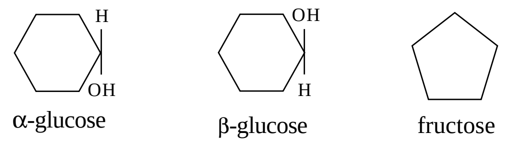
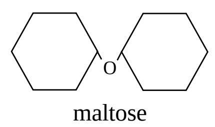
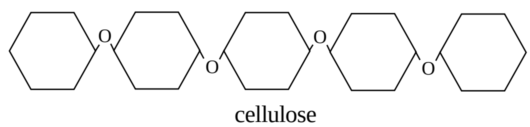
Bio Factsheet

Number 39

Carbohydrates: Revision Summary

Carbohydrates contain 3 elements: Carbon (C), Hydrogen (H) and Oxygen (O). Thus, if we remove water from carbohydrates, all that remains is carbon. Carbohydrates can be divided into 3 categories; monosaccharides, disaccharides and polysaccharides (Table 1).

Table 1. Structure of monosaccharides, disaccharides and polysaccharides

Category	Example	Site	Structure
Monosaccharide (made of 1 sugar molecule)	glucose fructose galactose	fruit fruit, nectar milk	
Disaccharide (made of 2 monosaccharides joined together)	maltose = α-glucose + α-glucose sucrose = glucose + fructose lactose = glucose + galactose	germinating seeds phloem tissue, fruit milk	
Polysaccharide (made of many monosaccharides joined together)	starch = polymer of glucose glycogen = polymer of α-glucose cellulose = polymer of β-glucose chitin = polymer of glucosamine (glucose with an amino acid attached)	chloroplast stroma muscle cells plant cell wall exoskelteton of arthropods	

Monosaccharides and Disaccharides

Monosaccharides and disaccharides are **sugars**. They all have the basic formula $(CH_2O)_n$ and can be classified according to how many carbon atoms they contain.

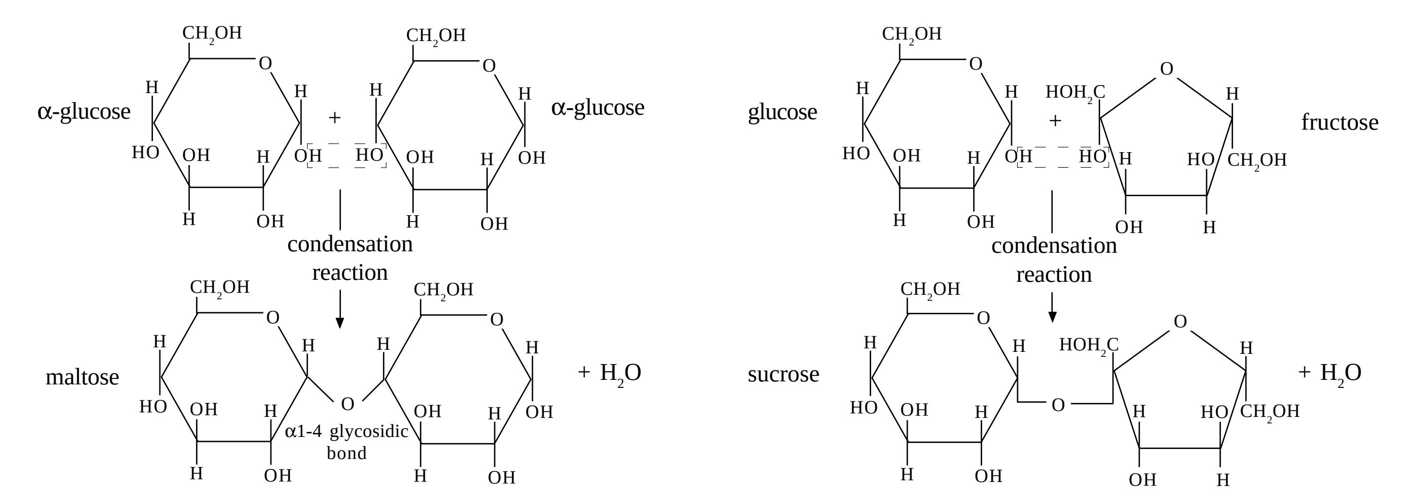
3C = **tri**ose sugars e.g. glyceraldehyde $C_3H_5O_2$
5C = **pent**ose sugars e.g. ribose $C_5H_{10}O_5$
6C = **hex**ose sugars e.g. glucose $C_6H_{12}O_6$

Formation of disaccharides - typical exam questions

Common exam questions include:
1. Name the reaction involved when a disaccharide is formed
2. Name the type of bond formed
3. Show, by drawing a diagram, how a disaccharide is formed

Questions 1 and 2 are very simple - Disaccharides form in a condensation reaction which forms a glycosidic bond. The only way to get Question 3 correct is to practice! Fig 1 shows how maltose and sucrose are formed from their monosaccharides.

