CELL BIOCHEMISTRY - Large molecules in the structure and functioning of cells (56p)

Contents

Biological molecules

- Monomers and polymers.
- Condensation and hydrolysis

Carbohydrates

- Structure and properties of carbohydrates.
- The structure of alpha and beta glucose, and the linking of these monomers by glycosidic bonds
- Biochemical tests for reducing sugars, non-reducing sugars, starch
- The basic structure and function of starch, glycogen and cellulose

Proteins

- Amino acid structure and the peptide bond
- Primary, secondary, tertiary and quaternary structure of proteins
- The relationship of tertiary structure to function in globular proteins
- The biuret test for proteins

Lipids

- The structure of saturated and unsaturated triglycerides and phospholipids
- The emulsion test for lipids

Chromatography

- The technique of chromatography for separating and identifying molecules
- The calculation and use of Rf value
- Two-way chromatography

BIOLOGICAL MOLECULES

The bodies of living organisms are made up of fewer than 20 different chemical elements and just six of these bioelements make up 99% of the total body mass (oxygen 65%, carbon 18%, hydrogen 10%, nitrogen 3%, calcium 2%, phosphorus 1%). Most of the important biological molecules are organic, which means that they are made up from carbon compounds (note that most but not all compounds containing carbon are organic; exceptions include carbon dioxide and carbonates). Organic biomolecules include carbohydrates, proteins, lipids and nucleic acids. Individual molecules can act as sub-units (**monomers**) to combine by reactions called **condensation reactions,** in which a molecule of water is lost as each sub-unit joins the next. In this way monomers can form dimers (two joined monomers e.g. glucose and fructose forming sucrose), or chains of repeating sub-units (**polymers**). Bonds formed by condensation may be broken down by the reverse process, **hydrolysis**, which involves the addition of a molecule of water for each bond broken. The following account describes the structure of carbohydrates, proteins and lipids and the relationship of molecular structure to their function in living organisms.

◆ CHECKPOINT SUMMARY

- ◆ Most of the important biological molecules are 'organic', which means that they are made up from carbon compounds
- ◆ Not all compounds containing carbon are organic. Exceptions include carbon dioxide and carbonates)
- ◆ Organic biomolecules include carbohydrates, proteins, lipids and nucleic acids
- ◆ Individual molecules (monomers) can join to form dimers of just two monomers, or longer chains (polymers) of repeating monomers.
- ◆ Polymers are very large molecules, built up by reactions called condensation reactions in which a molecule of water is lost as each sub-unit joins the next
- ◆ Bonds formed by condensation reactions may be broken down by the reverse process, hydrolysis, which involves the addition of a molecule of water for each bond broken
- ◆ Condensation and hydrolysis reactions are catalysed by enzymes in the living cell
- ◆ Under laboratory conditions, in the absence of a catalyst, hydrolysis requires extreme conditions of temperature and pH.

CARBOHYDRATES

Structure and properties of carbohydrates

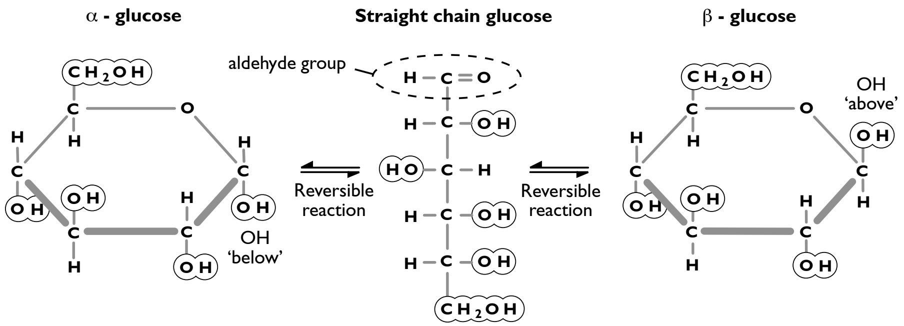
The structures of alpha and beta glucose

Carbohydrates are a family of molecules made up, as the name suggests, from carbon and the components of water (hydrogen and oxygen). Carbohydrates are manufactured by plants and are passed on to other organisms via food chains. You should already be familiar with the name and chemical formula of one of the simpler carbohydrate molecules, glucose, which is made from CO_2 and H_2O in the process of photosynthesis.

$$6CO_2 + 6H_2O \rightarrow \underset{\text{glucose}}{C_6H_{12}O_6} + 6O_2$$

Glucose has six carbon atoms in the form of a framework to which the oxygen and hydrogen atoms are attached. In dry glucose powder the carbon atoms are arranged in a straight chain, but if it is dissolved in water, the chains form themselves into ring structures. Two different ring forms exist called **alpha glucose** and **beta glucose**. The carbon atoms are numbered 1 to 6 starting in a clockwise direction from the position of the oxygen atom. As discussed later, the different structures of alpha and beta glucose result in the formation of polysaccharides with different properties.

