

FOOD SCIENCE AND TECHNOLOGY

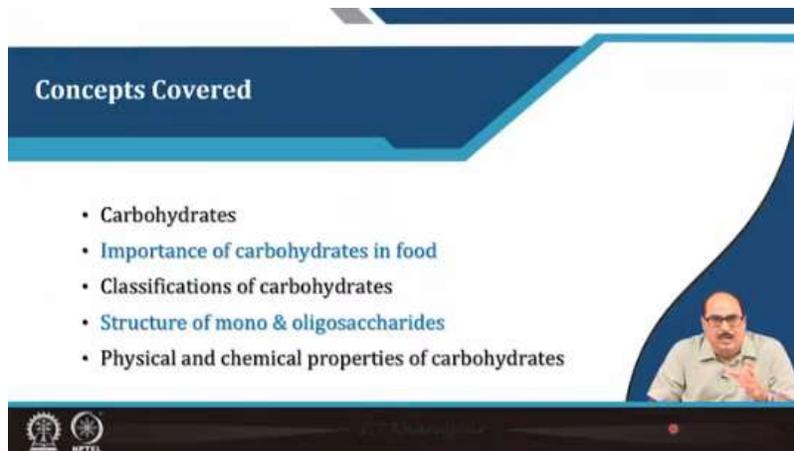
Lecture22

Lecture 22: Sugars and Oligosaccharides

Hello everyone, namaskar. Now, in this lecture, we will talk about sugars and oligosaccharides.



These sugars and oligosaccharides are carbohydrates, you know. They are very important constituents in food materials, so we will discuss what these carbohydrates are and their importance in foods.



Also, we will talk about the classification of carbohydrates, then the structure of mono- and oligosaccharides, and then properties, both physical and chemical properties of the

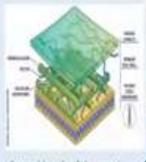
Importance of carbohydrates in foods

❖ Metabolic/Nutritional

- Form a major part of food and are the primary source of energy.
- Essential for brain function, muscle activity, and maintaining energy levels.

❖ Structural

- Insoluble carbohydrate polymers, such as cellulose, hemicellulose, and lignin, serve as structural and protective elements in the cell walls of plants and bacteria, and in animal connective tissues.
- Cellulose is the primary structural component of plant cell walls and a key fiber in animal feed.




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As far as their structural role, the insoluble carbohydrate polymers such as cellulose, hemicellulose, and lignin serve as structural and protective elements in the cell walls of plants and bacteria, as well as in animal connective tissues. They provide the structural material. Cellulose is the primary structural component of the plant cell wall and is a key fibre in animal feed, foods, etc.

Importance of carbohydrates in foods (Contd..)

❖ Communication

- Glycosaminoglycans as polymers of derivatives of carbohydrates are of critical importance in intercellular communication in organisms.
- More complex carbohydrate polymers covalently attached to proteins or lipids act as signals that determine the intracellular location or metabolic fate of these hybrid molecules, called glycoconjugates.

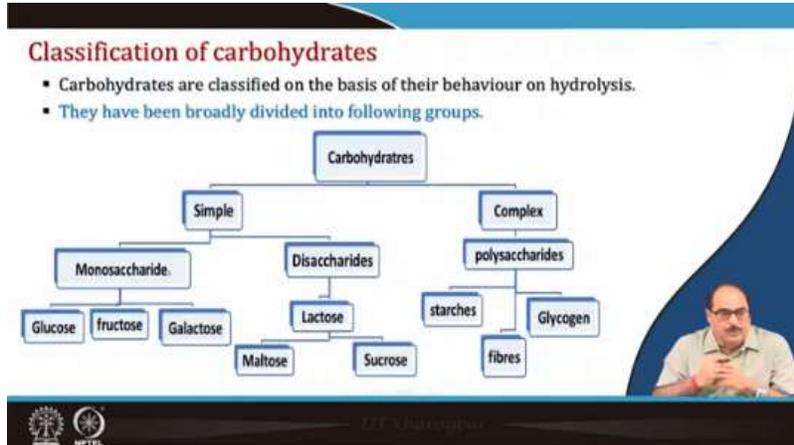
❖ Biosynthesis of other compounds

- Carbohydrates are source of carbon for biosynthesis of other compounds.
- Simple carbohydrate glucose (dextrose) gets oxidized by liver cells. In exchange, the cells produce adenosine triphosphate (ATP), the main energy-providing compound in the cell.



Then, in communication, glycosaminoglycans, as polymers of derivatives of carbohydrates, are of critical importance in intercellular communication in organisms. More complex carbohydrate polymers, which are covalently attached to proteins or lipids, act as signals that determine the intracellular location or metabolic fate of these hybrid molecules, and they are called glycoconjugates. So, they are also very important in internal communication among the macromolecules and all those processes, etcetera. Then, these carbohydrates are very important for the biosynthesis of many other compounds in the system, in the living system. Like, they are the source of carbon for biosynthesis of other

compounds like simple carbohydrates, glucose, dextrose, which get oxidized by liver cells. In exchange, the cell produces adenosine triphosphate, which is ATP, the main energy-providing compound in the cell.



So, the carbohydrates are different types of carbohydrates. They are classified on the basis of their behavior upon hydrolysis. Broadly classified into three major groups like monosaccharides, disaccharides, oligosaccharides, and polysaccharides. Monosaccharides may be glucose, fructose, galactose, etc. The disaccharides, when two monosaccharide units join together, are called disaccharides, like lactose, maltose, and sucrose. Similarly, there will be trisaccharide, tetrasaccharide, and pentasaccharide depending upon the number of monosaccharide units. And when there is a number of monosaccharides are about 10 less than 10. It is generally called oligosaccharide. When the number of monosaccharide units becomes more than 10, the resulting macromolecule is generally called a polysaccharide, such as starches, fibre, glycogen and so on.

Monosaccharides

- Cannot be hydrolysed further to give simpler unit of polyhydroxy aldehyde or ketone.
- About 20 monosaccharides are known to occur in nature
- Depending upon whether they contain an aldehyde or keto groups, they may be called aldoses or ketoses
- The most abundant monosaccharide is the six-carbon sugar, glucose (dextrose). Glucose occurs in ripe fruits, flowers, honey, beetroot, etc.
- Fructose (levulose) is found in fruits and honey. It is the building unit of the polysaccharide, inulin, and is one of the structural units of cane sugar (sucrose).

