thus, we can conclude that a hydrolysis reaction is the opposite of a condensation reaction.

3.1.2 Carbohydrates

Content

- Monosaccharides are the monomers from which larger carbohydrates are made. Glucose, galactose and fructose are common monosaccharides.
- A condensation reaction between two monosaccharides forms a glycosidic bond.
- Disaccharides are formed by the condensation of two monosaccharides:
- Maltose is a disaccharide formed by condensation of two glucose molecules
- Sucrose is a disaccharide formed by condensation of a glucose molecule and a fructose molecule
- Lactose is a disaccharide formed by condensation of a glucose molecule and a galactose molecule.
- Glucose has two isomers, α-glucose and β-glucose, with structures:



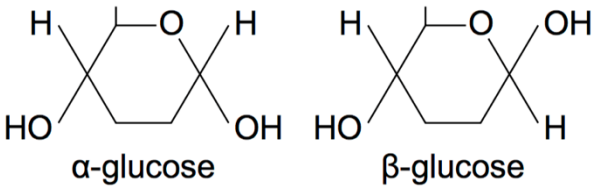
- Polysaccharides are formed by the condensation of many glucose units.
- Glycogen and starch are formed by the condensation of α-glucose.
- Cellulose is formed by the condensation of β-glucose.
- The basic structure and functions of glycogen, starch and cellulose. The relationship of structure to function of these substances in animal cells and plant cells.
- Biochemical tests using Benedict's solution for reducing sugars and non-reducing sugars and iodine/potassium iodide for starch.

Opportunities for Skills Development

- Students could use, and interpret the results of, qualitative tests for reducing sugars, non-reducing sugars and starch.
- Students could use chromatography, with known standard solutions, to separate a mixture of monosaccharides and identify their components.
- Students could produce a dilution series of glucose solution and use colorimetric techniques to produce a calibration curve with which to identify the concentration of glucose in an unknown solution.

Monosaccharides are a type of monomer that make up carbohydrates (sugars), examples include glucose, fructose and galactose. Condensation reactions join monosaccharides together, and the bond that forms is called a **glycosidic bond**. **Disaccharides** are the product of joining two monosaccharides together. Examples of disaccharides are **maltose**, which is the product of two glucose molecules. **Sucrose**, the product of glucose and fructose, or **lactose**, the product of glucose and galactose.

Glucose has two different isomers, alpha (α) glucose, and beta (β) glucose. These isomers have exactly the same general formula, just different structures. Their general structures are:



Polysaccharides are formed by the condensation of many glucose units. **Glycogen** and **starch** are examples of substances made from alpha glucose, whereas cellulose is formed by the condensation of beta glucose.

Glycogen is an energy store in animals, who store it as small granules. It is made of α 1,4 and α 1,6 glycosidic bonds, so is a branched molecule. It also has tightly packed helical coils, thus is an efficient store of energy as it takes up little space, so can fit in a small amount of space too. Furthermore, it is insoluble and easily hydrolysed so energy can be released quickly.

Starch is a carbohydrate made up of amylose and amylopectin. The amylose contains α 1,4 glycosidic bonds, whereas the amylopectin is made from α 1,4 and 1,6 bonds. Therefore starch is highly branched, and is also wound up very tight so can store a lot of energy in a small amount of space. For this reason it is an energy store used in plants. Since it is insoluble, it does not draw water into cells by osmosis either, so does not affect the amount of water in cells.

Cellulose is slightly different in the fact that it is made from β 1,4 glycosidic bonds. It therefore does not coil up and is a long, straight chain. They form chains that are joined together by hydrogen bonds. As more and more chains join together through hydrogen bonds, the structure becomes much stronger, and so is a useful structural molecule i.e. in cell walls of plant cells. These chains form what are referred to as **microfibrils**.

Biochemical tests using benedict's reagent for reducing sugars and non-reducing sugars. The definition of a reducing sugar is "A reducing sugar is any sugar that is capable of acting as a reducing agent because it has a free aldehyde group or a free ketone group." You do not need to remember this definition, but it is useful in getting context to what reducing sugars are. All monosaccharides are reducing sugars, this is a fact you should become familiar with. Also, some disaccharides and polysaccharides are also reducing sugars, but this is not very common. For instance, lactose is a reducing sugar whereas sucrose is not.

To test for reducing sugars you need to add **Benedict's Reagant to the sample and heat** it. If there is a colour change and it turns a **brick red**/orange colour then there is a reducing sugar present, i.e. a monosaccharide like glucose. However if there are no reducing sugars present then the solution will remain **blue**.

However, if there were a disaccharide present like sucrose, it is made up of two reducing sugars (the monosaccharides glucose and fructose). So if we were to hydrolyse any disaccharides or polysaccharides to their constituent monosaccharides, we would now have reducing sugars present, and would know that there were originally some non reducing sugars present i.e. the disaccharide sucrose.

To split them up we add dilute hydrochloric acid, and then **heat**, then add sodium hydrogen carbonate to neutralise the solution so that the Benedict's Reagant will work, as the

hydrochloric acid makes it acidic. Now if we add Benedict's Reagant again, and get a positive result (brick red) then we know that there were non reducing sugars present. However, if we get a blue colour again then we know there is no sugar at all.

Test for Starch... The test involves pipetting a few drops of iodine solution onto the sample. A blue/black colour indicates the presence of starch, and red indicates no starch is present.

AQA Jan 2013 Unit 2 Q1c

Question:

Give **one** feature of starch and explain how this feature enables it to act as a storage substance.

Answer:

- Coiled / helical / spiral;
    - (So) compact / tightly packed / can fit (lots) into a small space;
- Insoluble;
    - (So) no osmotic effect / does not leave cell / does not affect water potential;
- Large molecule / long chain;
    - (So) does not leave cell / contains large number of glucose units;
- Branched chains;
    - (So) easy to remove glucose;

June 2011 Q1bi)ii)

a) The equation shows the breakdown of lactose by the enzyme lactase.

Name monosaccharide X

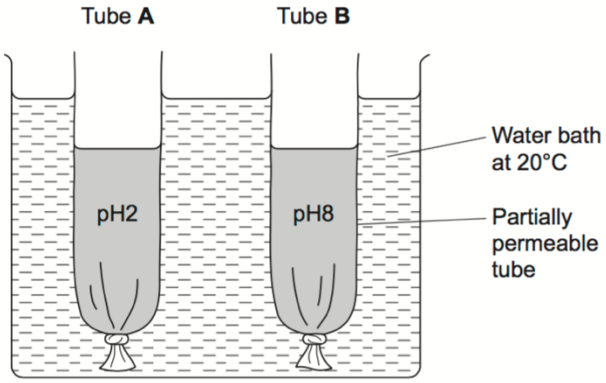
- α glucose

b) Describe how you would use a biochemical test to show that a reducing sugar is present'

- Add Benedict's reagent and **heat**
- Brick red/orange/yellow/green colour indicates presence

June 2012 Q6a

6 A student investigated the effect of pH on the activity of the enzyme amylase.
She set up the apparatus shown in the diagram.



The tubes were made from Visking tubing. Visking tubing is partially permeable.
She added an equal volume of amylase solution and starch to each tube.

- She added a buffer solution at pH2 to tube **A**.
- She added an equal volume of buffer solution at pH8 to tube **B**.

After 30 minutes, she measured the height of the solutions in both tubes.
She then tested the solutions in tubes **A** and **B** for the presence of reducing sugars.

a) Describe how the student would show that reducing sugars were present in a solution.

- 1. Add Benedict's;
- 2. Heat;
- 3. Red/orange/yellow/green (shows reducing sugar present)

b) After 30 minutes, the solution in tube **B** was higher than the solution in tube **A**. Explain why the solution in tube **B** was higher.

- Starch hydrolysed / broken down so glucose/maltose produced;
- This lower water potential;
- Water enters by osmosis;

c) The student concluded from her investigation that the optimum pH of amylase was pH8. Is this conclusion valid? Explain your answer

- Only 2 pHs studied/ more pHs need to be tested;

AQA June 2012 Unit 2 Q3bi)ii)

i. Complete the table to show two ways in which the structure of cellulose is different from the structure of starch

- **Starch**

1. (1,4 and) 1,6 bonds/contains 1,6 bonds /branching
2. All glucoses/ monomers same way up
3. Helix/coiled/compact
4. Alpha glucose
5. No (micro/macro) fibrils/fibres

- **Cellulose**

1. 1,4 bonds / no 1,6 bonds / unbranched / straight;
2. Alternate glucoses/monomer s upside down;
3. Straight;
4. Beta glucose;
5. Micro/macro fibrils/fibres;

ii. Explain one way in which the structure of cellulose is linked to its function

- H-bonds / micro/macro fibrils /fibres;
- Strength / rigidity / inelasticity;

3.1.3 Lipids

Content

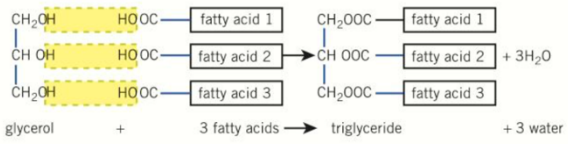
- Triglycerides and phospholipids are two groups of lipid.
- Triglycerides are formed by the condensation of one molecule of glycerol and three molecules of fatty acid.
- A condensation reaction between glycerol and a fatty acid (RCOOH) forms an ester bond.
- The R-group of a fatty acid may be saturated or unsaturated.
- In phospholipids, one of the fatty acids of a triglyceride is substituted by a phosphate-containing group.
- The different properties of triglycerides and phospholipids related to their different structures.
- The emulsion test for lipids.
- **Students should be able to**:
    - Recognise, from diagrams, saturated and unsaturated fatty acids
    - Explain the different properties of triglycerides and phospholipids.

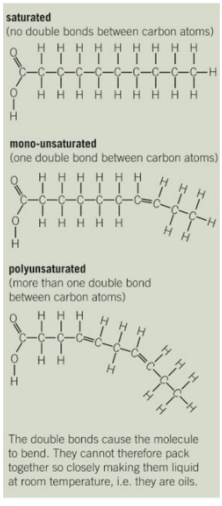
Opportunities for skills development

- Students could use, and interpret the results of, the emulsion test for lipids.

Lipids are basically fats, and can come in many groups, two of which being triglycerides and phospholipids.

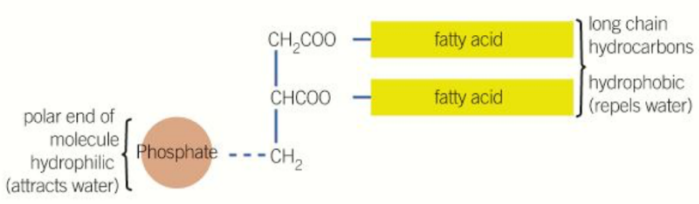
Triglycerides are formed in the condensation of one molecule of glycerol and three molecules of fatty acid. The condensation reaction that joins glycerol and fatty acids form a bond called an ester bond. A triglyceride is shown to the right, with the ester bond between the CH_2OOC and fatty acid. Since it is a condensation reaction, and is joining three molecules with three other molecules, three molecules of water are also formed too.





The fatty acids of the triglycerides have 'R groups' and these can be either **saturated, mono-unsaturated or polyunsaturated**. Essentially saturation is when there are no double bonds between carbon atoms in the R group (so there are a maximum number of hydrogen atoms attached), as you can see to the left there is an example of a saturated substance. Unsaturated is simply when there are double bonds between carbon atoms present. These double bonds prevent a maximum number of hydrogen atoms bonding to the carbon atoms. This can either be mono-unsaturation, where there is only one carbon double bond, or poly-unsaturation. The numerous carbon double bonds cause the molecule to bend, and so the molecules cannot pack as tightly together, so they are generally liquid at room temperature i.e. oils.

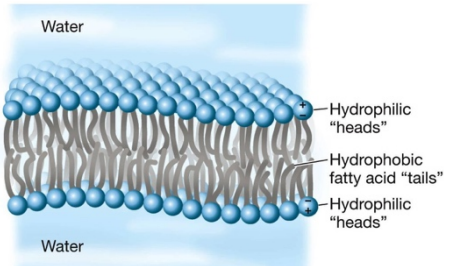
Phospholipids are very similar to triglycerides, however one of the fatty acid groups is substituted for a phosphate containing group, as is shown below.



Properties related to structure;

Triglycerides have a very high ratio of energy storing carbon-hydrogen bonds to carbon atoms so are a good source of energy. Also they have a low mass to energy ratio, so a lot of energy can be stored in a small space, good for storage. They are also insoluble in water so their storage does not affect the water potential of cells. Furthermore, they release water when oxidised so are a good source of water.

Phospholipids are polar molecules and so are involved in hydrophobic and hydrophilic interactions. Hydrophobic can be looked at as 'water hating' so essentially repelling and not mixing with water, whereas hydrophilic is the opposite. Phospholipids have a hydrophobic tail and hydrophilic head; therefore, they form a bilayer on water. This bilayer can be seen below, where the tails face inwards away from water, and the heads face towards the water. This bilayer is what makes up a cell surface membrane, and is important in regulating the movement of substances through the membrane. The structure also enables glycolipids to be formed when the phospholipids combine with lipids. These glycolipids are important in cell recognition.



The test for lipids is called the emulsion test. The steps follow below:

- **You require a dry, clean test tube**
- **Add ethanol to the sample**
- **Shake lightly**
- **Add water**
- **Shake**

If a cloudy-white colour appears, this indicates the presence of a lipid. If you were to run a **control** experiment alongside this, you could repeat the same steps but use water instead of the sample. The final result should be a clear solution. The control experiment would allow a comparison, to show that the results were due to the presence of a lipid.

AQA Jan 2012 Unit 1 Q1a

Question:

Some seeds contain lipids. Describe how you could use the emulsion test to show that a seed contains lipids.

Answer:

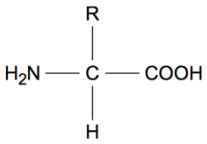
1. Crush/grind;
2. With ethanol/ alcohol;
3. Then add water/then add to water;
4. Forms emulsion / goes white/cloudy;

3.1.4 Proteins

3.1.4.1 General properties of proteins

Content

- Amino acids are the monomers from which proteins are made. The general structure of an amino acid as:

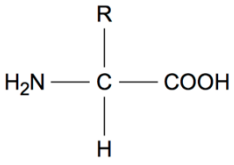


  Where NH_2 represents an amine group, COOH represents a carboxyl group and R represents a side chain. The twenty amino acids that are common in all organisms differ only in their side group.
- A condensation reaction between two amino acids forms a peptide bond.
  - Dipeptides are formed by the **condensation** of two amino acids.
  - Polypeptides are formed by the **condensation** of many amino acids.
- A functional protein may contain one or more polypeptides.
- The role of hydrogen bonds, ionic bonds and disulfide bridges in the structure of proteins.
- Proteins have a variety of functions within all living organisms. The relationship between primary, secondary, tertiary and quaternary structure, and protein function.
- The biuret test for proteins.
- **Students should be able to:**
  - Relate the structure of proteins to properties of proteins named throughout the specification.

Opportunities for Skills Development

- Students could use, and interpret the results of, a biuret test for proteins.
- Students could use chromatography with
  known standard solutions,
  to separate a mixture of amino acids and identify their components.

Amino Acids are the monomers that make up proteins. Their general structure is shown below



NH_2 is the amine group, COOH is the carboxyl group, R represents the side chain. There are twenty amino acids common to all organisms, whose structure differs only by their R side groups. **Peptide bonds** are formed in a condensation reaction between two amino acids. Dipeptides are formed when two amino acids join in a condensation reaction, and polypeptides are formed in the condensation of many amino acids. Polypeptides make up proteins, and proteins may contain one or more of these.

Proteins are held together by hydrogen bonds, ionic bonds and disulfide bridges. Proteins have a variety of different functions within all living organisms, for example proteins can be enzymes (enzymes lower activation energy of reactions by forming enzyme-substrate complexes, covered next). **They are also the building blocks of tissues** thus important in repair and maintenance of the body. Proteins can also be **antibodies**, which have a key role in the body's defence against pathogens. They also have a role in transportation within the body, for example **haemoglobin** which transports oxygen**.**

Protein structure begins at the primary structure, which develops into the secondary, tertiary and then quaternary structure.

Primary Structure: This is the basic structure, a simple sequence of amino acids that make up a polypeptide chain. The amino acids are linked by a peptide bond which is formed in a condensation reaction (where a molecule of water is removed). Therefore if there is a slight change in the amino acid sequence, it results in a change in the protein as the polypeptide progresses through the structures.

Secondary Structure: This involves folding and coiling of the primary structure (polypeptide chain). The chain will either coil into alpha helices or beta pleated sheets. These structures are held together by hydrogen bonds. The hydrogen bonds are held together by the **hydrogen in the amino group and the carboxyl group.**

Tertiary Structure: This contains a single polypeptide chain backbone, with one or more secondary structures. There are two types of tertiary structure, fibrous and globular. Fibrous are parallel polypeptide chains linked at intervals to form **fibres/sheets**, they are usually tough and so are play structural roles (collagen/keratin). In globular proteins the polypeptide chains are tightly folded to form a spherical shape (haemoglobin). They contain different hydrophobic and hydrophilic groups, with the hydrophilic groups being 'water loving' and the hydrophobic the opposite. The tertiary structure is the 3D structure of globular proteins. The shape of the tertiary structure is held together by hydrogen and ionic bonds; it may also contain disulphide bridges if there is sulfur present in the amino acids. However, the tertiary structure can be broken (denatured) where the bonds are broken. If the polypeptide were an enzyme then it would ultimately cause a non functional protein, as the polypeptide chain would unravel and lose its specific shape. This concept will be covered in further detail in the next chapter.

Quaternary Structure: This is the association of polypeptide chains, i.e. two or more. An example of this is haemoglobin.

How do you test for proteins? The test is called the **Biuret test**, and it detects the peptide bonds between the amino acids that make up proteins. The Biuret test involves adding a Biuret reagent to a sample, shaking the mixture and then a purple colour shows its presence, blue shows there is not a protein present.

3.1.4.2 Many proteins are enzymes

Content

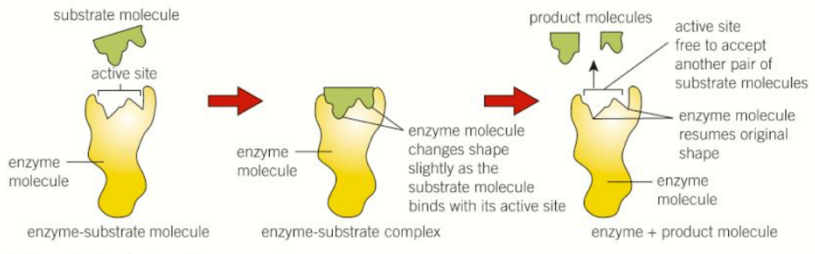
- Each enzyme lowers the activation energy of the reaction it catalyses.
- The induced-fit model of enzyme action.
- The properties of an enzyme relate to the tertiary structure of its active site and its ability to combine with complementary substrate(s) to form an enzyme-substrate complex.
    - The specificity of enzymes
    - The effects of the following factors on the rate of enzyme-controlled reactions – enzyme concentration, substrate concentration, concentration of competitive and of non-competitive inhibitors, pH and temperature.
- Students should be able to:
    - Appreciate how models of enzyme action have changed over time
    - Appreciate that enzymes catalyse a wide range of intracellular and extracellular reactions that determine structures and functions from cellular to whole-organism level.

Opportunities for Skills Development

- Students could be given the hydrogen ion concentration of a solution in order to calculate its pH, using the formula: $pH = -log_{10}(H^+)$

Enzymes lower the activation energy of reactions that they catalyse by forming an enzyme substrate complex (E-S complex). The way that these complexes form can be explained by a model called the induced fit model. This is the most recognised model of enzyme action, as it explains the properties of proteins related to their function as enzymes. There is another model called the lock and key model, however this model is not required for the course, but may help in furthering your understanding of enzyme action and how it has changed over time.

Induced Fit: This model states that the active site is able to undergo a conformational change to fit the shape of the substrate to ultimately form an enzyme substrate complex. Once the substrate has joined with the active site, then moved off, the active site is able to return to its original position. This explains the flexible nature of proteins as the active site is able to change its shape to allow the substrate to bind.

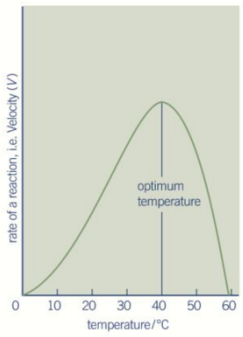


The Lock and Key Model: This model states that enzymes have a specific tertiary structure, and thus a specific active site in which the substrate will bind to. This means that the active site will not undergo a conformational change for the substrate to bind to it, and so only a substrate that has the complementary shape to the active site will bind to the active site.

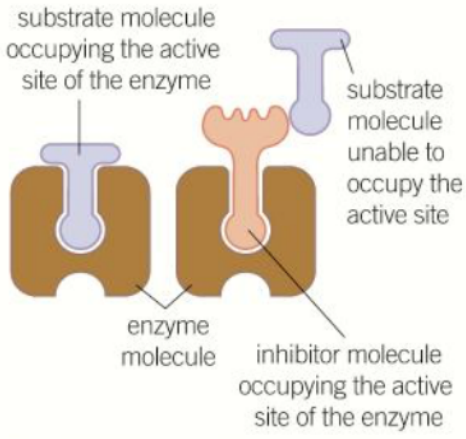
Hydrogen, ionic and other bonds hold the substrate in the active site, and the enzyme can change the structure of the substrate i.e. splitting it in half. Therefore if the active site were to change slightly, then it would no longer be complementary to the substrate thus the enzyme would be ineffective as enzyme-substrate complexes would be unable to form.

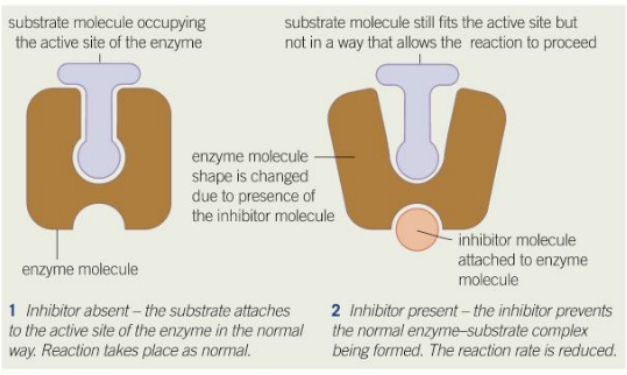
Factors affecting enzymes:

Temperature: The rate of an enzyme catalysed reaction increases up until a maximum, called the optimum temperature. This is the best temperature for enzyme action, so where the enzyme can form most E-S complexes. At suboptimal temperatures, increasing temperature increases the kinetic energy of reactants', so they move faster and there is a higher probability of a collision, so more chance of an E-S complex forming. After the optimum temperature the rate falls dramatically. This is because as the temperature is increased, it causes intramolecular vibrations within the enzyme, and causes a conformational change in the shape of the active site by breaking the hydrogen and ionic bonds in the structure. This means that the substrate would no longer be complementary to the active site, and so no E-S complex could form, so the reaction would not be catalysed. The enzyme is said to be denatured, and the structure is permanently broken. A graph of how temperature effects rate of reaction is shown to the right.



Competitive and Non-Competitive Inhibitors: The diagram below, on the left, shows competitive inhibition and on the right, non competitive inhibition.

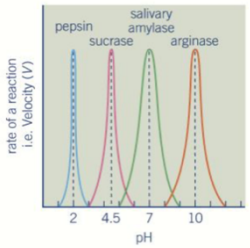




Competitive Inhibitors: These are characterised by the fact that they compete for the active site against the substrate. Therefore it has a shape resembling the substrate, and so is complementary to the shape of the active site. This prevents an E-S complex forming and instead forms an enzyme-inhibitor complex (E-I complex). Therefore the reaction cannot be catalysed. However the effects of competitive inhibition can be reversed by adding more substrate, so that it increases the probability of a substrate binding to the active site as opposed to the inhibitor.

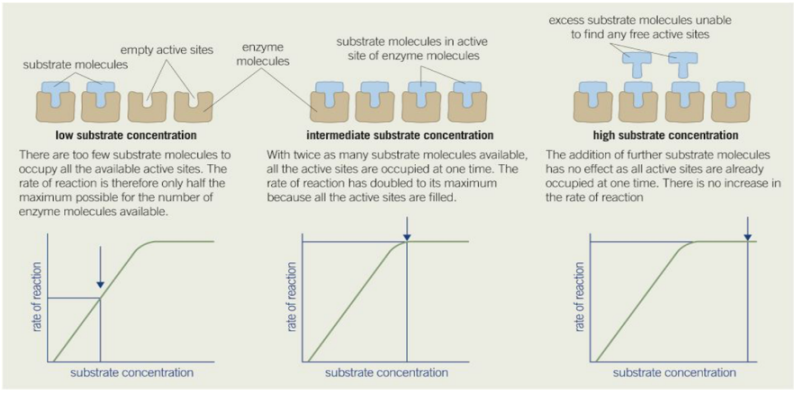
Non-Competitive Inhibitors: The effect of these on the other hand, cannot be reversed by adding more substrate. This is because the non-competitive inhibitors bind to a different size of the enzyme. An enzyme which has another site that an inhibitor for example, can bind to is called an **allosteric** enzyme. This other site can be filled by the non-competitive inhibitor, so these do not bind to the active site of the enzyme. However after the non-competitive inhibitor binds to the enzyme, it causes a conformational change to the structure of the enzyme and thus the active site. This then prevents the formation of an E-S complex as the active site would no longer be complementary to the active site. The non-competitive inhibitor causes a change in the way the protein folds into its tertiary structure, as it attaches to a side group of the protein chain.

pH: With pH you will get an optimum pH, and deviations from this, both higher and lower, will cause a decrease in the rate of a reaction. This is illustrated in the diagram to the right, which shows the various optimum temperatures for different enzymes.

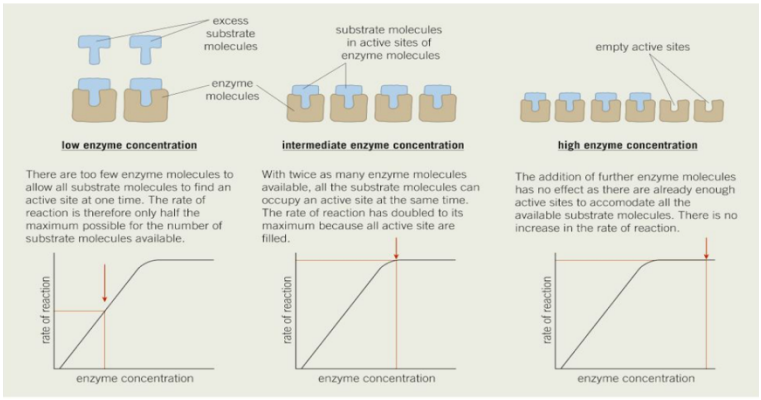


Deviations from optimum pH cause changes in the hydrogen and ionic bonding, amongst others, which denatures the enzyme and causes a conformational change in the structure of the enzyme, and thus the active site. If conditions are more acidic, the active site may pick up extra hydrogen ions, and so this will cause the conformational change in shape. This works in the opposite way for alkaline conditions, where they may lose hydrogen ions. pH is the hydrogen ion concentration, hence extra/less hydrogen ions. This therefore affects how the substrate is able to bind to the active site, and inhibits the production of an E-S complex.

Substrate Concentration: This causes enzyme catalysed reactions to increase in **direct proportion** to the concentration, up until a maximum. This is because the increased substrate concentration causes increased probability of an E-S complex forming. However once all active sites are occupied, then increasing the substrate concentration will no longer increase rate of reaction, so this is the 'maximum' mentioned earlier. This also means that there is another **limiting factor** present, i.e. temperature. The diagram below gives a good explanation of how substrate concentration impacts the rate of reaction.



Enzyme Concentration: As long as there is an excess of substrate, then increasing the amount of enzyme leads to a proportionate increase in the rate of reaction. However as soon as the substrate becomes limiting, and there is not sufficient substrate to combine with all of the enzymes active sites, then increasing the enzyme concentration will have no effect on rate of reaction. The diagram below illustrates the effect of enzyme concentration on rate of reaction.

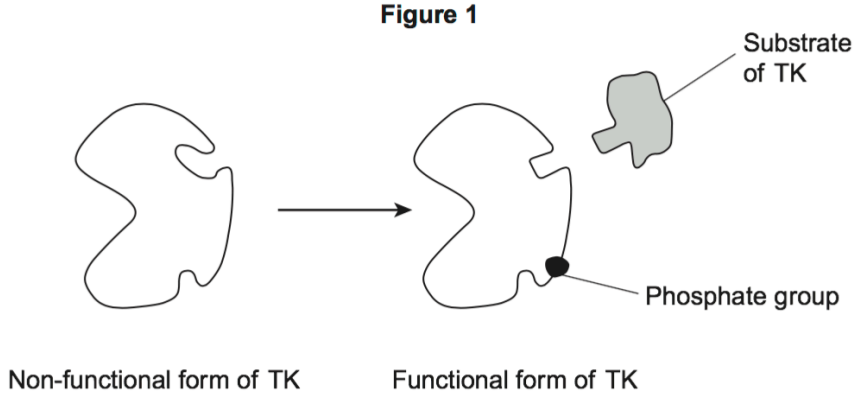


AQA Jan 2013 Q5b

The enzyme tyrosine kinase (TK) is found in human cells. TK can exist in a non-functional and a functional form. The functional form of TK is only produced when a phosphate group is added to TK.

This is shown in **Figure 1**.

Figure 1



Question:

The binding of the functional form of TK to its substrate leads to cell division. Chronic myeloid leukaemia is a cancer caused by a faulty form of TK. Cancer involves uncontrolled cell division.

