



UNIT 3

CARBOHYDRATES: DISACCHARIDES AND POLYSACCHARIDES

Structure

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	Sucrose		Glycoproteins
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3.1 INTRODUCTION

In Unit 2, we describe the structure and reactions of monosaccharides along with classification of carbohydrates. We had pointed out that monosaccharides are basic unit of carbohydrates. In this unit we shall discuss about oligosaccharides and polysaccharides. As defined earlier oligosaccharides upon hydrolysis yield between 2-10 monosaccharide units and, depending upon the number of monosaccharide units so obtained, they are known as disaccharides, trisaccharides, etc. Polysaccharides produce a large number of monosaccharide units (more than ten) upon hydrolysis. They may contain as many as 3000 monosaccharide units. Like monosaccharides, they also play important role in providing energy as they are hydrolyzed by digestive enzymes to their constituent monosaccharides. Smaller oligosaccharides like disaccharides and trisaccharides are commonly present in human diet. Higher oligosaccharides are more common in plants. Oligosaccharides are also found linked to other biomolecules such as proteins and lipids.

Most of the carbohydrates in nature are polysaccharides. They are also known as glycans. Some of them are simply polymers of monosaccharides like

starch, glycogen and cellulose while others in addition to being polymeric saccharides are also linked covalently to other biomolecules like amino acids, peptides, proteins and lipids. Some important examples are glycosaminoglycans, glycoproteins etc., such polysaccharides are called complex polysaccharides.

In this unit our main focus will be on disaccharides and some important polysaccharides. We will describe their structures, properties and biological importance.

Expected Learning Outcomes

After studying this unit, you should be able to,

- ❖ define oligosaccharides and polysaccharides;
- ❖ identify different types of glycosidic bonds;
- ❖ draw structures of common disaccharides: lactose, maltose, and sucrose;
- ❖ describe the importance of disaccharides;
- ❖ describe storage and structural polysaccharides; and
- ❖ describe some complex polysaccharides and their biological significance and;
- ❖ describe the biological roles of carbohydrates.

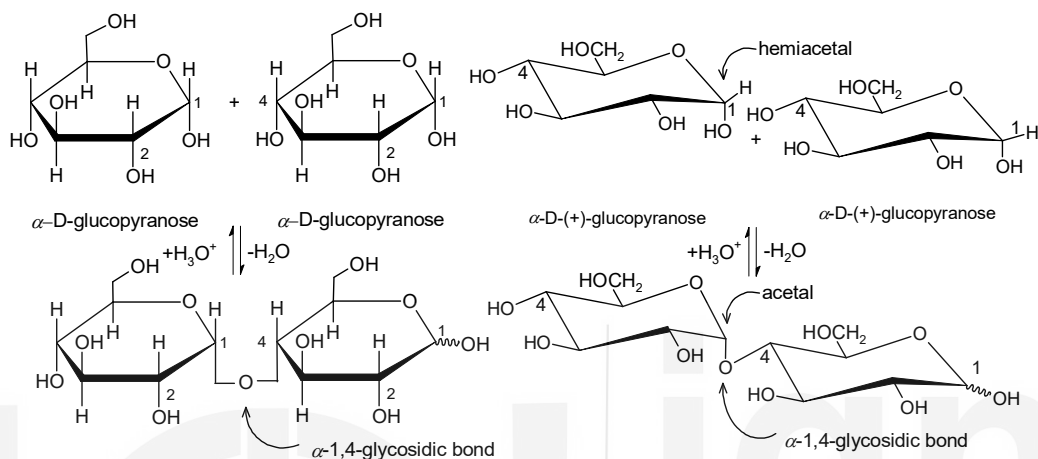
3.2 DISACCHARIDES

The disaccharides are the most commonly occurring oligosaccharides in nature and on hydrolysis yield two monosaccharide molecules. Maltose, lactose and sucrose are the three widely found disaccharides and each has a molecular formula of $C_{12}H_{22}O_{11}$.

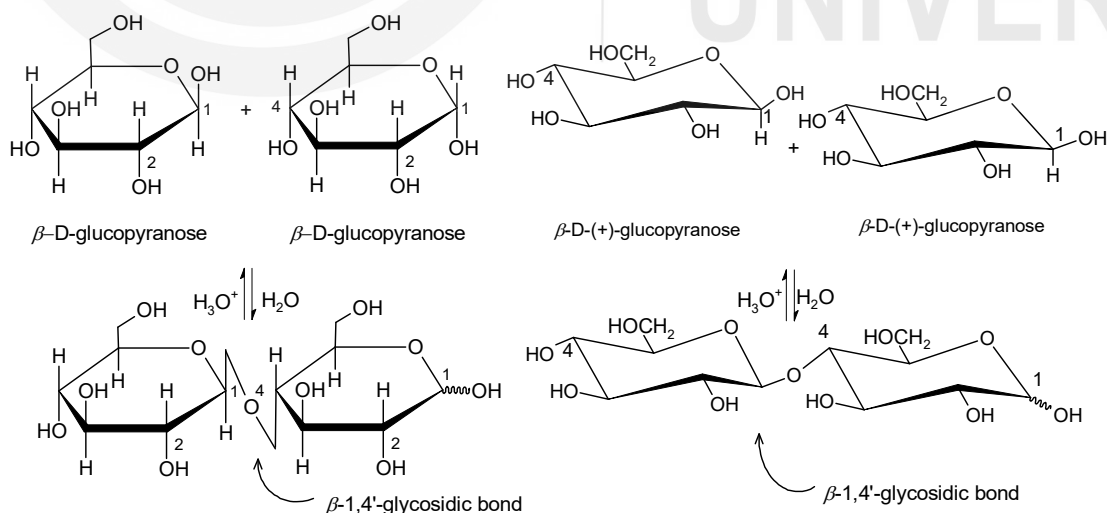
We have already discussed in earlier unit (Unit 2) about the formation of glycosides and glycosidic bonds. Therein, we also described how two units of monosaccharides (hemiacetals) form an acetal by condensation reaction between an alcohol groups attached to anomeric carbon of a monosaccharide with alcoholic group of another monosaccharide. The acetal so formed is also called glycoside. Both the monosaccharide units in a glycoside are attached together by the glycosidic bond. We had also pointed out that generally OH group on C-1 (anomeric carbon) of one monosaccharide reacts with the OH on C-4 or C-6 of another monosaccharide molecule. Based on the configuration of the anomeric carbon involved and positions of hydroxyl groups in both the monosaccharide units, the glycosidic bonds are categorized in different categories. For example, maltose is formed by the reaction of two D-glucose units. In this molecule both the units are linked through the C-1 hydroxyl group of one D-glucose in α form and C-4 hydroxyl group of other molecule. Thus the