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So, let us talk about monosaccharides like you see simple sugar honey in the milk in the maize apple fruits and vegetables etcetera that is the mainly the sugars is present in the monosaccharides in the form of monosaccharides. And they basically this is the building single unit of the carbohydrate that cannot be further hydrolysed into simpler units. The unit of polyhydroxy aldehyde or ketone, and there are about 20 monosaccharides which are known to occur in nature, depending upon whether they contain an aldehyde or keto group. They can be called aldose sugars or ketose sugars. The most abundant monosaccharide is the 6-carbon-containing sugar, glucose or dextrose. So, glucose occurs in ripe fruits, flowers, honey, beetroots, etc. That is, independent monosaccharides cause the sweetness, etc. Fructose, that is levulose, is found in fruits and honey. It is the building unit of polysaccharides. And it is one of the structural units of cane sugar, like sucrose, etcetera. So, this glucose and fructose are aldose sugars, whereas fructose is a ketose sugar.

❖ **Classification of monosaccharides** Monosaccharides (Contd...)

Number of carbon atoms	Kind of carbonyl group	
	Aldehyde	Ketone
3	Triose	Triulose
4	Tetrose	Tetulose
5	Pentose	Pentulose
6	Hexose	Hexulose
7	Heptose	Heptulose
8	Octose	Octulose
9	Nonose	Nonulose

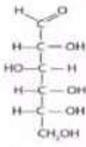


So, the classification is that these sugars, monosaccharides, can be derived, classified or named based on the number of carbon atoms. Like either 3, or they can be given in the number of either aldehyde groups or ketone groups. For example, a 3-carbon-containing aldehyde is called triose; a 3-carbon-containing sugar with a ketone group is called triulose. A 6-carbon-containing aldehyde group is called a hexose, like glucose, etc. If it is an aldehyde group, it is an aldose hexose; a ketone group is known as a ketose hexulose. Then similarly, 7 carbon heptose or heptulose, 8 carbon octose or octulose, 9 carbon nonose or nonulose and even more than 9, it becomes a different name, etc., are there. So, this is the system. In fact, sometimes these sugars were also earlier in the beginning monosaccharide, and they were named from the source from which they were derived. This is xylose wood

sugar, milk sugar, lactose, it is obtained from the lactose secretion, fruit sugar, fructose, like that. So, and these trivial names are even now also they are in commonly used.

❖ **Important monosaccharides**

Glucose



D-(+)-glucose

- Occurs in nature principally as optically dextrorotatory isomer.
- An essential constituent of human blood.
- It is prepared as follows

✓ **From sucrose (Cane sugar):** If sucrose is boiled with dilute HCl or H₂SO₄ in alcoholic solution, glucose and fructose are obtained in equal amounts.

$$\text{C}_{12}\text{H}_{22}\text{O}_{11} + \text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + \text{C}_6\text{H}_{12}\text{O}_6$$

Sucrose Glucose Fructose

✓ **From starch:** Commercially glucose is obtained by hydrolysis of starch by boiling it with dilute H₂SO₄ at 393 K under pressure.

$$(\text{C}_6\text{H}_{10}\text{O}_5)_n + n \text{H}_2\text{O} \rightarrow n \text{C}_6\text{H}_{12}\text{O}_6$$

Starch or cellulose Glucose

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So, important monosaccharides that is the ones that include Glucose, which is 6 6-carbon aldehyde sugar. It has 4 asymmetric carbon atoms, 4 chiral centres. It occurs in nature principally as optically deoxy dextrorotatory isomer. It is an essential constituent of human blood. It can be prepared from the cane sugar, also known as sucrose. Its sucrose is boiled with dilute HCL or hydrochloric acid or sulfuric acid in alcohol alcoholic solution. Glucose and fructose are obtained in equal concentration, like sucrose. When it is hydrolysed, cane sugar is hydrolysed, and you get a cumulative concentration of glucose and fructose. These two form the sucrose. Then, similarly, starch glucose is the major monomer unit component of the primary sugar, which is present in starch in the form of starch. So, if starch is hydrolysed, then you can get a glucose unit. It is obtained by the hydrolysis of starch by boiling with dilute sulphuric acid at 393 K under pressure. And in fact, that is the this is one of the major reasons that is the in the grains etcetera these reducing sugars that is they are present in the form of polymers that is where more reactive groups are prevented and these polymers that is like a starch and all those things, they have the longest shelf life they provide the longer stability to the grains etcetera. Whereas the likes of this in the fruits, etc., is the presence of monosaccharides, which are highly reactive substances and less stable.

Important monosaccharides (Contd...)

$$\begin{array}{c}
 \text{H} \\
 | \\
 \text{H}-\text{C}=\text{O} \\
 | \\
 \text{HO}-\text{C}-\text{H} \\
 | \\
 \text{H}-\text{C}-\text{OH} \\
 | \\
 \text{H}-\text{C}-\text{OH} \\
 | \\
 \text{CH}_2\text{OH} \\
 \text{D-(+)-glucose}
 \end{array}$$


$$\begin{array}{c}
 \text{CH}_2\text{OH} \\
 | \\
 \text{C}=\text{O} \\
 | \\
 \text{HO}-\text{C}-\text{H} \\
 | \\
 \text{H}-\text{C}-\text{OH} \\
 | \\
 \text{H}-\text{C}-\text{OH} \\
 | \\
 \text{CH}_2\text{OH} \\
 \text{D-(-)-fructose}
 \end{array}$$


Fructose

- An important ketohexose.
- D-Fructose occurs, along with glucose and sucrose, in honey (which is 40% fructose).
- It is obtained along with glucose by the hydrolysis of disaccharide, sucrose.
- In its pure form it is used as a sweetener.
- It is the sweetest sugar, being 1.7 times sweeter than sucrose.
- Levorotatory because it rotates plane polarized light towards the left.



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Then another sugar is fructose, you can see it is structural. That is fructose, it has a ketonic group here. It is an important ketohexose. D-fructose occurs along with glucose and sucrose in honey, with around 40 per cent fructose. It is obtained along with glucose by the hydrolysis of the disaccharide sucrose. In its pure form, it is used as a sweetener. It is the sweetest sugar and is 1.7 times sweeter than sucrose. It is levorotatory because it rotates plane-polarised light towards the left.