Figure 2 shows the faulty form of TK.

Suggest how faulty TK leads to chronic myeloid leukaemia

Answer:

1. Faulty TK has functional active site without phosphate;
2. (So, faulty) TK functional all the time/TK not controlled (by phosphate)

AQA Jan 2013 Unit 2 Q6c

Question:

A mutation in the gene coding for enzyme **B** could lead to the production of a non-functional enzyme. Explain how.

Answer:

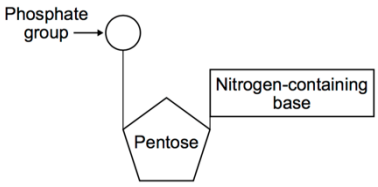
1. Change in base sequence (of DNA/gene);
2. Change in amino acid sequence / primary structure (of enzyme);
3. Change in hydrogen/ionic/ disulphide bonds;
4. Change in the tertiary structure/active site (of enzyme);
5. Substrate not complementary/cannot bind (to enzyme / active site) / no enzyme-substrate complexes form;

3.1.5 Nucleic acids are important information-carrying molecules

3.1.5.1 Structure of DNA and RNA

Content

- Deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) are important **information-carrying molecules**. In all living cells, DNA holds genetic information and RNA transfers genetic information from DNA to the ribosomes.
- Ribosomes are formed from RNA and proteins.
- Both DNA and RNA are polymers of nucleotides. Each nucleotide is formed from a pentose, a nitrogen-containing organic base and a phosphate group:



  - The components of a DNA nucleotide are deoxyribose, a phosphate group and one of the organic (nitrogen-containing) bases adenine, cytosine, guanine or thymine.
  - The components of an RNA nucleotide are ribose, a phosphate group and one of the organic bases adenine, cytosine, guanine or uracil.
  - A condensation reaction between two nucleotides forms a **phosphodiester bond.**
- A DNA molecule is a double helix with two polynucleotide chains held together by hydrogen bonds between specific complementary base pairs.
- An RNA molecule is a relatively short polynucleotide chain.
- Students should be able to
  - Appreciate that the relative simplicity of DNA led many scientists to doubt that it carried the genetic code.

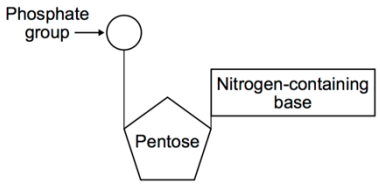
Opportunities for Skills Development

- Students could use incomplete information about the frequency of bases on DNA strands to find the frequency of other bases.

Deoxyribonucleic acid (DNA) and **ribonucleic acid (RNA)** are information carrying molecules. In all living cells, DNA holds genetic information and RNA transfers genetic information from DNA to the ribosomes.

Ribosomes are formed from RNA (rRNA) and proteins.

DNA and RNA are both polymers of nucleotides, each nucleotide is formed from a pentose sugar, a nitrogen-containing organic base, and a phosphate group. This is shown below.



DNA is composed of deoxyribose (a pentose sugar), a phosphate group, and one of the bases adenine, cytosine, guanine or thymine (nitrogen-containing base)

RNA is composed of ribose (a pentose sugar), a phosphate group, and one of the bases adenine, cytosine, thymine and uracil (nitrogen-containing base).

Therefore, the differences between the nucleotides of RNA and DNA are that DNA contains the pentose sugar deoxyribose, as opposed to ribose. Also RNA has the base uracil, whereas DNA has the base thymine.

A condensation reaction between two nucleotides forms a **phosphodiester bond**, these phosphodiester bonds therefore make up the backbone of DNA.

The differences between the structure of DNA and RNA as a whole… DNA is a formed of an antiparallel double helix, where two polynucleotide chains are held together by hydrogen bonds between their bases. However, the bases have to be complementary to each other, otherwise they will not bond to each other. There are four bases, the base adenine is complementary to the base thymine, and the base cytosine complementary to guanine. (A-T, C-G). RNA is a single polynucleotide chain, and is relatively short in comparison to DNA.

AQA June 2014 Unit 2 Q8a

Question:

Explain how the structure of DNA is related to its functions.

Answer:

1. Sugar-phosphate (backbone)/double stranded/helix so provides strength/stability /protects bases/protects hydrogen bonds;
2. Long/large molecule so can store lots of information;
3. Helix/coiled so compact;
4. Base sequence allows information to be stored/ base sequence codes for amino acids/protein;
5. Double stranded so replication can occur semi-conservatively/ strands can act as templates;
6. Complementary base pairing / A-T and G-C so accurate replication/identical copies can be made;
7. (Weak) hydrogen bonds for replication/ unzipping/strand separation;
8. Many hydrogen bonds so stable/strong;

3.1.5.2 DNA Replication

Content

- The semi-conservative replication of DNA ensures genetic continuity between generations of cells.
- The process of semi-conservative replication of DNA in terms of:
    - Unwinding of the double helix
    - Breakage of hydrogen bonds between complementary bases in the polynucleotide strands
    - The role of DNA helicase in unwinding DNA and breaking its hydrogen bonds
    - Attraction of new DNA nucleotides to exposed bases on template strands and base pairing
    - The role of DNA polymerase in the condensation reaction that joins adjacent nucleotides.
- Students should be able to
    - Evaluate the work of scientists in validating the Watson–Crick model of DNA replication.

Semi-conservative replication of DNA ensures that there is genetic continuity between generations of cells. It is described as semi-conservative because each daughter DNA helix contains one strand donated by its parent, and one strand newly synthesised as a result of replication (so the parent helix is semi-conserved in each daughter).

1. The first step of DNA replication is the unwinding of the double helix, so the breaking of the hydrogen bonds between the complementary bases on the polynucleotide strands. DNA helicase is responsible for breaking these hydrogen bonds.
2. Now you have an exposed, single polynucleotide chain. DNA nucleotides in the vicinity are attracted to the exposed bases, and this exposed chain acts as a template strand for complementary base pairing. DNA polymerase is responsible for the pairing of complementary bases in the condensation reaction that occurs.

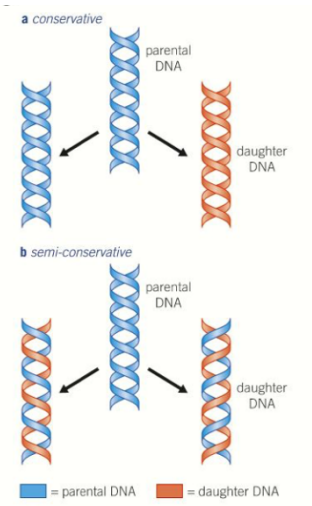
The **Watson-Crick** model of DNA replication was the first proposed model. They proposed the semi-conservative model. There was another model named the conservative model that was also yet to be proved/disproved, and it stated that new DNA molecules built up from freely floating molecules of deoxyribose, phosphates and bases.

These two hypotheses were then tested by **Meselsohn and Stahl**. They based their work on three facts:

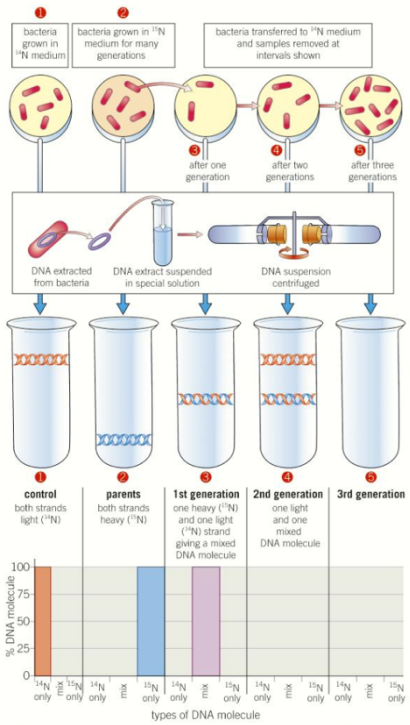
1. All of the bases in DNA contain nitrogen
2. Nitrogen has two forms, the lighter nitrogen ^{14}N and the isotope ^{15}N, which is heavier.
3. Bacteria will incorporate nitrogen from their growing medium into any new DNA they make.

The diagram below shows the two different hypotheses, and what the outcome should look like if either were true. As it turns out, the semi-conservative replication hypothesis was

shown to be correct. They worked this out because bacteria grown on a medium containing the lighter form of nitrogen ^{14}N would have DNA lighter than that grown on ^{15}N nitrogen.



Below shows an outline of the experiment carried out by **Meselsohn and Stahl**, and how they came to their conclusions.



AQA June 2013 Unit 2 Q4a

Question:

DNA helicase is important in DNA replication. Explain why.

Answer:

1. Separates/unwinds/unzips strands/helix / breaks H-bonds;
2. (So) nucleotides can attach/are attracted / strands can act as templates;

AQA Jan 2013 Unit 2 Q8a

Question:

Describe how DNA is replicated.

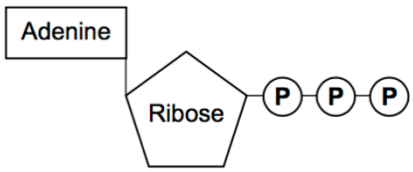
Answer:

1. Strands separate / H-bonds break;
2. DNA helicase (involved);
3. Both strands/each strand act(s) as (a) template(s);
4. (Free) nucleotides attach;
5. Complementary/specific base pairing / AT and GC;
6. DNA polymerase joins nucleotides (on new strand);
7. H-bonds reform;
8. Semi-conservative replication / new DNA molecules contain one old strand and one new strand;

3.1.6 ATP

Content

- A single molecule of adenosine triphosphate (ATP) is a nucleotide derivative and is formed from a molecule of ribose, a molecule of adenine and three phosphate groups.



- Hydrolysis of ATP to adenosine diphosphate (ADP) and an inorganic phosphate group (Pi) is catalysed by the enzyme ATP hydrolase.
    - The hydrolysis of ATP can be coupled to energy-requiring reactions within cells.
    - The inorganic phosphate released during the hydrolysis of ATP can be used to phosphorylate other compounds, often making them more reactive.
- ATP is resynthesised by the condensation of ADP and Pi. This reaction is catalysed by the enzyme ATP synthase during **photosynthesis**, or during **respiration**.

ATP (adenosine triphosphate) is a nucleotide derivative, as it has a nucleoside (a base attached to a pentose sugar) which is attached to 3 phosphate groups. The base is adenine, and the pentose sugar is ribose.

ATP is hydrolysed to **ADP + Pi**, where the Pi is an organic phosphate group. ADP stands for adenosine diphosphate, as it has two phosphate groups as opposed to three 'tri' in adenosine triphosphate. This hydrolysis is catalysed by the enzyme ATP hydrolase. The hydrolysis of ATP releases energy, and so can be used for energy-requiring reactions within cells. The inorganic phosphate that is released can then be used to phosphorylate (add an inorganic phosphate) other compounds, which can often make these compounds more reactive.

ATP is resynthesised by the condensation of ADP + Pi, which is catalysed by the enzyme ATP synthase, for example in photosynthesis or respiration.

The way that ATP stores energy is through the bonding between ADP and the inorganic phosphates. These bonds are unstable, thus have a low activation energy, so can be easily broken and release a high amount of energy when they are broken.

AQA Jan 2012 Unit 4 Q8a

Question:

ATP is useful in many biological processes. Explain why.

Answer:

1. Releases energy in small / manageable amounts;
2. (Broken down) in a one step / single bond broken;
3. Immediate energy compound/makes energy available rapidly;
4. Phosphorylates/adds phosphate;
5. Makes (phosphorylated substances) more reactive / lowers activation energy;
6. Reformed/made again;

3.1.7 Water

Content

- Water is a major component of cells. It has several properties that are important in biology. In particular, water:
    - Is a metabolite in many metabolic reactions, including condensation and hydrolysis reactions
    - Is an important **solvent** in which metabolic reactions occur
    - Has a relatively high heat capacity, buffering changes in temperature
    - Has a relatively large latent heat of vaporisation, providing a cooling effect with little loss of water through evaporation
    - Has strong cohesion between water molecules; this supports columns of water in the tube-like transport cells of plants and produces surface tension where water meets air.

Water has the chemical formula H_2O, so contains two atoms of hydrogen and one of oxygen. It is a major component of all cells, with many properties that make it ideal in its functions. Water is overall not chemically charged but the oxygen has a slight negative charge, and the hydrogen a slight positive charge. Since it has positive and negative sides, it is described as being dipolar.

Water is an important **metabolite** in many reactions, like condensation reactions and hydrolysis reactions. For example, it is used to break down complex molecules like proteins into amino acids.

Water also plays a role as a **solvent**, as it can readily dissolve other substances like oxygen or carbon dioxide. It is called a universal solvent as can dissolve more substances than any other liquid, and so is very important to living organisms. It can also dissolve small hydrophilic molecules like amino acids, monosaccharides or ATP.

Water also has quite a high **specific heat capacity**, which is good for buffering changes in temperature. It takes a lot of energy to separate water molecules as they all bond together, without its hydrogen bonding water would be a gas at the normal temperatures found on earth. So this is good for organisms, who are mostly made from water, in maintaining their body temperatures.

Furthermore, water has a relatively large **latent heat of vaporisation**, so provides a cooling effect with little loss of water through evaporation. The hydrogen bonds are responsible for the difficulty in evaporating water, and this energy required to evaporate the water is referred to as latent heat of vaporisation. In organisms attempting to cool down, heat is used to evaporate the water, so cools them down.

Water also has strong **cohesion** between molecules, and with its hydrogen bonding, it has large cohesive forces. This means it can be pulled up through a tube i.e. xylem vessels in plants. Also where water molecules meet air they tend to be pulled back to the body of water, this is called surface tension. Therefore the water surface acts as almost a floor for small organisms like pond skaters.

3.1.8 Inorganic Ions

Content

- Inorganic ions occur in solution in the cytoplasm and body fluids of organisms, some in high concentrations and others in very low concentrations.
- Each type of ion has a specific role, depending on its properties.
- **Students should be able to**
    - Recognise the role of ions in the following topics: hydrogen ions and pH; iron ions as a component of haemoglobin; sodium ions in the co-transport of glucose and amino acids; and phosphate ions as components of DNA and of ATP.

Inorganic ions occur in solution in the cytoplasm and body fluids of organisms, some in high concentration and others in very low concentrations. Each type of ion has its own specific role; however, this depends on its properties.

To give examples, hydrogen ions regulate pH, as pH is simply a measure of the hydrogen ion concentration. Also, iron ions are a component of haemoglobin vital to its ability in transporting oxygen. Other examples are sodium ions that are essential for the co-transport of glucose and amino acids. Phosphate ions are components of DNA and ATP. Another example is the **magnesium** ions present in chlorophyll, which is responsible for trapping sunlight in photosynthesis.

3.2 Cells

3.2.1 Cell structure

3.2.1.1 Structure of Eukaryotic Cells

Content

- The structure of eukaryotic cells, restricted to the structure and function of:
  - Cell-surface membrane
  - Nucleus (containing chromosomes, consisting of protein-bound, linear DNA, and one or more nucleoli)
  - Mitochondria
  - Chloroplasts (in plants and algae)
  - Golgi apparatus and Golgi vesicles
  - Lysosomes (a type of Golgi vesicle that releases lysozymes)
  - Ribosomes
  - Rough endoplasmic reticulum and smooth endoplasmic reticulum
  - Cell wall (in plants, algae and fungi)
  - Cell vacuole (in plants).
- In complex multicellular organisms, eukaryotic cells become specialised for specific functions. Specialised cells are organised into tissues, tissues into organs and organs into systems.
- **Students should be able to:**
  - Apply their knowledge of these features in explaining adaptations of eukaryotic cells.

Eukaryotic cells are cells that have a distinct nucleus, with membrane bound organelles.

Cell-surface membrane… All membranes around and within all cells have the same basic structure, called plasma membranes. The cell-surface membrane is specifically the name given to the plasma membrane that surrounds cells, and forms the boundary between the cell cytoplasm and environment. It therefore also controls the movement of substances in and out of the cell.

The structure of the cell surface membrane begins with the **phospholipid bilayer**. This bilayer forms due to the hydrophobic and hydrophilic interactions that have been covered in the course already. So the hydrophobic tails face inwards, and the heads face outwards, forming the bilayer on water. This structure allows lipid soluble substances to diffuse across the membrane easily, but prevents water soluble substances entering and leaving the cell. This bilayer also makes the membrane very flexible, which explains the model of cell surface membranes called ‘The fluid mosaic model’.

Within this bilayer you will find many structures, one of the main ones being proteins. These **proteins** sit intermittently within the bilayer. They come in two forms, intrinsic and extrinsic. Intrinsic proteins span the layer completely; some are protein channels which form water-filled tubes to allow water-soluble ions to diffuse across the membrane. Others are carrier proteins that bind to ions or other molecules like glucose or amino acids, and then change shape in order to move these molecules across the membrane. These carrier proteins therefore allow active transport across the membrane. And then if you look at extrinsic proteins, these

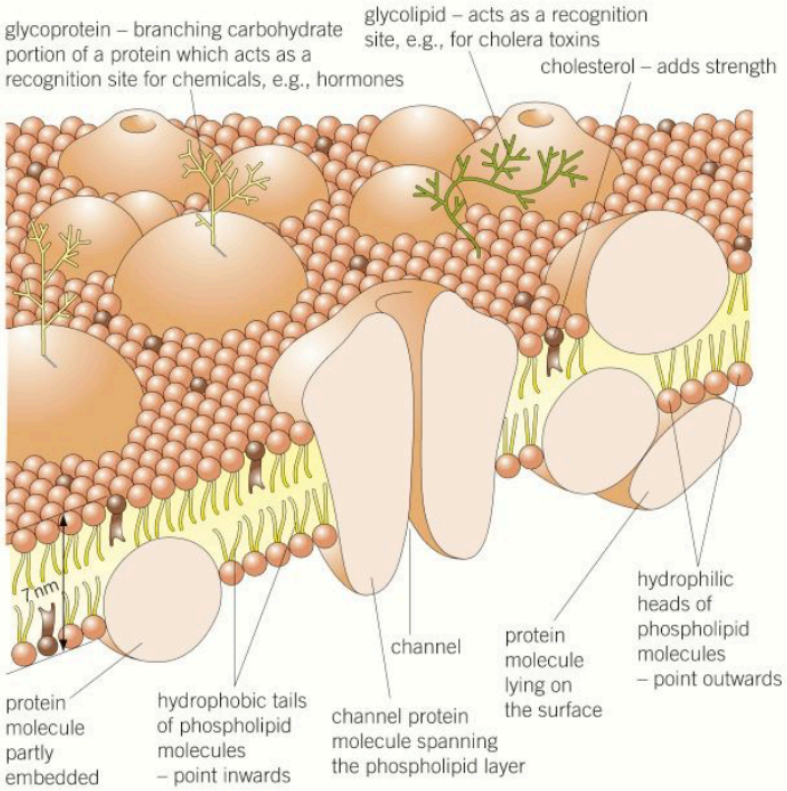
occur at the surface of the bilayer and do not extend across the whole membrane. They either act as mechanical support, or act as cell receptors in conjunction with glycolipids, for things like hormones.

Furthermore, within the bilayer you will find **cholesterol**, which adds strength to the membranes. Cholesterol molecules are also hydrophobic so play a hugely important role in preventing loss of water and dissolved ions from the cell. Also they pull together the fatty acid tails of the phospholipid molecules, so limit their movement without making the membrane too rigid.

On the surface of the membranes, you will find **glycolipids** made up of carbohydrates bonded covalently to lipids. The carbohydrate portion extends from the phospholipid bilayer into the environment outside of the cell, where it acts as a receptor for specific chemicals. They also maintain the stability of membranes and help cells to attach to one another, forming tissues.

The final structure required are **glycoproteins,** which are carbohydrates joined to proteins. These also act as receptors on the surface of cells, for hormones and neurotransmitters. They therefore also help cells to attach to one another and form tissues, and also allow cells to recognise one another.

The diagram below shows 'The Fluid Mosaic Model'. The fluid name comes from the fact the phospholipid molecules can move relative to each other. The mosaic names come from the fact the proteins are regularly embedded within the bilayer, almost like the way objects are arranged in a mosaic. This is the accepted model of cell-surface membranes.



Nucleus... (containing chromosomes, consisting of protein-bound, linear DNA, and one or more nucleoli). The nucleus is enclosed by a nuclear envelope, and consists of a double membrane perforated by small nuclear pores. The pores control the exchange of materials from the nucleus to the cytoplasm and vice versa. The nucleus also contains chromatin, which is the form chromosomes take when not dividing, and these contain DNA. DNA in the nucleus is linear, so is essentially arranged in straight lines, as opposed to circular DNA found in eukaryotic cells. The DNA is also protein bound in the chromosomes. Another structure you will find in a nucleus is the nucleolus, in fact some nuclei will have many nucleoli. The nucleolus manufactures ribosomal RNA, and assemble ribosomes.

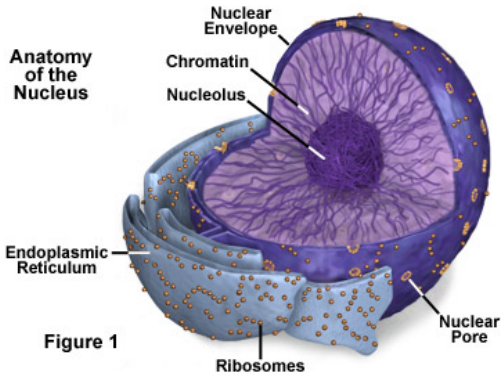
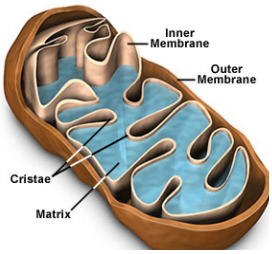


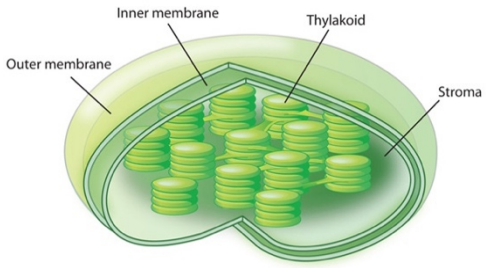
Figure 1

Mitochondria… are the site of aerobic respiration, and produce ATP from glucose. Mitochondria consist of a double membrane, with the inner membrane folded into crista, in order to increase the surface area of the cell. The matrix makes up the remainder of the mitochondrion, containing ribosomes and DNA. This allows the mitochondria to manufacture their own proteins, also many enzymes used in respiration are found in the matrix.

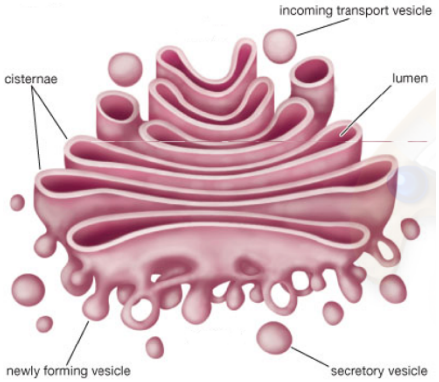


Chloroplasts… are found in plant cells, and are the site for photosynthesis, which provides plants with food in the form of organic compounds like glucose. They have a double membrane, and within this contain grana and stroma. The grana are stacks of thylakoid membranes, which are disc like structures. Within these thylakoids you find the pigment chlorophyll, which is essential to photosynthesis. The stroma is a fluid filled matrix, where you will find other structures like starch grains. Chloroplasts are adapted to their functions in photosynthesis, for example the fluid of the stroma possesses all the enzymes needed to make sugars in the second stage of photosynthesis.

They also contain DNA and ribosomes so can manufacture proteins needed for photosynthesis quickly.



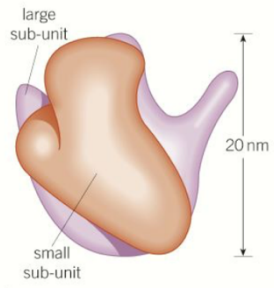
Golgi Apparatus and Golgi Vesicles… The Golgi apparatus, sometimes referred to as the Golgi body, has a role in receiving proteins in vesicles (packages) from the endoplasmic reticulum. It then modifies them by for example adding carbohydrates, and then packages them in a new vesicle, labels them to ensure they go to the correct destination, and then sends them out. The apparatus can also transport, modify and store lipids. The Golgi body is made of cisternae, which are flattened sacs. Vesicles are made by the cisternae, which essentially breaks off into a circular shaped package containing either proteins, carbohydrates or lipids. The Golgi apparatus also makes lysosomes.



Lysosomes… are formed when the Golgi apparatus produces vesicles with enzymes like proteases and lipases. They also contain lysozymes, which are enzymes that hydrolyse the cell walls of certain bacteria in order to digest them, i.e. if they are worn out or can be reused chemically. There may be as many as fifty enzymes in a lysosome, and these can hydrolyse material that has been ingested by phagocytic cells, like white blood cells. They also then release enzymes to the outside of the cells to destroy material around the cell that may be trying to attack the cell. They also play a part in breaking down cells after they have died (autolysis).

Ribosomes… are small granules found in all cells. The size of them differs dependent on if they are in prokaryotic or eukaryotic cells. Eukaryotic cells have 80S ribosomes, whereas prokaryotic cells have 70S ribosomes. Ribosomes can also be associated with the rough endoplasmic reticulum, namely ‘rough’ due to the ribosomes on their surface. Ribosomes are made of two sub units, one large and one small.

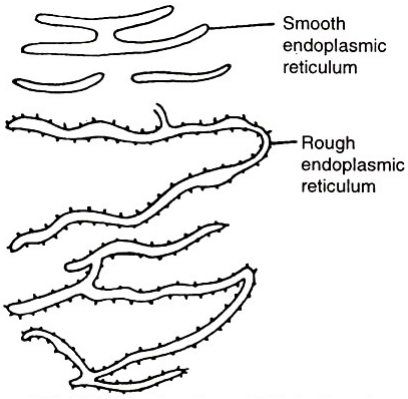
They each contain ribosomal RNA and protein, and are the site of protein synthesis.



Rough Endoplasmic Reticulum and Smooth Endoplasmic Reticulum… The two forms of the endoplasmic reticulum are the smooth and rough type. The rough endoplasmic reticulum has ribosomes on its surface, whereas the smooth endoplasmic reticulum does not. The endoplasmic reticulum is basically a system of membranes, enclosing a network of tubules and flattened sacs called cisternae.

The rough endoplasmic reticulum has the purpose of providing a large surface area for the synthesis of proteins and glycoproteins, and providing a pathway for materials throughout the cell i.e. proteins.

The smooth endoplasmic reticulum has the purpose of synthesising, storing and transporting both lipids and carbohydrates.



Cell Wall… part of every plant cell, and consists mainly of the polysaccharide cellulose. Cellulose **microfibrils** are very strong so add to the integrity of the cell. Ultimately the cell wall provides strength to the cell, so that it will not burst under the pressure created by water entering by osmosis. Cell walls are also present in algae and fungi. The cell walls of algae are made up of either cellulose or glycoproteins, or a mixture of both. Cell walls of fungi do not contain cellulose, only polysaccharides chitin and glycan, or glycoproteins.

Cell Vacuole… is a fluid filled sac found in plant cells. The membrane surrounding the vacuole is called a tonoplast. The fluid within the vacuole contains a solution of mineral salts, amino acids, sugars, and waste products. They also have a purpose of making cells turgid.

In complex multicellular organisms, eukaryotic cells become specialised for specific functions. Specialised cells are organised into tissues, tissues into organs and organs into systems.

AQA A Level Specimen (set 2) Q10.3

Question:

Contrast the structure of a bacterial cell and the structure of a human cell.

Answer:

Any **five** contrasting statements, eg

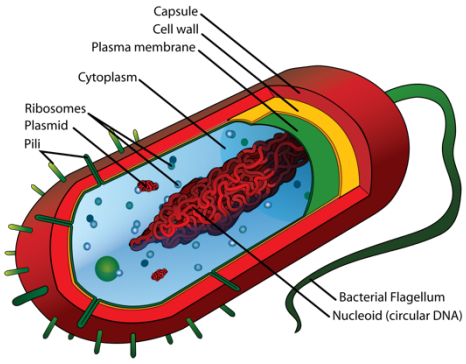
1. Bacterial cell is much smaller than a human cell;
2. Bacterial cell has a cell wall but human cell does not;
3. Bacterial cell lacks a nucleus but human cell has a nucleus;
4. Bacterial cell lacks membrane-bound organelles but human cell has membrane-bound organelles;
5. Bacterial ribosomes smaller than human ribosomes / bacteria have 70S ribosomes whereas humans have 80S ribosomes;
6. Bacterial DNA is circular but human DNA is linear;
7. Bacterial DNA is ‘naked’ whereas human DNA is bound to histones/proteins;

3.2.1.2 Structure of prokaryotic cells and of viruses

Content

- Prokaryotic cells are much smaller than eukaryotic cells. They also differ from eukaryotic cells in having:
    - Cytoplasm that lacks membrane-bound organelles
    - Smaller ribosomes
    - No nucleus; instead they have a single circular DNA molecule that is free in the cytoplasm and is not associated with proteins
    - A cell wall that contains **murein**, a **glycoprotein**.
- In addition, many prokaryotic cells have:
    - One or more plasmids
    - A capsule surrounding the cell
    - One or more flagella.
- Details of these structural differences are **not** required.
- Viruses are acellular and non-living. The structure of virus particles to include genetic material, capsid and attachment protein.