glycosidic bond so formed is named as α -1,4'-glycosidic bond. This can also be represented as α -(1 \rightarrow 4)-glycosidic bond.

The formation of disaccharides can be represented using Haworth projection formula as well as chair form as shown in Fig 3.1 and 3.2. You can notice in these figures that the α -position is axial when a monosaccharide is shown in a chair conformation and is down when the sugar is shown in a Haworth projection; the β -position is equatorial when a monosaccharide is shown in a chair conformation and is up when the sugar is shown in a Haworth projection.



If glycoside is formed by the linkage between the C-1 hydroxyl group of one D-glucose in β form and C-4 hydroxyl group of other molecule, the glycoside bond so formed is named as β -1,4'-glycosidic bond. Such bond is observed in cellobiose (see Fig 3.2). Similar to monosaccharides, disaccharides can also exist in both the α and β forms. In Fig. 3.1 and 3.2, wavy bond represent both the forms of disaccharides (α , β). Since, disaccharides can exist in both the α and β forms, similar to monosaccharides, mutarotation occurs when crystals of one pure form are dissolved in a solvent.



With this information, now let us study some very interesting disaccharides carbohydrates which are very common in nature briefly. We shall mainly describe the nature of monosaccharides, some of their properties and the type

of linkages which hold them together. But before that let's know how disaccharides are named.

Systematic Naming of Disaccharides

All disaccharides have a generic name as well as systematic name. Systematic name gives specific information about the exact configuration of the constituent monosaccharides as well as the type of glycosidic bond they form. These names are assigned following a sequence in which monosaccharides are joined together. The name begins with the 'O' as a reminder that the monosaccharide-monosaccharide linkage is through an oxygen atom (If other than oxygen atom is involved we use word accordingly e.g., *N* for nitrogen). After that name the type of conformation (α/β) of the first monosaccharide unit (on the left) followed by D/L form, then name the first monosaccharide root name followed by pyranosyl or furanosyl as per ring size. This is followed by a parenthesis indicating the number's of carbons in both monosaccharides forming glycoside bond, followed by the name of the second sugar in the same format as the first one. For example, systematic name of α -maltose will be *O*- α -D-glucopyranosyl-(1 \rightarrow 4)- α -D-glucopyranose and β -cellobiose is *O*- β -D-glucopyranosyl-(1 \rightarrow 4)- β -D-glucopyranose.

SAQ 1

How are monosaccharide units held together in disaccharide? Can a disaccharide exist in α and β forms?

3.2.1 Maltose

Maltose or malt sugar exists in small amounts in nature. It is obtained mainly by the incomplete hydrolysis of starch, glycogen or dextrans. This disaccharide is made up of two glucose units (or residues), linked through the C-1 hydroxyl of one residue in α -form and C-4 hydroxyl of the other, by an α -1,4'-glycosidic bond. Maltose has one free anomeric carbon that is not an acetal. Maltose undergoes mutarotation and its solution has an equilibrium mixture of α and β maltose (with a small quantity of the aldehyde form of maltose). Maltose reduces Tollen's reagent and Fehling's solution and thus it is a reducing sugar.

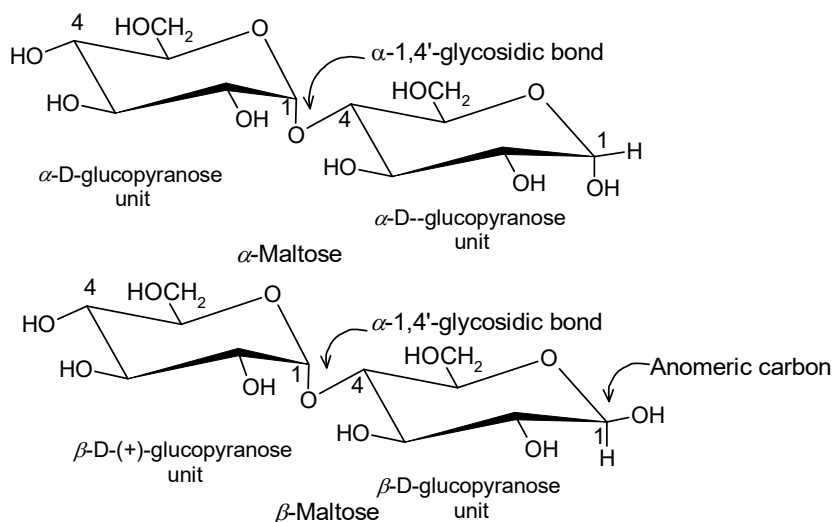


Fig. 2.3: Structures of α -maltose and β -maltose.

