CARBOHYDRATES

NSW Syllabus References:
Chemistry HSC syllabus
Core 9.2 Production of Materials

NSW Syllabus References:
Chemistry HSC syllabus
Option 9.9 Forensic Chemistry

CARBOHYDRATES

Carbohydrates make up a group of chemical compounds found in plant and animal cells. They have the empirical formula \( \text{C}_n\text{H}_{2n}\text{O}_n \) or \( (\text{CH}_2\text{O})_n \). An empirical formula tells the atomic composition of the compound, but nothing about structure, size or the chemical bonds that are present. Since this formula is essentially a combination of carbon and water, these materials are called “hydrates of carbon” or carbohydrates for short.

Carbohydrates are the primary products of plant photosynthesis. The simplified light-driven reaction of photosynthesis results in the formation of a carbohydrate:

\[
\text{nH}_2\text{O} + \text{nCO}_2 \rightarrow -(\text{CH}_2\text{O})_n + \text{nO}_2
\]

This type of carbohydrate is found in the structures of plants and is used in the reverse reaction of photosynthesis (respiration) or is consumed as fuel by plants and animals.

Carbohydrates are widely available, are inexpensive and are used as an energy source for our bodies and for cell structures. Food carbohydrates include the simple carbohydrates (sugars) and complex carbohydrates (starches and fibre). Before a big race, distance runners and cyclists eat foods containing complex carbohydrates (pasta, rice and bread) to give them sustained energy.

Carbohydrates are divided into monosaccharides, disaccharides and polysaccharides.

Monosaccharides

Monosaccharides are single-molecule sugars (the prefix "mono" means one) that form the basic units of carbohydrates. They usually consist of three to seven carbon atoms with attached hydroxyl (-OH-) groups in specific stereochemical configurations. The carbons of carbohydrates are traditionally numbered starting with the carbon of the carbonyl end of the chain (the carbonyl group is the carbon double-bonded to oxygen). The number of carbons in the molecule generally categorizes monosaccharides. For example, three-carbon carbohydrate molecules are called trioses, five-carbon molecules are called pentoses and six-carbon molecules are called hexoses.

Ribose and 2-deoxyribose are pentoses and both have a crucial role in reproduction as polymers known as ribonucleic acid (RNA) and deoxyribonucleic acid (DNA). One of the most important monosaccharides is glucose (dextrose). This molecule is the primary source of chemical energy for living systems. Plants and animals alike use this molecule for energy to carry out cellular processes. Mammals produce peptide hormones (insulin and glucagon) that regulate blood glucose levels and a disease of high blood glucose is called diabetes. Other hexoses include fructose (found in fruit juices) and galactose.

Different structures are possible for the same monosaccharide. Although glucose and fructose are identical in chemical composition, they are very different in structure (see molecular models). Such materials are called isomers. Isomers in general have very different physical properties based on their structure.
Disaccharides

Disaccharides are two monosaccharide sugar molecules that are chemically joined by a glycosidic linkage (-O-) to form a "double sugar" (the prefix "di" means two). When two monosaccharide molecules react to form a glycosidic bond (linkage), a water molecule is generated in the process through a chemical reaction known as condensation. Therefore, condensation is a reaction where water is removed and a polymer is formed. The most well-known disaccharide found in nature is sucrose, which is also called cane sugar, beet sugar or table sugar (see Figure 1C).

- Sucrose is a disaccharide of glucose and fructose.
- Lactose or milk sugar is a disaccharide of glucose and galactose and is found in milk.
- Maltose is a disaccharide composed of two glucose units.

Disaccharides can easily be hydrolysed (the reverse of condensation) to become monosaccharides, especially in the presence of enzymes (such as the digestive enzymes in our intestines) or alkaline catalysts. Invert sugar is created from the hydrolysis of sucrose into glucose and fructose. Bees use enzymes to create invert sugar to make honey. Taffy and other invert sugar type candies are made from sucrose using heat and alkaline baking soda. Disaccharides are classified as oligosaccharides (the prefix "oligo" means few or little). This group includes carbohydrates with 2 – 20 saccharide units joined together. Carbohydrates containing more than 20 units are classified as polysaccharides.