Prokaryotic cells are smaller than eukaryotic cells. They also have a cytoplasm that lacks membrane bound organelles. So whereas eukaryotic cells contain things like mitochondria/chloroplasts that are membrane bound, prokaryotic cells do not. Also, they have smaller ribosomes (70S), as well as not having a nucleus. Instead of a nucleus, prokaryotic cells have a single circular DNA molecule that floats free in the cytoplasm. Their cell walls also contain murein, which is a glycoprotein. Prokaryotic cells will also have one or more plasmids, a capsule that surrounds the cell, and one or more flagella. An example of a prokaryotic cell is given below, as well as a comparison between prokaryotic cells and eukaryotic cells.

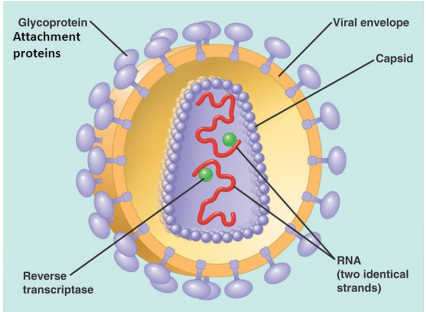


Prokaryotic cells	Eukaryotic cells
no true nucleus, only an area where DNA is found	distinct nucleus, with a nuclear envelope
(Pro) DNA is not associated with proteins	DNA is associated with proteins called histones.
some DNA may be in the form of circular strands called plasmids	There are no plasmids and DNA is linear.
no membrane-bounded organelles	membrane-bounded organelles, such as mitochondria, are present
no chloroplasts, only bacterial chlorophyll associated with the cell-surface membrane in some bacteria	chloroplasts present in plants and algae
ribosomes are smaller (70S)	ribosomes are larger (80S)
cell wall made of **murein** (peptidoglycan)	where present, cell wall is made mostly of cellulose (or chitin in fungi)
may have an outer mucilaginous layer called a capsule	no capsule

The table below shows the different structures of a prokaryotic cells, and gives their respective roles within the cell.

Cell structure	Role
cell wall	physical barrier that excludes certain substances and protects against mechanical damage and osmotic lysis
capsule	protects bacterium from other cells and helps groups of bacteria to stick together for further protection
cell-surface membrane	acts as a differentially permeable layer, which controls the entry and exit of chemicals
circular DNA	possesses the genetic information for the replication of bacterial cells
plasmid	possesses genes that may aid the survival of bacteria in adverse conditions, e.g. produces enzymes that break down antibiotics

Viruses are acellular and non-living. Acellular basically means they are ‘cell free’ so not contained within a cell. The structure of HIV, a type of virus, is shown below.



The features required for the course are the attachment proteins, genetic material and capsid. Viruses also contain nucleic acids like RNA, but they can only multiply inside living host cells. These nucleic acids are enclosed within the capsid. HIV has a further lipid envelope however, which is what the attachment proteins are attached to, but in some viruses this lipid envelope is not present so the attachment proteins are attached to the capsid. The attachment proteins are essential in allowing the virus to identify and attach to a host cell.

Bacteriophage viruses were added to a sterile growth medium and incubated for 10 days.

Which of the following is the most likely result?

- ○ The bacteriophages would have grown quickly, then died off as they depleted their resources.
- ○ The bacteriophages would have grown exponentially due to lack of competition from other organisms.
- ○ The bacteriophage population would have grown quickly and then stabilized.
- ◉ No bacteriophages would be present in the growth medium.

1 / 2 Viruses are unable to replicate on their own without the use of a host cell.

Because the growth environment was sterile and contained no cells to use as hosts, no bacteriophages would grow in the growth medium.

AQA Jan 2012 Unit 1 Q3

Question:

Complete the table.

Feature	Cell		
	Cholera bacterium	Epithelial cell from intestine	Epithelial cell from alveolus of lung
Cell-surface membrane			
Flagellum			
Nucleus			

Answer:

✓	✓	✓
✓		
	✓	✓

3.2.1.3 Methods of studying cells

Content

- The principles and limitations of optical microscopes, transmission electron microscopes and scanning electron microscopes.
- Measuring the size of an object viewed with an optical microscope. The difference between magnification and resolution.
- Use of the formula: $\text{magnification} = \frac{\text{size of image}}{\text{size of real object}}$
- Principles of cell fractionation and ultracentrifugation as used to separate cell components.
- **Students should be able to:**
    - Appreciate that there was a considerable period of time during which the scientific community distinguished between artefacts and cell organelles.

Opportunities for Skills Development

- Students could use iodine in potassium iodide solution to identify starch grains in plant cells.

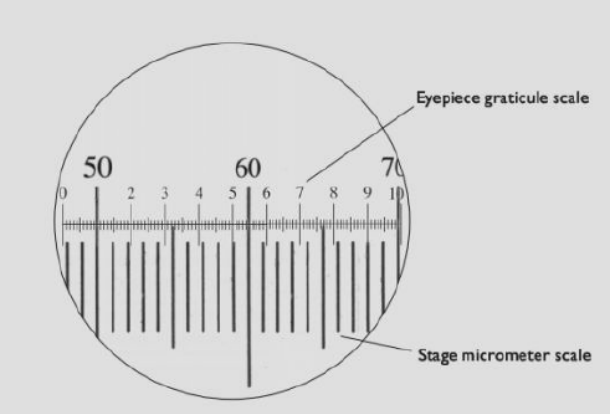
Optical Microscopes… These use light to create a magnified image of the objects being studied. However their main limitation is that they can only distinguish between objects 0.2µm or further apart. This is due to the relatively long wavelength of light, so the resolving power of optical microscopes is poor. Although optical microscopes do give a real colour image which is a positive.

Transmission Electron Microscope (TEM)… This microscope uses a beam of electrons to create an image. The specimen is stained, and as electrons pass through certain parts will absorb more than others, and so appear darker. This builds up a 2-D image of the specimen. This microscope has a much better resolving power, and can distinguish between objects 0.1nm apart, over 2000x better than an optical microscope. The reason for this is because electrons have a much shorter wavelength. However there are many limitations to this type of microscopy.

1. The beam of electrons is of very high energy, thus can damage the specimen.
2. The whole system needs to be in a vacuum, otherwise the electrons will be deflected by molecules in the air.
3. The preparation of the specimen involves a staining process, which can cause artefacts in the images produced. Artefacts are objects that should not be present, and may have resulted from the staining of the specimen, but it is difficult to distinguish between artefacts and what actually should be there.
4. This staining process, and the need for a vacuum also means specimens cannot be alive when they are analysed.
5. The image is also only a black and white image
6. The specimen must be very thin to allow electrons to pass through, so this only provides a flat, 2-D image. To overcome this the scanning electron microscope was put into practice.

Scanning Electron Microscope (SEM)… These use a beam of electrons firing onto the specimen from above on the surface, as opposed to below in the TEM. The beam is passed back and forth on the surface of the specimen, which scatters electrons and shows a pattern dependent on the contours in the specimen. This can be used to build up an image, however the resolving power is slightly lower at 20nm, but still ten times better than the optical microscope. In terms of limitations, these are the same as in a transmission electron microscope.

How to measure the size of an object using an optical microscope. An eyepiece graticule and stage micrometer is used. The eyepiece graticule is calibrated using a stage micrometer, as the stage micrometer is an accurate slide. The reason the eyepiece graticule is not, is due to the fact when you change the magnification of the microscope, it will change the magnification of the scale.



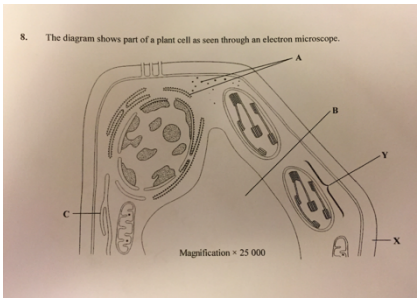
The stage micrometer will usually be around 2mm long, with around 0.01mm sub-divisions at its smallest. Once you line up the stage micrometer and graticule, you are able to calculate the actual length of the specimen. For example, if 10 units on the micrometer scale is equal to 40 on the graticule scale, then 1 unit on the micrometer equals 4 on the graticule. So as each unit on the micrometer equals 10μm, each unit on the graticule equals 10 divided by 4, so 2.5μm. From this you could work out the actual length of the specimen that you are analysing.

Magnification is the increase in size of an object.
Resolution is the ability to distinguish between two objects.

Using the equation below, you can calculate the actual size of an object if given a question in the exam.

$$\text{magnification} = \frac{\text{size of image}}{\text{size of real object}}$$

An example of a typical question is given below.



The question asks what the actual size of the object is. In the question you are given magnification. Although sometimes you could be given a scale which allows you to work out the actual size of the image, and you could be asked to find the magnification.

The size of the real object equals the size of the image divided by the magnification. So in this question, the size of the image is say 10cm. So the size of the real object would be $0.1m/25,000 = 4 \times 10^{-6}m$ or $4\mu m$, where $\mu = 10^{-6}$.

In order to study the ultrastructure of cells, and what they are actually composed of, we use a process of **cell fractionation** followed by **ultracentrifugation**.

Cell fractionation

This is the process by which cells are broken up and the different organelles contained are separated out. Before the cells can be broken up, the tissue needs to be in a cold, buffered, isotonic solution.

Cold to reduce enzyme activity thus preventing activity that may break down the organelles.
Buffered to maintain a constant pH, preventing the enzymes in the organelles denaturing or causing a change in structure of the organelle.
Isotonic to prevent organelles shrinking or bursting due to the osmotic gain/loss of water, and so maintaining a constant water potential.

Homogenisation is the process by which cells are broken up by a homogenizer, which releases the organelles into a resultant fluid (homogenate). This is then filtered to remove debris and leave the organelles.

Ultracentrifugation involves spinning the organelles in the homogenate at different speeds in a centrifuge. This results in the densest organelles collecting at the bottom of the container when the speed is at its lowest, this densest organelle happens to be the nucleus. The separated pellet of nuclei is left in the tube and the remaining supernatant is poured into a new tube for the process to be repeated. At a slightly faster speed the mitochondria will collect at the bottom, then at the fastest speed you will get ribosomes.

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Question:

Give one advantage of using a TEM rather than a SEM

Answer:

Higher resolution / higher (maximum) magnification / higher detail (of image);

OR

Allows internal details / structures within (cells) to be seen / cross section to be taken;

Question:

Give one advantage of using a SEM rather than a TEM.

Answer:

Thin sections do not need to be prepared / shows surface of specimen / can have 3-D images;

3.2.2 All cells arise from other cells

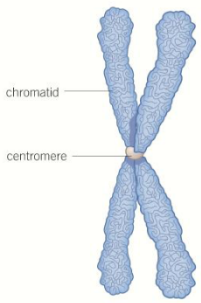
Content:

- Within multicellular organisms, not all cells retain the ability to divide.
- Eukaryotic cells that do retain the ability to divide show a cell cycle.
    - DNA replication occurs during the interphase of the cell cycle.
    - Mitosis is the part of the cell cycle in which a eukaryotic cell divides to produce two daughter cells, each with the identical copies of DNA produced by the parent cell during DNA replication.
- The behaviour of chromosomes during interphase, prophase, metaphase, anaphase and telophase of mitosis. The role of spindle fibres attached to centromeres in the separation of chromatids.
- Division of the cytoplasm (cytokinesis) usually occurs, producing two new cells.
- Meiosis is covered in section 3.4.3
- Students should be able to:
    - Recognise the stages of the cell cycle: interphase, prophase, metaphase, anaphase and telophase (including cytokinesis)
    - Explain the appearance of cells in each stage of mitosis.
- Mitosis is a controlled process. Uncontrolled cell division can lead to the formation of tumours and of cancers. Many cancer treatments are directed at controlling the rate of cell division.
- Binary fission in prokaryotic cells involves:
    - Replication of the circular DNA and of plasmids
    - Division of the cytoplasm to produce two daughter cells, each with a single copy of the circular DNA and a variable number of copies of plasmids.
- Being non-living, viruses do not undergo cell division. Following injection of their nucleic acid, the infected host cell replicates the virus particles.

There are many cells in the human body that will not divide, for example your nerve cells, brain cells or heart muscle cells. If these were to die, they will not come repair and come back. This is partly due to the fact that more divisions mean more chance for mutations, so more chance of cancerous cells forming.

However, many eukaryotic cells are able to divide, and undergo a cell cycle in which this division occurs. The cell cycle is the overarching name for how cells divide, and this is including the process of mitosis. The stages of the cell cycle in order are interphase, prophase, metaphase, anaphase, telophase and cytokinesis. Mitosis however, does not strictly include interphase, as interphase is essentially preparation for mitosis. Also, cytokinesis is not strictly included in the process of mitosis, since mitosis is defined as the process by which a cell divides to produce two genetically identical daughter cells (unless a mutation occurs).

Interphase… is the stage of the cell cycle that the cell replicates its DNA in preparation for mitosis. This forms chromosomes, which are two chromatids joined together by a centromere. In this stage the nucleus, nucleoplasm, nuclear envelope etc. are all still visible.



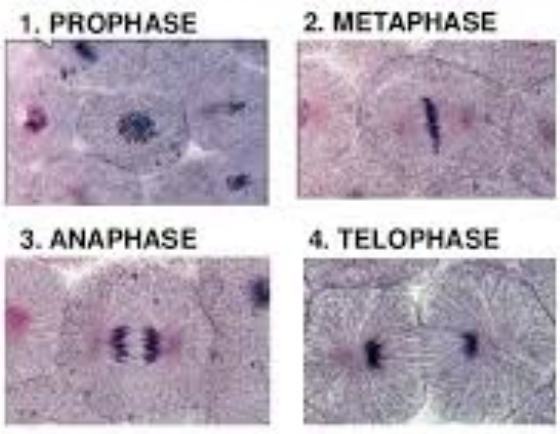
Prophase is where chromosomes become visible, as chromatin condenses to chromosomes, also the nucleus and nucleolus disappear. Spindle fibres begin to develop at each pole, chromosomes also begin to move towards equator (middle) of cell.

Metaphase is where chromosomes line up at the equator of the cell and spindle fibres attach to the centromeres of the chromosomes.

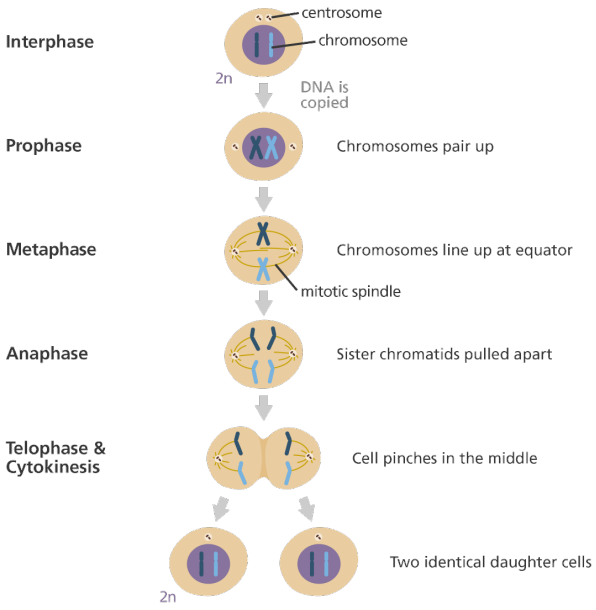
Anaphase is where spindle fibres pull one half of each chromosome in each direction, and each half moves towards opposite poles of the cells. Also, the centromere divides into two and moves towards each pole. The energy for this movement comes in the form of ATP from mitochondria.

Telophase and Cytokinesis… Telophase involves the chromosomes reaching each pole and two daughter cells starting to appear. The nucleus, nuclear envelope and nucleolus all reform in each cell, and the chromosomes return back to their resting form of chromatin. The chromosomes become longer and thinner when changing back to chromatin, thus they can no longer be seen. The spindle also disintegrates. Finally, the cytoplasm will divide and you are left with two daughter cells, in the last stage called cytokinesis.

It is possible that questions will ask you to identify the different stages of mitosis, an example of this is shown below.



To give an idealised version of the cell cycle including mitosis, the diagram below shows this.



Mitosis is a controlled division, as many uncontrolled divisions can result in cancers and tumours. Therefore many cancer treatments are aimed at controlling the rate of cell division.

Binary fission is the process by which prokaryotic cells divide, and is basically asexual reproduction. It begins by replication of the circular DNA and plasmids. Both copies of the circular DNA attach to the cell membrane, and then the cell membrane begins to grow between these two DNA molecules. The cytoplasm is the pinched inwards, dividing the cytoplasm in two. This produces two daughter cells, both with a single copy of the circular DNA and a variable number of plasmids.

Viruses, being non-living, do not undergo cell division. Following injection of nucleic acid of the virus, the infected host cell replicates the virus particles for it. The viruses attach the host cells on the attachment proteins and inject their nucleic acids. This then provides the instructions for the host cell to start producing the viral components.

AQA A Level Specimen (set 2) 3.3

Question:

Figure 4 shows that Rhizopus is able to reproduce both asexually and sexually. Suggest and explain **one** advantage of asexual reproduction and **one** advantage of sexual reproduction in this life cycle

Answer:

- **Asexual**
- Fewer stages so quicker OR
- Only one parent involved so can colonise new environment
- OR
- Produces clone so successful (geno/pheno)type maintained;
- **Sexual**
- increases genetic diversity so greater chance of survival/success;

3.2.3 Transport across membranes

Content

- The basic structure of all cell membranes, including cell-surface membranes and the membranes around the cell organelles of eukaryotes, is the same.
- The arrangement and any movement of phospholipids, proteins, glycoproteins and glycolipids in the fluid-mosaic model of membrane structure. Cholesterol may also be present in cell membranes where it restricts the movement of other molecules making up the membrane.
- Movement across membranes occurs by:
    - Simple diffusion (involving limitations imposed by the nature of the phospholipid bilayer)
    - Facilitated diffusion (involving the roles of carrier proteins and channel proteins)
    - Osmosis (explained in terms of water potential)
    - active transport (involving the role of carrier proteins and the importance of the hydrolysis of ATP)
    - co-transport (illustrated by the absorption of sodium ions and glucose by cells lining the mammalian ileum).
- Cells may be adapted for rapid transport across their internal or external membranes by an increase in surface area of, or by an increase in the number of protein channels and carrier molecules in, their membranes.
- **Students should be able to:** Explain the adaptations of specialised cells in relation to the rate of transport across their internal and external membranes
- Explain how surface area, number of channel or carrier proteins and differences in gradients of concentration or water potential affect the rate of movement across cell membranes.

The basic structure of all cell membranes, including cell-surface membranes and the membranes around the cell organelles of eukaryotes, is the same. These membranes are composed of the phospholipid bilayer that has been covered already in topic 3.2.1.1. To recap:

Cell-surface membrane… All membranes around and within all cells have the same basic structure, called plasma membranes. The cell-surface membrane is specifically the name given to the plasma membrane that surrounds cells, and forms the boundary between the cell cytoplasm and environment. It therefore also controls the movement of substances in and out of the cell.

The structure of the cell surface membrane begins with the **phospholipid bilayer**. This bilayer forms due to the hydrophobic and hydrophilic interactions that have been covered in the course already. So the hydrophobic tails face inwards, and the heads face outwards, forming the bilayer on water. This structure allows lipid soluble substances to diffuse across the membrane easily, but prevents water soluble substances entering and leaving the cell. This bilayer also makes the membrane very flexible, which explains the model of cell surface membranes called ‘The fluid mosaic model’.

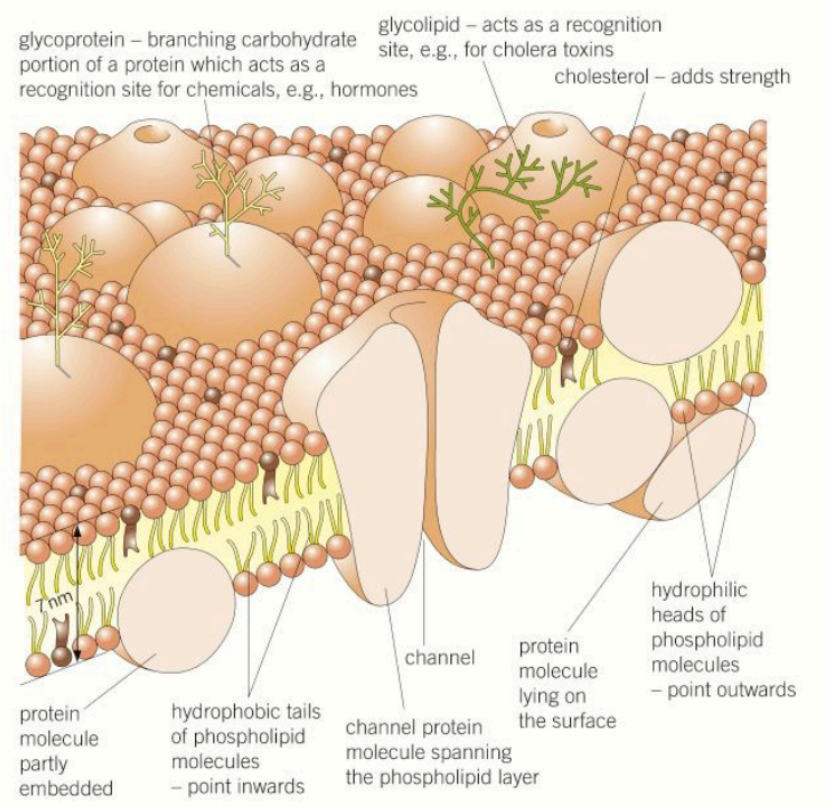
Within this bilayer you will find many structures, one of the main ones being proteins. These **proteins** sit intermittently within the bilayer. They come in two forms, intrinsic and extrinsic. Intrinsic proteins span the layer completely; some are protein channels which form water-filled tubes to allow water-soluble ions to diffuse across the membrane. Others are carrier proteins that bind to ions or other molecules like glucose or amino acids, and then change shape in order to move these molecules across the membrane. These carrier proteins therefore allow active transport across the membrane. And then if you look at extrinsic proteins, these occur at the surface of the bilayer and do not extend across the whole membrane. They either act as mechanical support, or act as cell receptors in conjunction with glycolipids, for things like hormones.

Furthermore, within the bilayer you will find **cholesterol**, which adds strength to the membranes. Cholesterol molecules are also hydrophobic so play a hugely important role in preventing loss of water and dissolved ions from the cell. Also they pull together the fatty acid tails of the phospholipid molecules, so limit their movement without making the membrane too rigid.

On the surface of the membranes, you will find **glycolipids** made up of carbohydrates bonded covalently to lipids. The carbohydrate portion extends from the phospholipid bilayer into the environment outside of the cell, where it acts as a receptor for specific chemicals. They also maintain the stability of membranes and help cells to attach to one another, forming tissues.

The final structure required are **glycoproteins,** which are carbohydrates joined to proteins. These also act as receptors on the surface of cells, for hormones and neurotransmitters. They therefore also help cells to attach to one another and form tissues, and also allow cells to recognise one another.

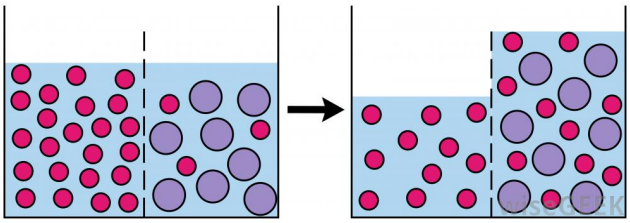
The diagram below shows ‘The Fluid Mosaic Model’. The fluid name comes from the fact the phospholipid molecules can move relative to each other. The mosaic names come from the fact the proteins are regularly embedded within the bilayer, almost like the way objects are arranged in a mosaic. This is the accepted model of cell-surface membranes.



Movement across this membrane occurs in many ways, which are as follows:

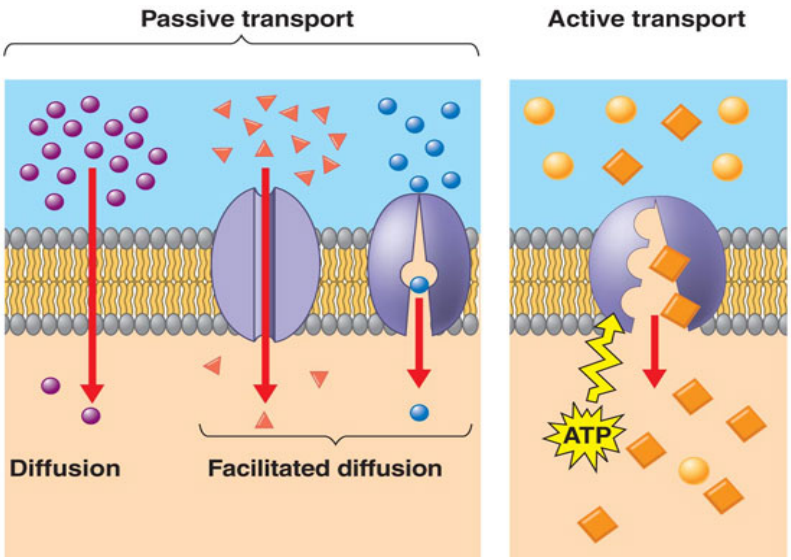
- **Simple diffusion…** this can only occur for lipid soluble substances, for example CO_2 or O_2, these molecules are also non polar and so can diffuse across. Simple diffusion does not require energy, and is a net movement that occurs down a concentration gradient (moves from a high concentration to a low concentration).
- **Facilitated diffusion…** also does not require energy, and occurs down a concentration gradient. However facilitated diffusion is for molecules/ions that are charged so non polar that cannot pass due to the hydrophobic nature of the fatty acid tails. The process of facilitated diffusion occurs down transmembrane carrier proteins or protein channels, hence facilitated diffusion as the proteins facilitate it.
    - **Protein Channels…** are channels filled with water, a hydrophilic channel. It will allow water soluble ions to pass. The channels are selective and will only open to specific ions, so can control the passage of substances across the membrane. The ions bind to one side, which changes the shape of the protein so that it can be released on the other side.
    - **Carrier Proteins…** When molecules like glucose are specific to the protein present, it causes a change in the shape of the protein that allows the molecule to pass out on the other side.
- **Osmosis…** is simply the movement of water from a high water potential to a lower water potential through a semi permeable membrane. Water potential is represented by the symbol Ψ, and is measured in kiloPascals (kPa). Water potential is just the pressure created by water, and so at 25 degrees, with a pressure of 100kPa, pure water is said to have a water potential of 0.

- A solute is anything that is dissolved in a solvent, in this case water is the solvent and so things that dissolve in water are called solutes. If solutes are added to water, the water potential decreases, so if there is a solution of solutes and water, then the water potential will be negative.
- If you wanted to find the water potential of cells/tissue, then you could place them in solutions of different water potentials. Where there is no net gain/loss of water from the cells/tissues, their water potential must have been the same as this.
- The image below shows a simplified version of the process of osmosis. In the diagram there is a partially permeable membrane, that will only allow water to pass. So on the left side there is a high water potential, and on the right there is clearly a low water potential as there are few water molecules (in red). So the water molecules move across to equalise the water potential, Since the solute potential on either side cannot change as the membrane will not allow that, the only thing that can change is the water potential, hence the movement of water from the left side to the right side. The diagram isn't perfect but it shows the basic idea. The highest value of water potential is 0, and once the water has moved down the water potential gradient and finally equalised the potential, there is no net movement.



- **Active transport…** is the movement of molecules/ions against a concentration gradient (from an area of low concentration to high concentration), using energy from ATP and through carrier proteins. Energy from ATP is used to directly move the particles, and the substances that are transported are very specific. The process of active transport is as follows:
  - Carrier proteins span the plasma membrane and bind to the molecule or ion that is being transported.
  - On the inside of the cell or organelle, ATP binds to the protein which causes it to split to ADP + P_i. As a result, the carrier protein changes shape and opens to the opposite side of the membrane.
  - The molecule or ion is then released onto the other side.
  - The phosphate is then released from the protein, and this causes the protein to revert back to its original shape, so the process can be repeated. The phosphate can then phosphorylate ADP again during respiration.

The processes of passive transport (simple diffusion and facilitated diffusion) are shown below, and also the process of active transport to give a comparison.

