1.2 Carbohydrates

Recap

In the previous chapter, we learnt that a monosaccharide is an example of a monomer, and that monosaccharides can be used to make polymers called carbohydrates. In this chapter we explore this in more detail.

Key Aims

1. *Monosaccharides, Disaccharides and Polysaccharides.*
2. *Polymers of glucose and their uses.*
3. *Chemical tests for sugars.*

Simple and Complex Sugars

- **Simple sugars include monosaccharides and disaccharides.** Collectively these molecules are referred to as simple sugars.

- **Simple sugars can function as small molecules.** Monosaccharides and disaccharides can exist on their own and have many important biological roles.

- **Simple sugars can also be joined to form complex sugars.** Simple sugars can be utilised as monomers to make polymers called **complex carbohydrates**, which also have various significant biochemical roles.

Biological Molecule	Type	Examples
Simple Sugar	Monosaccharide	Glucose, Fructose, Galactose
	Disaccharide	Lactose, Maltose
Complex Sugar	Complex Carbohydrates	Starch, Cellulose

Table 1. Types of sugars.

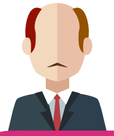
AQA Specification

Monosaccharides are the monomers from which larger carbohydrates are made. Glucose, galactose and fructose are common monosaccharides.

Monosaccharides

- Monosaccharides are **organic compounds.** This means that they contain the elements **C** and **H**, and additionally contain **O**.

- **Monosaccharides are the simplest sugars.** Monosaccharides just consist of a single monomer. Examples of monosaccharides are **glucose**, **fructose**, and **galactose**.



AQA Specification

Glucose has two isomers, α-glucose and β-glucose.

Glucose

- **Glucose is perhaps the most important biological monosaccharide.** Glucose is crucial as it is heavily involved in respiration, the process by which living organisms generate energy.

- Glucose is a **hexose sugar.** This means that it consists of 6 carbon atoms.

- **Glucose has two key isomers: α-glucose and β-glucose**. Memorise their structures for your exam. **Isomers** are chemical molecules that have similar chemical formulas, but different structures due to variation in atom arrangement. Isomers can have very different functions.

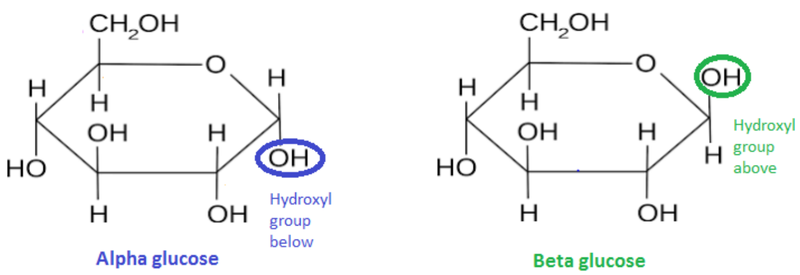


Fig 1. Molecular Formulas of A-Glucose and B-Glucose.
Note the structural differences between the two isomers.

Study Mind Tip

In addition to knowing the structures of α-glucose and β-glucose, it is really important that you spend some time learning the names and structures of some other common and biologically relevant sugars, shown in Figure 2.

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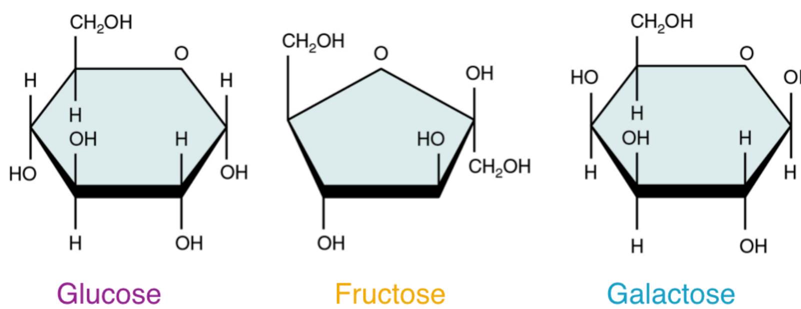


Fig 2. Molecular Formulas of Glucose, Fructose and Galactose.