Figure 1 – molecular models of different carbohydrates

A. Glucose, a six-membered ring monosaccharide.
B. Fructose, a five-membered ring monosaccharide.
C. Sucrose, a disaccharide containing glucose and fructose.
D. Molecular representation of starch illustrating the alpha-glycosidic linkages joining monosaccharides to form the polysaccharide structure.
Polysaccharides

Polysaccharides (the prefix "poly" means many) are formed when many single sugars are joined together chemically. Carbohydrates were one of the original molecules that led to the discovery of what we call polymers. Polysaccharides include starch, glycogen (storage starch in animals) and cellulose (found in the cell walls of plants).

Starch is the predominant storage molecule in plants and provides the majority of the food kilojoules consumed by people worldwide. Most starch granules are composed of a mixture of two polymers: a linear polysaccharide called amylose and a branched-chain polysaccharide called amylopectin.

- Amylopectin chains branch approximately every 20 – 25 saccharide units. Amylopectin is the more common form of starch found in plants. Animals store energy in the muscles and liver as glycogen. This molecule is more highly branched than amylopectin. For longer-term storage, animals convert the food kilojoules from carbohydrates into fat. In the human and animals, fats are stored in specific parts of the body called adipose tissue.

Cellulose is the main structural component of plant cell walls and is the most abundant carbohydrate on earth. Cellulose serves as a source of dietary fibre since, as explained below, humans do not have the intestinal enzymes necessary to digest it.

- Starch and cellulose are both homopolymers (“homo” means same) of glucose. The glucose molecules in the polymer are linked through glycosidic covalent bonds. There are two different stereochemical configurations of glycosidic bonds – an alpha linkage and a beta linkage. The only difference between the alpha and beta linkages is the orientation of the linked carbon atoms. Therefore, glucose polymers can exist in two different structures, with either alpha or beta linkages between the glucose residues.

- Starch contains alpha linkages (see Figure 1D) and cellulose contains beta linkages. Because of this difference, cornstarch has very different physical properties compared to those for cotton and wood. Salivary amylase only recognises and catalyses the breakdown of alpha glycosidic bonds and not beta bonds. This is why most mammals can digest starch but not cellulose (grasses, plant stems, and leaves).

Food uses of carbohydrates

Carbohydrates are widely used in the food industry because of their physical and chemical properties. The sweet taste of sucrose, glucose and fructose is used to improve the palatability of many foods. Lactose is used in the manufacture of cheese food, is a milk solids replacer in the manufacture of frozen desserts and is used as a binder in the making of pills/tablets.

Another useful aspect of some carbohydrates is their chemical reducing capabilities. Sugars with a free hemiacetal group can readily donate an electron to another molecule. Glucose, fructose and lactose are all reducing sugars. Sucrose or table sugar is not a reducing sugar because its component monosaccharides are bonded to each other through their hemiacetal group. Reducing sugars react with the amino acid lysine in a reaction called the Maillard reaction. This common browning reaction produced by heating the food (baking, roasting or frying) is necessary for the production of the aromas, colours and flavours in caramels, chocolate, coffee and tea. This non-enzymatic browning reaction differs from the enzymatic browning that occurs with fresh-cut fruit and vegetables, such as apples and potatoes.
Carbohydrates can protect frozen foods from undesirable texture and structural changes by retarding ice crystal formation. Polysaccharides can bind water and are used to thicken liquids and to form gels in sauces, gravies, gelatine desserts and candies like jelly beans and orange slices. They are also used to stabilise dispersions, suspensions and emulsions in foods like ice cream, infant formulas, dairy desserts, creamy salad dressings, jellies, jams and candy. Starches are used as binders, adhesives, moisture retainers, texturisers and thickeners in food.

**Pectin**

In the following experiment we will investigate pectin. Pectin is a polysaccharide that is found in green apples and in the peel of limes and lemons. Pectin forms a gel when heated with an acid and a sugar, and is used to make high-sugar jellies, jams and marmalade.

Pectin solutions form gels when acid and sugar are added. The acid will reduce the pH of the solution and cause the carbohydrate molecules to form junctions. From these junctions a network of polymer chains can entrap an aqueous solution. The sugar increases junction formation. The pectin makes the gel and the low pH and the amount of soluble solids adjusts the rigidity. The optimum conditions for jelly strength are 1% pectin, a pH of 3.2, and a sugar concentration of 55% (by weight).

**Activity**

To observe how pectin can be used to form a gel and the effects of too little and too much sugar on gelling.