3.2.2 Lactose

Lactose or milk sugar is a disaccharide present in the milk of mammals and is synthesised in the mammary glands after child birth, from glucose and galactose under hormonal regulation. Cow's milk contains on average 4% lactose while human milk contains 6-8%. It is a white powder that is nearly tasteless. It is, therefore, used in special high calorie diets.

Lactose is formed by the condensation reaction between anomeric hydroxyl of β -D-galactose and C-4 hydroxyl of D-glucose, in a β -1, 4'- glycosidic link. Lactose has one free anomeric carbon and thus, exists in anomeric α and β forms and exhibit mutarotation (see Fig. 2.4). It reacts with Tollen's reagent, Fehling's solution and Benedict's reagent and therefore it is a reducing sugar. Systematic name of β - lactose is O- β - D-galactopyranosyl-(1 \rightarrow 4)- β -D-glucopyranose.

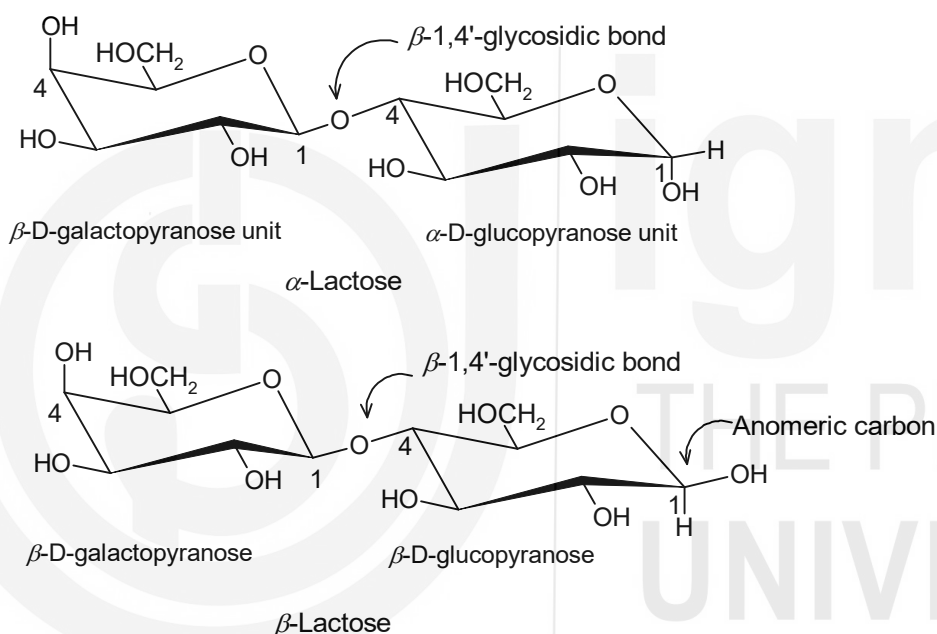


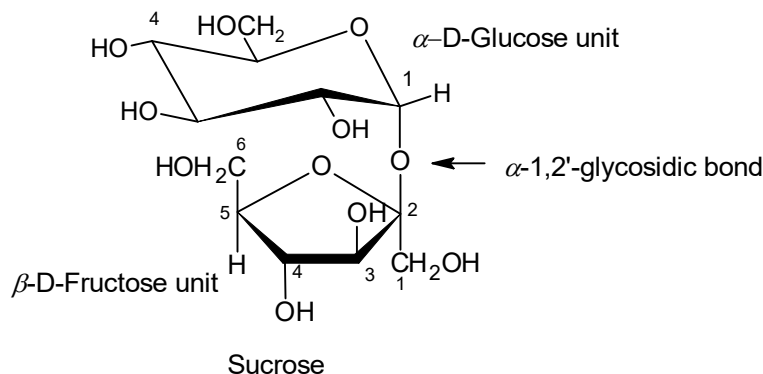
Fig. 2.3: Structures of α -Lactose and β -lactose.

3.2.3 Sucrose

Sucrose (table sugar, cane sugar, beet sugar) is the most widely employed sweetening agent and is found in higher plants (e.g., in juices of fruits, vegetables) and also in honey. It is commercially obtained from sugar cane or sugar beet. Upon hydrolysis, sucrose yields one molecule each of glucose and fructose. In comparison to maltose and lactose, it has properties which are unique. It does not undergo mutarotation and is a non-reducing sugar. This is because α -glucose and α -fructose are held in an α -1,2' glycosidic bond instead of the more common 1,4'-glycosidic bond. As a result the anomeric carbons of both the constituent sugars are involved in the linkage formation. Therefore, none of these is available for mutarotation or for undergoing oxidation reaction with Tollen's reagent, Fehling's solution and Benedict reagent. The systematic name of sucrose is O- α -D-glucopyranosyl-(1 \rightarrow 2)- β -D-fructofuranose.

