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.

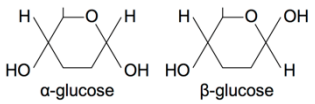
It joins two molecules together and forms a chemical bond, removing a molecule of water in the process, hence ‘condensation’. So essentially a molecule of H_2O is removed in a condensation reaction.

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:



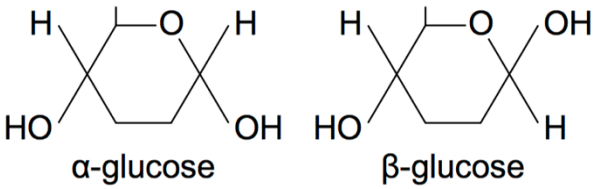
- Polysaccharides are formed by the condensation of many glucose units.
- Glycogen and starch are formed by the condensation of α-glucose.
- Cellulose is formed by the condensation of β-glucose.
- The basic structure and functions of glycogen, starch and cellulose. The relationship of structure to function 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

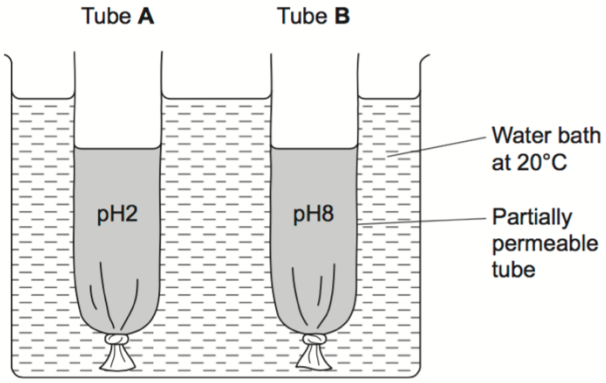
- α glucose

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

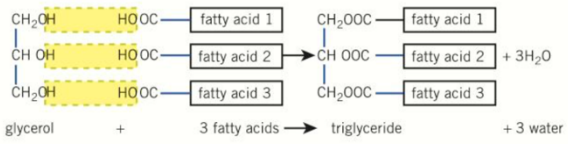
- Triglycerides and phospholipids are two groups of lipid.
- Triglycerides are formed by the condensation of one molecule of glycerol and three molecules of fatty acid.
- A condensation reaction between glycerol and a fatty acid (RCOOH) forms an ester bond.
- The R-group of a fatty acid may be saturated 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.

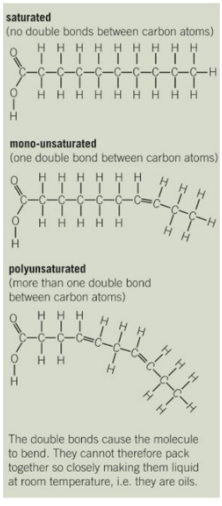
Opportunities for skills development

- 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.

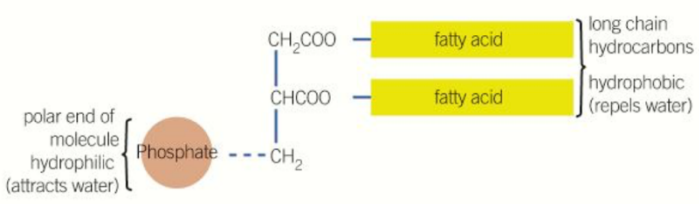
Triglycerides are formed in the condensation of one molecule of glycerol and three molecules of fatty acid. The condensation reaction that joins glycerol and fatty acids form a bond called an ester bond. A triglyceride is shown to the right, with the ester bond between the CH_2OOC and fatty acid. Since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

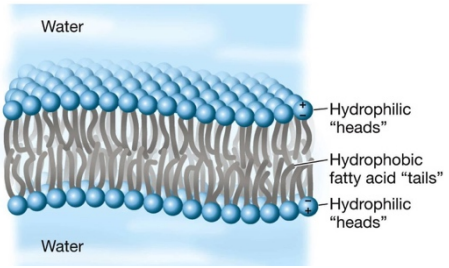
Phospholipids are very similar to triglycerides, however one of the fatty acid groups is substituted for a phosphate containing group, as is shown below.