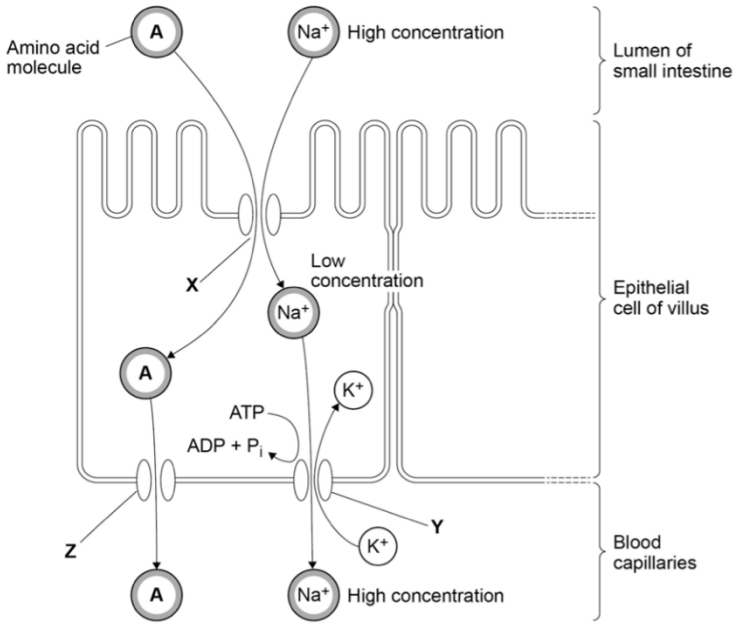


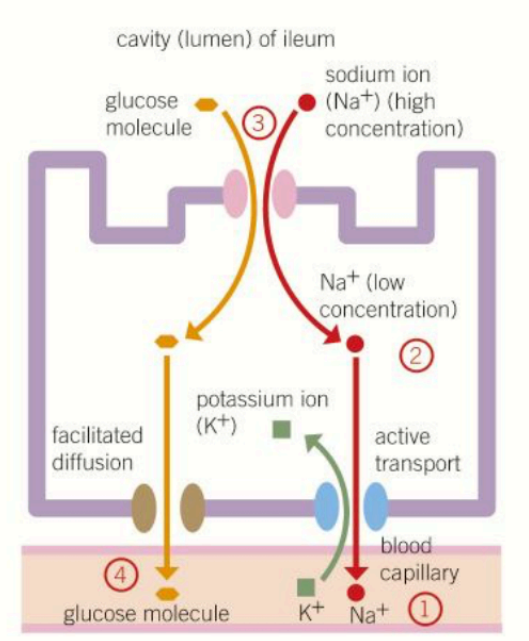
Co-transport… is a process in which two substances are simultaneously transported across a membrane by one protein, or protein complex, in the same direction, and does not necessarily require energy from ATP.
It can be illustrated by the absorption of sodium ions and glucose by cells lining the mammalian ileum (the final part of the small intestine).
Epithelial cells form a lining on the ileum, and possess microvilli, which are millions of tiny projections made from the cell surface membranes. These microvilli increase the surface area and increase the number of carrier proteins within the membrane, which can be used for diffusion, facilitated diffusion or Since carbohydrates and proteins are always being digested, you will usually find there is a concentration by which glucose moves down by facilitated diffusion from the ileum to the blood. Glucose is constantly being used by cells in respiration and moved around so the concentration gradient is usually maintained. However the facilitated diffusion will only equalise the amount of glucose on either side, which is not good as the body needs to absorb as much glucose as possible. To ensure that almost all of the glucose is moved into the blood from the ileum, the body uses a process called co-transport:

1. First of all, sodium ions are actively transported from the epithelial cells into the blood, by the sodium-potassium pump. This causes a lower concentration of sodium ions, and a higher concentration of potassium ions. The active transport occurs through a carrier protein in the cell-surface membrane.
2. There is now a low concentration of sodium ions in the epithelial cell, and a much higher concentration in the lumen of the ileum.
3. Sodium ions diffuse into the epithelial cells down a concentration gradient, through a different type of protein carrier called a co-transport protein found in the cell-surface membrane. As the sodium ions diffuse across, they carry glucose molecules with them (and sometimes amino acid molecules).
4. Therefore there is now a higher concentration of glucose in the epithelial cell than in the blood, so the glucose (or amino acids) move by facilitated diffusion into the blood plasma through a carrier protein.

The movement of sodium ions down their concentration gradient provides the power for the movement of glucose and the amino acids into the cells. The diagram below illustrates the

processes that like place in the co-transport of glucose from the ileum into the epithelial cells and then blood plasma. There are two diagrams given below, both illustrating the process.





Cells may be adapted for rapid transport across their internal or external membranes by an increase in surface area of, or by an increase in the number of protein channels and carrier molecules in, their membranes. This is illustrated in the epithelial cells lining the ileum, which contain microvilli to increase the surface area, and also increase the number of protein channels and carrier proteins in their membranes.

AQA June 2012 Q7abcde

'Read the following passage. Gluten is a protein found in wheat. When gluten is digested in the small intestine, the products include peptides. Peptides are short chains of amino acids. These peptides cannot be absorbed by facilitated diffusion and leave the gut in faeces.

Some people have coeliac disease. The epithelial cells of people with coeliac disease do not absorb the products of digestion very well. In these people, some of the 5 peptides from gluten can pass between the epithelial cells lining the small intestine
and enter the intestine wall. Here, the peptides cause an immune response that leads to the destruction of microvilli on the epithelial cells.

Scientists have identified a drug which might help people with coeliac disease.
It reduces the movement of peptides between epithelial cells. They have 10 carried out trials of the drug with patients with coeliac disease.

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

a) Name the type of chemical reaction which produces amino acids from proteins.

- Hydrolysis (reaction)

b) The peptides released when gluten is digested cannot be absorbed by facilitated diffusion (lines 2 – 3). Suggest why.

- Too big/ wrong shape;
- To fit/ bind/ pass through (membrane/ into cell/through carrier/ channel protein);
- Carrier / channel protein;

c) The epithelial cells of people with coeliac disease do not absorb the products of digestion very well (lines 4 – 5). Explain why.

- Villi /microvilli damaged/ destroyed;
- Reduced surface area;
- For (facilitated) diffusion/ active transport;

d) Explain why the peptides cause an immune response (lines 7 – 8).

- **Foreign, they act as antigens.**

e) Scientists have carried out trials of a drug to treat coeliac disease (lines 10 – 11). Suggest two factors that should be considered before the drug can be used on patients with the disease.

- **Dose to be given;**
- **No (serious) side effects;**
- **How effective;**
- **Cost of drug;**

AQA June 2013 Unit 1 Q5

Question:

5 Imatinib is a drug used to treat a type of cancer that affects white blood cells. Scientists investigated the rate of uptake of imatinib by white blood cells. They measured the rate of uptake at 4 °C and at 37 °C.

Their results are shown in the table.

	Mean rate of uptake of imatinib into cells / µg per million cells per hour	
Concentration of imatinib outside cells / µmol dm^{-3}	**4 °C**	**37 °C**
0.5	4.0	10.5
1.0	10.7	32.5
5.0	40.4	420.5
10.0	51.9	794.6
50.0	249.9	3156.1
100.0	606.9	3173.0

The scientists measured the rate of uptake of imatinib in µg per million cells per hour. Explain the advantage of using this unit of rate in this investigation.

Answer:

1. To allow comparison;
2. Because different number of cells in samples / different times for incubation / numbers become easier to manipulate;

Question:

Calculate the percentage increase in the mean rate of uptake of imatinib when the temperature is increased from 4°C to 37°C at a concentration of imatinib outside the cells of 1.0 µmol dm.

Give your answer to one decimal place.

32.5 – 10.7 = 21.8 then 21.8/10.7 x 100 = 203.7%.

Question:

The scientists measured the rate of uptake of imatinib in µg per million cells per hour. Explain the advantage of using this unit of rate in this investigation

Answer:

1. (At every concentration) uptake is faster at 37°C/at higher temperature;
2. Due to faster respiration/ATP production;

Question:

Explain how the data for concentrations of imatinib outside the blood cells at 50 and 100 μmol dm^{-3} at 37°C support the statement that imatinib is taken up by active transport.

Answer:

1. Uptake at 37C only small increase /levelling off/almost constant;
2. As carrier proteins full;
3. Concentration of imatinib is not the limiting factor;

AQA June 2013 Q7bii

Question:

Microfold cells take up the antigens and transport them to cells of the immune system (lines 6 - 7). Antigens are not able to pass through the cell-surface membranes of other epithelial cells. Suggest **two** reasons why.

Answer:

1. Not lipid soluble;
2. Too large (to diffuse through the membrane);
3. Antigens do not have the complementary shape/cannot bind to receptor/channel/carrier proteins (in membranes of other epithelial cells);

AQA Jan 2013 Unit 1 Q9a

Question

Some substances can cross the cell-surface membrane of a cell by simple diffusion through the phospholipid bilayer.
Describe other ways by which substances cross this membrane

Answer:

By osmosis (no mark)

1. From a high water potential to a low water potential/down a water potential gradient;
2. **Through aquaporins/water channels;**

By facilitated diffusion (no mark)

3. Channel/carrier protein;
4. Down concentration gradient;

By active transport (no mark)

5. Carrier protein/protein pumps;
6. Against concentration gradient;
7. Using ATP/energy (from respiration);

By phagocytosis/endocytosis (no mark)

8. Engulfing by cell surface membrane to form vesicle/vacuole;

By exocytosis/role of Golgi vesicles (no mark)

9. Fusion of vesicle with cell surface membrane

3.2.4 Cell recognition and the immune system

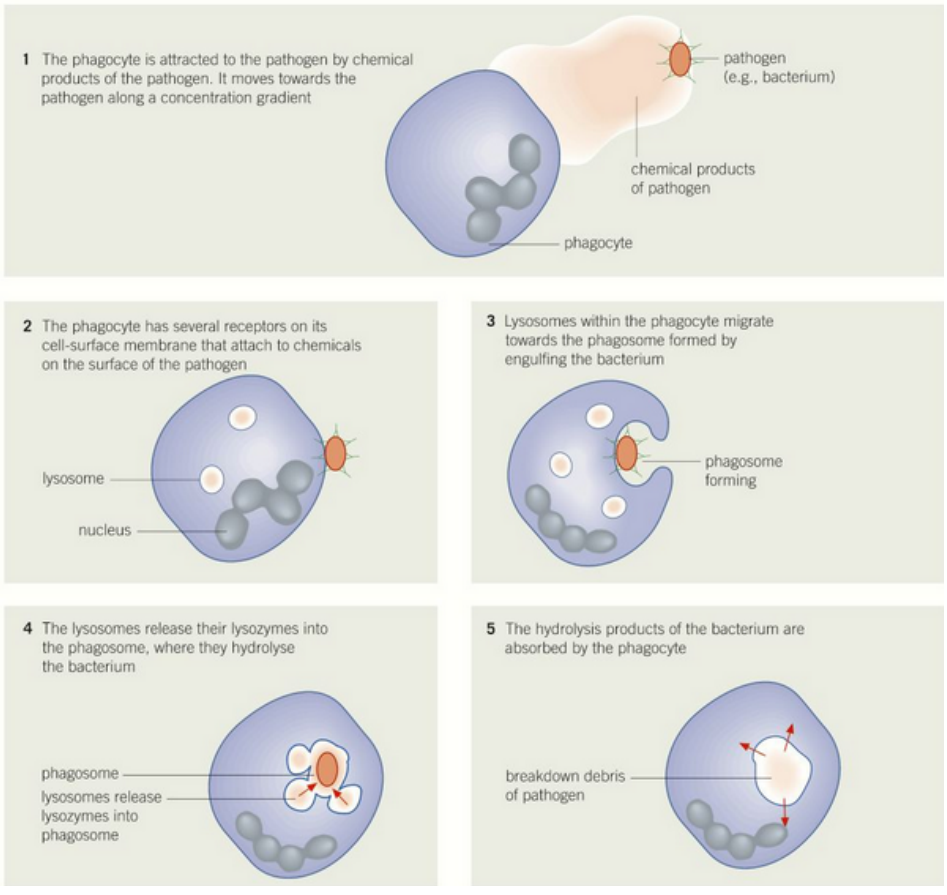
Content

- Each type of cell has specific molecules on its surface that identify it. These molecules include proteins and enable the immune system to identify:
  - Pathogens
  - Cells from other organisms of the same species
  - Abnormal body cells
  - Toxins.
- Definition of antigen. The effect of antigen variability on disease and disease prevention.
- Phagocytosis of pathogens. The subsequent destruction of ingested pathogens by lysozymes.
- The response of T lymphocytes to a foreign antigen (the cellular response).
  - The role of antigen-presenting cells in the cellular response.
  - The role of helper T cells (T_H cells) in stimulating cytotoxic T cells (T_c cells), B cells and phagocytes. The role of other T cells is not required.
- The response of B lymphocytes to a foreign antigen, clonal selection and the release of monoclonal antibodies (the humoral response).
  - Definition of antibody.
  - Antibody structure.
  - The formation of an antigen-antibody complex, leading to
  - The destruction of the antigen, limited to agglutination and phagocytosis of bacterial cells.
  - The roles of plasma cells and of memory cells in producing primary and secondary immune responses.
- The use of vaccines to provide protection for individuals and populations against disease. The concept of herd immunity.
- The differences between active and passive immunity.
- Structure of the human immunodeficiency virus (HIV) and its replication in helper T cells.
- How HIV causes the symptoms of AIDS. Why antibiotics are ineffective against viruses.
- The use of monoclonal antibodies in:
  - **Targeting medication to specific cell types by attaching a therapeutic drug to an antibody**
  - **Medical diagnosis.**
- Details of the commercial or scientific production of monoclonal antibodies are not required.
- Ethical issues associated with the use of vaccines and monoclonal antibodies.
- The use of antibodies in the ELISA test.
- Students should be able to:
  - Discuss ethical issues associated with the use of vaccines and monoclonal antibodies
  - Evaluate methodology, evidence and data relating to the use of vaccines and monoclonal antibodies.

Every cell has specific molecules on its surface that identify it, these molecules include proteins and enable the immune system to identify: pathogens, cells from other organisms of the same species, abnormal body cells and toxins. **Pathogens** are microorganisms that cause disease and harm to a body, which produces an immune response.

Antigens are substances that cause an immune response and production of antibodies, they exist on the surfaces of cells and are usually proteins. The nature of proteins, and the tertiary structure of proteins is very specific, so this enables the immune system to differentiate between different threats. Antigenic variability can occur when pathogens mutate frequently, which causes their antigens to change rapidly. This is dangerous as it means that all previous immunity to the pathogen will be lost, so a previous vaccine will now be ineffective as the immune system will not produce antibodies that kill the pathogen. The Influenza virus is an example of where antigenic variability occurs frequently, which means that people can experience many isolated bouts of influenza in their lifetime. Antigenic variability also makes it difficult to vaccinate against every type of pathogen. For example, the common cold has hundreds of different forms of pathogens each carrying different antigens, of which most are constantly evolving as well. This makes it almost impossible to vaccinate against.

Phagocytosis is a non-specific response to pathogens, where large particles, like some types of bacteria, can be engulfed by cells in vesicles formed by their cell-surface membrane. Ultimately, phagocytosis of pathogens causes the subsequent destruction of ingested pathogens by lysozymes. Some phagocytes travel in the blood but can move out of the blood vessels into other tissues.



The process is illustrated above, and follows the steps:

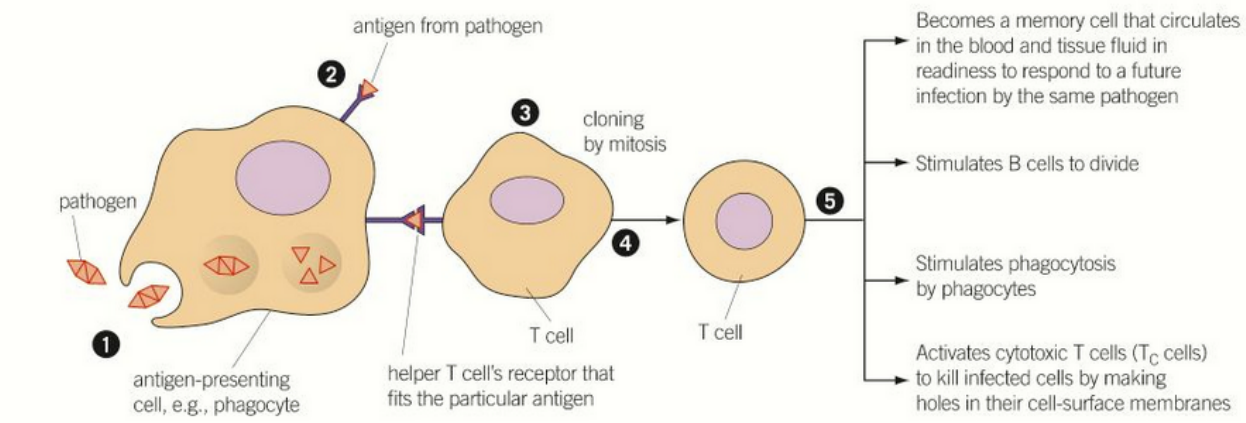
1. Chemical products released by the pathogen attract the phagocyte.
2. The phagocytes have receptors that **attach** to the pathogens.
3. They **engulf** the pathogen; this forms a vesicle called a **phagosome**.
4. Lysosomes move towards the phagosome and **fuse** with it; they then release the enzymes called lysozymes into the phagosome. These enzymes destroy the ingested bacteria by **hydrolysis** of their cell walls.
5. The soluble products from the breakdown of the pathogen are absorbed into the cytoplasm of the phagocyte.

The immune response from phagocytes is non-specific, so will always occur. However there are things that provide a specific response, a type of white blood cell called a lymphocyte. Lymphocytes are produced by stem cells in the bone marrow. There are two types of lymphocyte:

- T lymphocytes (T cells), provide a cellular response to foreign antigens. They are called T cells because they mature in the thymus gland. They provide cellular response, so respond to immunity involving body cells.
- B lymphocytes (B cells), play a role in the humoral response to foreign antigens, as they are involved with antibodies that are in body fluids like blood plasma. They are called B cells as they mature in the bone marrow.

T lymphocytes respond to infection within cells, and can distinguish between normal cells and invader cells as phagocytes that have engulfed and hydrolysed a pathogen will present some of the pathogen's antigens on their own cell-surface membrane. Also body cells invaded by viruses will present the viral antigens on their own cell-surface membrane. They will also identify different antigens on the cell-surface membrane of transplanted cells. Moreover, cancerous cells will also present antigens on their cell-surface membrane, which are different from normal body cells.

However, T cells will only respond to antigens present on a body cell, which is the cellular response, referred to as cell mediated immunity. T cells have receptors which will only respond to a single antigen. The way that T cells respond to infection is shown below:



1. Either pathogens will invade body cells, or will be taken in by phagocytes.
2. These phagocytes, or the body cells will then place the antigens from the pathogen on their cell-surface membrane.

3. Helper T cells (T_H) will come and attach to the antigens that have been placed on the cell-surface membrane, providing there is a complementary fit.
4. Once they have attached, the T_C cell will divide rapidly by mitosis, and form genetically identical clones.
5. These cloned T cells can do one of four things that are shown on the diagram above.
    - They can develop into memory cells. These memory cells will stay in the blood and tissue fluid, ready to respond to a future infection by the same pathogen.
    - They can stimulate B cells to divide (B cells are covered next)
    - They can stimulate phagocytosis by phagocytes.
    - They can activate cytotoxic T cells (T_C cells) which kill infected cells by making holes in their cell-surface membranes. They do this by producing a protein called perforin, which makes these holes. Since the cell now becomes open to any substance that is passing, the cell loses its integrity and will die as a result.

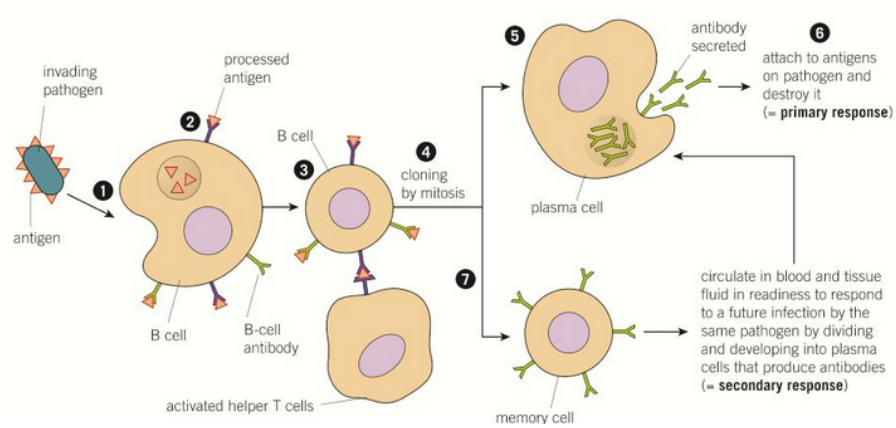
T cells are therefore most effective against viruses, as viruses replicate inside cells, so T cells are able to fight off the virus.

Some of the T cells stimulate the division of B cells, and it is these **B lymphocytes** that are involved with the humoral immunity. Humoral immunity involves antibodies; B cells produce a specific antibody to attack a certain antigen. When an antigen is presented on the surface of a cell that seems to pose a threat, there will be one B cell with a complementary shape to fit the antigen. This antigen then enters the B cell by endocytosis, and is then presented on the surface of the B cell.

Helper T cells (T_H) bind to these processed antigens and simulate the B cells to divide by mitosis. Now you have cloned B cells that produce the antibody specific to the foreign antigen. This process is referred to as **clonal selection**.

However, most pathogens will present many different proteins on their surface, and some pathogens like cholera will also produce toxins which also act as antigens. This means that B cells have to make clones, each of which produces its own type of antibody. This concept is called **monoclonal antibodies** as each clone produces one specific antibody. When the B cells are cloned they will develop into one of two types of cell:

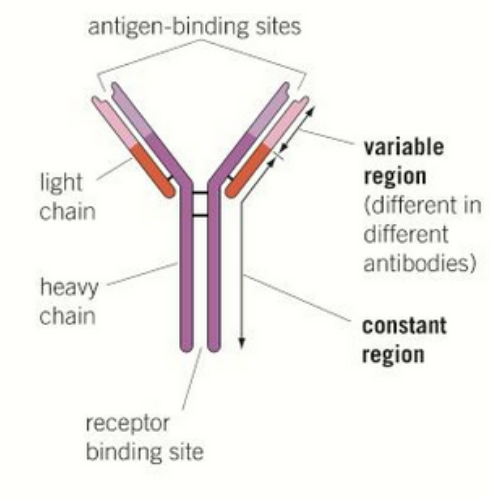
- **Plasma cells** which secrete antibodies into the blood plasma. These plasma cells are called plasma cells simply because they will move around in the blood plasma. They last only a few days but can make over 2000 antibodies a second. Antibodies cause the destruction of pathogens, and so plasma cells are involved in the immediate defence of the body against infection (The **primary immune response**).
- **Memory cells** last much longer than plasma cells, they can be present for decades, but do not produce antibodies directly. However if they come into contact with the same antigen at another point, they will divide rapidly to form plasma cells and more memory cells. Memory cells provide long-term immunity to pathogens, and provide the **secondary immune response**.



The action of B cells is shown above, and follows:

1. B cells will take in antigens from the pathogens in a process called endocytosis.
2. The B cells will then process these antigens and present them on their surface.
3. **COMPLEMENTARY** helper T cells will come and bind to the antigens that the B cells have presented on their surface. This process activates the B cells.
4. The B cell now divides by mitosis to produce either plasma cells or memory cells.
5. Plasma cells produce and secrete the specific antibody that fits exactly into the antigen on the pathogens surface. These antibodies attach to the antigens on the pathogens and destroy the pathogens.
6. The memory cells that have been produced will remain dormant until they come into contact with the same antigen again in the future. When they do come into contact with the same antigen, they can divide rapidly to form plasma cells which will then produce antibodies. (Secondary immune response).

Antibodies are proteins that have specific binding sites that have been produced by B cells in order to target a specific antigen. The binding sites of the antibody are therefore said to be complementary to that of the antigen. The diagram blow shows the structure of an antibody. It has antigen-binding sites, two light chains and two heavy chains, a constant region, receptor binding site, as well as a variable region that is different for each antibody, depending on the antigen they are targeting.



Antibodies only prepare the antigen for destruction, and so do not destroy it directly. First of all they form an antigen-antibody complex, which then leads to the destruction of the antigen. This is achieved by agglutination and then phagocytosis of bacterial cells.

- **Agglutination** of bacterial cells is where the antibodies will attach to the antigens on the pathogens. Since they have two binding sites, they can bind to the antigens on two pathogens. Therefore you will get pathogens with more than one antibody binding to its surface. This forms a compact structure where all of the pathogens are brought together in one small area (agglutination).
- Once agglutination of these bacterial cells has occurred, they act as a marker, and phagocytes will engulf the bacterial cells attached to the antibodies, causing phagocytosis of the bacterial cells and consequent destruction.

Vaccines provide protection for individuals and populations against disease. Vaccination is the process of introducing an antigen into the body, either by injection or mouth. The intention is to stimulate an immune response against a particular disease. The material introduced is called a vaccine, and contains one or more types of antigen from the pathogen. This stimulates an immune response, however the amount introduced is not that vast. The main thing is that memory cells are produced, as these remain in the blood and allow a much greater, quicker response if the pathogen returns. So this means that if the pathogen does enter the body, the response will be so fast that few symptoms should be felt.

On a large scale this provides something called **herd immunity.** This arises when a sufficiently large proportion of the population has been vaccinated. Since pathogens are passed from individual to individual, so if you reduce the number of individuals that are susceptible to the pathogen (due to immunity), then there is less chance of a person coming into contact with someone that is infected. This concept is very important, as in large populations it is difficult to vaccinate everyone, for example babies whose immune system is not yet fully functional, or those that are ill/have compromised immune systems. To conclude, the definition of **herd immunity** is where enough people have been vaccinated to significantly reduce the spread of the pathogen through the population, by reducing the chance of an infected person meeting someone that is not vaccinated.

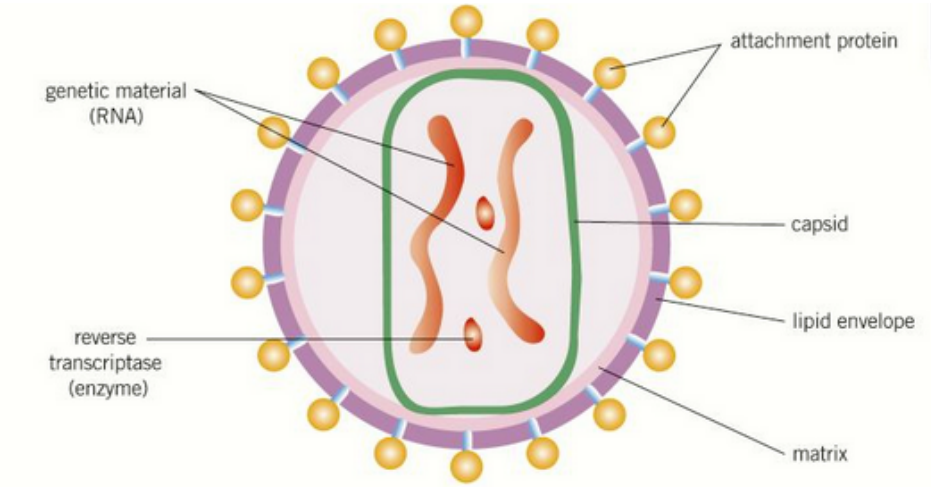
Immunity can come in two different forms, **active** and **passive** immunity.

- **Active immunity** is produced by stimulating the production of antibodies by the individuals own immune system. This requires direct contact with a pathogen and its antigen. Active immunity is of two types:
    - Natural active immunity, which is as a result of an individual becoming infected directly by the pathogen.
    - Artificial active immunity, which is essentially vaccination. This involves actually inducing an immune response in an individual.
- **Passive Immunity** is the process by which antibodies are introduced into an individual from an outside source, so no contact between pathogens or their antigens are required. This means that no memory cells are created, so no more antibodies are produced once the antibodies have been broken down. An example of this is anti-venom, or the immunity required by the fetus when antibodies pass across the placenta from the mother.

Vaccinations, to be successful, must meet a whole plethora of requirements. For example they must be economically available in sufficient quantities to actually immunise most of the population. There must also be few side effects, a means of producing, storing and transporting the vaccine must also be available. There must be a means of administering the vaccine properly at the appropriate time, which involves training staff with appropriate skills around the population. Also it must be possible to vaccinate the vast majority of the vulnerable population to produce herd immunity.

However, one of the biggest reasons that vaccinations can be ineffective is due to the antigenic variability. This concept was covered at the beginning of this topic. Also for people with immune systems that are defective, it will not induce immunity, or those that develop the disease immediately after the vaccination, so immunity levels are not high enough. Some pathogens will conceal themselves from the body's immune system i.e. cholera within the intestines. People may also object on ethical, medical or religious grounds to vaccination.

The Human Immunodeficiency Virus (HIV) has the general structure shown below. It causes the disease **Acquired Immune Deficiency Syndrome (AIDS)**



The capsid encloses the two single strands of RNA and some enzymes. One of these enzymes is reverse transcriptase, because it catalyses the production of DNA from RNA, so the reverse

reaction to that carried out by transcriptase. The presence of this enzyme means that HIV belongs to a group of viruses called retroviruses.

HIV is unable to replicate itself, as it is a virus. It instead invades body cells and uses its genetic material to instruct the host cell to produce the components required to make HIV. Therefore, HIV will enter the bloodstream and circulate around the body, it will then readily bind to a protein called CD4. This is a protein that predominantly occurs on helper T cells, so HIV attaches to helper T cells. The protein capsid then fuses with the cell-surface membrane, and the RNA and enzymes of the HIV enter the helper T cell. Once this stage is finished, the HIV reverse transcriptase converts the virus's RNA into DNA. The DNA that has been made moves into the helper T cell's nucleus, where it is inserted into the cell's DNA.
The HIV DNA in the nucleus creates messenger RNA (mRNA), using the cells enzymes, and this mRNA contains the instructions for making new viral proteins and the RNA to go into the new HIV. The mRNA passes out of the nucleus through a nuclear pore, and uses the cell's protein synthesis mechanisms to make HIV particles. The HIV particles break away from the helper T cell with a piece of its cell-surface membrane surrounding them, which forms their lipid envelope.

HIV replication usually goes into dormancy, and only recommences, which leads to AIDS, many years later.

HIV causes **AIDS** by interfering with the normal functioning of helper T cells. It can reduce the number of helper T cells down to around one sixth of their normal value in some cases. Since helper T cells are vital in cell-mediated immunity, and in stimulating B cells to produce antibodies, or the cytotoxic T cells that kill cells infected by pathogens. Memory cells can also be infected and destroyed, so the body is unable to produce a sufficient immune response and becomes susceptible to all kinds of infections and cancers. Secondary diseases are the ultimate cause of death, as a result of the immune system becoming more and more suppressed.

Why are **antibiotics ineffective** against viruses? Well, one way in which antibodies work is by preventing bacteria from making normal cell walls. In bacterial cells, their cell wall that surrounds them, made of murein, is a tough material that prevents the cells from bursting under osmotic pressure. So certain antibodies like penicillin inhibit certain enzymes required for the synthesis and assembly of the peptide cross-linkages in bacterial cell walls. This means the bacteria are unable to stand the pressure, and so the cell bursts under osmotic pressure and dies.