Alpha and beta glucose are **isomers**; they have the same chemical formula but a slightly different arrangement of atoms in the molecule (fructose and galactose are also isomers of glucose).



Glycogen has a similar structure to amylopectin but has a large number of shorter branches. It is more suited to animal metabolism as it is capable of being broken down more rapidly than starch.

Cellulose is the major component of plant cell walls. The characteristic fibrous structure of cellulose is created by chains of 1-4 linked beta glucose molecules. The beta molecules, when joined together, have their oxygen bridges on alternate sides of the chain, and thus it cannot form into a helix, but by forming hydrogen bonds with other chains lying side by side they make flat ribbons, which in turn form fibres.

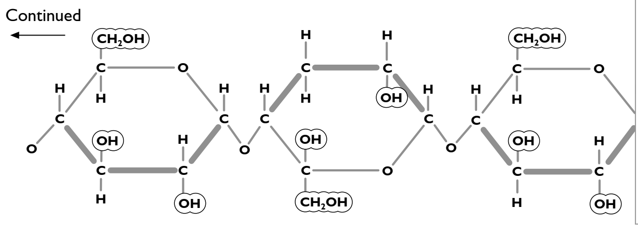
The basic meshwork of cellulose fibres in plant cell walls is strengthened and cemented by other materials such as pectin and lignin. Cellulose is the main component of numerous textiles e.g. cotton, linen, hemp; timber products, paper and plastics e.g. celluloid.

Starch and cellulose have very different properties which arise as a result of one difference between alpha and beta glucose. Starch has no distinct structure (amorphous), no structural strength, is slightly soluble in water, and digestible by vertebrates. Cellulose has a distinct fibrous structure, great structural (tensile) strength, is insoluble in water and indigestible by vertebrates. (Herbivorous vertebrates harbour mutualistic microorganisms in specialised compartments of their gut which secrete cellulase enzyme which digests cellulose.)

◆ CHECKPOINT SUMMARY

- ◆ Simple formula for glucose - $C_6H_{12}O_6$
- ◆ Forms straight chain in dry powder form
- ◆ Forms ring structure in solution
- ◆ alpha and beta glucose are isomers differing in the 3D arrangement of their atoms
- ◆ Monosaccharides (glucose, fructose and galactose) combine together with the elimination of water to form glycosidic bonds - a condensation reaction.
- ◆ Glycosidic bonds are broken by the addition of the elements of water across the bond - a hydrolysis reaction
- ◆ Starch is a mixture of amylose (unbranched chains) and amylopectin (branched chains).
- ◆ Both being long chains (polymers) of alpha glucose molecules
- ◆ When combined the alpha glucose molecules have their oxygen bridges on the same side of the chain, hydrogen bonds form between them and cause the chain to coil into a helix
- ◆ Starch molecules are relatively insoluble in water
- ◆ Cellulose is a polymer of beta glucose which have their oxygen bridges on alternate sides of the chain and so cannot form a helix
- ◆ Instead they form hydrogen bonds with other adjacent chains to make flat ribbons which form cellulose fibres.