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:

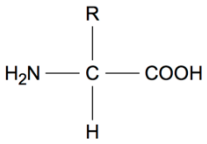
1. Crush/grind;
2. With ethanol/ alcohol;
3. Then add water/then add to water;
4. Forms emulsion / goes white/cloudy;

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:

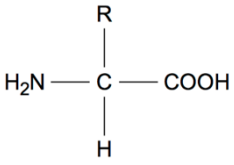


  Where NH_2 represents an amine group, COOH represents a carboxyl group and R represents a side chain. The twenty amino acids that are common in all organisms differ only in their side group.
- A condensation reaction between two amino acids forms a peptide bond.
  - Dipeptides are formed by the **condensation** 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

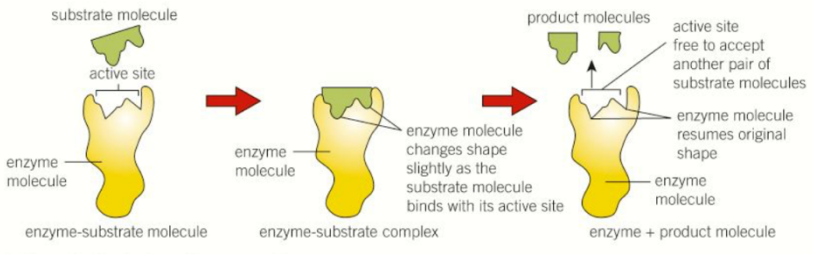
- Each enzyme lowers the activation energy of the reaction it catalyses.
- The induced-fit model of enzyme action.
- The properties of an enzyme relate to the tertiary structure of its active site and its ability to combine with complementary substrate(s) to form an enzyme-substrate complex.
    - The 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.

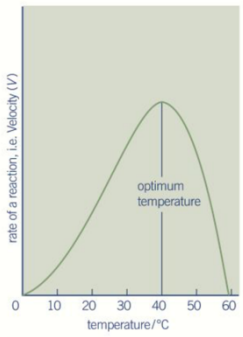


The Lock and Key Model: This model states that enzymes have a specific tertiary structure, and thus a specific active site in which the substrate will bind to. This means that the active site will not undergo a conformational change for the substrate to bind to it, and so only a substrate that has the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

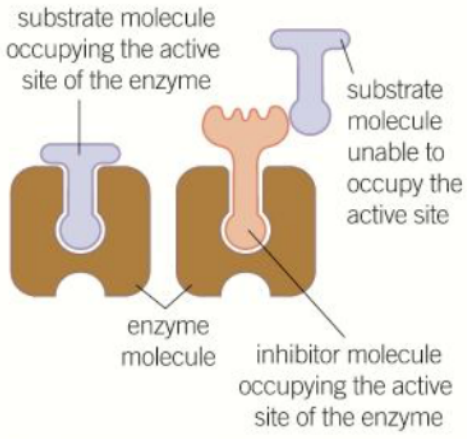
Hydrogen, ionic and other bonds hold the substrate in the active site, and the enzyme can change the structure of the substrate i.e. splitting it in half. Therefore if the active site were to change slightly, then it would no longer be complementary to the substrate thus the enzyme would be ineffective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

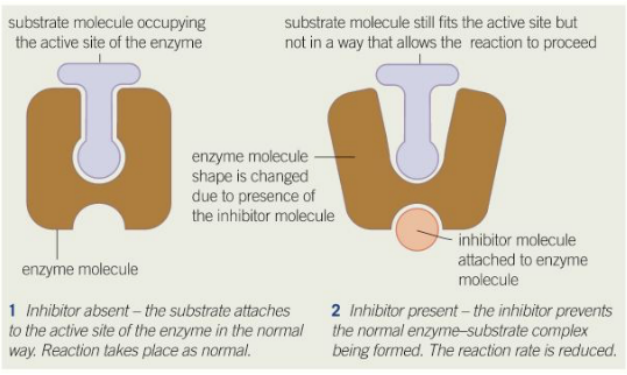
Factors affecting enzymes:

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.