Sweetness of sugars is measured relative to the sweetness of sucrose, which has been assigned a value of 100. The sweetness value of other sugars relative to sucrose is as follows:

Relative sweetness value	
Lactose	16
Galactose	32
Maltose	33
Glucose	74
Sucrose	100
Fructose	173



Sucrose can be hydrolysed, by acids or enzymes found in intestines and in yeast, to a mixture of fructose and glucose. Sucrose has a specific rotation of $+66.5^\circ$. When it is hydrolyzed, the resulting equimolar mixture of glucose and fructose has a specific rotation of -22.0° . As the sign of the rotation changes (gets inverted from $+$ to $-$) when sucrose is hydrolyzed, a mixture of glucose and fructose is called invert sugar.

SAQ 2

Which monosaccharides are obtained by the hydrolysis of each disaccharide?

- a) maltose b) lactose c) sucrose

SAQ 3

Draw Haworth projection formula for maltose, lactose and sucrose.

SAQ 4

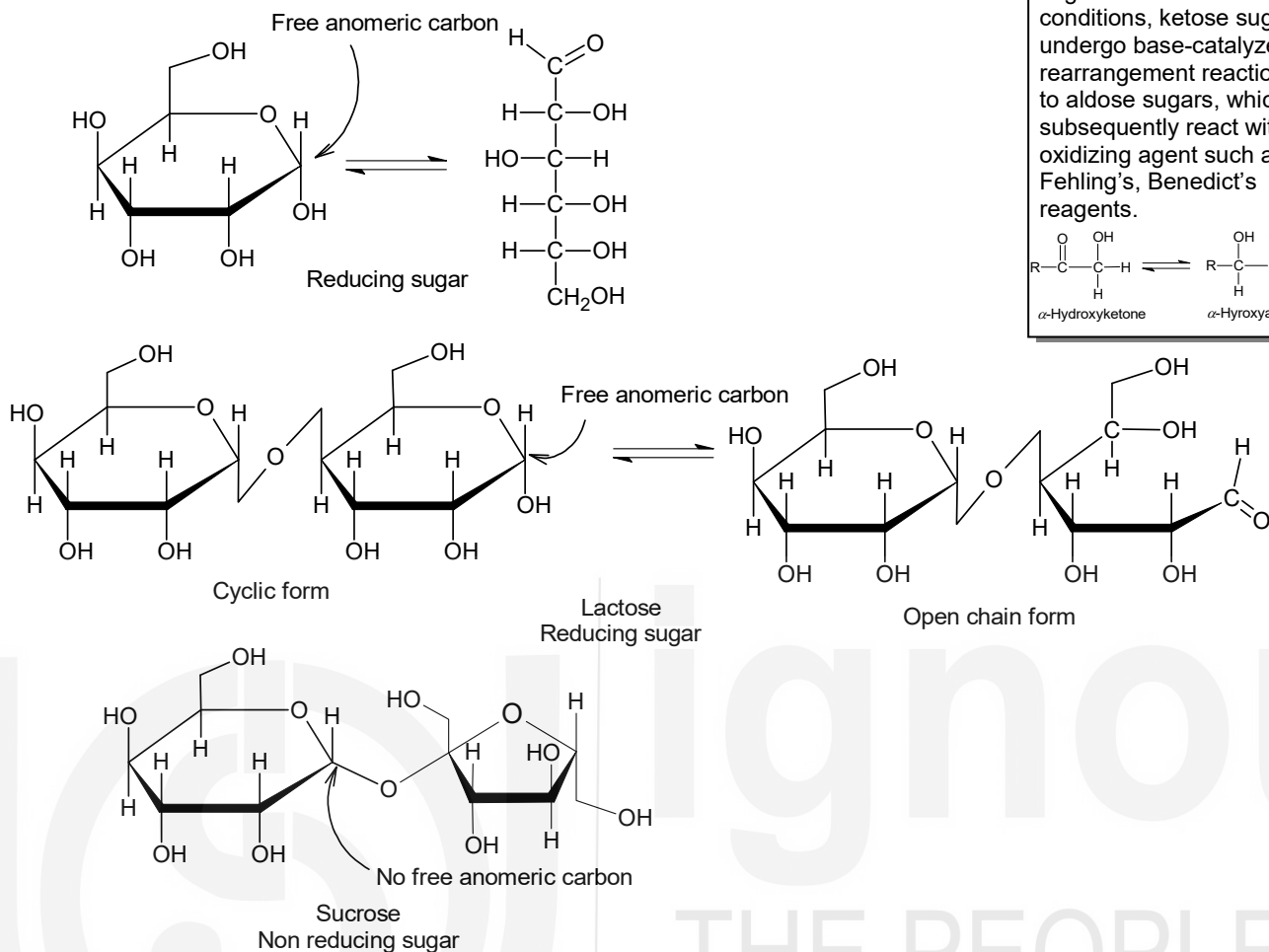
Which of the following is the correct systemic name of maltose? Tick [\checkmark] mark your answer.