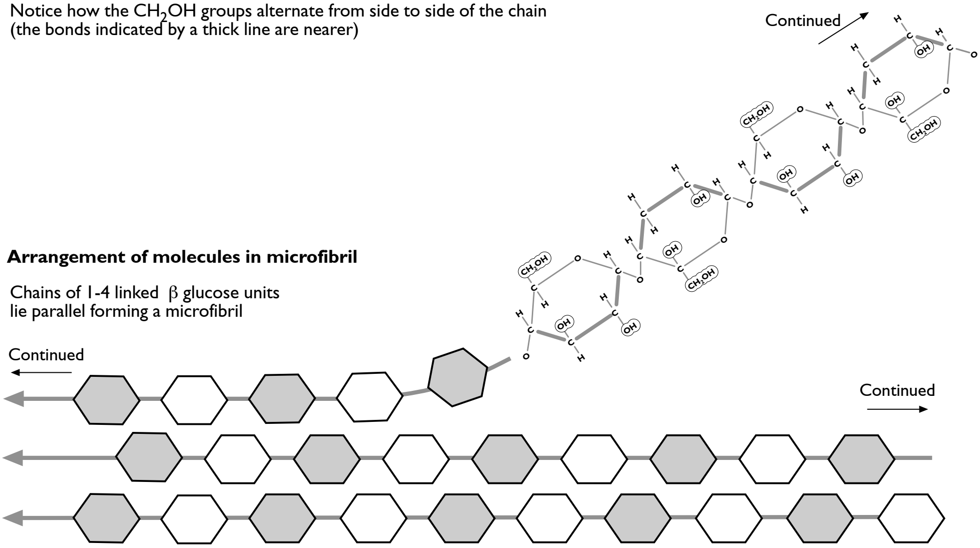
Part of a cellulose molecule chain



Notice how the CH_2OH groups alternate from side to side of the chain (the bonds indicated by a thick line are nearer)

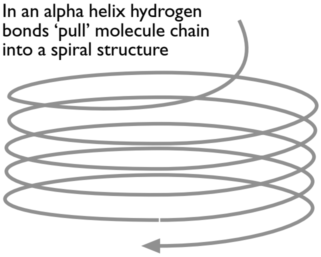
Arrangement of molecules in microfibril

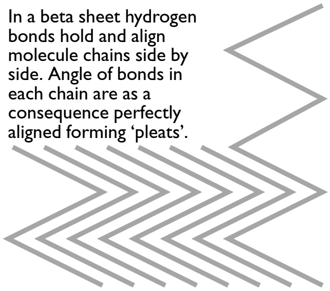
Chains of 1-4 linked β glucose units lie parallel forming a microfibril



Hydrogen bonds form between alternating CH_2OH units bind molecules together side by side into microfibrils.

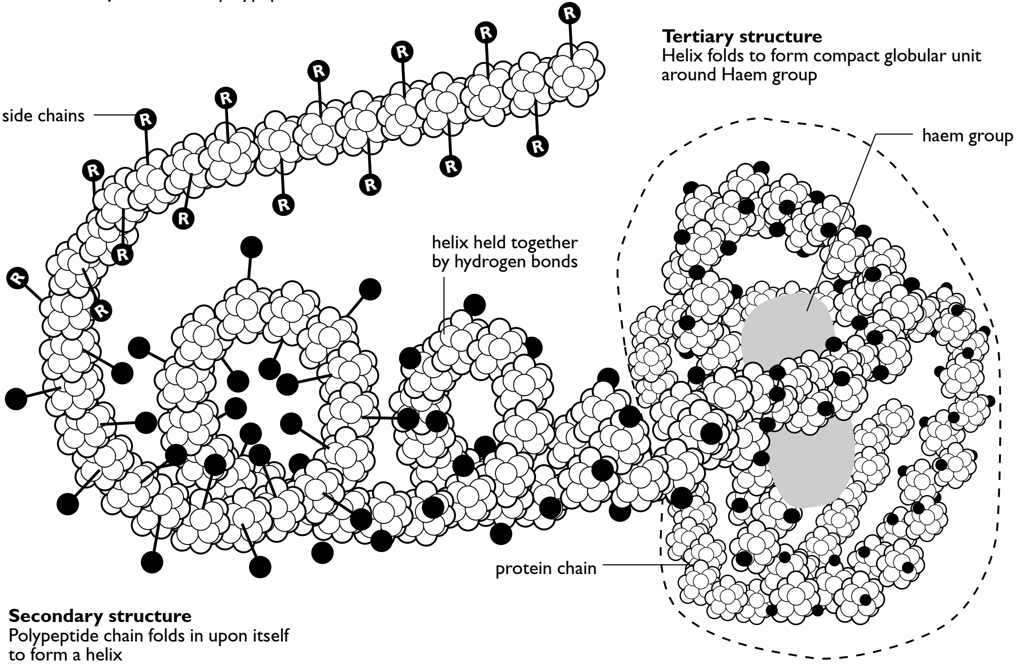
Secondary structure of proteins





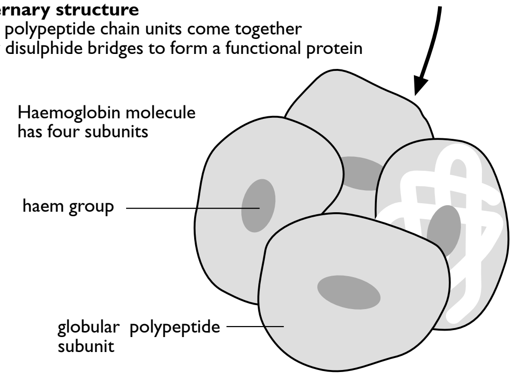
Primary structure
Amino acids join to form a polypeptide chain