However, viruses rely on the host cells to carry out their metabolic activities, so do not actually have their own metabolic pathways or structures. This means that antibiotics are ineffective as they cannot disrupt any structures or metabolic pathways. They also have a protein coat as opposed to murein cell wall, so do not have sites where antibiotics can work. Also when viruses are inside body cells, antibiotics are unable to reach them.

Monoclonal antibodies are antibodies produced by a single cloned B cell. Therefore they are antibodies that recognise and attach to specific proteins produced by cells. Each monoclonal antibody recognises one particular protein. They work in different ways depending on the protein they are targeting. Monoclonal antibodies play a role in cancer treatments as these monoclonal antibodies will target a specific antigen. These antibodies can be given directly to patients, and they will attach to the receptors on the cancer cells which

will inhibit the chemical signals and block the growth of the cancer cells. These monoclonal antibodies are good because they are so specific so produce few side effects. Also monoclonal antibodies can be used alongside a radioactive or cytotoxic drug so that when the antibody attaches to the cancer cells it kills them.

They can also be used for diagnosis e.g. of influenza or chlamydia, or types of cancer. For example, men with prostate cancer will produce more of a protein called prostate specific antigen. This causes high levels in the blood, so by using a monoclonal antibody and seeing its interaction with this antigen, it is possible to measure the levels of the antigen in the blood. This can provide early detection.

Pregnancy testing is another use of these monoclonal antibodies. They rely on the fact that the placenta produces a hormone called human chorionic gonadatrophin (hCG). This can be found in the urine of the mother, if hCG if present then it will bind to the antibodies present on a test strip of a pregnancy testing kit. The hCG-antibody-colour complex moves along the strip until it is trapped by a different type of antibody, creating a coloured line.

There are many different ethical issues in the use of both monoclonal antibodies and vaccinations. For example, production of **monoclonal antibodies** uses mice, who are used to produce antibodies and tumour cells. This induces cancer in the mice, and so there are people that are against this from an ethical standpoint. There can also be dangers when using monoclonal antibodies, in some cases there have been deaths, so it is important that patients are informed of the risks and provide consent. Furthermore, the **trials** of these new types of drugs can have fatal consequences.

These ethics of **vaccines** raise similar questions to that of the use and production of monoclonal antibodies. For example, the development uses animals which may be seen as unacceptable. Some vaccines also have side-effects which may cause long-term harm, so these may outweigh the actual risk of obtaining the infection. Furthermore, the trialing of vaccines can be dangerous, when the health risks may be unknown. These are some of the main objections when using vaccinations, and there are many others.

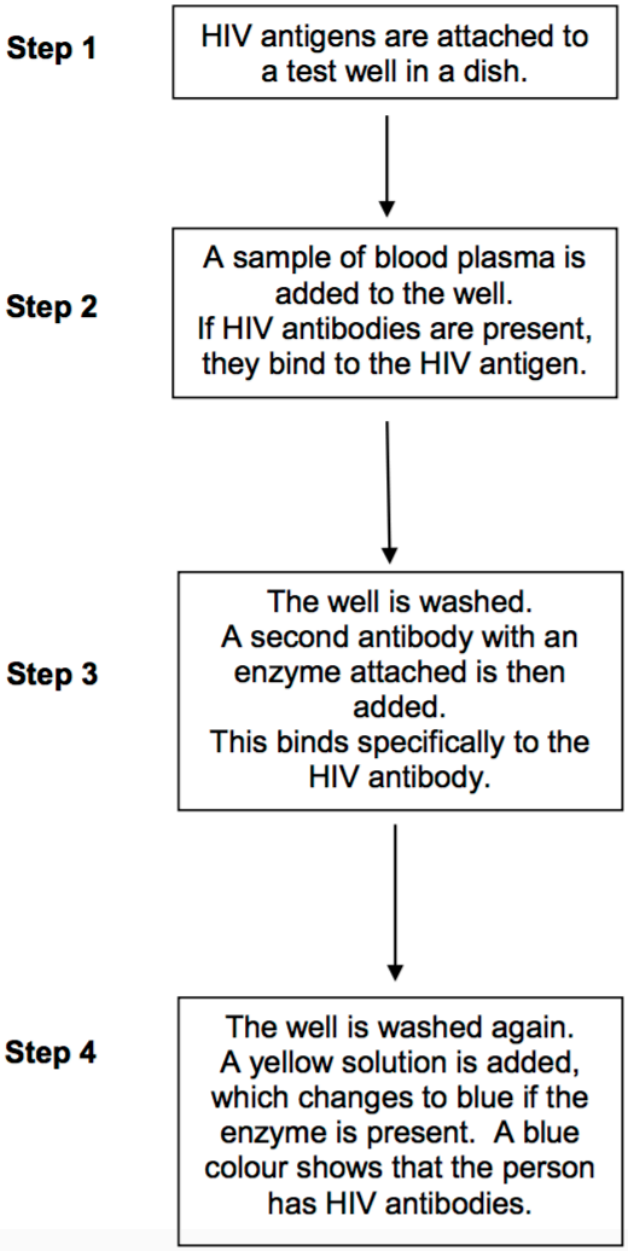
The **ELISA** test stands for enzyme linked immunosorbant assay. It uses antibodies to detect the presence of a protein in a sample, and also the quantity. It is very sensitive so can detect small amounts of molecules. So the test aims to find a particular antigen and works as follows:

- The sample is applied to a surface, i.e. a slide, to which all the antigens in the sample will attach.
- Ensure the surface is washed to remove any unattached antigens.
- Add the antibody that is specific to the antigen that is trying to be found, and leave the two to bind together.
- Wash the surface to remove excess antibody.
- Add a second antibody that binds with the first antibody, this second antibody has an enzyme attached to it.
- Add the colourless substrate of the enzyme, this enzyme acts on the substrate the change it into a coloured product.
- The amount of antigen present is relative to the intensity of the colour produced.

In the AQA Specimen 1 (2014) Paper, they gave this description of the Elisa test.

Figure 5 shows a test that has been developed to find out if a person has antibodies to the human immunodeficiency virus (HIV) antigen.

Figure 5



AQA Biology May 2011 Q8a

Question:

'Different cells in the body have different functions.

Some white blood cells are phagocytic. Describe how these phagocytic white blood cells destroy bacteria.'

Answer:

- Phagocyte attracted to bacteria by chemicals/recognise antigens on bacteria as foreign;
- Engulf/ingest bacteria into a phagosome
- Bacteria in vacuole/vesicle (phagosome)
- Lysosome fuses with/empties enzymes (lysozymes) into vacuole;
- Bacteria digested/hydrolysed

AQA Biology May 2012 Q5abc

Question

'What is a pathogen?'

Answer:

Microorganism that cause disease and harm to a body, also stimulating an immune response

Question:

'When a pathogen enters the body it may be destroyed by phagocytosis. Describe how.'

Answer:

- Phagocyte attracted by a substance/ recognises (foreign) antigen;
- (Pathogen)engulfed/ ingested;
- Enclosed in vacuole/ vesicle/ phagosome;
- (Vacuole) fuses/joins with lysosome;
- Lysosome contains enzymes;
- Pathogen digested/molecules hydrolysed;

Question:

'When a pathogen causes an infection, plasma cells secrete antibodies which destroy this pathogen.

Explain why these antibodies are only effective against a specific pathogen.'

Answer:

- Antigens on the pathogen are a specific shape, with a specific tertiary (3D) structure;
- Antibody is complementary to antigen, ie an antibody-antigen complex forms;

OR

- Antibodies are a specific shape, as they have specific tertiary (3D) structure;
- Antigens on the pathogen are complementary to the antibody, ie an antibody-antigen complex forms;

AQA June 2013 Q7c

Read the following passage.

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

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

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

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

Question:

Scientists believe that it may be possible to develop vaccines that make use of microfold cells (lines 9 -10). Explain how this sort of vaccine would lead to a person developing immunity to a pathogen.

Answer:

1. (Vaccine contains) antigen/attenuated/dead pathogen;
2. Microfold cells take up/bind and present/transport antigen (to immune system/lymphocytes/T- cells);
3. T-cells activate B-cells;
4. B-cells divide/form clone/undergo mitosis;
5. B-cells produce antibodies;
6. Memory cells produced;
7. More antibodies/antibodies produced faster in secondary response/on reinfection;

AQA June 2013 Unit 2 Q5ai)ii)

Question:

Give **one** way in which antibiotics can prevent the growth of bacteria.

Answer:

Prevent cell wall formation / cause (cell) lysis / inhibit ribosomes / inhibit protein synthesis / prevent DNA replication / affect function of cell membrane;

Question:

Describe how bacteria can become resistant to antibiotics by *vertical* gene transmission.

Answer:

(Plasmid/genes transmitted through) cell division/reproduction/replication/generations

AQA Jan 2013 Q8a

The human immunodeficiency virus (HIV) leads to the development of acquired immunodeficiency syndrome (AIDS). Eventually, people with AIDS die because they are unable to produce an immune response to pathogens.

Scientists are trying to develop an effective vaccine to protect people against HIV. There are three main problems. HIV rapidly enters host cells. HIV causes the death of T cells that activate B cells. HIV shows a lot of antigenic variability.

Scientists have experimented with different types of vaccine for HIV.
One type contains HIV in an inactivated form. A second type contains attenuated HIV which replicates in the body but does not kill host cells. A third type uses a different, non-pathogenic virus to carry genetic information from HIV into the person's cells. This makes the person's cells produce HIV proteins. So far, these types of vaccine have not been considered safe to use in a mass vaccination programme

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

People with AIDS die because they are unable to produce an immune response to pathogens (lines 2– 4).

Question:

Explain why this leads to death.

Answer:

1. Infected by/susceptible to (other) pathogen(s)/named disease caused by a pathogen (from environment);
2. Pathogen(s) reproduce/cause disease (in host);
3. Damage cells/tissues/organs;
4. Release toxins;

Question:

Explain why each of the following means that a vaccine might **not** be effective against HIV.

HIV rapidly enters host cells (lines 6 –7).

Answer:

1. (HIV enters cells) before antibodies can bind to/destroy it;
2. Antibodies cannot enter cells (to destroy HIV)/stay in blood;

OR

3. (Enters cells) before (secondary) immune response caused/before memory cells have time to respond;
4. So no antibodies present (to attack HIV);

OR

5. Vaccine taken up too quickly to cause immune response;
6. So no antibodies/memory cells formed;

Question:

HIV shows a lot of antigenic variability (lines 7– 8).

Answer:

1. Antigen (on HIV) changes;
2. (Specific) antibody/receptor no longer binds to (new) antigen;

OR

3. Many different strains of HIV/many antigens present on HIV;
4. Not possible to make a vaccine for all antigens/vaccine may not stimulate an antibody for a particular antigen;

Question:

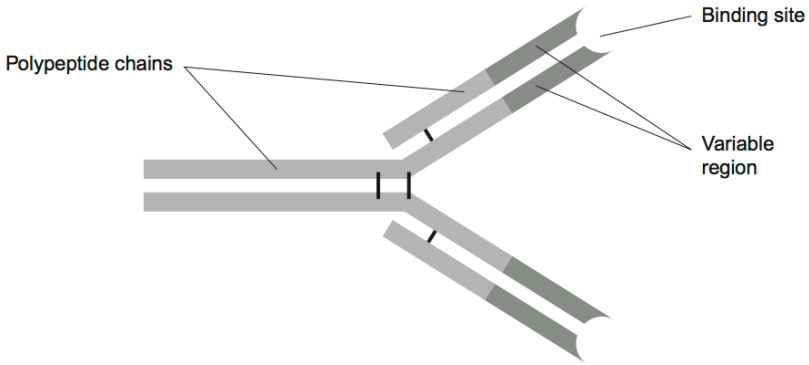
So far, these types of vaccine have not been considered safe to use in a mass vaccination programme (lines 14 – 15).

Suggest why they have **not** been considered safe.

Answer:

1. Inactive virus may become active/viral transformation;
2. Attenuated virus might become harmful;
3. Non-pathogenic virus may mutate and harm cells;
4. Genetic information/protein (from HIV) may harm cells;
5. People (may) become/test HIV positive after vaccine used;
6. This may affect their work/life;

AQA Jan 2012 Unit 1 Q6b



Question:

Scientists use this antibody to detect an antigen on the bacterium that causes stomach ulcers. Explain why the antibody will only detect this antigen

Answer:

1. Antibody/variable region has specific amino acid sequence/primary structure;
2. The shape/tertiary structure of the binding site;
3. Complementary to/fits/binds with these antigens;
4. Forms complex between antigen and antibody;

AQA Jan 2012 Unit 1 Q8a

Question:

Vaccines protect people against disease. Explain how.

Answer:

1. Vaccines contain antigens / antigens are injected;
2. Dead pathogens / weakened pathogens;
3. Memory cells made;
4. On second exposure memory cells produce antibodies / become active / recognise pathogens;
5. Rapidly produce antibodies / produces more antibodies;
6. Antibodies destroy pathogens;
7. Herd effect / fewer people to pass on disease;

AQA Jan 2011 Unit 1 Q6

Read the passage below.

Most cases of cervical cancer are caused by infection with Human Papilloma Virus (HPV). This virus can be spread by sexual contact. There are many types of HPV, each identified by a number. Most of these types are harmless but types 16 and 18 are most likely to cause cervical cancer.

A vaccine made from HPV types 16 and 18 is offered to girls aged 12 to 13. Three 5 injections of the vaccine are given over six months. In clinical trials, the vaccine has proved very effective in protecting against HPV types 16 and 18. However, it will be many years before it can be shown that this vaccination programme has reduced cases of cervical cancer. Until then, smear tests will continue to be offered to women, even if they have been vaccinated. A smear test allows abnormal cells in 10 the cervix to be identified so that they can be removed before cervical cancer develops.

The Department of Health has estimated that 80% of girls aged 12 to 13 need to be vaccinated to achieve herd immunity to HPV types 16 and 18. Herd immunity is where enough people have been vaccinated to reduce significantly the spread of 15 HPV through the population.

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

Question:

HPV vaccine is offered to girls aged 12 to 13 (line 5). Suggest why it is offered to this age group.

Answer:

Girls are not sexually active / not likely to carry HPV / vaccine may not work if already infected / few girls sexually active (at this age)

Question:

The vaccine is made from HPV types 16 and 18 (line 5). Explain why this vaccine may **not** protect against other types of this virus.

Answer:

- Other (HPV) types have different antigens;
- No memory cells for other types / memory cells not activated;
- Antibodies cannot attach to antigen / correct antibodies not produced / antibodies are not complementary

Question:

Three injections of the vaccine are given (lines 5 to 6). Use your knowledge of immunity to suggest why.

Answer:

- More antigen
- More memory cells;
- So more antibodies produced / antibodies produced quicker (if infected);

Question:

It will be many years before it can be shown that this vaccination programme has reduced cases of cervical cancer (lines 7 to 9). Suggest **two** reasons why.

Answer:

- Cancer takes years to develop / develops later in life;
- Takes time for females to become sexually active / females must become sexually active to obtain data;
- Few people / only teenagers vaccinated

Question:

Smear tests will continue to be offered to women, even if they have been vaccinated (lines 9 to 10). Suggest why women who have been vaccinated still need to be offered smear tests.

Answer:

- (Cervical cancer) can be caused by other types of HPV / other factors / example given;
- OR
- (Some) women may have been infected (with HPV) before receiving the vaccine;
- OR
- (As a precaution) in case vaccine does not work / a way of monitoring if the vaccine has worked ;

Question:

Suggest **one** reason why vaccinating a large number of people would reduce significantly the spread of HPV through the population (lines 14 to 16).

Answer:

- Virus cannot replicate / is destroyed / is not carried (in vaccinated people);
- Non-vaccinated people more likely to contact vaccinated people

AQA A Level Specimen (set 2) Q10.1

Question:

Bacterial meningitis is a potentially fatal disease affecting the membranes around the brain. *Neisseria meningitidis* (Nm) is a leading cause of bacterial meningitis.

In the UK, children are vaccinated against this disease. Describe how vaccination can lead to protection against bacterial meningitis.

Answer:

1. Antigen/epitope on surface of *N. meninigitidis* / bacterium binds to surface protein / surface receptor on a (specific/single) B cell;
2. (Activated) B cell divides by mitosis / produces clone;
3. (Division) stimulated by cytokines / by T cells;
4. B cells/plasma cells release antibodies;
5. (Some) B cells become memory cells;
6. Memory cells produce plasma / antibodies faster

3.3 Organisms exchange substances with their environment

3.3.1 Surface area to volume ratio

Content:

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

Opportunities for Skills Development:

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

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

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

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

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

Features of specialised exchange surfaces:

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

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

3.3.2 Gas exchange

Content

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

Opportunities for Skills Development

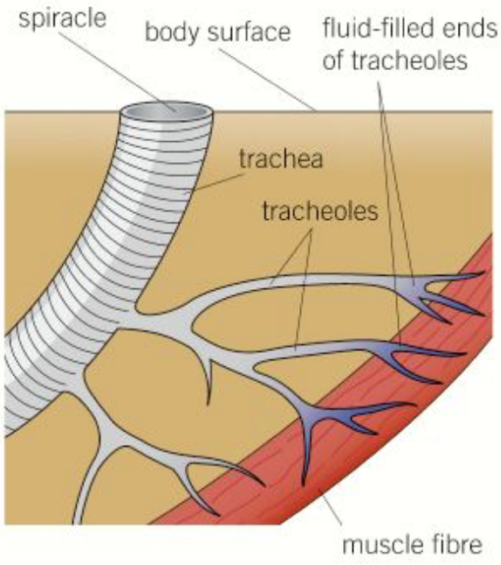
- Students could dissect mammalian lungs, the gas exchange system of a bony fish or of an insect.
- Students could use an optical microscope to:
  - Examine prepared mounts of gas exchange surfaces of a mammal, fish and insect, or temporary mounts of gills
  - Examine vertical sections through a dicotyledonous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

Gas exchange in single-celled organisms:

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

Gas exchange in insects:

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



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

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

further into them. This means the final diffusion pathway is in gas rather than liquid phase, so diffusion is more rapid. Thus increasing the rate at which air is moved in the tracheoles but leads to greater water evaporation.

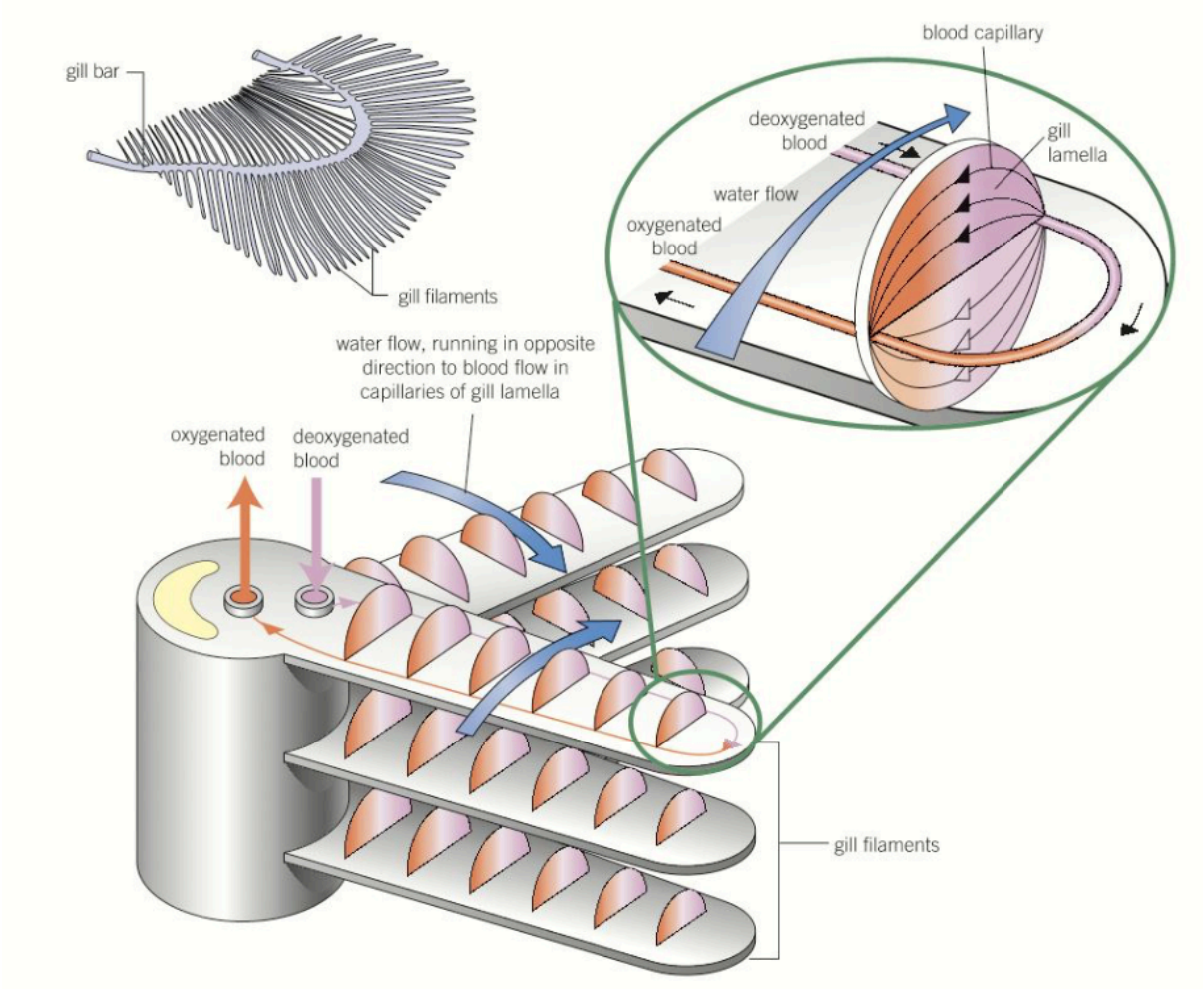
Gases enter and leave the trachea in tiny pores called spiracles on the body surface. These may be opened and closed by a valve. When they open, water vapour can evaporate from the insect. For much of the time insects keep their spiracles close to prevent water loss.

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

Gas exchange in fish:

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

The structure of the gills is shown below:



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

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

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

Gas exchange by the leaves of dicotyledonous plants:

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

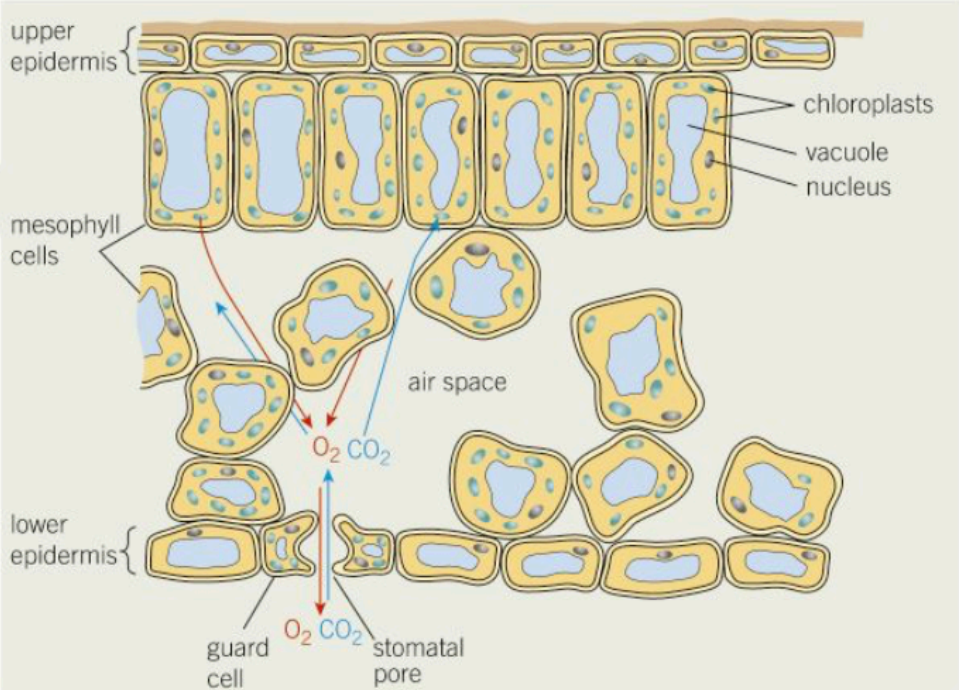
- When photosynthesis is taking place, although some carbon dioxide comes from respiration of cells, most of it is obtained from the external air. In the same way, some oxygen from photosynthesis is used up in respiration but most diffuses out of the plant.
- In the dark, when no photosynthesis occurs,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

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

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

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

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



Limiting water loss

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

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

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

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

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

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

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

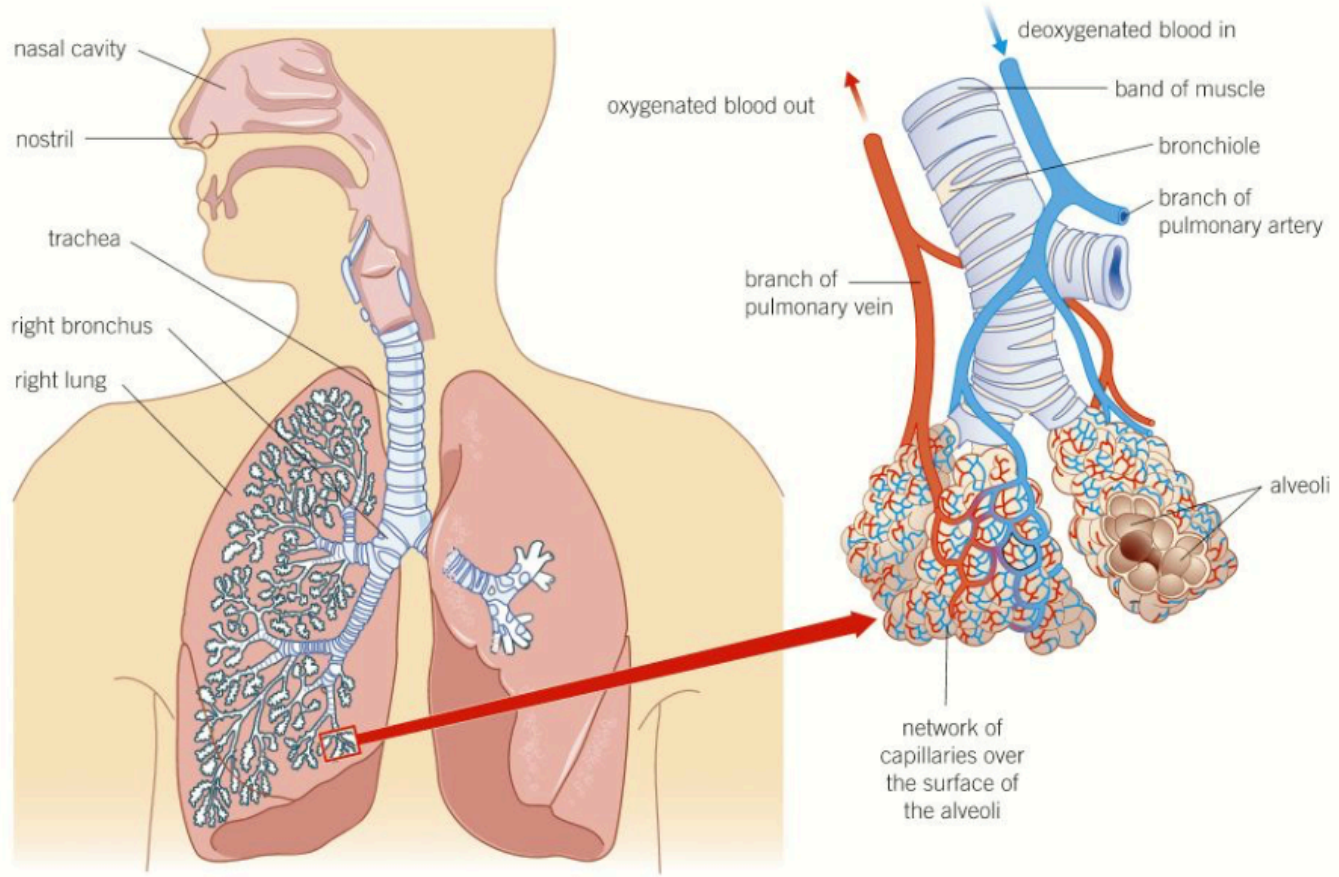
- A thick cuticle, although water can still escape it limits it drastically. Leaves like holly have a very thick cuticle so less water can escape by this means.
- Rolling up of leaves is another adaptation. Since stomata are almost exclusively found on the lower epidermis, the rolling of leaves traps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

The human gas-exchange system:

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

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

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



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

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

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

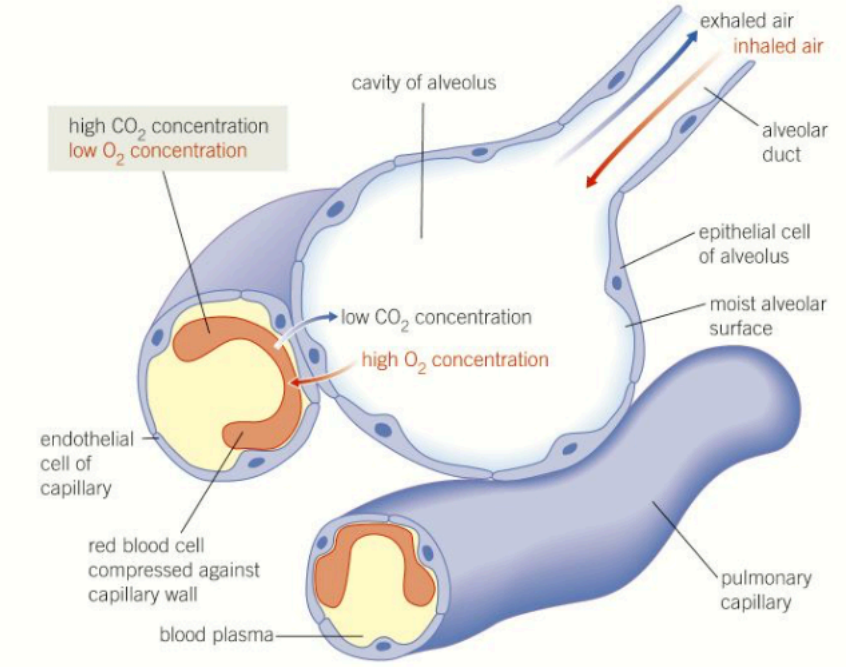
- The alveoli are small air sacs at the end of the bronchioles. Between alveoli are some collagen and elastic fibres. The alveoli are lined with epithelium and the elastic fibres allow the alveoli to stretch as they fill with air when breathing in. They then spring back during breathing out in order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

Gas exchange over epithelium of alveoli

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

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

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



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

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

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

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

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

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

AQA June 2014 Q4ab

Question:

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

Answer:

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

Question:

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

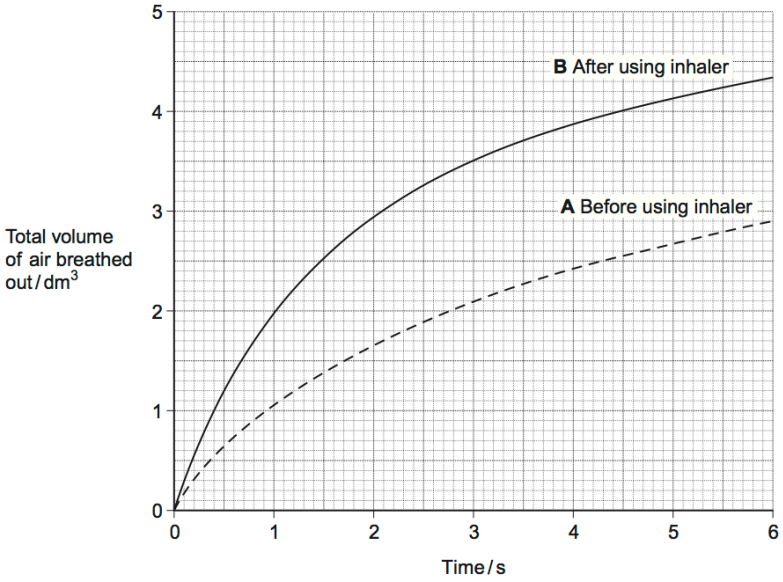
AGD reduces the efficiency of gas exchange in fish. Give **two** reasons why.