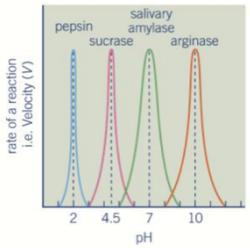




Competitive Inhibitors: These are characterised by the fact that they compete for the active site against the substrate. Therefore it has a shape resembling the substrate, and so is complementary to the shape of the active site. This prevents an E-S complex forming and instead forms an enzyme-inhibitor 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.

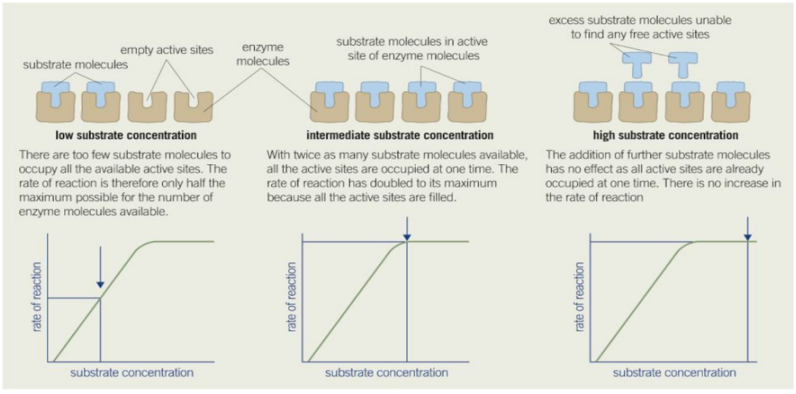
Non-Competitive Inhibitors: The effect of these on the other hand, cannot be reversed by adding more substrate. This is because the non-competitive inhibitors bind to a different size of the enzyme. An enzyme which has another site that an inhibitor for example, can bind to is called an **allosteric** 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.

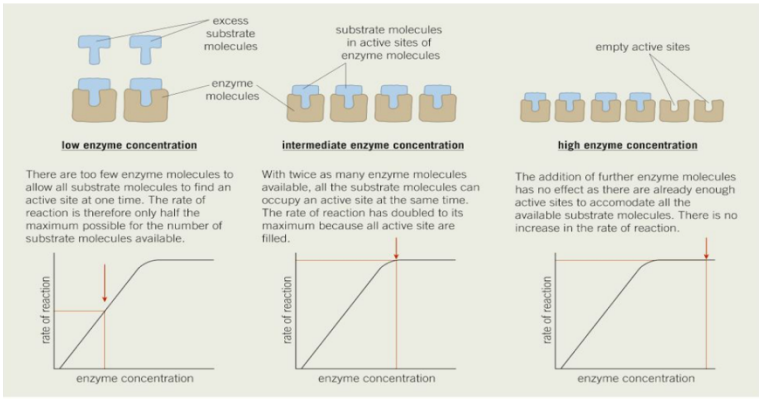


Deviations from optimum pH cause changes in the hydrogen and ionic bonding, amongst others, which denatures the enzyme and causes a conformational change in the structure of the enzyme, and thus the active site. If conditions are more acidic, the active site may pick up extra hydrogen ions, and so this 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.