- a) O- α -D-glucopyranosyl-(1 \rightarrow 4)- α -D-glucopyranose. []
- b) O- β -D-glucopyranosyl-(1 \rightarrow 4)- β -D-glucopyranose []
- c) O- α -D-glucopyranosyl-(1 \rightarrow 2)- β -D-fructofuranose []

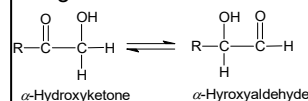
3.3 REDUCING AND NON-REDUCING SUGARS

Any Sugar which is capable of being oxidised and causes the reduction of mild oxidising agents such as Copper(II) ions (Cu^{2+}) to copper(I) ions (Cu^+) or Silver ions (Ag^+) to silver metal (Ag) is known as reducing sugar. Those sugars which are unable to be oxidised and do not reduce oxidising these agents are known as non-reducing sugars. As discussed earlier, all monosaccharides are reducing sugars. They all have a free reactive carbonyl group in the form of aldehyde group. Though sugars exist mainly in cyclic hemiacetal form, but during reaction conditions, cyclic hemiacetal form of sugar is converted to an acyclic form which has free aldehyde group. Similar to monosaccharides some disaccharides also react with silver and copper(II) ions. On that basis,

we can categorise disaccharides in two groups, that is reducing disaccharides such as maltose, lactose and non-reducing disaccharides such as sucrose.

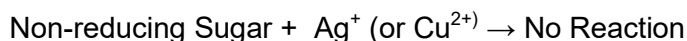
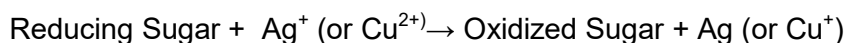


Both aldose and ketose sugars can be reducing sugars. Under reaction conditions, ketose sugars undergo base-catalyzed rearrangement reaction to aldose sugars, which subsequently react with oxidizing agent such as Fehling's, Benedict's reagents.



The disaccharides such as maltose and lactose have free anomeric carbon and they are reducing sugars. These sugars in solution have some amount of open chain form which has active aldehyde group. In contrast, both anomeric carbons in sucrose have glycosidic bonds, so formation of an acyclic intermediate with an active aldehyde group is not possible. As a result, sucrose does not reduce the mild oxidizing agents that oxidized maltose, and lactose, so it is a non-reducing sugar. Large polymer such as starch, are not reducing sugars, since the concentration of hemiacetal group is very low.

Most disaccharides are reducing sugars, sucrose (common table sugar) being an exception as it is a non-reducing sugar.



Reducing sugars reduce silver ion (Ag^+) to elemental silver (Ag) that deposits on the sides of the reaction test tube as a shiny "silver mirror". Similarly, they reduce copper(II) ions (Cu^{2+}) to copper(I) ions (Cu^+) that precipitates from basic aqueous solutions as the brick-red solid Cu_2O . One can visually monitor the formation of a silver mirror or a Cu_2O precipitate; these oxidizing agents provide diagnostic tests for the presence or absence of a reducing sugar.

Commonly used reagent for silver ion is Tollen's reagent which is prepared by dissolving silver nitrate (AgNO_3) and a small amount of ammonia in aqueous base. The Cu^{2+} reagents are Fehling's solution and Benedict's solution. Both the reagents are prepared by dissolving copper sulphate (CuSO_4) in aqueous

In the case of reducing sugars, the presence of alkali increases the formation of acyclic intermediate with an active aldehyde group. This leads to a higher susceptibility to oxidation reactions that at neutral or acidic pH. These sugars, therefore, become potential agents capable of reducing certain mild oxidants such as copper(II) ions and Ag^+ ions. Most commonly used reagents of this category for differentiating between reducing and non-reducing sugars are Fehling's test and Benedict's test.

base. We generally use base such as NaOH or KOH to dissolve CuSO_4 which can precipitate copper ions as copper hydroxide. Therefore, to prevent precipitation of copper ion as copper hydroxide and to improve the solubility of copper(II) ions, complexing agents are used. For Fehling's solution we use tartrate ions and for Benedict's solution we use citrate ions.

3.4 POLYSACCHARIDES

We have already described monosaccharides and disaccharides in Unit 2 and in section 3.2 respectively. You have been introduced to some general reactions of monosaccharides as well, including the glycosidic bond formation. This helped you in understanding the formation of disaccharides also. Now let us describe polysaccharides with emphasis on the linkage that hold the monosaccharide units in them. Polysaccharides, also known as glycans, are large polymers of hundreds of thousands of monosaccharide units held together by glycosidic linkages.

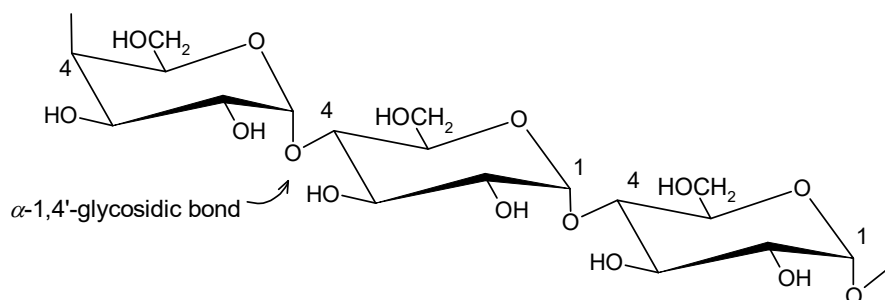
The polysaccharide chains may be linear or branched and may be composed of only one type of monosaccharide (homopolysaccharide, e.g., starch which is polymer of D-glucose), or two or more types of monosaccharides (heteropolysaccharides, e.g., glycosaminoglycans).

In nature, polysaccharides are employed as part of the structural tissues (known as **structural polysaccharides**) or may be used for storing energy (known as **storage polysaccharides**). Polysaccharides are not sweet and do not mutarotate. They are generally unreactive as most of their hemiacetal groups are bonded in the glycosidic bonds. We shall now describe more about some storage polysaccharides.