Answer:

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

AQA Jan 2012 Unit 1 Q2b

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



Question:

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

Answer:

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

Question:

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

Answer:

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

Question:

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

Answer:

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

3.3.3 Digestion and absorption

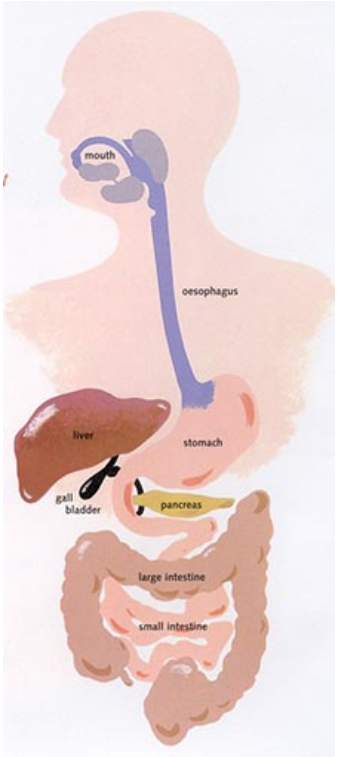
Content

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

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

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

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



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

Digestion consists of physical breakdown and chemical breakdown.

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

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

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

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

The process takes place as follows:

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

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

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

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

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

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

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

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

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

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

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

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

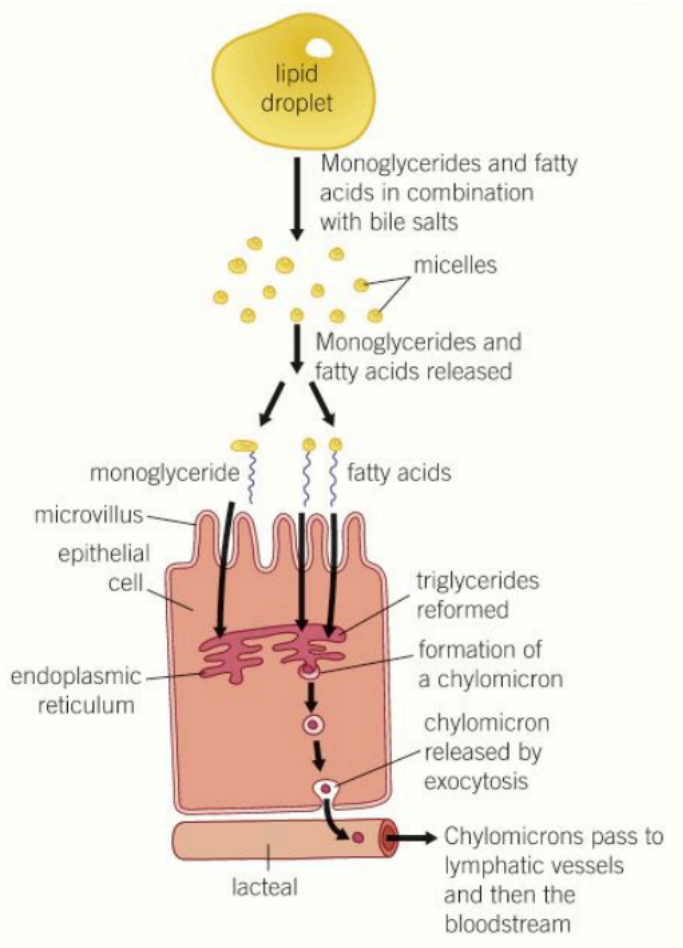
The ileum absorbs **amino acids** and **monosaccharides** in the same way, by diffusion and co-transport.

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

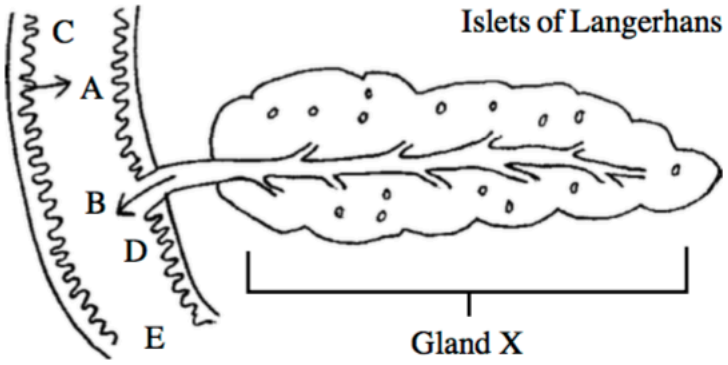
the micelles come into contact with the epithelial cells lining the villi of the ileum. Here, the micelles break down and release monogylcerides and fatty acids. As these are non-polar molecules, they can easily diffuse across the cell-surface membrane into the epithelial cells.

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

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



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



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

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

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

Answers

Marking points are shown by semicolons

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

2. (a) pancreas;

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

   (c) A = Maltase;
   Lactase;
   Sucrase;

   B = Amylase

AQA June 2013 Q6b

Question:

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

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

Answer:

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

AQA June 2013 Q7a

'Read the following passage.

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

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

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

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

Question:

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

Answer:

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

AQA Jan 2013 Unit 1 Q4a

Question:

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

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

Answer:

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

AQA Jan 2009 Unit 1 Q7a

Question:

Describe how lipids are digested and absorbed in the ileum.

Answer:

Bile increases SA / Emulsification;

Bile creates alkaline conditions / optimum pH (for lipase)

Lipase produces fatty acids and glycerol;

Diffusion into epithelial cells;

Lipids / Micelles / chylomicrons enter lacteal / lymph capillary;

3.3.4 Mass Transport

3.3.4.1 Mass transport in animals

Content

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

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

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

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

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

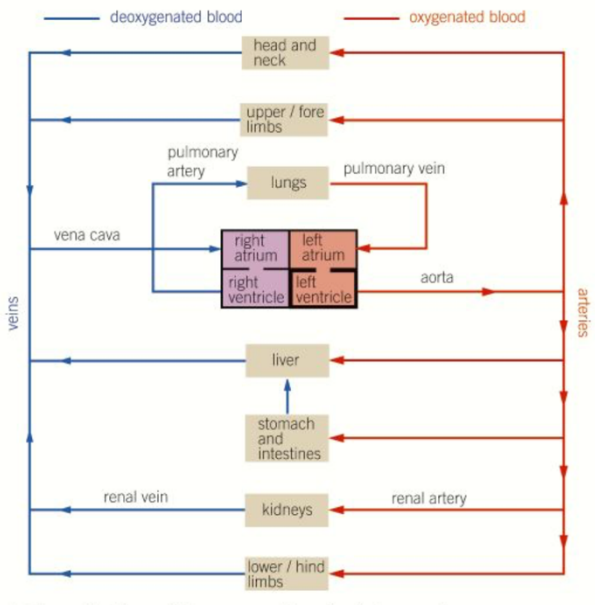
Different animals have different variations of the haemoglobin molecule depending on their oxygen transport properties and requirements. Each species produces a haemoglobin with a slightly different amino acid sequence, so the haemoglobin of these species therefore have a different tertiary and quaternary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

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

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

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

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



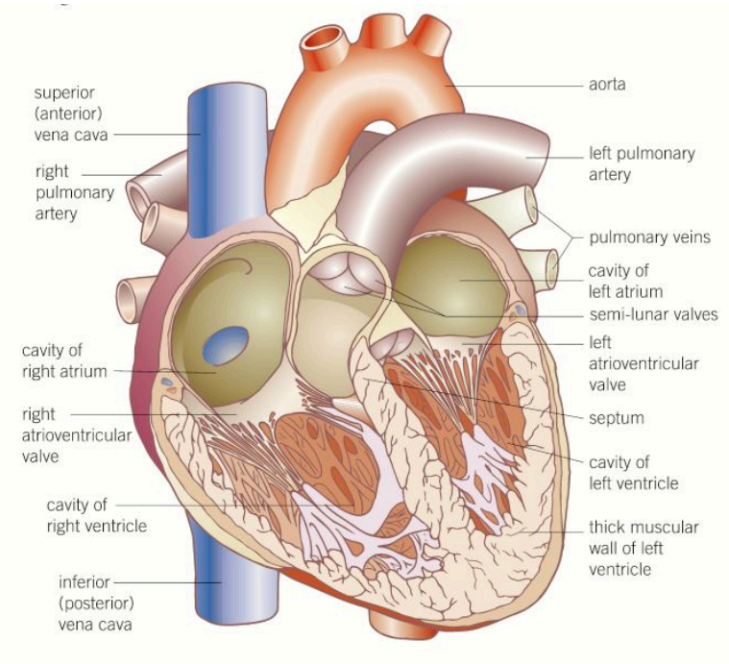
The **heart** is essentially made up of two pumps, one transporting oxygenated blood, one deoxygenated. The atrium is thin walled and elastic, stretching as it collects blood. The ventricle has a much thicker muscular wall as it has to contract strongly to pump blood some distance, either to the lungs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

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

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

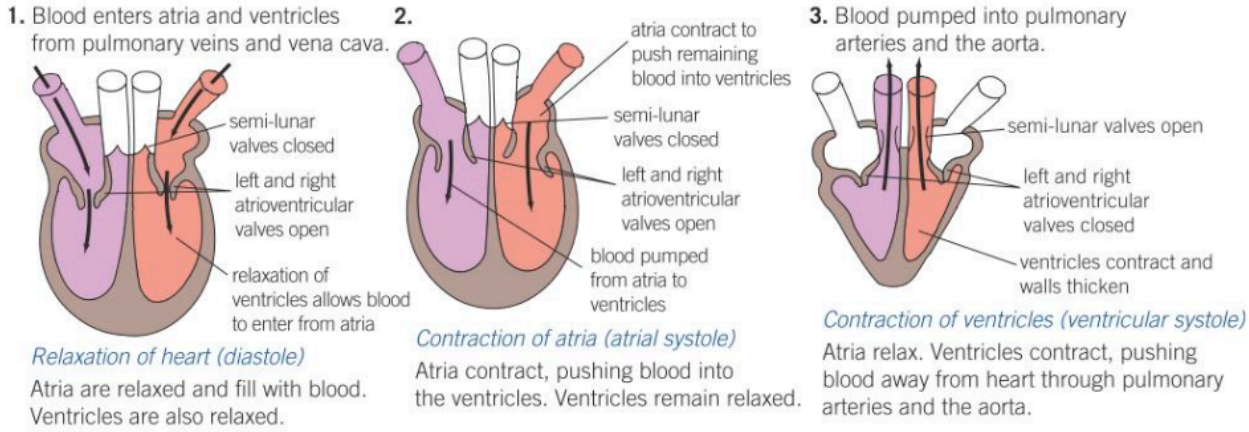
Pulmonary artery: connected to the right ventricle and carries deoxygenated blood to the lungs, where its oxygen is replenished and its carbon dioxide removed. Unusually for the artery, it carries deoxygenated blood.

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



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

The Cardiac Cycle



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

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

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

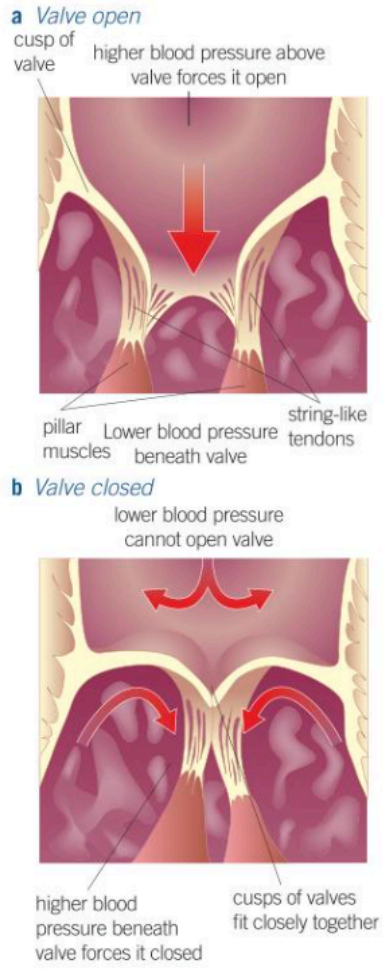
Contraction of the atria (atrial systole) – the contraction of the atrial walls, along with the recoil of the relaxed ventricle walls, forces the remaining blood into the ventricles from the atria. Throughout this stage the muscle of the ventricle walls remains relaxed.

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

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

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

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

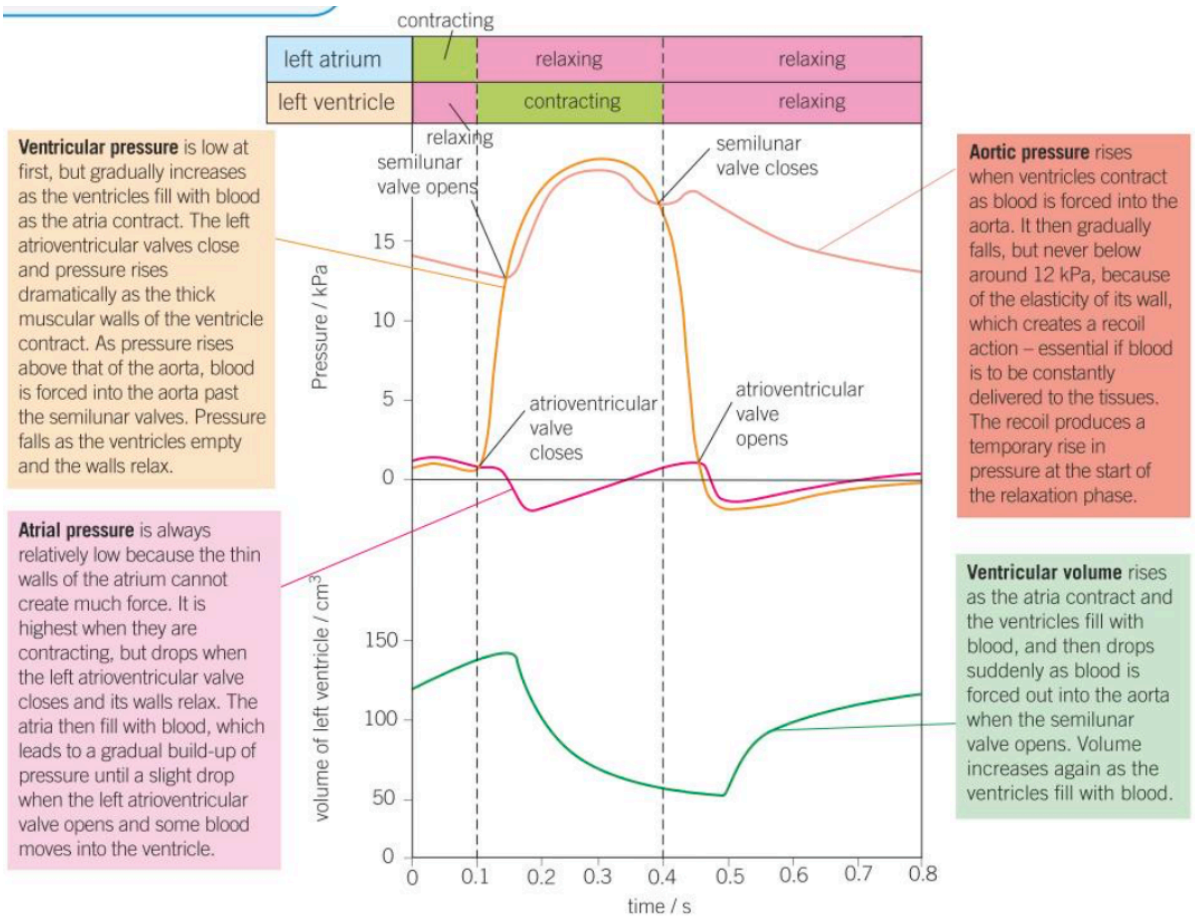


Since the blood system is closed, it allows the pressure within the vessels to be maintained easily.

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

Cardiac output = heart rate x stroke volume

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



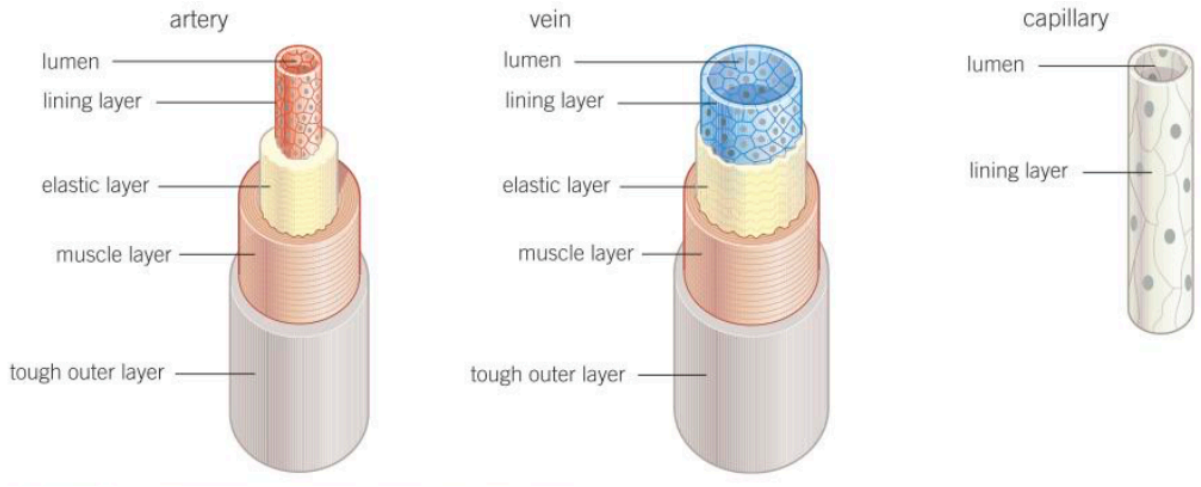
The graph above is quite complex, but remember that pressure and volume are inversely related in this situation, where PV = constant. Thus pressure decreases cause volume increases. Also, blood moves down a pressure gradient, which can also be used to simplify the graph.

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

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

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

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



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

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

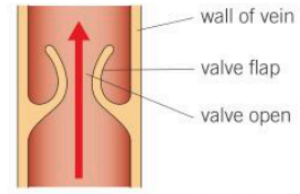
- The muscle layer is thick relative to veins. This means smaller arteries can be constricted and dilated in order to control the volume of blood passing through them.
- The elastic layer is relatively thick compared to veins. This is because it is important pressure in the arteries is kept high if blood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

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

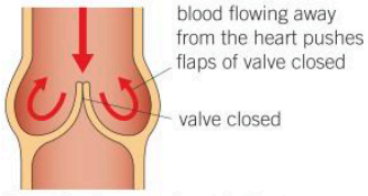
- The muscle layer is relatively thicker than in arteries. The contraction of this muscle layer allows constriction of the lumen of the arteriole, to restrict the flow of blood and so control its movement into the capillaries that supply the tissues with blood
- The elastic layer is relatively thinner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

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

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



Blood flowing towards the heart passes easily through the valves.



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

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

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

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

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

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

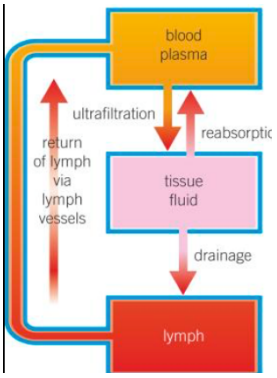
- Hydrostatic pressure of the tissue fluid outside the capillaries, which resists outward movement of liquid
- The lower water potential of the blood, due to the plasma proteins, causing water to move back into the blood within the capillaries.

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

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

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

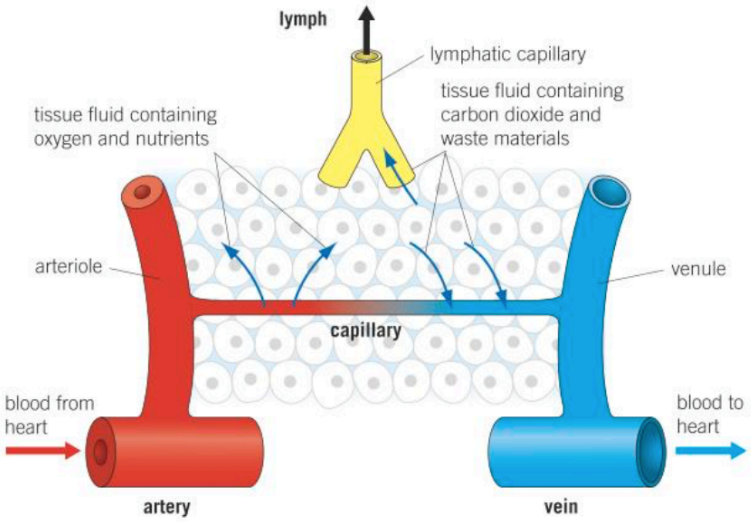
The diagram to the right shows the passage of the contents of the lymphatic system. The contents are not moved by the heart, instead by hydrostatic pressure of the tissue fluid leaving the capillaries. Also by contraction of body muscles, that squeeze lymph vessels. Also, valves in these lymph vessels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



The return via the capillaries is summarised below:

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

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



Past paper question related to tissue fluid:

AQA June 2012 Unit 2 Q8c

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

- Formation:

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

Return:

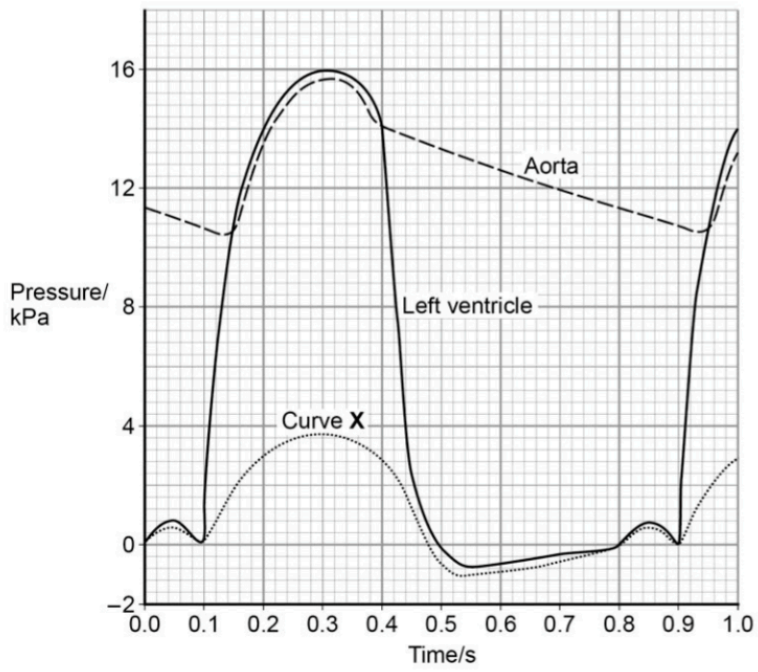
1. Low water potential in capillary / blood;
2. Due to (plasma) proteins;
3. Water enters capillary / blood;
4. (By) osmosis;
5. Correct reference to **lymph**;

AQA International 2018 Specimen

Question:

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

Figure 3



At what time do the semilunar valves close?

Answer:

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

Question:

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

Answer:

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

Question:

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

Answer

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

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

Question:

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

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

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

Answer:

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

Accept converse for pulmonary vein Incorrect function of artery disqualifies mark

Question:

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

Answer:

(Aorta wall) stretches;

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

AQA June 2012 Unit 1 Q8a

Question:

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

Answer:

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

AQA June 2012 Unit 2 Q8c

Question:

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

Answer:

- Formation:

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

Return:

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

AQA June 2013 Unit 1 Q8ab

Question:

'Describe how a heartbeat is initiated and coordinated'

Answer:

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

Question:

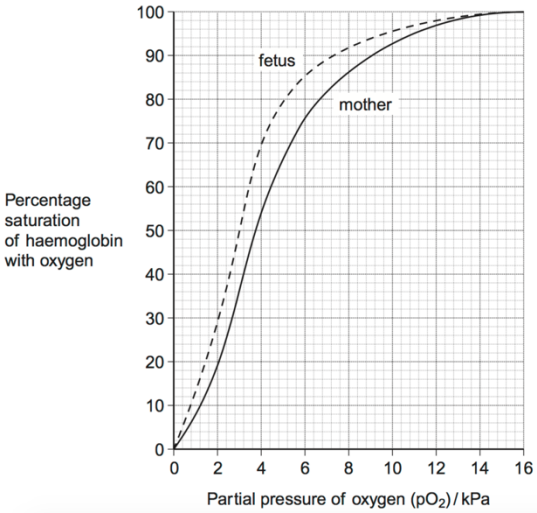
'Explain how the heart muscle and the heart valves maintain a one-way flow of blood from the left atrium to the aorta.

Answer:

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

AQA June 2013 Unit 2 Q6cde

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



Question:

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

Answer:

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

Question:

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

Answer:

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

Question:

Hereditary persistence of fetal haemoglobin (HPFH) is a condition in which production of fetal haemoglobin continues into adulthood. Adult haemoglobin is also produced.

People with HPFH do not usually show symptoms. Suggest why.