AQA Specification

A condensation reaction between two monosaccharides forms a glycosidic bond.

Disaccharides

- **Disaccharides are made from two monosaccharides**. Disaccharides are **dimeric** molecules, made of two monomer monosaccharides.

- **Disaccharides can be homogenous or heterogenous**. The constituent monosaccharides can be the same (homogenous) or different (heterogenous).

- **Disaccharides are made via condensation reactions.** We learnt about condensation reactions earlier in this chapter. Disaccharide formation occurs via a condensation reaction between two monosaccharides. Figure 6 below demonstrates this reaction to synthesise the disaccharide maltose.

AQA Specification

Disaccharides are formed by the condensation of two monosaccharides.

- The covalent bond joining two monosaccharides together is a **glycosidic bond**.

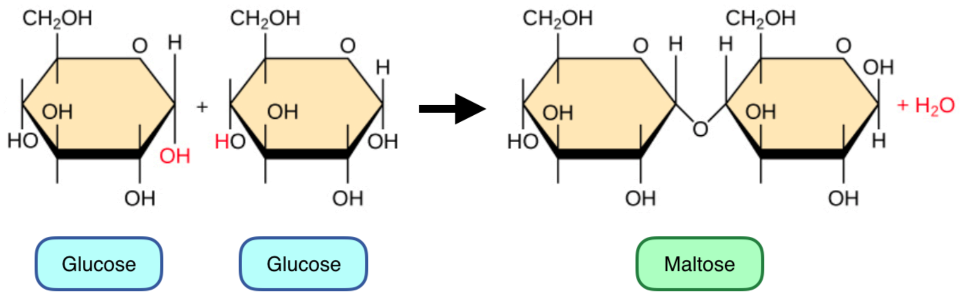


Fig 3. Formation of Maltose. Maltose is formed via condensation between two molecules of α-glucose. The individual glucose molecules are held together by a glycosidic bond (aka glycosidic linkage).

Study Mind Tip

For your exams, you need to know how to draw out the synthesis reactions of some common disaccharides. As such, it is important that you memorise the molecular structures of the common monosaccharides.

Outlined below for you are the disaccharide forming mechanisms you need to learn:

- **Maltose** is formed via a condensation reaction between two molecules of **a-glucose**.

- **Sucrose** is formed via a condensation reaction between a molecule of **glucose** and a molecule of **fructose**.

- **Lactose** is formed via a condensation reaction between a molecule of **glucose** and molecule of **galactose**.

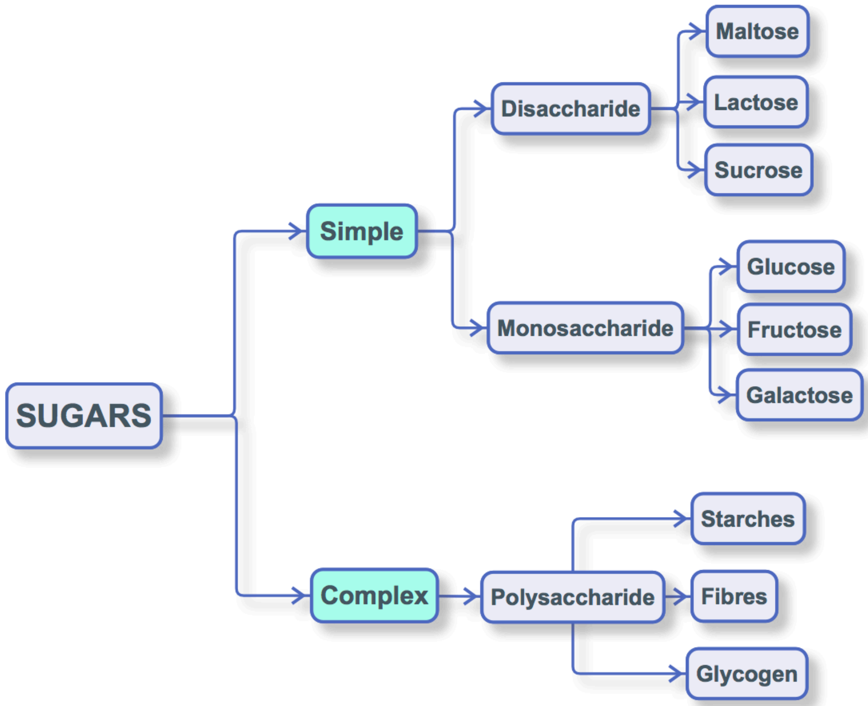


Fig 4. Examples of Simple and Complex Sugars.