3.4.1 Storage Polysaccharides

Starch is the principal storage polysaccharide in plants. It not only serves as a reserve food in plants but is also a major source of carbohydrates for human beings. It is a glucose polymer and when excess glucose enters a plant cell, it is linked by an enzyme to the end of starch molecules. In case of shortfall of glucose in the cell, starch is hydrolysed within the cell to release glucose. Dietary starches are present in potatoes, rice, wheat, corn and many other plant sources. Natural starch ($\text{C}_6\text{H}_{10}\text{O}_5$)_n, is a mixture of two components, namely, **amylose** and **amylopectin**.

The proportion of amylose and amylopectin varies in starches from different sources, but usually consists of 25% amylose and 75% amylopectin. Amylose (molecular weight 50,000-60,000) consists of D-glucose units lined in a linear manner by α -1, 4'-glycosidic bonds.



Three subunits of amylose

The average chain length is 300-350 glucose units. You would observe that due to α -1,4'-linkage, amylose has a non-reducing as well as a reducing end. In solution amylose assumes a helical structure as shown below. It is soluble in hot water, which is due to the formation of a colloidal suspension.

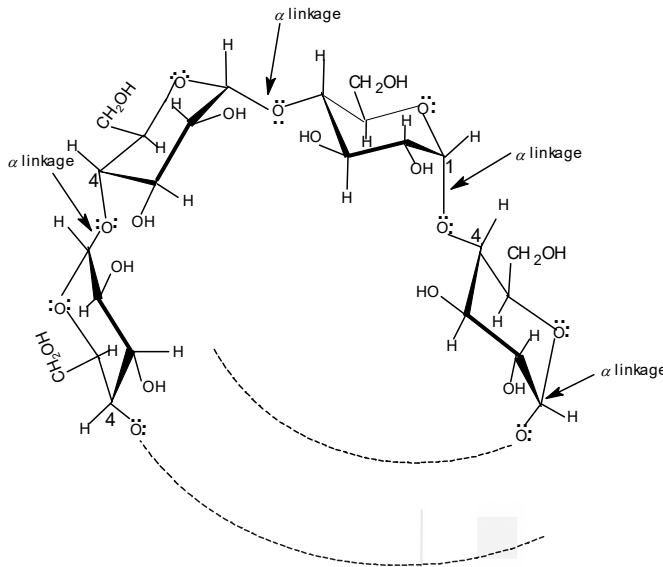
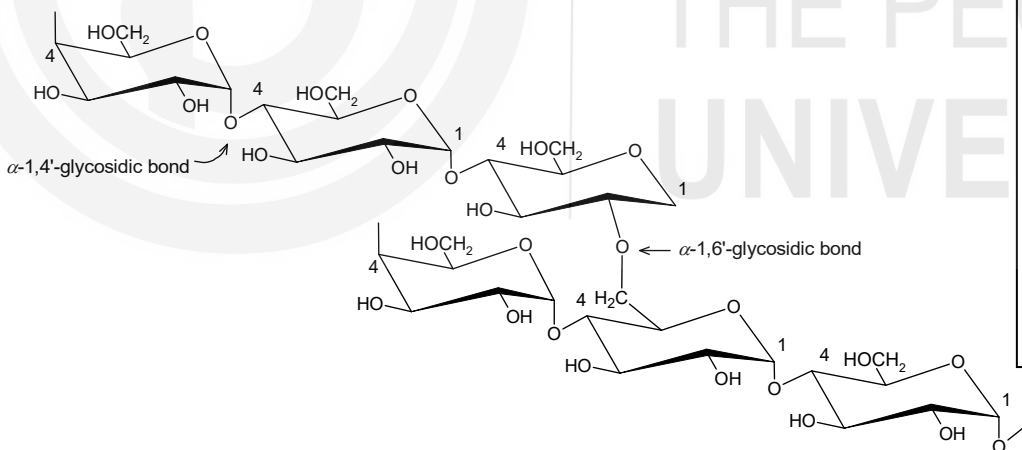


Fig. 3.1: Amylose: helical structure.

Amylopectin (molecular weight larger than 500,000) is a highly branched glucose polymer. The linear chains have glucose molecules bonded by α -1, 4'-glucosidic links. Unlike amylose, however, amylopectin also contains α -1, 6'- linkages. These linkages create the branches in the polysaccharide. Amylopectin molecules are significantly larger than amylose molecules, and are insoluble in hot water.



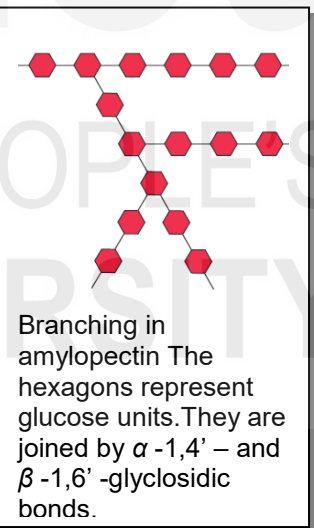
Six subunits of amylopectin

Amylose is hydrolysed by an enzyme, amylase, which is present in saliva and pancreatic juice, to a mixture of maltose and glucose. β -Amylase, hydrolyses from the non-reducing end to yield successive units of maltose only. Amylopectin, resists hydrolysis with α and β -amylase enzymes at branch points and also at β -1,6-linkages, resulting in a highly branched core of amylopectin called the **limit dextrin**, as one of the products of digestion.