Tertiary structure
Helix folds to form compact globular unit around Haem group

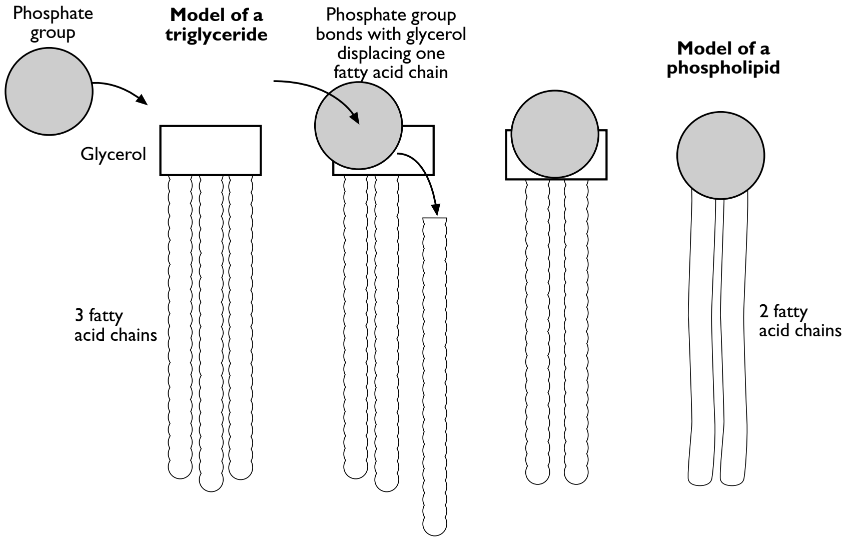


Secondary structure
Polypeptide chain folds in upon itself to form a helix

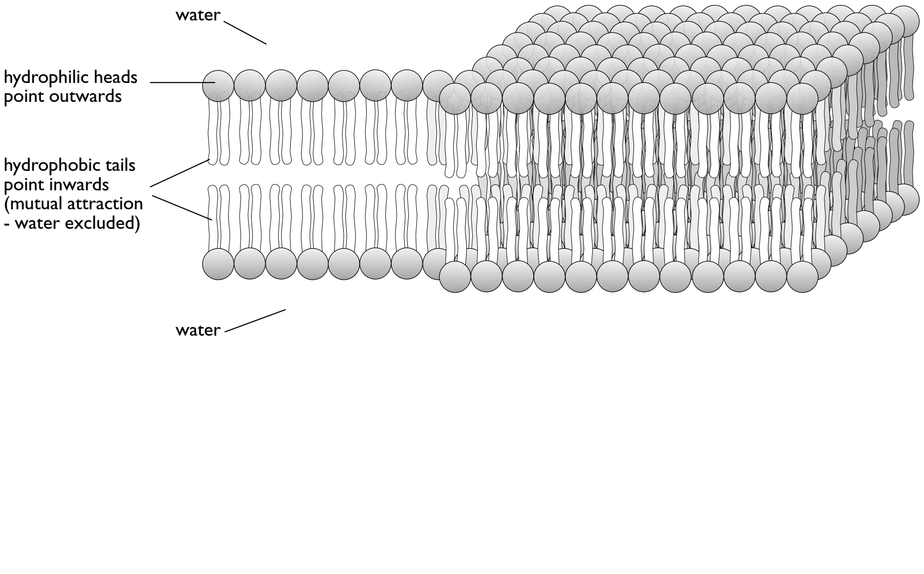
Quaternary structure
Several polypeptide chain units come together held by disulphide bridges to form a functional protein