Polysaccharides

- **Polysaccharides are complex carbohydrates**. Moving onwards from simple sugars (i.e. monosaccharides and disaccharides), we encounter a third class of sugar based compounds which we refer to as polysaccharides.

- **Polysaccharides are made by condensation of many glucose units.** **Polysaccharides** are polymers made up of multiple glucose monosaccharides. Like disaccharides, polysaccharides are made through **condensation reactions** between glucose monosaccharides, resulting in the formation of glycosidic bonds.

Study Mind Tip

Make sure that you take time to practice drawing out the monosaccharides and the resulting disaccharides so that you can quickly reproduce these diagrams in the exam.

Knowledge Recall

1. *Name two types of simple sugars?*
2. *What is the structural difference between α-glucose and β- glucose?*
3. *What monomers is lactose made from?*
4. *How many carbon atoms are in a glucose molecule?*

AQA Specification

Polysaccharides are formed by the condensation of many glucose units..

- **Polysaccharides can be broken down by hydrolysis**. Polysaccharides can be broken down into disaccharides or constituent monosaccharides via a hydrolysis reaction.

Different types of polysaccharides:

- **Glycogen is made from α-glucose**. Glycogen is branched and consists of many α-glucose monomers.

- **Starch is made from α-glucose**. Starch is also made from many α-glucose monomers. There are two types of starch: **amylose** (non-branched) and **amylopectin** (branched).

- **Cellulose is made from β-glucose**. Cellulose consists of non-branched β-glucose chains.

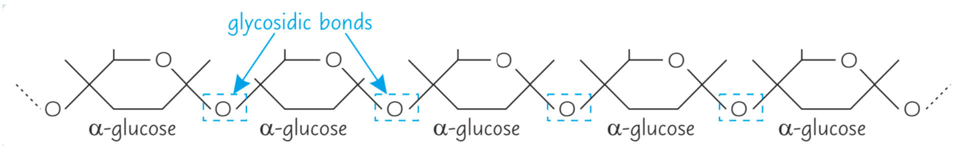


Fig 5. Structure of Polysaccharides. This diagram shows an example of a starch polysaccharide called amylose. Notice how it has been formed by joining many α-glucose molecules.

AQA Specification

Glycogen and starch are formed by the condensation of α-glucose. Cellulose is formed by the condensation of β-glucose.

Functions of Polysaccharides

Polysaccharides are involved in various key processes important in the maintenance of homeostasis in an organism**.**

Starch

- **Starch is the key energy store in plants.** Most living organisms obtain their energy from glucose. Excess amounts of glucose can be stored in the form of starch, which can later be broken down by a cell to obtain energy.

- **Starch is made from amylose and amylopectin.** The major starch that we will be concerning ourselves with is a carbohydrate that is actually

AQA Specification

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.

made up of two polysaccharides of α-glucose: amylose and amylopectin.

- **Starch is only found in plants.** It is important to note that starches are only found in plants, not animals.

- **Starch is insoluble.** This is also an adaptation for storage, because starch does not alter the water potential of cells. If it did, there could be an influx of water down an osmotic gradient, making cells swell (and even burst!).

Amylose

- **Amylose has a structure adapted for compact storage.**

- **Amylose is an unbranched chain of α-glucose.** Amylose is unbranched, and exists in a **coiled helical** structure, which gives it an overall cylindrical shape.

- **Amylose is compact and easy to store.** The purpose of this structure is simply because it allows the amylose to be neatly compacted, thereby allowing cells to store larger amounts of amylose.

Study Mind Tip

Students often get mixed up between the structure of amylopectin and glycogen. They are both made of branched, α-glucose chains, but glycogen has more branches - a branch per ~10 subunits, compared to per ~20 subunits in amylopectin.