Answer:

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

AQA Jan 2013 Unit 1 Q7c

Question:

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

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

Answer:

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

AQA Jan 2013 Unit 2 Q2c

Question:

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

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

Answer:

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

AQA Jan 2012 Unit 2 Q9a

Question:

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

Answer:

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

3.3.4.2 Mass transport in plants

Content

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

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

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

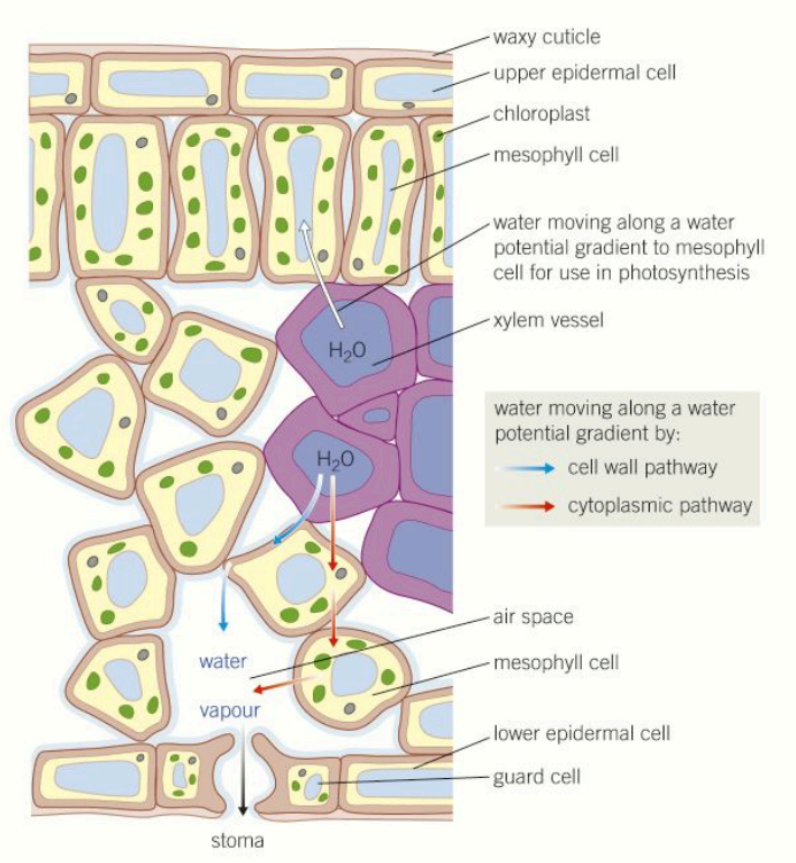
Water is lost from mesophyll cells by evaporation from their cell walls to the air spaces of the leaf. This water is then replaced by water reaching the mesophyll cells from the xylem either via cell walls or via the cytoplasm. In the case of the cytoplasmic route, it is as follows:

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

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

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

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

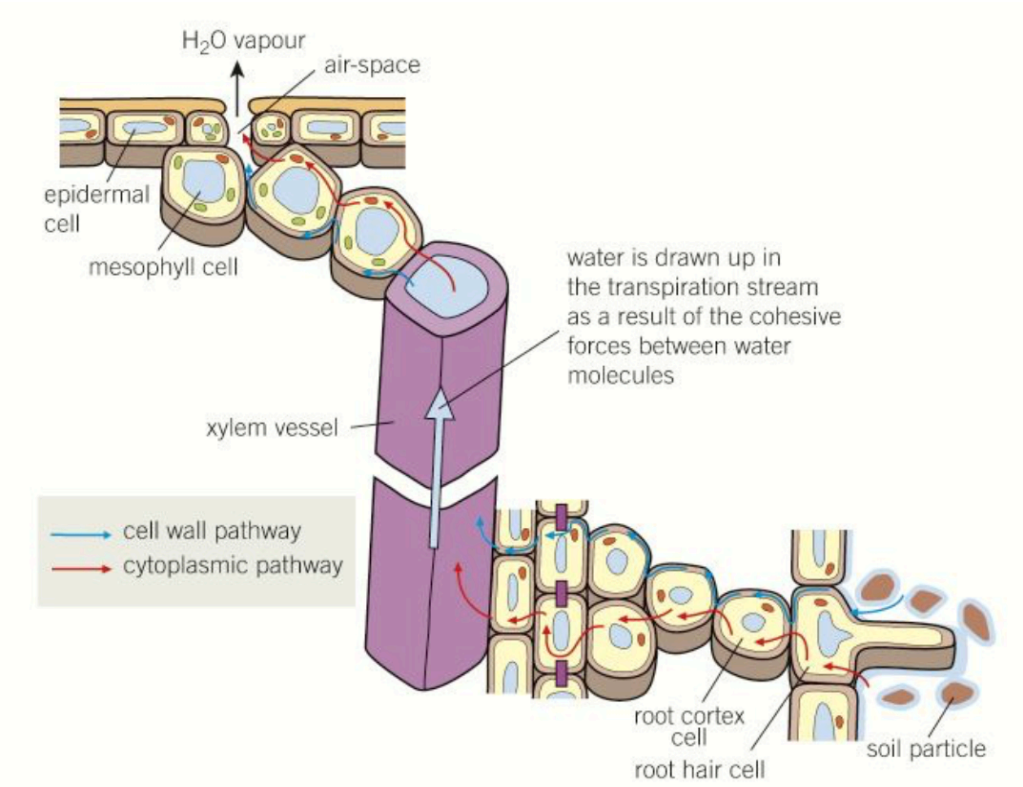


- As water evaporates from the mesophyll cells in the leaf into the air spaces beneath the stomata, more molecules of water are drawn up behind it as a results of this cohesion
- A column of water is therefore pulled up the xylem as a result of transpiration, called a transpiration pull
- Transpiration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

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

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

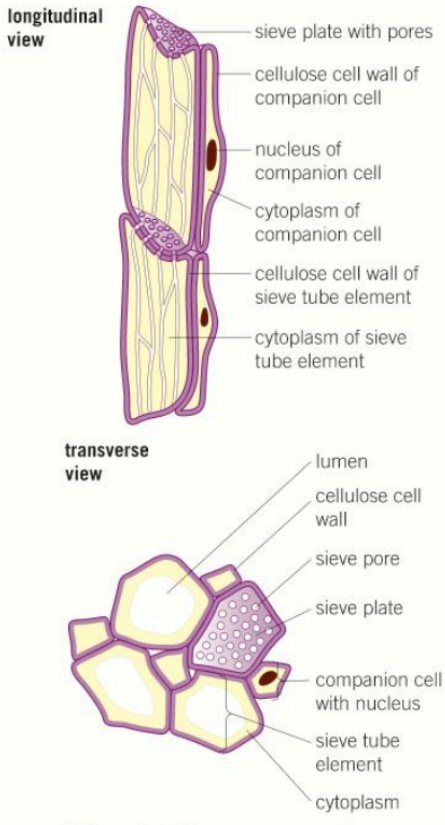
Transpiration pull is a passive process and therefore does not require metabolic energy to take place. The xylem vessels are dead so cannot actively move water, but form a continuous, unbroken tube from root to leaves, essential to the cohesion-tension theory of water flow up the stem. Energy is nevertheless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



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

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

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



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

1. Transfer of sucrose into sieve elements from photosynthesising tissue

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

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

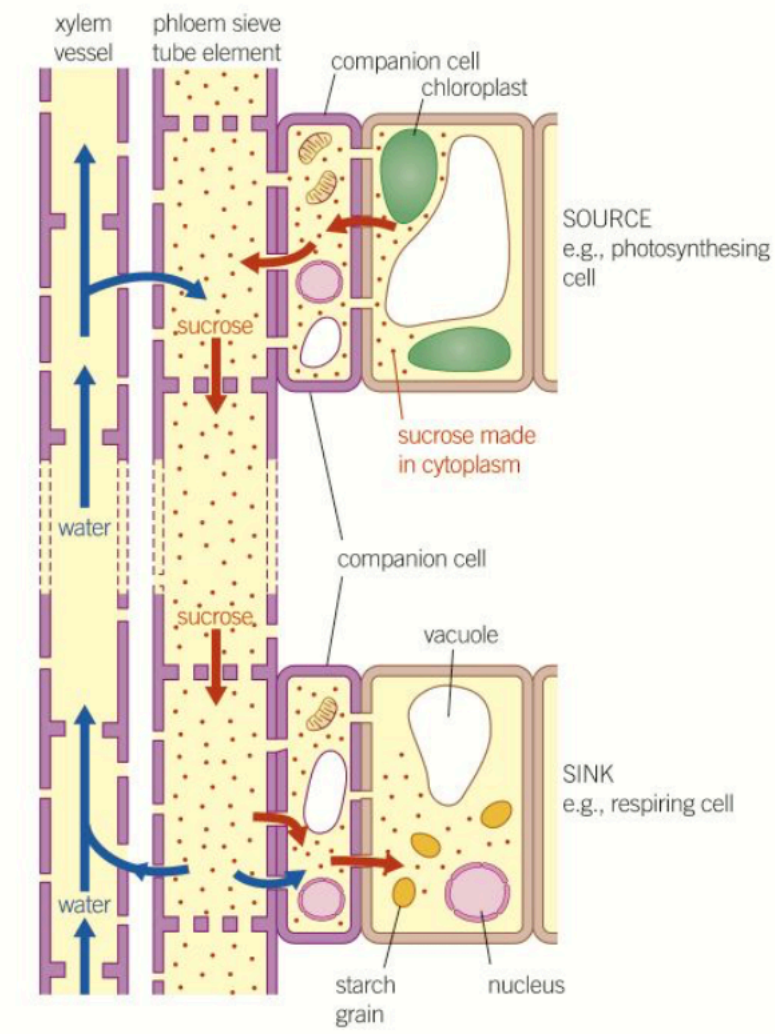
- The sucrose produced by photosynthesising cells (source) is actively transported into the sieve tubes as described above
- This causes the sieve tubes to have a lower water potential
- As the xylem has a much higher water potential, water moves from the xylem into the sieve tubes by osmosis, creating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

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

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

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

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



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

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

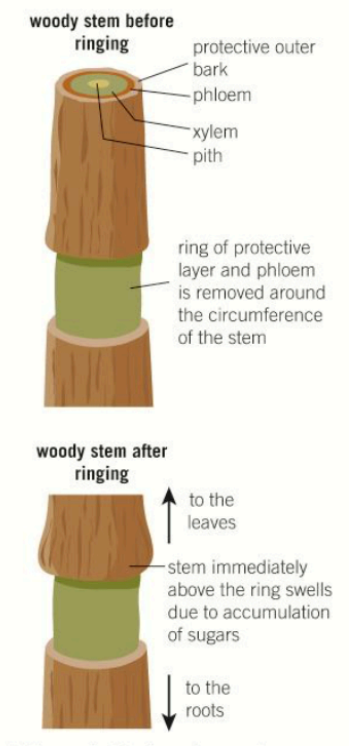
The diagram below shows how a section of the outer layer of the stem and phloem is removed. After a period of time, the region of the stem immediately above the missing ring of tissue swells, and samples of liquid that accumulates in this area is rich in sugars and other dissolved substances. Also, some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

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

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

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

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



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

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

Other evidence that phloem transports organic molecules is given below:

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

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

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

AQA Specimen A2 Paper 1 Q9.1

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

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

3.4 Genetic information, variation and relationships between organisms

3.4.1 DNA, genes and chromosomes

Content

- In prokaryotic cells, DNA molecules are short, circular and not associated with proteins.
- In the nucleus of eukaryotic cells, DNA molecules are very long, linear and associated with proteins, called histones. Together a DNA molecule and its associated proteins form a chromosome.
- The mitochondria and chloroplasts of eukaryotic cells also contain DNA which, like the DNA of prokaryotes, is short, circular and not associated with proteins.
- A gene is a base sequence of DNA that codes for:
    - the amino acid sequence of a polypeptide
    - a functional RNA (including ribosomal RNA and tRNAs).
- A gene occupies a fixed position, called a locus, on a particular DNA molecule.
- A sequence of three DNA bases, called a triplet, codes for a specific amino acid. The genetic code is universal, non-overlapping and degenerate.
- In eukaryotes, much of the nuclear DNA does not code for polypeptides. There are, for example, non-coding multiple repeats of base sequences between genes. Even within a gene only some sequences, called exons, code for amino acid sequences. Within the gene, these exons are separated by one or more non-coding sequences, called introns.

In **prokaryotic** cells, DNA molecules are short, circular and not associated with proteins or a nucleus. On the contrary, in the nucleus of **eukaryotic** cells, DNA molecules are very long, linear and associated with proteins, called histones. Together a DNA molecule and its associated proteins form a chromosome. Mitochondria and chloroplasts of eukaryotic cells also contain DNA which, like the DNA of prokaryotes, is short, circular and not associated with proteins.

DNA is made up of genes, ie short sections of DNA that code for specific polypeptides and functional RNA. The coded information is in the form of a specific sequence of bases along the DNA molecule. Polypeptides make up proteins and so genes determine the proteins of an organism. Enzymes are proteins which control chemical reactions, and are responsible for an organism development and activities. Therefore, genes determine (alongside environmental factors), the nature and development of all organisms. A gene is a section of DNA located at a particular position, this particular position is called the ‘locus’. The gene is a base sequence of DNA that codes for the amino acid sequence of a polypeptide, or a functional RNA for the process of polypeptide synthesis. It codes for ribosomal RNA as well as tRNAs.

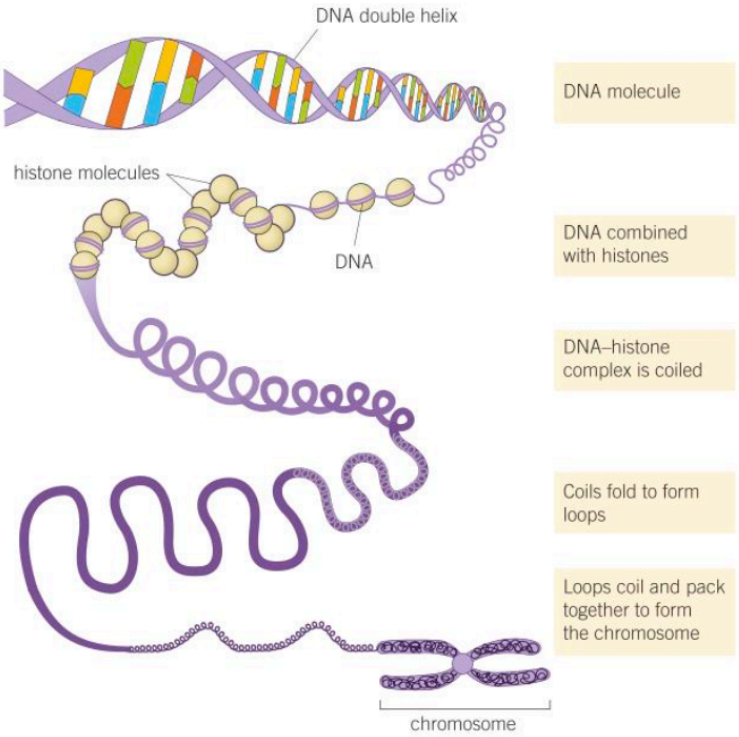
In trying to discover how DNA bases coded for amino acids, scientists suggested that there must be a minimum of three bases that coded for each amino acid. This is called a triplet, although there are 64 different triplets that can be coded for and only 20 regularly occurring amino acids, thus some triplets code for the same amino acids. Another thing worth

mentioning is that if there were pairs of bases, only 16 possible codes would be possible, less than the amount of naturally occurring amino acids found.

The genetic code is universal, non-overlapping and degenerate. It is **degenerate** because most amino acids are coded for by more than one triplet. These triplets are read in only one direction, and the start of a DNA sequence that codes for a polypeptide is always the same triplet (start codon). This start codon always codes for methionine in eukaryotes, and if this first molecule does not form part of the final polypeptide, it is removed. There are three different triplets that encode stop codons, whose role is to designate the termination of translation. The code is **non-overlapping** in that successive triplets are read in order. Each nucleotide is part of only one triplet codon. The code is also **universal,** with minor exceptions ie protozoan species, in that each triplet codes for the same amino acid in all organisms.

Although a large proportion of the DNA in eukaryotes does not code for polypeptides. Only certain parts of sequence code for amino acids, called exons. The non-coding sequences are called introns. There are also non-coding multiple repeats of base sequences between genes. The other genes code for ribosomal RNA and transfer RNAs.

Chromosome structure – chromosomes are only visible as distinct structures when a cell is dividing. For the remainder of time, they are widely dispersed throughout the nucleus. When they first become visible at the start of cell division, chromosomes appear as two threads, joined as a single point. Each thread is called a chromatid because DNA has already replicated to give two identical DNA molecules. The DNA in chromosomes is held together by histones.



DNA is a double helix, wound around histones to fix it in position. The DNA-histone complex is then coiled, and this coil, in turn, is looped and further coiled before being packed into the chromosome. In this way, a lot of DNA is condensed into a single chromosome. It is clear from the diagram above that a chromosome contains just a single DNA molecule. This single DNA molecule has many genes along its length, each gene occupying a specific locus along the DNA molecule.

Homologous chromosomes – these are a pair of chromosomes, one maternal and one paternal, that have the same gene loci. Sexually produced organisms are as a result of the fusion of a sperm and an egg, each of which contributes one complete set of chromosomes to the offspring. Therefore, one of each pair is derived from the chromosomes provided by the mother in the egg, and the other from the paternal DNA. These are known as homologous pairs and the total number of these chromosomes is referred to as the **diploid** number. A homologous pair is always two chromosomes that carry the same genes but not necessarily the same alleles of the gene.

During meiosis, the halving of the number of chromosomes is done in a manner which ensures that each daughter cell receives one chromosome from each homologous pair. In this way each cell receives one gene for each characteristic of an organism, and when these haploid cells combine, the diploid state with paired homologous chromosomes is restored.

An **allele** is one of a number of alternative forms of a gene. We have seen that genes are sections of DNA that contain coded information in the form of specific sequences of bases. Each gene exists in two, occasionally more, different forms. Each individual inherits one allele from each of its parents, these two alleles may be the same but they may be different. Any change in the base sequence of a gene produces a new allele of that gene (a mutation), resulting in a different sequence of amino acids being coded for. This results in a different primary structure that gives rise to a different tertiary structure, hence a different protein. The consequences of this lie with the inability for enzyme substrate complexes to form if the substrate is no longer a complementary fit to the active site of the enzyme.

In eukaryotic cells, the DNA is largely confined to the nucleus. Although, the synthesis of proteins takes place in the cytoplasm as sections of the code of the DNA are transcribed onto a single-stranded molecule called RNA. There are a number of types of RNA, mRNA, tRNA and rRNA. mRNA is messenger RNA, as it takes the role of transferring the DNA code from the nucleus to the cytoplasm. The mRNA is small enough to leave the nucleus through nuclear pores and enter the cytoplasm, where its coded information is used to determine the sequence of amino acids in the proteins which are synthesised there. The structure and function of these different types of RNAs are given in the next section.

3.4.2 DNA and protein synthesis

Content

- The concept of the genome as the complete set of genes in a cell and of the proteome as the full range of proteins that a cell is able to produce.
- The structure of molecules of messenger RNA (mRNA) and of transfer RNA (tRNA).
- Transcription as the production of mRNA from DNA. The role of RNA polymerase in joining mRNA nucleotides.
    - In prokaryotes, transcription results directly in the production of mRNA from DNA.
    - In eukaryotes, transcription results in the production of pre-mRNA; this is then spliced to form mRNA.
- Translation as the production of polypeptides from the sequence of codons carried by mRNA. The roles of ribosomes, tRNA and ATP.
- **Students should be able to:**
- Relate the base sequence of nucleic acids to the amino acid sequence of polypeptides, when provided with suitable data about the genetic code
- Interpret data from experimental work investigating the role of nucleic acids.
- Students will **not** be required to recall in written papers specific codons and the amino acids for which they code.

The **genome** is the complete set of genes in a cell and the **proteome** is the full range of proteins that a cell is able to produce. The words **complete proteome** refers to the the proteins produced by a given type of cell under a set of **conditions**.

RNA has two forms, one being messenger RNA and the other transfer RNA. mRNA is small enough to leave the nucleus through nuclear pores to enter the cytoplasm, where the coded information it contains is used to determine the sequence of amino acids in the proteins which are synthesised here.

The term **codon** means the sequence of three bases on mRNA that codes for a single amino acid.

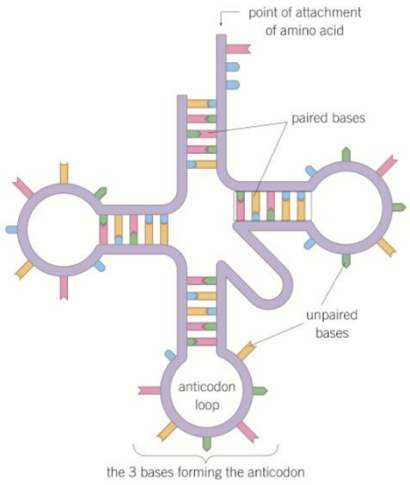
RNA is a polymer made up of repeating mononucleotide sub-units. It forms a single strand where each nucleotide is made up of: a pentose sugar, A G C or U and a phosphate group.

Messenger RNA (mRNA) consists of thousands of mononucleotides. It is a relatively long strand arranged in a single helix. The base sequence on the mRNA is determined by the sequences of bases on a length of DNA in a process called transcription. mRNA then leaves the nucleus via nuclear pores in the nuclear envelope entering the cytoplasm, where it associates with ribosomes. It then stays there and acts as a template for protein synthesis, as tRNA molecules bind.

Its structure is suited to its function because it possesses information in the form of codons (three bases that are complementary to a triplet in DNA). The sequence of codons ultimately determines the amino acid sequence of a specific polypeptide that will be made.

Transfer RNA (tRNA) is a relatively small molecule that is made up of around 80 nucleotides. It is a single-stranded chain folded into a clover-leaf shape, where one end of the chain extends slightly above the other. This is the side of the tRNA that the amino acid can attach easily too, and you get different types of tRNA that bind to different specific amino acids. At the opposite end you find an anticodon, made up of three other organic bases. Each tRNA is specific to one amino acid, with an anticodon specific to one amino acid. Although you do find as many different tRNA molecules as there are coding triplets due to the degenerate code of DNA.

Its structure is suited to it function by having an end for attaching to amino acids, as well as its anticodon for complementary base pairing with the codon of the mRNA. Also it is suited for lining up amino acids on the mRNA template during protein synthesis.



In RNA you find the base uracil instead of thymine, and so the different complementary base pairings you find are:

- Guanine and cytosine
- Adenine and uracil (RNA) or Thymine (DNA).

DNA	Messenger RNA	Transfer RNA
double polynucleotide chain	single polynucleotide chain	single polynucleotide chain
largest molecule of the three	molecule is smaller than DNA but larger than tRNA	smallest molecule of the three
double-helix molecule	single-helix molecule (except in a few viruses)	clover-shaped molecule
pentose sugar is deoxyribose	pentose sugar is ribose	pentose sugar is ribose
organic bases are adenine, guanine, cytosine and thymine	organic bases are adenine, guanine, cytosine and uracil	organic bases are adenine, guanine, cytosine and uracil
found mostly in the nucleus	manufactured in the nucleus but found throughout the cell	manufactured in the nucleus but found throughout the cell
quantity is constant for all cells of a species (except gametes)	quantity varies from cell to cell and with level of metabolic activity	quantity varies from cell to cell and with level of metabolic activity
chemically very stable	Less stable than DNA or tRNA, individual molecules are usually broken down in cells within a few days.	chemically more stable than mRNA but less stable than DNA

Proteins are polypeptides, and essential to our life, particularly enzymes. However each organism needs to make its own unique proteins, and the biochemical chemistry in the cytoplasm of each cell has the capacity to make every protein from just 20 amino acids. Exactly which protein is made is determined by the DNA.

The process of polypeptide synthesis is as follows:

- DNA provides the instructions in the form of a long sequence of bases
- A complementary section of part of this sequence is made in the form of a molecule called pre-mRNA – a process called **transcription**
- Pre-mRNA is splices to remove introns and form mRNA
- The mRNA is used to act as a template to which complementary tRNA molecules attach and the amino acids they carry are linked to form a polypeptide – a process called **translation**

Transcription involves making pre-mRNA using DNA as a template.

- First of all, an enzyme acts on a specific region of DNA causing the two strands to separate and expose the nucleotide bases of that region.
- The nucleotide bases on the two DNA strands act as template strands, where complementary RNA nucleotides pair with these exposed bases. The enzyme RNA polymerase then moves along the strand and joins the nucleotides together to form a pre-mRNA molecule.
- However, the base pairs are now different, with adenine and uracil as opposed to adenine and thymine in DNA.
- As the RNA polymerase adds the nucleotides one at a time to build a strand of pre-mRNA, the DNA strand rejoins behind it. As a result, only about 12 base pairs on the DNA are exposes at any one time.
- When the RNA polymerase reaches a particular sequence of bases on the DNA that it recognises as a 'stop' triplet code, it detaches and then the production of pre-mRNA is complete.

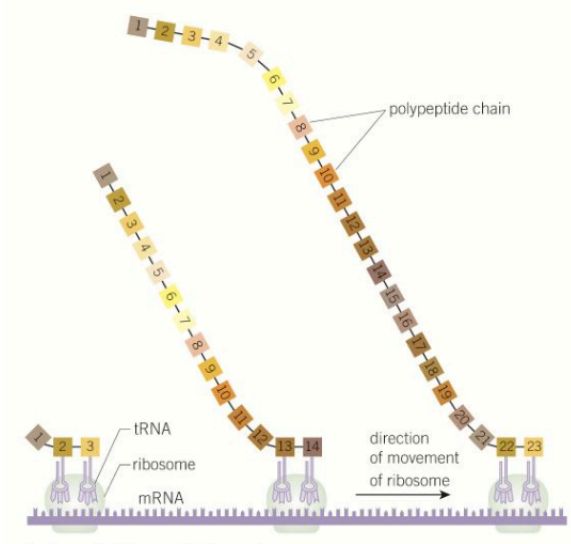
Splicing of pre-mRNA does not occur in prokaryotic cells, as transcription results directly in the production of mRNA from DNA. However, in eukaryotic cells the DNA is made up of introns and exons, which are non coding sections and coding sections. These introns would prevent the synthesis of a polypeptide.

The mRNA molecules formed are too large to diffuse out of the nucleus so leave via the nuclear pore. Once outside the nucleus, the mRNA moved towards the ribosome and attaches to it, ready for the next stage in the process called **translation**. This stage involves translating the codons on the mRNA into a sequence of amino acids. The process is given below:

- A ribosome becomes attached to the starting codon at one end of the RNA molecule
- The tRNA molecule with the complementary anticodon sequence moves to the ribosome and pairs up with the codon on the mRNA. The tRNA carries a specific amino acid
- Another tRNA molecule with a complementary anticodon moves and pairs with the next codon on the mRNA. This tRNA molecule carries another amino acid

- The ribosome moves along the mRNA, bringing together two tRNA molecules at any one time, each pairing up with the corresponding two codons on the mRNA
- The amino acids on the tRNA then join by a peptide bond, using an enzyme and ATP which is hydrolysed to provide the required energy
- The ribosome moves on to the third codon in the sequence and links the next amino acids
- As this is happening, the first tRNA is released from its amino acid and is free to collect another amino acid from the amino acid pool in the cell
- The process continues in this way until a polypeptide chain is built up
- The synthesis of a polypeptide continues until the ribosome reaches a stop codon, where the ribosome, mRNA and the last tRNA all separate and the polypeptide is made.

In this process, up to 50 ribosomes are able to pass on the mRNA so the same polypeptide can be built up many times.



3.4.3 Genetic diversity can arise as a result of mutation or during meiosis

Content

- Gene mutations involve a change in the base sequence of chromosomes. They can arise spontaneously during DNA replication and include base deletion and base substitution. Due to the degenerate nature of the genetic code, not all base substitutions cause a change in the sequence of encoded amino acids. Mutagenic agents can increase the rate of gene mutation.
- Mutations in the number of chromosomes can arise spontaneously by chromosome non-disjunction during meiosis.
- Meiosis produces daughter cells that are genetically different from each other.
- The process of meiosis only in sufficient detail to show how:
    - Two nuclear divisions result usually in the formation of four haploid daughter cells from a single diploid parent cell
    - Genetically different daughter cells result from the independent segregation of homologous chromosomes
    - Crossing over between homologous chromosomes results in further genetic variation among daughter cells.
- **Students should be able to:** Complete diagrams showing the chromosome content of cells after the first and second meiotic division, when given the chromosome content of the parent cell
- Explain the different outcome of mitosis and meiosis
- Recognise where meiosis occurs when given information about an unfamiliar life cycle
- Explain how random fertilisation of haploid gametes further increases genetic variation within a species.

Opportunities for Skills Development

- Students could examine meiosis in prepared slides of suitable plant or animal tissue.
- Students could:
    - Use the expression to calculate the possible number of different combinations of chromosomes following meiosis, without crossing over
    - Derive a formula from this to calculate the possible number of different combinations of chromosomes following random fertilisation of two gametes,
    - Where n is the number of homologous chromosomes pairs.

Gene mutations involve a change in the base sequence of chromosomes. They can arise spontaneously during DNA replication and include base deletion and base substitution. Due to the degenerate nature of the genetic code, not all base substitutions cause a change in the sequence of encoded amino acids. Also, you can get mutagenic agents which increase the rate of mutation.

Two examples of mutations are substitutions and deletions.

Substitution: It is where a nucleotide in a DNA molecule is replaced by another nucleotide that has a different base. If the change in base sequence encodes a different amino acid, then it could be significant depending on the original role of the amino acid. For example if it were important in forming bonds that determine the final tertiary structure of the protein, then the replacement amino acid may not form the same bonds. The protein may then be a different shape and therefore not function properly, so if the protein were an enzyme it could cause a non-functional enzyme.

Deletion: A gene mutation by deletion arises when a nucleotide is lost from the normal DNA sequence. This causes a frame shift to the left, so each triplet code becomes different and the overall structure of the polypeptide becomes different.

Chromosome mutations occur when there are changes in the structure or number of whole chromosomes. They can arise spontaneously and come in two forms:

- **Changes in whole sets of chromosomes** occur when organisms have three or more sets of chromosomes rather than the usual two. This condition is called **polyploidy** and occurs mainly in plants.
- **Changes in the number of individual chromosomes** happens because sometimes individual homologous pairs of chromosomes fail to separate during meiosis. This is called **non-disjunction** and usually results in a gamete having one more or one fewer chromosome. Down's syndrome is as a result of an additional chromosome, an example of non-disjunction.

Meiosis produces daughter cells that are genetically different to each other, unlike mitosis. The process of meiosis must only be known in such detail to show that

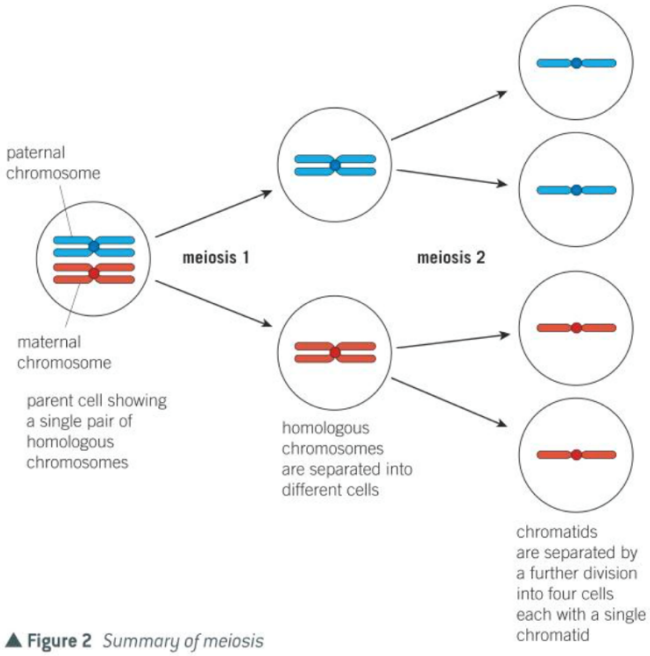
- Two nuclear divisions result usually in the formation of four haploid daughter cells from a single diploid parent cell
- Genetically different daughter cells result from the independent segregation of homologous chromosomes
- Crossing over between homologous chromosomes results in further genetic variation among daughter cells.