Important monosaccharides (Contd...)

$$\begin{array}{c}
 \text{H} \\
 | \\
 \text{H}-\text{C}=\text{O} \\
 | \\
 \text{HO}-\text{C}-\text{H} \\
 | \\
 \text{H}-\text{C}-\text{OH} \\
 | \\
 \text{H}-\text{C}-\text{OH} \\
 | \\
 \text{CH}_2\text{OH} \\
 \text{D-(+)-glucose}
 \end{array}$$


$$\begin{array}{c}
 \text{CH}_2\text{OH} \\
 | \\
 \text{C}=\text{O} \\
 | \\
 \text{HO}-\text{C}-\text{H} \\
 | \\
 \text{H}-\text{C}-\text{OH} \\
 | \\
 \text{H}-\text{C}-\text{OH} \\
 | \\
 \text{CH}_2\text{OH} \\
 \text{D-(-)-fructose}
 \end{array}$$


$$\begin{array}{c}
 \text{H} \\
 | \\
 \text{H}-\text{C}=\text{O} \\
 | \\
 \text{HO}-\text{C}-\text{H} \\
 | \\
 \text{H}-\text{C}-\text{OH} \\
 | \\
 \text{H}-\text{C}-\text{OH} \\
 | \\
 \text{CH}_2\text{OH} \\
 \text{D-(-)-galactose}
 \end{array}$$


Galactose

- D-Galactose does not occur in nature in the uncombined state.
- It is released when lactose, a disaccharide found in milk, is hydrolyzed.
- The galactose needed for the synthesis of lactose is obtained by the metabolic conversion of D-glucose to D-galactose.
- Galactose is also an important constituent of the glycolipids that occur in the brain, thus it is also known as brain sugar.



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Then, galactose, another important sugar, D-galactose, does not occur in nature in the uncombined state; it is released when lactose, a disaccharide found in milk, is hydrolysed. So, it is the glucose and galactose, galactose is the major constituent in the milk sugar lactose. The galactose needed for the synthesis of lactose is obtained by the metabolic conversion of D-glucose. into the galactose. Galactose is also an important constituent of glycolipids that occur in the brain, and thus, it is also known as a brain sugar, and that is

why, for children, etc. Giving them milk, as adequate consumption of milk is very important because milk is a major source of the brain sugar, such as lactose or galactose.

❖ Structure of monosaccharides

- Monosaccharides are either present as linear chains or ring-shaped molecules.
- In a ring form, glucose's hydroxyl group (-OH) can have two different arrangements around the anomeric carbon (Carbon-1 that becomes asymmetric in the process of ring formation).
- If the hydroxyl group is below carbon number 1 in the sugar, it is said to be in the alpha (α) position, and if it is above the plane, it is said to be in the beta (β) position.

Open-chain structure of glucose

Cyclic structure of glucose

Pyranose structure of glucose

If we talk about the structure of monosaccharides, monosaccharides are either present as linear chains, that is, an open chain structure or a ring shape, that is, the Haworth cyclic formula in the ring. So, they have either an open chain structure or a closed chain structure. In a ring form, that glucose hydroxyl group (OH) can have two different arrangements, found that is, at the anomeric carbon atom, which is one. Either OH may be below the site of the plane, or it may go above the site of the plane. Accordingly, these two are the either alpha polymer that is, alpha glucose or the beta, that is when these two you can say, if they are on the same side, it becomes alpha position, beta position. So, these are in the open fissure chain. If you see that all these, this hexane glucose, etc., it has one aldehyde group and then one CH₂OH primary. Secondary hydroxyl group, primary hydroxyl group.

▪ Chiral centre

Structure of monosaccharides (Contd...)

- ✓ All monosaccharides, except dihydroxyacetone, contain one or more asymmetric (chiral) carbon atoms, making them optically active enantiomers.
- ✓ A molecule with n chiral centers can have 2^n stereoisomers.
- ✓ For example, glyceraldehyde, with one chiral center, has $2^1 = 2$ stereoisomers, while glucose, with four chiral centers, has $2^4 = 16$ stereoisomers.

▪ D and L isomerism

- ✓ The two enantiomers of glyceraldehyde are designated as D or L isomers based on the orientation of the -OH group on the carbon farthest from the carbonyl.
- ✓ If the -OH is on the right, it's a D isomer; if on the left, it's an L isomer. Most sugars in biological systems are D isomers.

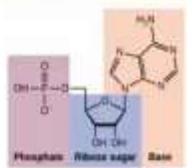
L-Glucose

D-Glucose

There are more; there are 4 asymmetric hydroxyl groups that are also known as chiral centres. So, this is a molecule with n chiral centers; it will have 2 to the power n stereoisomers. So, this hexose, 6-carbon containing sugar, glucose, etc., they have 4 asymmetric carbon atoms; the 2 to the power n means there are 16 stereoisomers. So, there are 2 to the power 4 , or 16, isomers of glucosar form. Then another important thing is the D and L isomers; these isomers can be dextrorotatory or they can be levorotatory; that is, the 2 enantiomers of glyceraldehyde, if you see the simplest sugar, glyceraldehyde. This is designated either D or L; that is, particularly that glyceraldehyde has one asymmetric carbon atom. So, whether it is the plane, if the OH is on the right side, it becomes D, and if the OH is on the left side, that is, it is a mirror image, it will become. So, similarly, if you see in this CH_2OH , that is on the penultimate carbon atom, that is, this is at the fifth position. If OH is towards the right side, which is towards the D glyceraldehyde, then it also becomes D glucose, and its mirror image becomes the L glucose. It is a D isomer, or the left is an L isomer. Most sugars in the biological system are mainly the D isomers. There is, and then there is a third structure, the stable structure, either in the chair form or boat form, etcetera.

❖ **Function of monosaccharides**

- Glucose ($\text{C}_6\text{H}_{12}\text{O}_6$) is an important source of energy in humans and plants. Plants synthesize glucose using CO_2 and water, which in turn is used for their energy requirements. They store the excess glucose as starch which humans and herbivores consume.
- The presence of galactose is in milk sugar (lactose), and fructose in fruits and honey makes these foods sweet.
- Ribose is a structural element of nucleic acids and some coenzymes.
- Mannose is a constituent of mucoproteins and glycoproteins required for the proper functioning of the body.