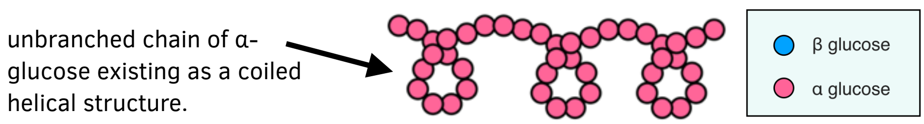


Fig 6. Amylose.

Amylopectin

- **Amylopectin has a structure adapted for fast breakdown.**

- **Amylopectin is a branched chain of α-glucose.** Unlike amylose, amylopectin is not in a helical structure, but instead exists as a long chain with branches extending outwards along the backbone.

Knowledge Recall

1. Is starch found in both animal and plant cells?
2. Name the two types of starch polysaccharides?
3. What are the structural adaptations of amylase?
4. What are the structural adaptations of amylopectin?

- **Amylopectin is easy to break down.** The branched structure means that the glycosidic bonds are much more readily available to various enzymes, which break down these branches in order to release glucose for respiration.

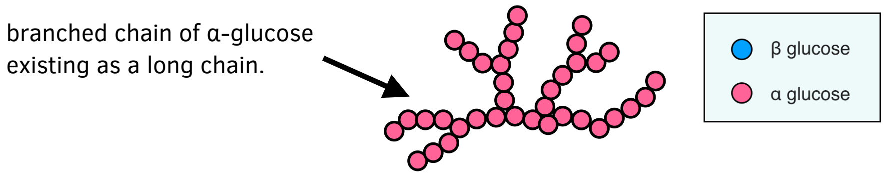


Fig 7. Amylopectin.

Glycogen

- **Glycogen is a key energy store in animals.** Whilst starch is the key energy store in plants, glycogen is the key energy store in animals.

- **Glycogen also consists of α-glucose.** Excess α-glucose molecules can be linked together to form very long polymers of glycogen.

- **Glycogen is stored in the liver.** Glycogen is typically stored in the liver. When energy levels in an organism run low, signals produced by the hypothalamus in the brain can activate the production of certain endocrine hormones which trigger the release and breakdown of glycogen into **glucose**. This glucose is then utilised by cells during cellular respiration in order to obtain energy.

- **Glycogen has a structure adapted for storage and fast breakdown.** Glycogen has more branches than amylopectin, and therefore can easily be broken down. Glycogen is also compact, like starch.

Knowledge Recall

1. Is glycogen found in both plants and humans?
2. Where is glycogen stored?
3. What has more branches, glycogen or amylopectin?
4. What structural adaptation do both starch and glycogen have?

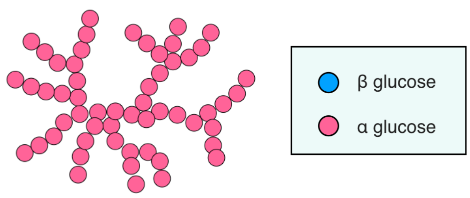


Fig 8. Glycogen.

Cellulose

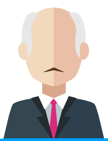
So far, the two carbohydrates which we have discussed (starch and glycogen) have primary been involved in energy processes and are made up of α-glucose.

- **Cellulose is found in plant cell walls**. Cellulose primarily functions as a **structural support** for plant cells and is found primarily in plant cell walls.

- **Cellulose is made from β-glucose**. Monomers of β-glucose form very strong chains held together by glycosidic bonds, which result in the formation of long cellulose chains

- **Cellulose is unique to plants**. Just like starch.

- **Cellulose is adapted to be strong**. The β-glucose cellulose chains are very tough and are able to form very strong fibres called **microfibrils**. This makes plant cell walls strong.



Knowledge Recall

1. *Is cellulose found in both plants and animals?*
2. *What monosaccharide is cellulose made from?*
3. *What part of the cell is cellulose found?*
4. *What is a structural adaptation of cellulose?*

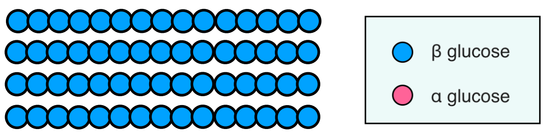


Fig 9. Cellulose.