Phospholipids

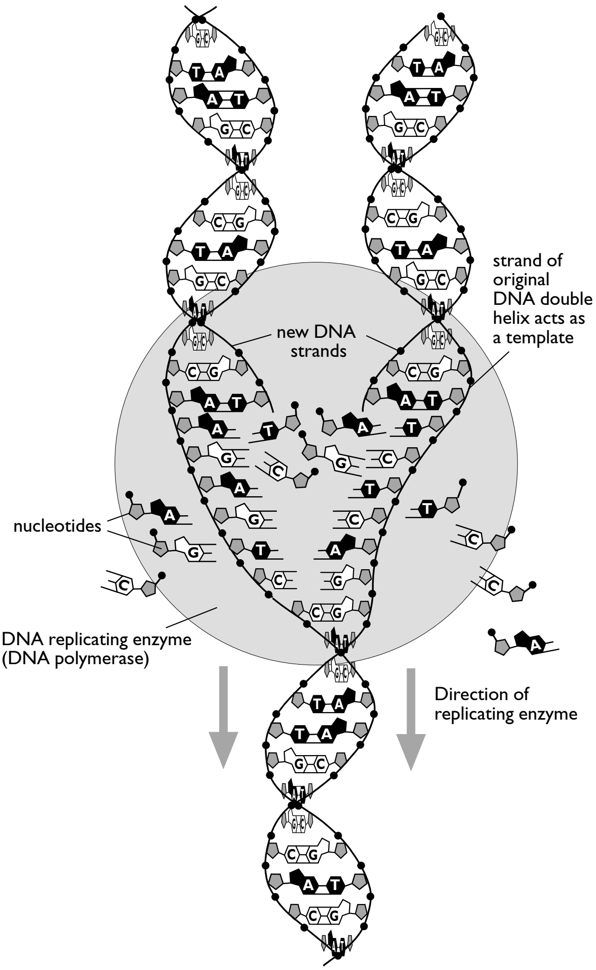


Phospholipid bilayer



Replication of DNA

In the process of DNA replication the original strands separate, and each acts as a pattern (template) for the formation of another new strand of DNA. Each of the daughter DNA molecules retains (conserves) one of the original strands and has one new one. For this reason, the process of replication is said to be **semi-conservative**. The process requires a supply of the four different nucleotides, energy in the form of ATP, and an enzyme called DNA polymerase, which is required to catalyse the condensation reactions by which free nucleotides form a copy of the template strand.



◆ CHECKPOINT SUMMARY

- The nucleus of cells contains mostly DNA and protein
- The DNA content doubles in cells just prior to dividing
- It was also found that, in the formation of gametes (sperms and eggs), the amount of DNA halved. This evidence underlines its central role in inheritance
- Now it has become possible to analyse the molecular structure of DNA, to unravel the chemical code it contains, and to transfer pieces of this code between one organism and another in the process known as genetic engineering
- DNA and RNA are long chain polynucleotide molecules with repeating sub-units of nucleotides
- Nucleotides consist of a 5 carbon sugar, a phosphate, and an organic base
- In DNA the sugar is deoxyribose and the organic base can be one of adenine, thymine, cytosine and guanine
- In RNA the sugar is ribose and the organic base can be one of adenine, uracil, cytosine and guanine
- The DNA molecule is a double stranded helix with the two strands held together by hydrogen bonds between complementary base pairs adenine-thymine and cytosine-guanine
- RNA is a single stranded helix with base pairs of adenine-uracil and cytosine-guanine
- There are three types of RNA - messenger, transfer and ribosomal
- DNA carries out semi-conservative replication in which each strand of the original molecule acts as a template for the construction of a new one, so that each new double stranded molecule of DNA consists of one original strand and a new complementary strand.