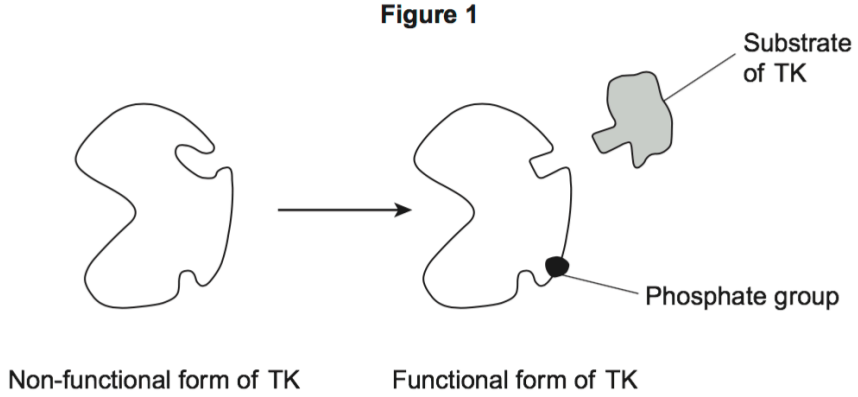


AQA Jan 2013 Q5b

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:

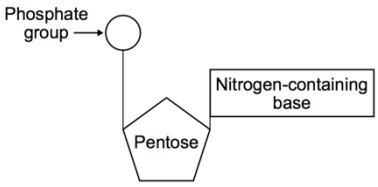
1. Change in base sequence (of DNA/gene);
2. Change in amino acid sequence / primary structure (of enzyme);
3. Change in hydrogen/ionic/ disulphide bonds;
4. Change in the tertiary structure/active site (of enzyme);
5. Substrate not complementary/cannot bind (to enzyme / active site) / no enzyme-substrate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

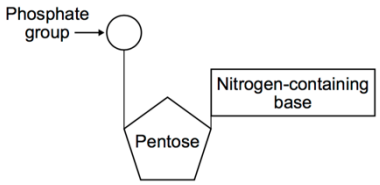
Opportunities for Skills Development

- 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.

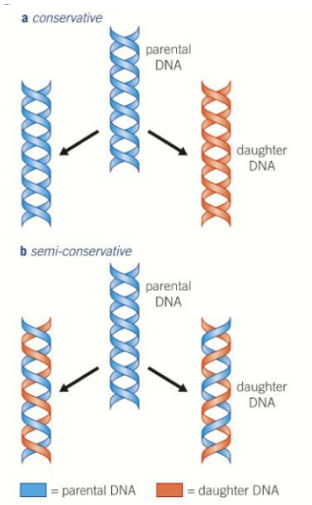
The **Watson-Crick** model of DNA replication was the first proposed model. They proposed the semi-conservative model. There was another model named the conservative model that was also yet to be proved/disproved, and it stated that new DNA molecules built up from freely floating molecules of deoxyribose,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

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

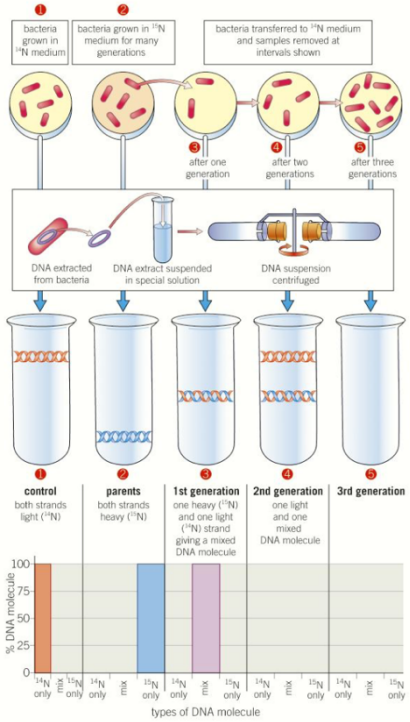
1. All of the bases in DNA contain nitrogen
2. Nitrogen has two forms, the lighter nitrogen ^{14}N and the isotope ^{15}N, which is heavier.
3. Bacteria will incorporate nitrogen from their growing medium into any new DNA they make.

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.

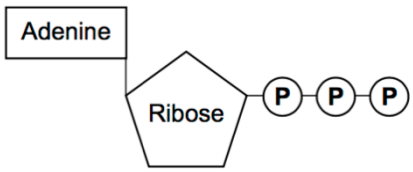
Answer:

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.