	Cellulose	Starch		Glycogen
		Amylopectin	Amylose	
Source	Plant	Plant	Plant	Animal
Subunit	β glucose	α glucose	α glucose	α glucose
Bonds	1-4	1-4	1-4 and 1-6	1-4 and 1-6
Branched	No	No	Yes (per ~20 subunits)	Yes (per ~10 subunits)

Table 1. Cellulose, Starch and Glycogen. It is important to memorise the subunit of each polysaccharide, and also useful to have a rough idea of the structure and shape.

AQA Specification

Biochemical tests using Benedict's solution for reducing sugars and non-reducing sugars and iodine/potassium iodide for starch.

Biochemical Tests for Sugars

Two types of sugars: reducing and non-reducing.

- **Reducing sugars** act as reducing agents in chemical reactions (i.e. donates electrons to other molecules). Reducing sugars include all monosaccharides (e.g. glucose) and some disaccharides (e.g. lactose and maltose).

- **Non-Reducing sugars** do not act as reducing agents in chemical reactions. They include most disaccharides (e.g. sucrose) and simple polysaccharides.

Benedict's Test: Reducing Sugars

1. **Add Benedict's solution.** To test for the presence of a sugar, you add blue Benedict's solution to your sample.

2. **Heat the mixture.** Place the sample in a water bath and bring it to a boil.

3. **Observe the colour change**. If your sample contains reducing sugars, the chemical reaction between the reducing sugar and the Benedict's solution will result in the formation of a **coloured precipitate** (solid particles formed after a reaction between two liquids). The greater the concentration of the reducing sugar, the greater the colour change in the flow diagram below.

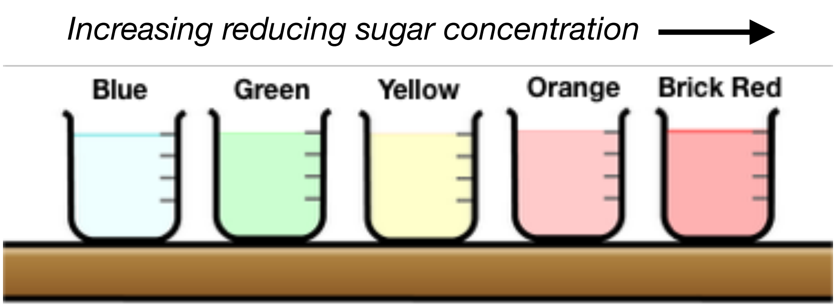


Fig 10. Colour Changes in Benedict's Test. The concentration of the reducing sugars in your sample dictates the extent of the precipitate formation and the colour change that you will observe.

Knowledge Recall

1. *What is the name of the test for Sugars?*
2. *What change in solution should you expect to observe for a reducing sugar?*
3. *What will no colour change indicate?*
4. *What further tests are needed to confirm the presence of a non-reducing sugar?*

Knowledge Recall

1. *What colour change indicates the presence of starch during an iodine test?*
2. *The iodine solution used for the iodine test is also known as?*
3. *Does the solution need to be heated during an iodine test?*

Benedict's Test: Non-reducing Sugars

No colour change (i.e. the solution remains blue), indicates a lack of reducing sugars in the sample. This could mean that there are non-reducing sugars present, or no sugars at all.

We can test further:

4. **Add dilute hydrochloric acid, then neutralise**. The acid will break down the non-reducing sugars into monosaccharides. After adding acid, neutralise the solution with sodium hydrogencarbonate.

5. **Heat and observe colour change**. We can then do the Benedict's test, as we did above for reducing sugars. If there are non-reducing sugars in the sample, we will observe a colour change similar to the one we see with reducing sugars (blue to green to yellow to orange to brick red).

Iodine Test: Starch

1. **Add aqueous iodine solution to sample.** This is also known as Lugol's solution. It is brownish-orange in colour, and is formed by adding potassium iodide to water.

2. **Observe the colour change.** If starch is present, the solution will immediately change to a dark blue-black colour. If the colour does not change, this means that the sample did not contain and starch.