Restriction endonuclease enzymes

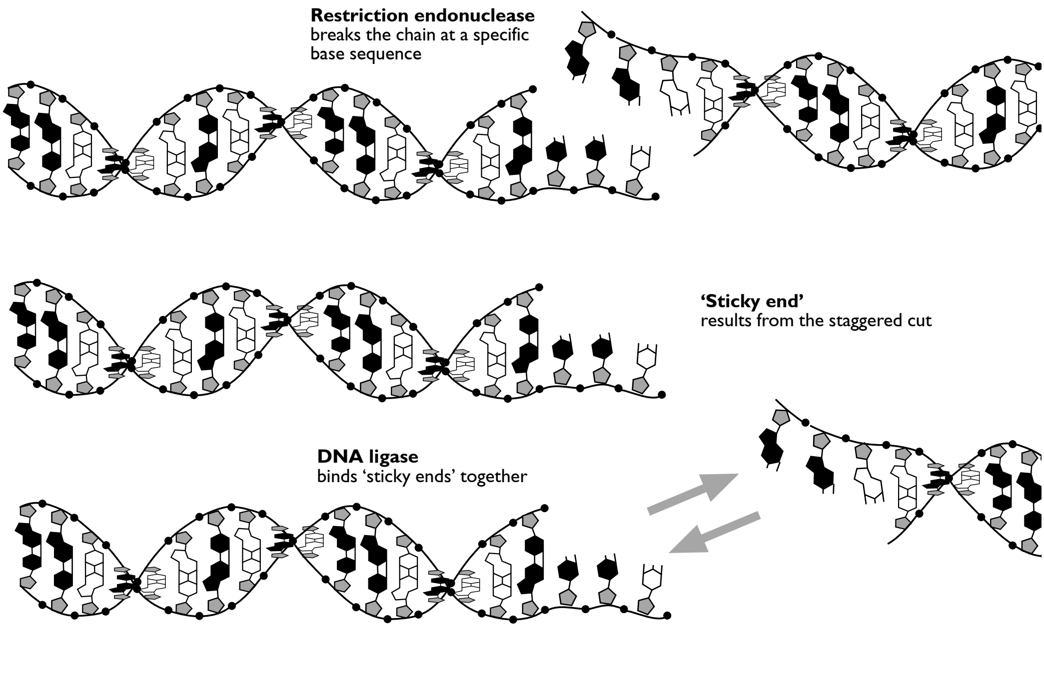
Another vital tool for gene technologists are enzymes called restriction endonucleases (restriction enzymes) which act like scissors to chop up DNA at specific base code sites into smaller polynucleotide fragments. Restriction enzymes are extracted from bacteria. In bacteria they serve to protect the organism from invading viral DNA. In gene technology they are used to cut DNA into fragments which can be separated and isolated. Often the cut leaves '**sticky ends**' which are exploited in another stage of the process.

DNA ligase

To 'ligate' is to join. DNA ligase is a joining enzyme. It is used to stick the sticky ends of DNA fragments together creating new combinations (**recombinant DNA**).

The techniques for transferring genes from one organism to another can be considered in five main stages.

Action of restriction and ligase enzymes



Topic Guide

Session:

KEY SKILLS C3.1b: IT3.3

Carbohydrates

Check List

- Simple formula for glucose - $C_6H_{12}O_6$
- Forms straight chain in dry powder form.
- Forms ring structure in solution.
- alpha and beta glucose are isomers differing in the 3D arrangement of their atoms.
- Monosaccharides (glucose, fructose and galactose) combine together with the elimination of water to form glycosidic bonds - a condensation reaction.
- Glycosidic bonds are broken by the addition of the elements of water across the bond - a hydrolysis reaction.
- Starch is a mixture of amylose (unbranched chains) and amylopectin (branched chains).
- Both being long chains (polymers) of alpha glucose molecules.
- When combined the alpha glucose molecules have their oxygen bridges on the same side of the chain, hydrogen bonds form between them and cause the chain to coil into a helix.
- Starch molecules are relatively insoluble in water.
- Cellulose is a polymer of beta glucose which have their oxygen bridges on alternate sides of the chain and so cannot form a helix.
- Instead they form hydrogen bonds with other adjacent chains to make flat ribbons which form cellulose fibres.

Student Activity

Materials

- Molecular model of alpha and beta glucose.
- Gravy powder, bunsen, gauze, and beaker with water
- Small tasting samples of glucose, fructose, sucrose in powdered form on sterile filter papers
- ❑ OHT Monosaccharides and disaccharides
- ❑ OHT Polysaccharides

Procedure

❑ OHT Monosaccharides and disaccharides recaps structure of alpha and beta glucose

Observe molecular models of glucose.

❑ OHT Polysaccharides

To illustrate the principle of starch hydration, dissolve the gravy powder in a small volume of water, then heat gently in the beaker (safety glasses etc). Describe how and when it thickens, then discuss why this happens.

'Blind' tasting of fructose, glucose and sucrose.

Put the substances in order of sweetness. Discuss how properties can vary with small molecular differences. (Caution - do not use galactose. Some people are intolerant)

Set work

Make molecular diagrams to show the structure of alpha and beta glucose, maltose, starch and cellulose.

Notes:

Biology or Biology (Human)

Examination Style Question Papers

Year Set 1

Complete with Assessment Grids & Mark Schemes