Structure of DNA



Then we talk about the functions of monosaccharides. This glucose is an important sugar. It is a source of energy in humans and plants. Plants synthesize glucose using carbon dioxide and water, which in turn is used for their energy requirements. They store the excess glucose as starch. With humans and herbivores, they consume that. In fact, as I told you earlier, it is the solar energy converted into a form of chemical energy kept in the grain, it is stored in the form of starch, etc., which we ultimately consume in our system. Then, starch is further broken down into glucose, and finally, glucose is utilised for energy

purposes. So, the presence of galactose in the milk sugar, lactose and fructose in the fruit sugar, honey makes these foods sweet. Ribose is a structural element of nucleic acids and some coenzymes. Also, there is another isomer, mannose. It is a constituent of mucoproteins and glycoproteins, which are required for the proper functioning of the body. So, I think these are different forms of monosaccharides in their different isomers. They are required for various purposes in the body, as they play many important functions in our system.

Disaccharides and oligosaccharides

- It can be hydrolysed into a definite number of monosaccharide molecules.
- Generally found either O- or N-linked to compatible amino acid side chains in proteins or to lipid moieties.
- They (homo- and hetero-oligosaccharides) are also liberated as intermediate products of saccharification by action of glycosidases on polysaccharide.
- Depending upon the number of monosaccharides that are obtained from them on hydrolysis, they may be called di-, tri- or tetra-saccharides.
 - ✓ **Disaccharides:** Sucrose, lactose, maltose.
All these have the same molecular formula $C_{12}H_{22}O_{11}$
 - ✓ **Trisaccharides:** Raffinose ($C_{18}H_{32}O_{16}$)
 - ✓ **Tetrasaccharides:** Stachyose ($C_{24}H_{42}O_{21}$)
- Amongst these the most common are disaccharides found in sugarcane, milk, cereal malts, sprouted legumes, etc.

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So, now let's talk about disaccharides and oligosaccharides. So, these disaccharides and oligosaccharides, as we mentioned earlier, when these two sugar molecules (monosaccharide units) combine together, one water molecule is released, and you get and they are linked together by glycosidic linkages. So, this glycosidic linkage may be alpha 1-4 linkage, alpha-beta, or alpha 1-6 linkage, etcetera, that is. So, depending on this glycosidic linkage. So, if there are 2, it is a disaccharide; 3 sugars, trisaccharide; 4 sugars, tetra, penta, hexa, and so on. Up to 10, it is an oligosaccharide. So, generally, they are found in the O- or N-linked to compatible amino acids and side chains in proteins or their lipid molecules. These disaccharides or oligosaccharides may be homo- or hetero-oligosaccharides also. They are also liberated as intermediate products of saccharification by the action of glycosidases on polysaccharides. So, depending upon the number of monosaccharides, they are obtained from them and hydroxyl groups. They may be called di-, tri-, tetra-, as I told you. So, important disaccharides are sucrose, lactose, maltose, etcetera. Maltose basically has 2 glucose units joined together with an alpha 1,4 linkage. Lactose, that is, galactose and glucose, is joined. Sucrose, glucose and fructose are joined.

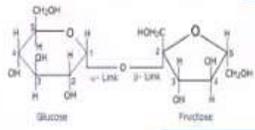
So, all these have the same molecular formula, like $C_{12}H_{22}O_{11}$. Then trisaccharides like raffinose $C_{18}H_{32}O_{11}$. Then tetrasaccharide stachyose is $C_{12}H_{32}O_{11}$. So, these are oligosaccharides, basically. So, the number that is there, normally, the various molecular units are joined together with an alpha 1,4, and there is also an alpha 1,6 linkage. The 1,6 linkage is there. So, attached by side chains are attached. So, they become higher polysaccharides, etcetera. And these oligosaccharides, particularly higher polysaccharides, are often indigestible material, and they are not digested. That 1,6 linkage you know, and they contain they are mostly found in pulses, etcetera, and sometimes they cause a source of toxicity and all those things. Although when these pulses are broken down during the cooking process, they are broken down into smaller stems and then become easily digestible. Otherwise, they may be a source of or cause problems when these pulses contain higher oligosaccharides. When we consume them, they pass our small intestine undigested and go into the large intestine, where the bacterial flora act on this and then it is else into flatulence and other stomach problems. and all those things. So, that is why these are normally pulses, they are cooked and then consumed. During cooking, these higher oligosaccharides are converted into smaller ones. So, among these, the same common disaccharides are found in sugar cane, milk, cereal malt, sprouted legumes, etc.

❖ **Important disaccharides**

- Disaccharides consist of two sugar units. When subjected to a dehydration reaction (condensation reaction or dehydration synthesis), they release two monosaccharide units.

Sucrose, $C_{12}H_{22}O_{11}$

- Sucrose is the most abundant disaccharide of all and is composed of one D-glucose molecule and one D-fructose molecule.
- The systematic name for sucrose is **O- α -D-glucopyranosyl-(1 \rightarrow 2)-D-fructofuranoside**.
- It is colourless, crystalline substance, sweet in taste. It is soluble in water and the solution is dextrorotatory $[\alpha]_D = +66.5$.
- When heated slowly, sucrose melts and solidifies into a pale-yellow glassy mass called "barley sugar." At 473 K, it dehydrates into a brown amorphous mass called caramel, and with strong heating, it chars to nearly pure carbon, producing the characteristic smell of burnt sugar.



The diagram shows the chemical structure of sucrose, a disaccharide composed of one D-glucose molecule and one D-fructose molecule. The glucose unit is in its pyranose form (six-membered ring) and is linked to the fructose unit (five-membered ring) via an alpha-1,2-glycosidic bond. The glucose unit is labeled 'Glucose' and the fructose unit is labeled 'Fructose'.