The two nuclear divisions usually occur immediately after each other. In the first division (meiosis 1), homologous chromosomes pair and their chromatids wrap around each other. Equivalent portions of these chromatids may be exchanged in a process called crossing over, this process involved exchange of genetic information. By the end of this division the homologous pairs have separated, with one chromosome from each pair going into one of the two daughter cells. In the second division (meiosis 2), the chromatids move apart. Thus four cells are formed, each containing 23 chromosomes in humans.

In addition to halving the number of chromosomes, meiosis also produces genetic variation among the offspring, which may lead to adaptations that could improve survival chances. Meiosis brings about this genetic variation in the following two ways:

- Independent segregation of homologous chromosomes

- New combinations of maternal and paternal alleles by crossing over (formation of chiasmata).



▲ **Figure 2** *Summary of meiosis*

The law of independent assortment – during meiosis 1, each chromosome lines up alongside its homologous partner. In humans, this means 23 homologous pairs will be lying side by side. However, they arrange themselves at random in the line, and only one of each pair will pass to each daughter cell. Since the pairs line up at random, the combination of chromosomes of maternal and paternal origin entering the daughter cell at meiosis 1 is also a matter of chance, called independent segregation. The independent assortment of these chromosomes therefore produces new genetic combinations.

The random fusion of gamete also ensures genetic diversity.

Crossing over contributes to genetic recombination in that genetic information is transferred between the chromosomes. The chromatids of each pair become twisted around one another, and during this twisting process portions of the chromatids break off. These broken portions may rejoin with the chromatids of its homologous partner, and usually it is the equivalent portions of homologous chromosomes that are exchanged. The broken off portions of chromatid recombine with another chromatid, so this process is called recombination.

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Question:

'Explain the role of independent segregation in meiosis'

Answer:

- (To provide) genetic variation;
- (Allows) different combinations of maternal and paternal chromosomes/ alleles;
- (To produce) haploid cells/half the chromosome number;
- (Allows) homologous chromosomes/ homologous pairs to arrange randomly (at equator/middle of cell)/separate;

3.4.4 Genetic diversity and adaptation

Content

- Genetic diversity as the number of different alleles of genes in a population.
- Genetic diversity is a factor enabling natural selection to occur.
- The principles of natural selection in the evolution of populations.
    - Random mutation can result in new alleles of a gene.
    - Many mutations are harmful but, in certain environments, the new allele of a gene might benefit its possessor, leading to increased reproductive success.
    - The advantageous allele is inherited by members of the next generation.
    - As a result, over many generations, the new allele increases in frequency in the population.
- Directional selection, exemplified by antibiotic resistance in bacteria, and stabilising selection, exemplified by human birth weights.
- Natural selection results in species that are better adapted to their environment. These adaptations may be anatomical, physiological or behavioral.
    - **Students should be able to:**
- Use unfamiliar information to explain how selection produces changes within a population of a species
- Interpret data relating to the effect of selection in producing change within populations
- Show understanding that adaptation and selection are major factors in evolution and contribute to the diversity of living organisms.

Genetic diversity is the number of different alleles of genes in a population. It is the factor that enables natural selection to occur. Differences in DNA are the reason behind the vast genetic diversity found on Earth. Furthermore, a population is a group of individuals of the same species that live in the same place and can interbreed. A species consists of one, or more, populations. The greater range of alleles, the higher chance that some individuals in a population will survive environmental change.

Natural selection is part of the evolution of populations, as not all alleles of a population are equally likely to be passed on to the next generation. This is because only certain individuals are reproductively successful and so pass on their alleles.

Differences between reproductive success of individuals affects allele frequency in populations. This process works as follows:

- Within any population of a species there will be a gene pool containing a wide variety of alleles
- Random mutations of alleles within this gene pool may result in a new allele of a gene in which most cases will be harmful
- However, in certain environments, the new allele of a gene might give its possessor an advantage over other individuals in the population
- These individuals will be better adapted and therefore more likely to survive in their competition with others

- These individuals are more likely to obtain the available resources and so grow more rapidly and live longer. As a result, they will have a better chance of breeding successfully and producing more offspring
- Only those individuals that reproduce successfully will pass on their alleles to the next generation
- Therefore it is the new allele that gave the parents an advantage in the competition for survival that is most likely to be passed on to the next generation
- As these new individuals also have the new, 'advantageous' allele, they in turn are more likely to survive, so reproduce successfully
- Over many generations, the number of individuals with the new 'advantageous' allele will increase at the expense of the individuals with the 'less advantageous' alleles.
- Over time, the frequency of the new, 'advantageous' allele in the population increases whilst that of the 'non-advantageous' one decreases.

The different types of selection are as follows: directional selection and stabilising selection.

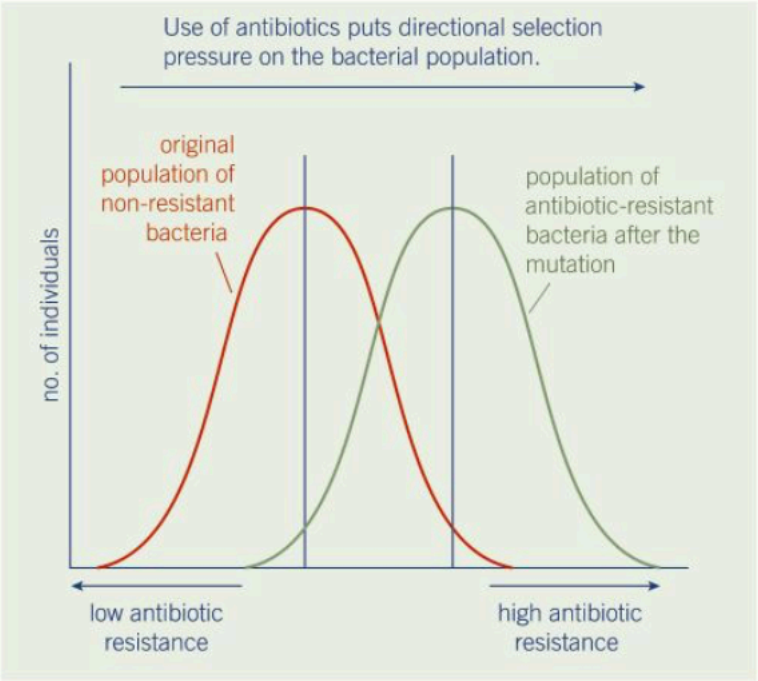
Directional selection is where selection may favour individuals that vary in one direction from the mean of the population. This changes the characteristics of a population, hence directional.

The phenotypes (observable physical and biochemical characteristics of an organism) that are best suited to the new conditions are most likely to survive. Some individuals, which fall to either the left or right of the mean, will posses a phenotype more suited to the new conditions. These individuals are more likely to survive and breed, so will contribute more to the offspring and the alleles of the offspring. So over time the mean phenotype will move in the direction of these individuals.

An example is antibiotic resistance in bacteria because shortly after the discovery of antibiotics it became apparent that the effectiveness of some antibiotics at killing bacteria was reduced. The bacteria had developed resistance, due to mutations within the bacteria. The case of resistance to penicillin is shown below:

- A spontaneous mutation occurred in the new allele of a gene in a bacterium that enabled it to make a new protein. The new protein was an enzyme that broke down the antibiotic penicillin before it was able to kill the bacterium. The enzyme was called penicillinase.
- The bacterium happened, by chance, to be in a situation where penicillin was being used to treat an individual. In these circumstances, the mutation gave the bacterium an advantage of being able to use penicillinase to break down the antibiotic and so survive while the rest of the population of bacteria were killed by it
- The bacterium that survived was able to divide by binary fission and build up a population of resistant bacteria
- Members of this population were more able to survive, and so multiply in the presence of penicillin
- This population increases at the expense of the other population, so the frequency of the allele that enabled production of penicillinase increased in the population
- The population's normal distribution curve shifted in the direction of a population having greater resistance to penicillin.

The graph below shows directional selection.



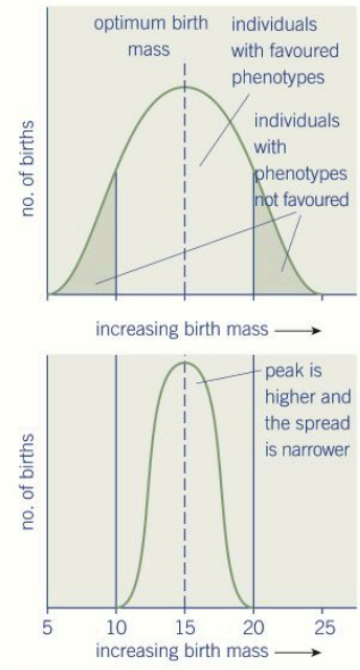
With continued use of antibiotics, there is a greater chance that the mutant population will out-compete, and replace, the original population. Directional selection therefore results in phenotypes at one extreme of the population being selected for and those at the other extreme selected against.

Stabilising selection occurs where the environmental conditions remain stable, so the individuals with phenotypes closest to the mean are favoured. These individuals are more likely to pass their alleles on to the next generation, and those at the extremes are less likely. Stabilising selection tends to eliminate those at the extremes.

An example of stabilising selection is human **birth weights**.

The mortality rate is higher at the extremes of birth weights, as it seems the optimum masses are between 2.5-4kg. The infants with higher and lower masses are more likely to die, thus are being selected against.

Stabilising selection therefore results in phenotypes around the mean of the population being selected for and those at both extremes being selected against.



Natural selection results in species better adapted for the environment that they are living in, these adaptations are:

- **Anatomical** – such as shorter ears and thicker fur in arctic foxes compared to foxes in warmer climates
- **Physiological** – for example oxidising of fat rather than carbohydrate in kangaroo rats to produce additional water in a dry desert environment
- **Behavioural** – such as the autumn migration of swallows from the UK to Africa to avoid food shortages in the UK winter.

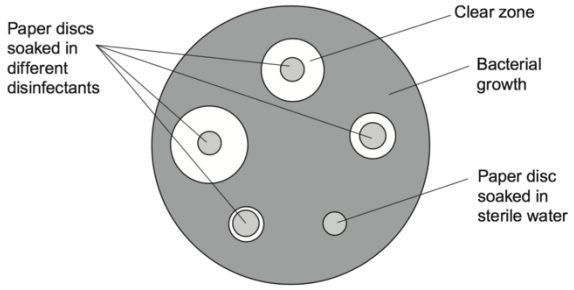
AQA June 2013 Unit 2 Q5d

Pseudomonas aeruginosa is a bacterium that can cause infections in hospital patients suffering from burns. Disinfectants are substances used to kill bacteria on non-living objects, such as medical equipment. Doctors in one hospital investigated how effective four disinfectants were at killing *P. aeruginosa*.

The doctors:

- Took samples from many patients in the hospital
- Isolated *p. Aeruginosa* from those samples
- Suspended the *p. Aeruginosa* in a solution
- Spread many samples of this solution on nutrient jelly in many petri dishes.

The doctors then placed five small paper discs on the jelly in each dish. Each disc had been soaked in a different disinfectant or sterile water. The doctors left the plates for 24 hours to allow bacteria to grow and divide. The diagram shows a typical Petri dish after 24 hours.



Question:

Doctors in a different hospital repeated this investigation. They found that hypochlorite had little effect on samples of *P. aeruginosa* they obtained. Suggest how this different result may have arisen.

Answer:

1. Mutation (in bacterium);
2. Gene/allele for resistance;

AQA Jan 2013 Unit 2 Q3ci)ii)

Question:

All modern cheetahs are thought to have descended from a single female. This female was part of a small population that survived an ice age a long time ago that killed almost all cheetahs. After the ice age, the number of cheetahs increased.

Use this information to explain what is meant by a genetic bottleneck

Answer:

1. Drop in population / many killed / only single female left;
2. Idea of reduced/low genetic variation/diversity / reduction in (variety of) alleles / smaller gene pool;

Question:

The fertility of cheetahs is low. The proportion of abnormal sperm cells produced is higher in cheetahs than in other members of the family Felidae. Suggest an explanation for this.

Answer:

1. Mutation affecting sperm cell or production (in small population);
2. Errors during meiosis;
3. Inbreeding / closely related cheetahs breed;
4. High chance of inheriting allele / high frequency of allele (in the population)

AQA A Level Specimen (set 2) Q10.2

Question:

Penicillin has been the antibiotic of choice for the treatment of bacterial meningitis. Since the year 2000, strains of *Neisseria meningitidis* that are resistant to penicillin, sulfonamides and rifampin have been discovered in the UK.

Describe how a population of *Neisseria meningitidis* (Nm) can become resistant to these antibiotics.

Answer:

1. Mutation;
2. Results in Nm cell with allele for resistance to one antibiotic/to named antibiotic;
3. (This) cell survives and passes the allele for resistance to offspring;
4. Process repeated with different genes conferring resistance to each of the other (two) antibiotics

3.4.5 Species and taxonomy

Content

- Two organisms belong to the same species if they are able to produce fertile offspring. Courtship behaviour as a necessary precursor to successful mating. The role of courtship in species recognition.
- A phylogenetic classification system attempts to arrange species into groups based on their evolutionary origins and relationships. It uses a hierarchy in which smaller groups are placed within larger groups, with no overlap between groups. Each group is called a taxon (plural taxa).
- One hierarchy comprises the taxa: domain, kingdom, phylum, class, order, family, genus and species.
- Each species is universally identified by a binomial consisting of the name of its genus and species, eg, *Homo sapiens*.
- Recall of different taxonomic systems, such as the three domain or five kingdom systems, will **not** be required.
- **Students should be able to** appreciate that advances in immunology and genome sequencing help to clarify evolutionary relationships between organisms.

It can be said that two organisms belong to the same **species** if they are able to breed to produce fertile offspring. Essentially, when a species reproduces sexually, any of the genes of its individuals can, in theory, be combined with any other.

Before breeding, courtship behaviour is necessary for successful mating as it plays a role in species recognition. Members of the same species will resemble each other physically and biochemically, helping them to distinguish members of their own species from others. The same is true of behaviour, and the behaviour of members of the same species is more alike than that of members of different species.

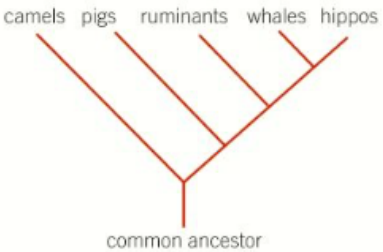
The ability to display behaviour is genetically determined, so individuals can therefore recognise members of their own species by the way they act. Reproduction is the means by which a species can survive over time, so each individual has adaptations to help ensure their DNA is passed on. The females of most species only produce eggs at specific times, sometimes as little as once a year. It is therefore important to ensure mating is successful and that the offspring have the maximum chance of survival.

Courtship behaviour helps to achieve mating is successful by:

- Recognising members of their own species: to ensure mating only takes place between members of the same species because only members of the same species can produce fertile offspring
- Identify a mate that is capable of breeding because both partners need to be sexually mature, fertile and receptive to mating
- Form a pair bond that will lead to successful mating and raising of offspring
- Synchronise mating so it takes place when there is maximum probability of the sperm and egg meeting
- Become able to breed by bringing a member of the opposite sex into a physiological state that allows breeding to occur.

A **phylogenetic classification** system attempts to arrange species into groups based on their evolutionary origins and relationships. It uses a **hierarchy** in which smaller groups are placed within larger groups, with no overlap between groups. Each group is called a taxon (plural taxa). There is also another type of classification called **artificial classification** which divides organisms according to differences useful at the time ie colour, size, number of legs etc.

The hierarchical order of taxonomic ranks is based upon the supposed evolutionary line of descent of the group members. The evolutionary relationship between organisms is known as phylogeny, and the term derives from 'phylum', which, in classification is a group of related or similar organisms. The phylogeny of an organism reflects the evolutionary branch that led up to it. In a phylogenetic tree-like diagram, the oldest species is at the base of the tree, and most recent at the ends of the branches. An example is shown below.



The closer the branches, the closer the evolutionary relationship. Hippos and whales are more closely related than hippos and ruminants.

Taxonomy is the theory and practice of biological classification. Each group within the phylogenetic biological classification is called a taxon (plural taxa). Taxonomy is the study of these groups in a hierarchical order, called taxonomic ranks.

One **hierarchy** comprises the taxa: domain, kingdom, phylum, class, order, family, genus and species. The highest rank is domain and it comprises of bacteria, archaea and eukarya.

Each species is universally identified by a **binomial** consisting of the name of its genus and species, eg, *Homo sapiens*. It is a universal system based upon Latin or Greek names. The first name, called the **generic** name, denotes the genus which an organism belongs to ie the surname of a human. The second name called the **specific** name, denotes the species to which an organism belongs, equivalent to the first name of a human. However, these specific names are never shared between other species in the genus.

There are rules when using the binomial system, including:

- The names are printed in italics or, if handwritten they are underlined to indicate scientific names
- The first name of the genetic name is in upper case but the specific name is all lower case
- If the specific name is not known is can be written as '*sp*'

AQA Jan 2012 Unit 2 Q3cii

Question:

The variety of colours displayed by catfish is important in courtship. Give **two** ways in which courtship increases the probability of successful mating

Answer:

1. Attracts/recognises same species;
2. Attracts/recognises mate/opposite sex;
3. Indication of sexual maturity/ fertility / synchronises mating;
4. Stimulates release of gametes;
5. Form pair bond;

3.4.6 Biodiversity within a community

Content

- Biodiversity can relate to a range of habitats, from a small local habitat to the Earth.
- Species richness is a measure of the number of different species in a community.
- An index of diversity describes the relationship between the number of species in a community and the number of individuals in each species.
- Calculation of an index of diversity (d) from the formula $d = \frac{N(N-1)}{\Sigma n(n-1)}$
- Where N = total number of organisms of all species and n = total number of organisms of each species.
- Farming techniques reduce biodiversity. The balance between conservation and farming.

Opportunities for Skills Development

- Students could be given data from which to calculate an index of diversity and interpret the significance of the calculated value of the index.

Biodiversity can relate to a range of habitats, from a small local habitat to the Earth. It can come in three forms:

- Species diversity: refers to the number of different species and the number of individuals of each species within any one community
- Genetic diversity: refers to the variety of genes possessed by the individuals that make up a population of a species
- Ecosystem diversity: refers to the range of different habitats, from a small local habitat to the whole of the Earth.

One measure of species diversity is **species richness**, which is the measure of the number of different species in a community in a particular area at a given time. Two communities may have the same number of species by the proportions of the community made up of each species may differ markedly.

Measuring the index of diversity is done by using the equation $d = \frac{N(N-1)}{\Sigma n(n-1)}$

An example of how this equation is used is given below

Species	Numbers (n) found in habitat X	$n(n-1)$	Numbers (n) found in habitat Y	$n(n-1)$
A	10	$10(9) = 90$	3	$3(2) = 6$
B	10	$10(9) = 90$	5	$5(4) = 20$
C	10	$10(9) = 90$	2	$2(1) = 2$
D	10	$10(9) = 90$	36	$36(35) = 1260$
E	10	$10(9) = 90$	4	$4(3) = 12$
	$\sum n(n-1)$	450	$\sum n(n-1)$	1300

You can now calculate the species diversity index for each habitat.

Habitat X: $d = \frac{50(49)}{450} = \frac{2450}{450} = 5.44$

Habitat Y: $d = \frac{50(49)}{1300} = \frac{2450}{1300} = 1.88$

The higher the value d, the greater is the species diversity. So, in this case, although the total number of species and the total number of individuals are the same in both habitats, the species diversity of habitat X is much greater.

Farming techniques reduce biodiversity, thus there is difficulty in finding a balance between conservation and farming.

Impact of **agriculture** on biodiversity: As natural ecosystems develop over time they become more complex communities with many individuals of a large number of different species, thus a high index of diversity. Agricultural ecosystems are controlled by humans so very different, as farmers often select species for particular qualities that make them more productive. As a result, the number of species, and the genetic variety of alleles they possess, is reduced to the few that exhibit the desired features.

Since any particular area can only support a certain amount of biomass, if a farmer has taken most of the area up by one species they see as desirable, it leaves less space for other species. These many other species have to compete for the remaining resources and space, but most will not survive this competition. Even if species evolved to adapt to the changes, the population would be drastically reduced. In addition, pesticides are used to exclude these species because they compete for the light, mineral ions, water and food required for farmed species. The overall effect is reduced species diversity.

The balance between conservation and farming is difficult to get as food is essential to life, so with an ever-expanding human population there is pressure to produce it more and more intensively. The food production in the UK has been boosted by things like improved genetic varieties of plant and animal species, greater use of chemical fertilisers and pesticides, greater use of biotechnology and changes in farm practices, leading to larger farms and the conversion of land supporting natural communities into farmland. These changes have had many ecological impacts, but the overriding effect of intensive food production has been to reduce the variety of habitats within ecosystems and consequently reduce species diversity.

Certain practices directly remove habitats and reduce species diversity:

- Removal of hedgerows and grubbing out woodland
- Creating monocultures, for example replacing natural meadows with cereal crops or grass for silage
- Filling in ponds and draining marsh and other wetland
- Over-grazing of land, for example upland areas by sheep, thereby preventing regeneration of woodland

Other practices have had a more indirect effect:

- Use of pesticides and inorganic fertilisers
- Escape of effluent from silage stores and slurry tanks into water courses
- Absence of crop rotation and lack of intercropping or undersowing

However, there are management techniques that can be applied to increase species and habitat diversity, without unduly raising food costs or lowering yields. Examples of these include:

- Maintain existing hedgerows at the most beneficial height and shape, an A-shape provides better habitats than rectangular ones.
- Plant hedges as opposed to erecting fences at field boundaries
- Maintain existing ponds and where possible create new ones
- Leave wet corners of fields rather than draining them
- Plant native trees on lands with a low species diversity rather than in species-rich areas
- Use organic, rather than inorganic, fertilisers
- Use crop rotation that includes nitrogen-fixing crop, rather than fertilisers, to improve soil fertility
- Use intercropping rather than herbicides to control weeds and other pests
- Create natural meadows and use hay rather than grasses for silage
- Leave the cutting of verges and field edges until after flowering and when seeds have dispersed
- Introduce conservation headlands – areas at the edges of fields where pesticides are used restrictively so that wild flowers and insects can breed

These practices will make food production slightly more expensive, so financial incentives are provided to farmers ie from DEFRA or the Department for Environment, or the EU. If biodiversity is reduced the global living system will become more unstable and we all rely on the global system for food and other resources.

AQA June 2014 Unit 2 Q7a

Question:

What two measurements are needed to calculate an index of diversity

Answer:

1. Number of (individuals of) each species;
2. Total number of individuals / number of species;

AQA June 2013 Unit 2 Q2bii

Question:

'The forest was cleared to make more land available for agriculture

After the forest was cleared the species diversity of the insects in the area decreased. Explain why.'

Answer:

1. Decrease in variety of plants / fewer plant species;
2. Fewer habitats/niches;
3. Decrease in variety of food / fewer food sources;
4. Aspect of clearing forest (killing insects) eg machinery, pesticides;

3.4.7 Investigating diversity

Content

- Genetic diversity within, or between species, can be made by comparing:
  - The frequency of measurable or observable characteristics
  - The base sequence of DNA
  - The base sequence of mRNA
  - The amino acid sequence of the proteins encoded by DNA and mRNA.
- **Students should be able to:** interpret data relating to similarities and differences in the base sequences of DNA and in the amino acid sequences of proteins to suggest relationships between different organisms within a species and between species
- Appreciate that gene technology has caused a change in the methods of investigating genetic diversity; inferring DNA differences from measurable or observable characteristics has been replaced by direct investigation of DNA sequences.
- Knowledge of gene technologies will **not** be tested.
- Quantitative investigations of variation within a species involve:
  - Collecting data from random samples
  - Calculating a mean value of the collected data and the standard deviation of that mean
  - Interpreting mean values and their standard deviations.
- Students will **not** be required to calculate standard deviations in written papers.

Opportunities for Skills Development

- Students could:
  - Design appropriate methods to ensure random sampling
  - Carry out random sampling within a single population
  - Use random samples to investigate the effect of position on the growth of leaves.
- Students could use standard scientific calculators to calculate the mean values of data they have collected or have been given.
- Students could calculate, and interpret the values of, the standard deviations of their mean values.

Genetic diversity within, or between species, can be made by comparing:

1. The frequency of measurable or observable characteristics
2. The base sequence of DNA
3. The base sequence of mRNA
4. The amino acid sequence of the proteins encoded by DNA and mRNA.

An explanation of each factor is given below

1. This was the traditional method of assessing genetic diversity. The method is based on the fact that each observable characteristic is determined by a gene or genes (with environmental influences), so the variety within a characteristic depends on the number and variety of alleles of that gene (plus environmental influences). Although

this has limitations as a large number of observable characteristics are coded for by more than one gene (polygenic). Also differences may be as a result of environmental conditions as opposed to allelic differences. Human height for example, is determined by a number of genes but environmental factors like diet can affect the actual height reached. Therefore, inferring DNA sequences has been replaced by directly observing DNA sequences

2. Comparing DNA base sequences has been enabled by gene technology. DNA sequencing is now done by computer systems, and in these systems each nucleotide base can be tagged with a different coloured fluorescent dye to produce a series of bands, each of which represents one of the four nucleotide bases. We can measure the genetic diversity of a species by comparing the appearance of coloured bands between different species, or between species to show diversity within species. These techniques can also be used to determine the evolutionary relationships between species. When one species gives rise to another species during evolution, the DNA of the new species will initially be very similar to that of the species that gave rise to it. However, as time progresses, and mutations occurs, the sequences of nucleotide bases will become more and more different. As a result, species more closely related should show more similarity in their DNA base sequences than species less closely related.
3. The base sequence of mRNA is determined by the sequence of DNA, as they are complementary to that of the DNA strand that has made it. By comparing sequences of mRNA you are able to see genetic diversity.
4. Comparing amino acid sequences in proteins is useful as the amino acid sequence is determined by mRNA, which is in turn determined by DNA. The degree of similarity will also reflect the degree of similarity between different species.

Quantitative investigations of variation

Random sampling involves taking measurements of individuals, selected from the population of organisms which is being investigated. In theory, if these individuals are representative of the whole population then the measurements can be relied upon. However, they are not always representative, for reasons including:

- Sampling bias. The selection process may be biased, and the investigators may be making unrepresentative choices, either deliberately or unwittingly.
- Chance. Even if sampling bias is avoided, the individuals chosen may, by pure chance, not be representative.

The best way to prevent sampling bias is to eliminate, as far as possible, any human involvement in choosing the samples. This can be achieved by carrying out random sampling:

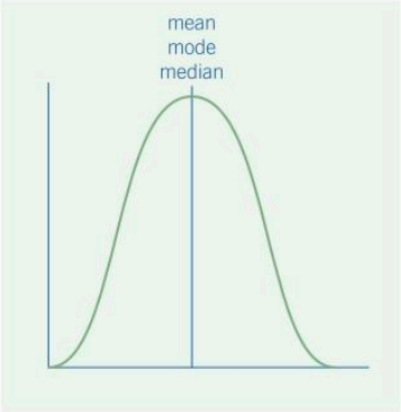
- Divide the study area into a grid of numbered lines, for example by stretching two long tape measures at right angles to each other
- Using random number generated from a table or by a computer to obtain a series of coordinates
- Take samples at the intersection of each pair of coordinates

We can only minimise the effect of chance from the sampling process by:

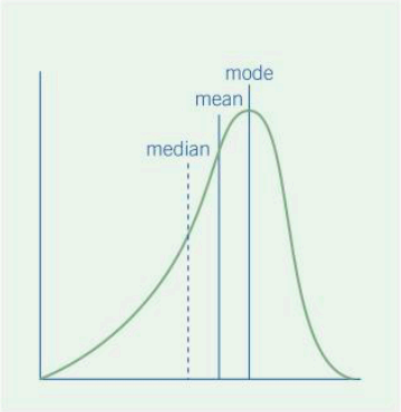
- Using a large sample size. The more individuals that are selected the smaller is the probability that chance will influence the result, also the less influence anomalies will have.
- Analysis of the data collected – this can be done using statistical test to determine the extent to which chance may have influenced the test (chi-squared test). These test allow us to decide whether any variation observed is the result of chance or is more likely to have some other cause.

The normal distribution curve usually shows a bell-shape for a continuous variation (ie height in humans). The graph is symmetrical about a central value. Occasionally the curve is shifted slightly to one side, called a skewed distribution. There are three terms related with normal distribution curves:

- The mean (arithmetic mean)
- The mode
- The median



▲ **Figure 2** *A normal distribution curve where the mean, mode and median have the same value*



▲ **Figure 3** *A skewed distribution where the mean, mode and median have different values*

The mean does not give useful information when comparing one sample with another. The standard deviation (s) is a measure of the width of the curve. It gives an indication of the range of values either side of the mean. To calculate standard deviation you use the equation below:

$$\text{standard deviation} = \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}}$$

Where:

$\sum$ = **the sum of**

x = **measured value (from the sample)**

$\bar{x}$ = **mean value**

n = **total number of values in the sample.**

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