Glycogen is the storage form of glucose in animals and is the equivalent of plant starches. It is mainly concentrated in the liver and muscles. A well nourished body has enough glucose in the form of glycogen, to supply it with

A solution of iodine and KI is used to test for the presence of starch and the degree to which it is hydrolysed. Starch-iodine complexes range in colour from blue black to red. Amylose gives a blue black colour an amylopectin a red colour with iodine.

Partial hydrolysis of starch by acids, enzymes or dry heat, produces polysaccharides known as **dextrins**. Dextrins get sticky when wet and are, therefore employed as adhesives. The golden colour of bread crust is due to the formation of dextrins.

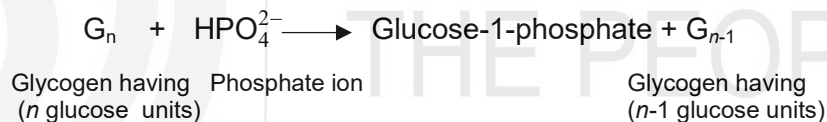


energy for about 18 hours. Glycogen is similar in structure to amylopectin, except that the branching occurs with much more frequency after every 8-10 glucose units. Most glycogen molecules have molecular weights higher than one million.



Fig. 3.5: Glycogen; each circle in the above chain represents a D-glucose unit, linked by α -1,4', bonds in the main chain and by α -1,6'-bonds at the branches.

When required for metabolism in the body, glucose units are removed one by one from glycogen, by a process of phosphorylation (i.e., bond rupture with the addition of a molecule of phosphoric acid) in the presence of an enzyme, glycogen phosphorylase, to yield glucose-1-phosphate. The glucose 1-phosphate so formed can be used for ATP synthesis in muscle or converted to free glucose in the liver. This is then utilised for the metabolic needs of the body.



SAQ 5

Tick [] marks the appropriate statement.

Limit dextrin is

- a) Product left after digestion of starch by amylase. []
- b) Highly branched portion of amylase. []
- c) Non-reducing end of amylopectin. []

SAQ 6

Polysaccharides do not mutarotate, why?

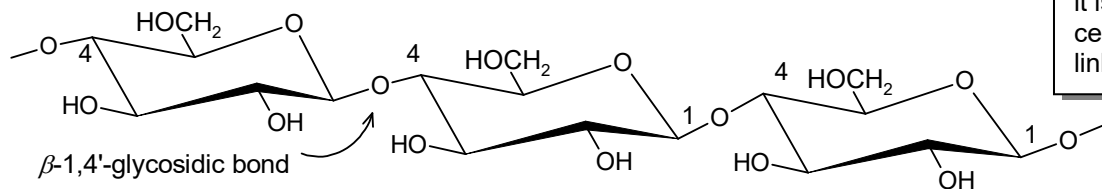
We shall now describe a common structural polysaccharide.

3.4.2 Cellulose: A Structural Polysaccharide

Cellulose is structural polysaccharide and the rigid cell wall of plants is composed primarily of this substance. It constitutes nearly one half of the

carbon in the extent in jute (50-70%) and wood (40-50%). Cellulose is insoluble in water, due to its size and structure.

Cellulose is a linear polymer of D-glucose units bonded by β -1, 4-linkages as shown below. It has a molecular formula of $(C_6H_{10}O_5)_n$, where $n = 500$ to 5,000, depending on the source, method of extraction and treatment.



Three subunits of cellulose

The difference between amylose and cellulose is in the nature of the glycosidic bond holding glucose units together. In amylose it is α -1,4 link, while in cellulose it is a β -1, 4-linkage.

Unlike starch, it is highly resistant to acidic or enzymatic hydrolysis. However, rumen bacteria in grazing animals and also termites possess an enzyme, cellulase, which hydrolyses cellulose to glucose. Other animals, such as man, lack this enzyme and cannot utilise cellulose as a source of energy. Any cellulose we eat, therefore, passes through the digestive tract undigested, providing the roughage we require for proper elimination.

Cellulose is a valuable commercial compound and as cotton it is used in clothing. On chemical treatment, cellulose forms a wide variety of products, such as celluloid, rayon, guncotton (an explosive), cellulose acetate, methyl and ethyl cellulose, etc. These derivatives are useful plastics that can be spun into fibres and spread into films. Cellulose in wood is also used to manufacture paper and a number of paper products.

3.5 COMPLEX POLYSACCHARIDES

In the preceding sections, we have described polysaccharides essentially made up of hexose monomer units. In addition to these, there are many complex carbohydrate molecules that contain amino nitrogen, which is either acetylated or combined with sulphuric or phosphoric acid. These complex polysaccharides are important as intercellular substances and exist either free or in combination with proteins or lipids.

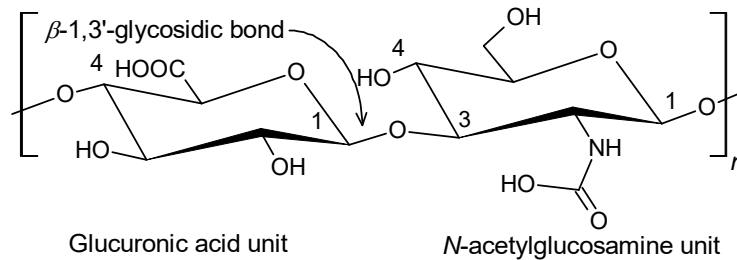
Let us describe the structure and role of some of these important complex molecules.