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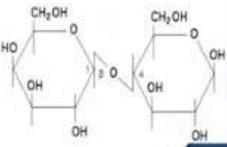
So, the disaccharide is an important group of sugars. So, take important disaccharides like they consist of 2 sugar units when subjected to a dehydration reaction, this condensation reaction or dehydration synthesis releases 2 water molecules, see. So, like this sucrose, if you see, sucrose is the most abundant disaccharide of all the compounds. There is one D-glucose unit and the other is the D-fructose unit, a D-fructose unit, and this is basically

alpha-D glucopyranose and beta-D fructofuranoside. Combined together, linkages alpha-1 beta-2. So, accordingly, you can write the name of this structure as alpha-D glucopyranosyl 1 to 2 D-fructofuranoside. So, it is basically this one is the alpha here, and beta is 2 to 2 beta fructofuranoside. It is a colorless crystalline substance, sweet in taste, soluble in water, and the solution is dextrorotatory, that is alpha-D is plus 66.5. When heated slowly, sucrose melts and solidifies into a pale-yellow glossy mass called barley sugar, and at 473 K, it dehydrates into a brown amorphous mass called caramel. With strong heating, it changes to nearly pure carbon, producing the characteristic smell of burnt sugar.

Lactose

- Lactose occurs naturally in mammalian milk. Cow's milk contains 4-5 % and human milk 6-7 % lactose.
- It is composed of one D-galactose molecule and one D-glucose molecule. The systematic name for lactose is **O-β-D-galactopyranosyl-(1→4)-D-glucopyranose**. Ordinary commercial lactose is α-lactose monohydrate.
- Has a molecular weight of 342.3g/mol, it contains water of crystallisation, which increases the molecular mass to 360.3 g/mol.
- Occurs naturally in either of two crystalline form α- monohydrate and anhydrous β or as an amorphous "glass" mixture of α- and β-lactose.

Important disaccharides (Contd...)








Similarly,
you see,

lactose, if
occurs

mainly in mammalian milk. Cow milk contains about 4 to 5 percent, and human milk about 6 to 7 percent lactose. It is composed of one D-galactose molecule and one D-glucose molecule. The systematic name is O-beta-D-galactopyranosyl-(1→4)-D-glucopyranose. Ordinarily, commercial lactose is alpha. So, you see here in the beta form, the glucose, and then that is ok. Ordinarily, commercial lactose is alpha-lactose monohydrate. It has a molecular weight of 342.3 grams per mol. It contains water of crystallisation, which increases the molecular mass to 360.3 grams per mole. It occurs naturally in either of two crystalline forms: alpha-monohydrate and anhydrous beta, or as an amorphous glass mixture of alpha and beta lactose.

Important disaccharides (Contd...)

Maltose

- It tastes sweet but is only 30-60% as sweet as sugar.
- The hydrolysis reaction of maltose in the presence of an acid catalyst gives two molecules of α -D-glucose.
- There is a free anomeric carbon present in the structure of maltose which can undergo mutarotation in solution. The resultant solution will be a mixture of alpha and beta maltose.
- Since the aldehydic group is formed in the solution, maltose gives a positive test with Benedict's and Tollens reagents.

α -D-glucose D-glucose

$\alpha(1-4)$ glycosidic bond





Then, maltose: here, the two units of glucose are both alpha-D-glucose. Alpha-D glucose, when combined with two molecules, forms maltose. So, the hydrolysis reaction, you can say, even in starch, is the repeating unit of maltose. The starch hydrolysis reaction of maltose. So, in the presence of an acid catalyst, it gives 2 molecules of alpha-D-glucose. There is a free anomeric hydroxyl group in this maltose, and because of that, the free anomeric hydroxyl group makes it a reducing sugar. Lactose and maltose are reducing sugars, whereas sucrose is a non-reducing sugar, because there is no free anomeric hydroxyl group. Also, since the aldehydic group is formed in the solution, maltose gives a positive test with Benedict's and Tollen's reagents.

Important disaccharides (Contd...)

- Some other examples of disaccharides include lactulose, chitobiose, kojibiose, nigerose, isomaltose, sophorose, laminaribiose, gentiobiose, turanose, maltulose, trehalose, palatinose, gentiobulose, mannobiose, melibiose, melibulose, rutinose, rutinulose, and xylobiose.

Disaccharide	Monomer Units
Sucrose	Glucose and Fructose
Lactose	Galactose and Glucose
Maltose	Glucose and Glucose (α -1,4 linkage)
Trehalose	Glucose and Glucose (α -1, α -1 linkage)
Cellobiose	Glucose and Glucose (β -1,4 linkage)
Gentiobiose	Glucose and Glucose (β -1,6 linkage)



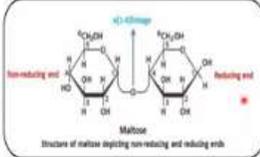


Then, some examples of other disaccharides include Kgbios, Negros, Lactos, Trehalos, Cellobios, Centibios, etc., and their linkages are also given here. So, these are some of the

others which may be present either bound with macromolecules or other components in the port system.

❖ Structure of disaccharides

- A hydroxyl group from one monosaccharide combines with a hydrogen from another to form a glycosidic bond, releasing water.
- A glycosidic bond forms between two sugar molecules, representing the transition from a hemiacetal to an acetal.
- Glycosidic bonds can be α - or β -: Alpha when the OH on carbon-1 is below the ring plane, and beta when it's above.
- Hydrolysis of sucrose yields glucose and fructose (invert sugar), as fructose is levorotatory and reverses sucrose's dextrorotation.
- When the anomeric carbon forms a glycosidic bond, the sugar becomes non-reducing since the linear form required for oxidation is prevented.
- The reducing end of a disaccharide or polysaccharide has a free anomeric carbon.



Structure of maltose depicting non-reducing and reducing ends

Now, we talk about the structure of disaccharides: a hydroxyl group from one monosaccharide combines with a hydrogen from another to form a glycosidic bond, releasing water, as I told you earlier. This is one monosaccharide, and there is another monosaccharide here HOH and HOH. So, these two combined with alpha 1,4 linkage, form one maltose molecule equally, and this is the maltose resulting in the disaccharide maltose, etc. So, glycoside bonds can be alpha linkage or beta linkage depending upon the type of sugar that is involved. So, hydrolysis of sucrose is glucose and fructose, which are inward sugars, and fructose is liver rotatory, and it reverses, glucosucrose is vector rotation. When the anomeric carbon forms a glycosidic bond, the sugar becomes a non-rotating sugar as the linear form required for the oxidation is prevented. The reducing end of a disaccharide or polysaccharide has a free anomeric carbon. So, there may be reducing sugars, monosaccharides, almost all of which are reducing. Similarly, disaccharides and oligosaccharides can also be reducing, depending on whether one of the anomeric hydroxyls is a free one.