**Materials**

- Jelly crystals
- Concentrated fruit juice (apple, grape) - unfrozen
- Table sugar
- Water
- 600mL beakers
- Bunsen burner and tripod, or a hot plate
- Heatproof gloves
- Balance or scale
- Measuring cylinder
- Heatproof mat
- Stirring rod

**Procedures**

**Part 1**

1. Measure out 53g of sugar.
2. Put 18 mL of fruit juice concentrate, 60mL of water and 7 grams of Jelly crystals into a 600ml beaker.
3. Place the beaker on a hot plate or a tripod with a Bunsen burner and stir constantly over a high heat until bubbles form all around the edge.
4. Add the sugar. Bring the mixture to a boil and boil hard, while stirring, for one minute.
5. **Caution!** Be sure to adjust the heat source so that the liquid does not boil up the sides of the beaker. This can boil over very quickly if it's not carefully watched.
6. Using gloves, remove the beaker from the heat source. Place the beaker on a heat proof pad to cool. Allow the jelly to cool. Use a spoon to skim off the foam on the top.
7. Record your results.
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Student worksheet

Part 2
1. Measure out 26g of sugar.
2. Repeat steps 2, 3, 4 and 5 in Part 1.
3. Record your results.

Part 3
1. Measure out 106g of sugar.
2. Repeat steps 2, 3, 4 and 5 in Part 1.
3. Record your results.

Data Table - Jelly Consistency

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Jelly</th>
<th>Consistency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part 1</td>
<td>Normal</td>
<td></td>
</tr>
<tr>
<td>Part 2</td>
<td>Half sugar</td>
<td></td>
</tr>
<tr>
<td>Part 3</td>
<td>Twice sugar</td>
<td></td>
</tr>
</tbody>
</table>

Questions

1. How did the consistency of the jelly change when you changed the ratio of sugar to pectin?

2. Why did the consistency change when you changed the ratio of sugar to pectin?
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Student worksheet

NAME: ________________________
CLASS: ________________

Cryptic carbohydrates

Fill in the blank spaces with the appropriate terms to complete the sentences. Solve the hidden message by entering the boxed letters in the spaces at the bottom of the page.

1. __  __  __  __  __  __ are identical in chemical composition but differ structurally.

2. __  __  __  __  __  __  __  __ is a polymer of glucose and serves as a source of dietary fibre for humans.

3. __  __  __  __  __  __  __  __ __  __  __ __  __  __ are an inexpensive and widely available source of energy for our bodies.

4. __  __  __  __  __  __  __  __ is a disaccharide found in cow’s milk.

5. __  __  __  __  __  __  __  __ is a disaccharide composed of glucose and fructose.

6. __  __  __  __  __  __  __  __ is a starch that has gelling properties and is used in making jams and preserves.

7. Glucose is a __  __  __  __  __  __  __  __  __  __  __

8. The __  __  __  __  __  __  __ reaction is a non-enzymatic browning reaction that occurs when foods are roasted or baked.

9. __  __  __  __  __  __  __  __ bonds chemically join two or more monosaccharide molecules.

10. Carbohydrates that are the primary products of plants.

HIDDEN MESSAGE:
A polysaccharide called carrageenan is a seaweed extract. Carrageenan is used as a stabiliser in what popular frozen dessert product?

__  __  __  __  __  __  __  __  __  __  __
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Name: ___________________________  Class: ____________

Cool Carbs

Find the words listed below in the word search. After all the words are found, the letters that are not used reveal a hidden message at the bottom of this sheet.

M A I L L A R D S C H O O O H P
S E E R A V A A R T G I C E O
T Y T O E F F O G L N R O D L
S W A I T M H I U U A A N E Y
A C R H F O O C O T S D L G S
R O D U E P O S S F K G Q P A
G L Y C O S I D I C B O N D C
A S H B E B O J E F O R G E C
A Y O L D Z M L R V E N Q S H
I F B T V K E U U M L M N O A
R P R J Z D C Y Y L C N P T R
O J A P B T P L N T L A K C I
F M C O O X O N I T C E P A D
L E G S Q P E N E R G Y C L E
Y J E B N J E W W J H G O U R

HIDDEN MESSAGE: We should __ __ __ __ __ __ __ __ __ __ __ __ __ __ __ __ __ __.