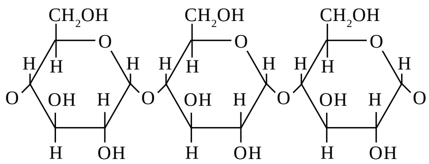
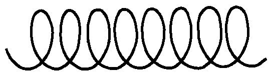
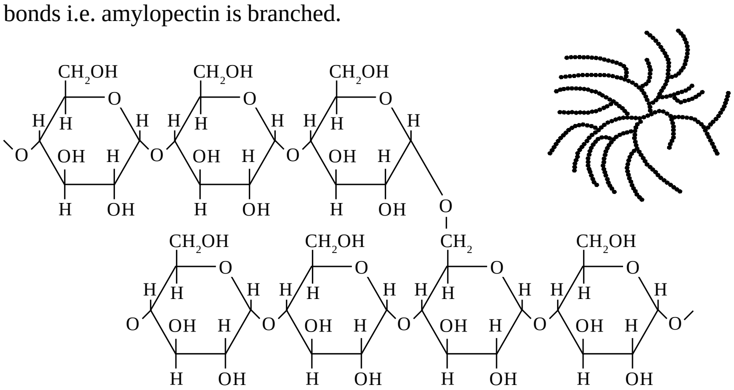
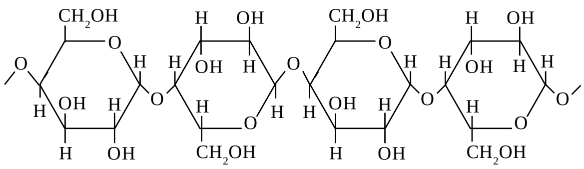
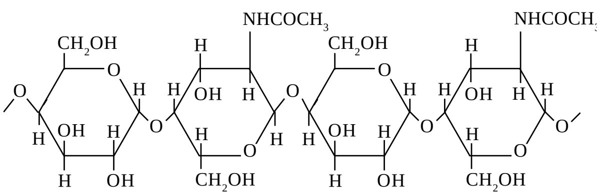
Fig 1. Formation of maltose and sucrose from their monosaccharides



Polysaccharides

Polysaccharides are polymers i.e. they are made up of many repeating units. Three polysaccharides which commonly feature in exam questions are starch, cellulose and glycogen. By far the most common question asks "How is the structure of polysaccharides related to their function?". It should be noted that all 3 have the advantage that they are insoluble in water and therefore have no osmotic effect i.e. effect on water potential and are unable to diffuse out of the cell. More specific features are summarised in Table 2.

Table 2. Structure:Function of polysaccharides

Polysaccharide	Structure	Structure:Function
Starch – Main storage polysaccharide in plants.	Made of two polymers of α-glucose; amylose and amylopectin **amylose** – a chain of glucose molecules joined by α-1,4-glycosidic bonds which, by hydrogen bonding, form a helix. It is this helix which holds and forms a complex with iodine when we test for starch   **amylopectin** – glucose molecules joined by α-1,4-glycosidic bonds **but** after every 25 glucose molecules adjacent chains are connected by α-1,6-glycosidic bonds i.e. amylopectin is branched. 	Insoluble in water, therefore good **storage** compound e.g. in stroma of chloroplasts The helix forms a compact shape which allows tight packing and is therefore an excellent storage molecule. Amylopectin has many protruding ends (glucose molecules) which can be hydrolysed rapidly – allows rapid release of glucose to provide energy via respiration. Starch from different sources is unique. Each source has characteristic proportions of amylose and amylopectin and the lengths of these two molecules differ. Thus, microscopic analysis of a starch grain can be used to identify which type of plant it came from.
Glycogen – main storage polysaccharide of animal and fungal cells.	Similar structure to amylopectin (in that it is a polymer of α-glucose) of starch but has many more branches and the branches are shorter. Glycogen is even more compact than amylopectin.	**Compact storage** molecule in mammalian liver and in fungal cells and can be broken down to release glucose. The structure of glycogen allows faster hydrolysis than starch which is important as animals may need emergency glucose faster than plants.
Cellulose – structural polysaccharide in plants.	Long unbranched chains of glucose linked by β-1,4-glycosidic bonds. The individual chains are then linked to each other by hydrogen bonds. These are formed into **strong** microfibrils. 	Hydrogen bonding prevents water entering the molecule. Cellulose is therefore resistant to enzyme hydrolysis which makes it an excellent **structural** polysaccharide. Cellulose cell walls provides protection to all plant cells. Humans cannot digest cellulose but herbivores have bacteria and protoctists in their digestive system which produce cellulase (β-1,4-glycosidase). The long unbranched fibrous structure provides great mechanical strength.
Chitin – structural polysaccharide found in hard exoskeletons of all arthropods and in hyphal walls of many fungi.	Made of glucosamine units (glucose + amino acid) and is linked by β-1,4-glycosidic bonds. 	The presence of the amino group causes even more hydrogen bonding between the chains than in cellulose. Chitin is therefore an extremely **resilient** and **tough** polysaccharide.