❖ **Functions of disaccharides**

- **Sucrose** is a product of photosynthesis, which functions as a major source of carbon and energy in plants.
- **Lactose** is a major source of energy in animals.
- **Maltose** is an important intermediate in starch and glycogen digestion.
- **Trehalose** is an essential energy source for insects.
- **Cellobiose** is essential in carbohydrate metabolism.
- **Gentiobiose** is a constituent of plant glycosides and some polysaccharides.



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Then, as far as the functions of disaccharides are concerned, sucrose is a product of photosynthesis, which functions as a major source of carbon and energy in the plants. Lactose is a major source of energy in animals. Maltose is an important intermediate in starch glycogen digestion. Trehalose is an essential energy source for insects. Cellobiose is essential in carbohydrate metabolism. Gentiobiose is a constituent of plant glycosides and some other polysaccharides.

❖ **Functions of oligosaccharides**

- **Glycoproteins** are carbohydrates attached to proteins involved in critical functions such as antigenicity, solubility, and resistance to proteases. Glycoproteins are relevant as cell-surface receptors, cell-adhesion molecules, immunoglobulins, and tumor antigen
- **Glycolipids** are carbohydrates attached to lipids that are important for cell recognition and modulate membrane proteins that act as receptors.
- Cells produce specific carbohydrate-binding proteins known as lectins, which mediate cell adhesion with oligosaccharides.
- Oligosaccharides are a component of fiber from plant tissues.




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The oligosaccharides, the functions of oligosaccharides, are primarily or normally present in glycans. They are linked to either lipids or amino acid side chains in the proteins by N or O glycosidic bonds known as glycolipids or glycoproteins. The glycosidic bonds are formed in the presence of glycosylation, in which a carbohydrate is covalently attached to an anomeric molecule. So, N-linked oligosaccharides involve the attachment of an oligosaccharide to asparagine via a beta linkage to an amine nitrogen of the side chain.

Structure of oligosaccharides

- The oligosaccharides are normally present as glycans. They are linked to either lipids or amino acid side chains in proteins by N- or O-glycosidic bonds known as glycolipids or glycoproteins.
- The glycosidic bonds are formed in the process of glycosylation, in which a carbohydrate is covalently attached to an organic molecule.
- N-Linked oligosaccharides:** It involves the attachment of oligosaccharides to asparagine via a beta linkage to the amine nitrogen of the side chain.
- O-Linked oligosaccharides:** It involves the attachment of oligosaccharides to threonine or serine on the hydroxyl group of the side chain.

The slide includes several chemical diagrams. At the top, two structures show N-linked glycoproteins (left) and O-linked glycoproteins (right). Below these, three oligosaccharide structures are shown: Manninotriose (a branched chain of mannose, galactose, and glucose), Galactobiose (a chain of galactose and glucose), and Raffinose (a chain of galactose, glucose, and fructose). A small inset video of a presenter is visible in the bottom right corner of the slide.

Whereas, O-linked oligosaccharides involve the attachment of oligosaccharide to threonine or serine on the hydroxyl group of the side chain. And these are some other structural oligosaccharides: raffinose, stachyose, mannantri-ose. Regarding the functions of oligosaccharides, like glycoproteins or carbohydrates attached to proteins, they are involved in critical functions such as antigenicity, solubility, and resistance to proteases. Glycoproteins are relevant to cell structure receptors, cell adhesion molecules, immunoglobulins, tumor antigens, etc. Glycolipids are carbohydrates attached to lipids that are important for cell recognition and modulate membrane proteins that act as receptors. Cells produce specific carbohydrate-binding proteins known as lectins, which mediate cell adhesion with oligosaccharides. Oligosaccharides are a component of fiber from plant tissues, etc.

Physical and chemical properties of carbohydrates

Physical properties

- Stereoisomerism** – Compound having the same structural formula but they differ in spatial configuration. **Example:** Glucose has two isomers with respect to the penultimate carbon atom. They are D-glucose and L-glucose.
- Optical activity** – It is the rotation of plane-polarized light forming (+) glucose and (-) glucose.
- Diastereo isomers** – It the configurational changes with regard to C2, C3, or C4 in glucose. **Example:** Mannose, galactose.
- Anomerism** – It is the spatial configuration with respect to the first carbon atom in aldoses and the second carbon atom in ketoses.

A small inset video of a presenter is visible in the bottom right corner of the slide.

Now, if you talk about the physical properties of carbohydrates, they exhibit stereoisomerism, as I mentioned earlier—compounds having the same structural formula but differing in spatial configuration. For example, glucose has two isomers with respect to the penultimate carbon atom. They are D glucose and L glucose then they have up they have. So, the optimal activity is the rotation of the plane polarised light, forming, plus, which is the glucose and minus, which rotates the plane either towards the positive side or the negative side, left or right. Then diastereoisomers mean configurational changes with regard to C2, C3 and C4 in glucose, like mannose, galactose. Then anomerism in the spatial configuration with respect to the first carbon atom in aldose and the second carbon atom in ketose.

❖ **Physical properties of monomers**

- Most monosaccharides have a sweet taste (fructose is sweetest; 73% sweeter than sucrose).
- They are solids at room temperature.
- They are extremely soluble in water: Despite their high molecular weights, the presence of large numbers of -OH groups makes the monosaccharides much more water-soluble than most molecules of similar MW.
- **Physical properties of glucose**
 - ✓ It is colorless sweet crystalline compound having melting point 419 K.
 - ✓ It is readily soluble in water, sparingly soluble in alcohol and insoluble in ether.
 - ✓ It forms a monohydrate having melting point 391 K.
 - ✓ It is optically active and its solution is dextrorotatory. The specific rotation of fresh solution is +112 °C.
 - ✓ It is about three fourth as sweet as sugarcane i.e. sucrose glucose form a straight chain.