Testing for Carbohydrates

The most common tests for carbohydrates are summarised in Table 3.

Table 3.Common carbohydrate tests

Test	Reagent	Method	Positive result
Starch	Iodine	Add 2-3 drops of iodine	Blue/black precipitate (ppt) forms
Reducing Sugar e.g. glucose fructose maltose	Benedicts' reagent	Add volume of Benedicts' reagent = volume of test solution. Mix. Heat to 70^{o}C (Do not boil because this would split a disaccharide e.g. sucrose into reducing sugars (glucose and fructose) and give a false positive test)	Solution turns from blue to pale green to yellow to orange to brick red ppt of copper (I) oxide. The intensity of the colour, which can be measured accurately using a colorimeter, indicates how much reducing sugar was present.
Non-reducing sugar e.g. sucrose	Benedicts' reagent	To 2cm^3 test solution add 1cm^3 dilute HCl. Boil. Cool and neutralise with excess NaOH. Repeat test for reducing sugar	Brick red ppt

Functions of carbohydrates: a summary

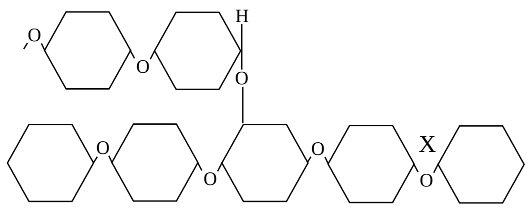
1. Immediate respiratory substrates e.g. glucose
2. Energy stores e.g. glycogen in mammals
   starch in plants
3. Structural components e.g. cellulose in plant cell walls
   chitin in arthropod exoskeleton
   pentose sugars - ribose and deoxyribose are components of RNA and DNA respectively.
4. Metabolites i.e. intermediates in biochemical pathways
5. Cell-to-cell attachment molecules e.g. combined with proteins to form glycoproteins or lipids to form glycolipids on plasma membrane
6. Transport e.g. sucrose in plant phloem tissue

Digestion of polysaccharides

	Stage	Enzyme
Starch	Starch → Maltose	salivary and pancreatic amylase. α amylase breaks 1-4 links randomly. β amylase breaks alternate 1-4 links.
	Maltose → Glucose	Maltase in intestinal juice
Glycogen	Glycogen → Glucose	β cells in islets of Langerhans secrete glucagon which activates enzymes for glycogenolysis
Cellulose	Herbivores have bacteria and protoctists in their digestive systems	Cellulase (β-1,4-glycosidase)

Practice questions

1. The diagram shows part of a starch molecule



   (a) Name the type of bond found at position X (1 mark)
   (b) Name the reaction which formed this bond (1 mark)
   (c) Explain how the structure of this molecule is related to its function (2 marks)

2. Outline a biochemical test which you could use to distinguish between a solution of glucose and a solution of sucrose (3 marks)

Answers

Semicolons indicate marking points

1. (a) Glycosidic;
   (b) Condensation;
   (c) Compact/tightly packed/ref to amylase helix;
   efficient storage;
   amylopectin glucose units;
   allow rapid hydrolysis/release of glucose;

2. Add Benedicts' reagent to each solution;
   heat to 60-80^{o}C;
   glucose solution would give brick red precipitate;
   sucrose solution would not change;

Acknowledgements;
This Factsheet was researched and written by Kevin Byrne
Curriculum Press, Unit 305B, The Big Peg, 120 Vyse Street, Birmingham. B18 6NF

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