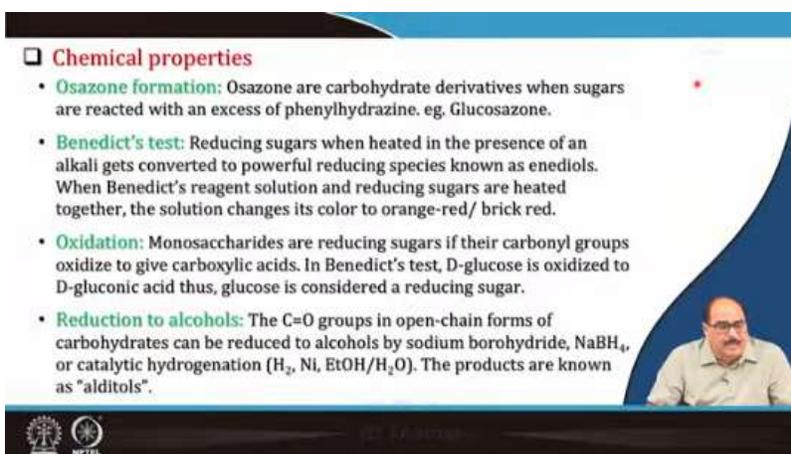
Physical properties of monomers (Contd...)

Physical properties of fructose

- It is sweetest of all known sugars.
- It is readily soluble in water, sparingly soluble in alcohol and insoluble in ether.
- It is white crystalline solid with melting point 375 K.
- Fresh solution of fructose has a specific rotation -133°.



Then the monosaccharides have a sweet taste, fructose is the sweetest, it is 73 per cent sweeter than sucrose. Then they are solids at room temperature, they are extremely soluble in water, and also the physical properties of glucose, if you see it, are a colourless, sweet, crystalline compound with a melting point of 419 °c. It is readily soluble in water. It forms a monohydrate with a melting point of 391 K. It is optically active, and its solution is dextrorotatory. It is absolutely three-fourths as sweet as sugarcane. Fructose is the sweetest among all known sugars. It is readily soluble in water, sparingly soluble in alcohol, and insoluble in ether. It is a white crystalline solid with a melting point of 375 K. A fresh solution of fructose has a specific rotation of minus 133 degrees.



Chemical properties

- **Osazone formation:** Osazones are carbohydrate derivatives when sugars are reacted with an excess of phenylhydrazine. eg. Glucosazone.
- **Benedict's test:** Reducing sugars when heated in the presence of an alkali gets converted to powerful reducing species known as enediols. When Benedict's reagent solution and reducing sugars are heated together, the solution changes its color to orange-red/ brick red.
- **Oxidation:** Monosaccharides are reducing sugars if their carbonyl groups oxidize to give carboxylic acids. In Benedict's test, D-glucose is oxidized to D-gluconic acid thus, glucose is considered a reducing sugar.
- **Reduction to alcohols:** The C=O groups in open-chain forms of carbohydrates can be reduced to alcohols by sodium borohydride, NaBH₄, or catalytic hydrogenation (H₂, Ni, EtOH/H₂O). The products are known as "alditols".

Chemical properties include osazone formation. Osazones are carbohydrate derivatives formed when sugars react with an excess of phenyl hydrazine. Then, Benedict's test for reducing sugars: when heated in the presence of an alkali, they get converted into powerful reducing species known as enediols. That is, when Benedict's reagent solution and reducing sugars are heated together, the solution changes colour from orange to red or brick red, etc. That is, the formation of enediols is what occurs when these sugars react with reducing sugars react with alcohols and hydroxyl groups, etcetera, and so on, under alcoholic conditions. Oxidation: Monosaccharides are reducing sugars if they have a carbonyl group. Oxidized, they give respect to carboxylic acid. When de-glucose is oxidised to de-gluconic acid, glucose is considered as a reducing sugar, then reduced to alcohols like CO in the open-chain form of carbohydrate, which can be reduced to alcohol by sodium borohydride, or catalytic hydrogenation. These products are known as alditols.

this cuprous sulfate solution reduced to cupric form? Cuprous is reduced to cupric form, and you get a brick red solution. So, a failing solution is reducing sugar exhibited by the reducing sugars.

Chemical properties of monomers (Contd...)

Reduction

- Glucose is reduced to sorbitol or glucitol on treatment with sodium amalgam and water.

$$\text{CH}_2\text{OH}(\text{CHOH})_4\text{CHO} + 2[\text{H}] \xrightarrow[\text{H}_2\text{O}]{\text{Na/Hg}} \text{CH}_2\text{OH}(\text{CHOH})_4\text{CH}_2\text{OH}$$

Glucose Sorbitol

- On reduction with concentrated HI and red P at 373 K glucose gives a mixture of n-hexane and 2-iodohexane.

$$\text{CH}_2\text{OH}(\text{CHOH})_4\text{CHO} \xrightarrow{\text{HI/red P}} \text{CH}_3(\text{CH}_2)_4\text{CH}_3 + \text{CH}_3(\text{CH}_2)_3\text{CHICH}_3$$

Glucose n-hexane 2-iodohexane



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In the reduction reaction, glucose is reduced to sorbitol or glucitol on treatment with sodium amalgam and water. You can see here this reaction upon reduction, they reduce to sorbitol. Even in reaction with concentrated HI and red P, glucose gives a mixture of n-hexane and 2-iodohexane that is, upon reduction.

Then the chemical reactions that is a glucose when it reacts with a HCN, glucose with HCN it gives glucose cyanohydrin. Also, reaction with hydroxylamine glucose forms glucose oxime.

Chemical properties of monomers (Contd...)

Glucose chemical reactions

- **Reaction with HCN:** Like aldehydes, glucose reacts with HCN forming cyanohydrins.

$$\text{CH}_2\text{OH}(\text{CHOH})_4\text{CHO} + \text{HCN} \longrightarrow \text{CH}_2\text{OH}(\text{CHOH})_4\text{CH} \begin{matrix} \text{OH} \\ \text{CN} \end{matrix}$$

Glucose Glucose cyanohydrin

- **Reaction with hydroxylamine:** Glucose forms glucose oxime.

$$\text{CH}_2\text{OH}(\text{CHOH})_4\text{CHO} + \text{NH}_2\text{OH} \longrightarrow \text{CH}_2\text{OH}(\text{CHOH})_4\text{CH}=\text{NOH} + \text{H}_2\text{O}$$

Glucose Glucose oxime

- **Reaction with acetic anhydride or acetyl chloride:** Glucose forms penta acetate with acetic anhydride of acetyl chloride.

$$\begin{array}{c} \text{CHO} \\ | \\ (\text{CHOH})_4 \\ | \\ \text{CH}_2\text{OH} \\ \text{Glucose} \end{array} + 5(\text{CH}_3\text{CO})_2\text{O} \xrightarrow[\text{Heat}]{\text{ZnCl}_2} \begin{array}{c} \text{CHO} \\ | \\ (\text{CHOCOCCH}_3)_4 \\ | \\ \text{CH}_2\text{OCOCCH}_3 \\ \text{Glucose penta-acetate} \end{array} + 5\text{CH}_3\text{COOH}$$

Acetic anhydride



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Reaction with acetic anhydride or it forms acetyl chloride that glucose plus acetic anhydride is heated, it gives glucose pentacetate.

Chemical reaction of glucose (Contd...)

- Reaction with methyl alcohol:** Glucose reacts with methyl alcohol in the presence of dry HCl gas to form methyl glucoside.

$$C_6H_{12}O_6 + n H OCH_3 \xrightarrow{\text{Dry HCl}} C_6H_{12}O_5(OCH_3)_n + n H_2O$$

Glucose Methyl glycoside
- Reaction with metallic hydroxides:** Glucose reacts with calcium hydroxide to form calcium glucosate which is water soluble.

$$C_6H_{12}O_6 + n H OCaOH \longrightarrow C_6H_{12}O_5(OCaOH)_n + n H_2O$$

Glucose calcium hydroxide calcium-glucosate
- Reaction with alkalis:**

D-Glucose \rightleftharpoons D-Mannose \rightleftharpoons D-Fructose

Then, the reaction with methyl

reaction with alcohol:

glucose with methyl alcohol reacts in the presence of an acetic catalyst, giving methyl glucosides. Reaction with metallic hydroxylase: glucose reacts with calcium hydroxide to form calcium glucosate, which is water-soluble like glucose plus calcium hydroxide, it gives calcium glucosate. Then, with alkali, glucose may undergo analysis reactions under various conditions, and then undergo isomerisation reactions, and glucose is converted into mannose; mannose is converted into fructose, etc., under varying conditions of alkali, that is, whether the alkali reaction time or alkali concentration varies. So, analysis reaction takes place, and then various isomers and enomers of the sugars are formed.

Chemical properties of monomers (Contd...)

Fructose chemical reactions

- Reactions due to ketonic group**
 - Reaction with HCN**

Fructose \xrightarrow{HCN} Fructose cyanohydrin
 - Reaction with hydroxylamine**

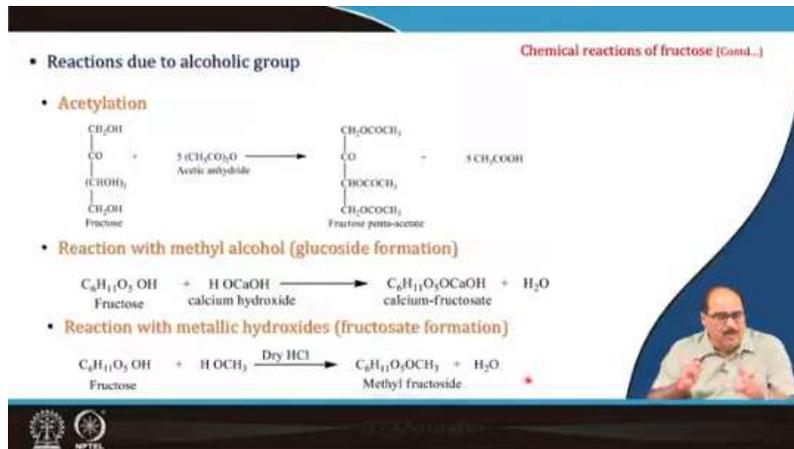
Fructose $\xrightarrow{H_2NOH}$ Fructose oxime
- Oxidation**

Fructose $\xrightarrow{O_2}$ Glycolic acid + Trihydroxy glutaric acid + Tartaric acid
- Reduction**

Fructose $\xrightarrow{[H]}$ Mannitol + Sorbitol

Then, similarly, fructose: the chemical reaction of fructose is reaction with hydrocyanic acid; fructose is cyanohydrin. It reacts with hydroxyl amine, it gives fructose amine, that is, fructose. There is oxidation that is the glycolic acid and citric acid, and upon reduction

the fructose is converted into mannitol and sorbitol, a mixture of mannitol and sorbitol. So, again, these sugars, that is, these are mainly the reactions to the fructose. Ketonic group. You get mannitol, sorbitol, tartaric acid, and glycolic acid. So, under various conditions upon chemical reaction, these reactions take place in the food system under varying conditions. Also, reactions due to alcoholic groups, that is, these sugars have aldehyde, ketone, and alcohol. So, aldehyde group, ketonic group reactions we have shown.



Now, with the alcoholic group, when this, like fructose for example, reacts with acetic anhydride, it gives fructose pentaacetate or the reaction with methyl alcohol, there is a glucoside formation that will take place, N-glycoside, O-glycoside, S-glycoside, depending upon whether Clear compounds like fructose plus calcium hydroxide give calcium fructose. Fructose plus methyl acetyl gives methyl fructoside, and various other compounds are formed.

Summary

- Carbohydrates are essential macronutrients found in a wide range of foods, providing a primary source of energy for the body.
- Carbohydrates play a crucial role in diet, offering energy, supporting digestion through dietary fibers, etc.
- Carbohydrates are classified into monosaccharides (e.g., glucose, fructose), oligosaccharides (e.g., maltose, lactose), and polysaccharides (e.g., starch, cellulose).
- Carbohydrates are sugars with a structure of carbon, hydrogen, and oxygen atoms, typically arranged in rings or chains.



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Now I can summarize this lecture by saying that carbohydrates are essential. Macronutrients are found in a wide range of foods, providing a primary source of energy for the body. Carbohydrates play a crucial role in the diet, offering energy and supporting digestion through dietary fibers. They are classified into monosaccharides, oligosaccharides, or polysaccharides. They are sugars with a structure of carbon, hydrogen, and oxygen atoms, typically arranged in ring form, chain form, or even open-chain structure, etc. And they are very important constituents of the food system.

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So, these are the references.



Thank you very much for your patient hearing. Thank you.