3.5.1 Glycosaminoglycans

The extracellular spaces, especially of connective tissues like cartilage, tendon, skin and the walls of blood vessels, consist of proteins, collagen and elastin, embedded in a gel like matrix called the **ground substance**. This ground substance is mostly made up of complex polysaccharides called **glycosaminoglycans** or **mucopolysaccharides**. These complex molecules have a slimy, mucus like consistency, which makes them highly viscous and elastic.

Glycosaminoglycans are made up of alternating glucuronic acid and hexosamine residues. Hyaluronic acid is an example of a Glycosaminoglycan. It is an important component of the ground substance present in the synovial

fluid of joints and vitreous humour of eyes. It consists of about 250-25,000 repeating units of alternative β -D-glucuronic acid and *N*-acetylglucosamine which are linked by β -1,3' bonds. The repeating units are, in turn, joined by β -1, 4' bonds as shown:



A section of Hyaluronic acid

Hyaluronic acid tightly binds ions like Na^+ , K^+ and Ca^{2+} . It is a rigid and highly hydrated molecule. In solution, it occupies a volume about 1000 times of that in its dry state. These properties make it highly suitable as an excellent biological shock absorber in the joints and also as a lubricant. Another glycosaminoglycan, chondroitin-4-sulphate, is a major component of cartilage and other connective tissues. Its structure is similar to hyaluronic acid, except that the *N*-acetyl-D-glucosamine residue is replaced by *N*-acetyl-D-glucosamine-4-sulphate.

Dermatin sulphate present in the skin tissue, keratin sulphate found in the keratin of nails and hooves, and heparin are other examples of complex polysaccharides. Heparin is variably sulphated glycosaminoglycan, consisting mostly of alternating α -1 4-linked residues of D-glucuronate-2-sulphate and D-glucosamine sulphated at N and at C-6. It occurs almost exclusively in the arterial walls and inhibits blood clotting. It is, therefore, a widely used powerful blood anticoagulant.

3.5.2 Glycoproteins

Many proteins in the cells are covalently associated with carbohydrate molecules, resulting in a type of biomolecule known as glycoproteins. The carbohydrate content of such glycoproteins varies from 1% (e.g., in immunoglobulins) upto 85% (e.g., in blood group substances). These molecules occur in almost all forms of life and include most of the plasma proteins, enzymes, hormones, etc. Most of the proteins in membranes and lipid bilayers are glycoproteins. In general, glycoproteins consist of a core protein to which the carbohydrates like glycosaminoglycans, or *N*-acetyl amino sugars are covalently linked.

Glycoproteins serve diverse functions, but in general they act as recognition sites for various biological interactions. Glycoproteins like immunoglobulins act as antibodies; γ globulins fight in infectious diseases, and mucin in saliva and gastric juice aids in the digestive process. Another glycoprotein, interferon, is produced by cells in response to viral infection. Some glycoproteins in the Antarctic fishes protect them against freezing.

3.5.3 Blood Group Substances

Plasma membranes of animal cells are linked to a number of carbohydrates, and literally appear as "sugar coated". These carbohydrates are basically

components of glycoproteins and glycolipids, and are a part of the mechanism by which various cell types identify (recognise) each other and act as biochemical markers (antigenic determinants). These membrane bound carbohydrates contain as many as 4 to 20 monosaccharide units, predominant among which are D-galactose, L-fucose, N-acetyl-D-glucosamine and N-acetyl-D-galactosamine.

Blood group substances were the first-discovered and well-understood of all membrane-bound carbohydrates. They are chiefly found on the surface of erythrocytes, but can also be found on proteins and lipids in other parts of the body. In the ABO group system, put forth in 1900 by Karl Landsteiner, four blood groups have been identified. These are A, B, AB and O. The chemical basis for this classification is the relatively small, membrane bound carbohydrate. The carbohydrate composition on the erythrocytes of A, B, AB and O blood groups is shown in Fig. 2.6 and 2.7.

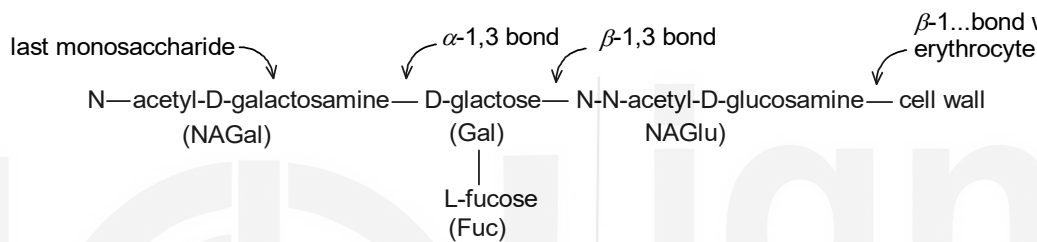
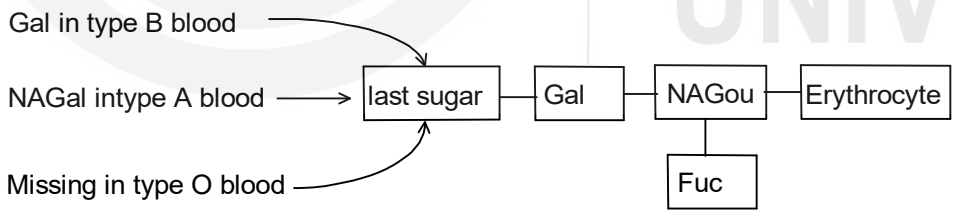


Fig. 3.6: Carbohydrate composition of erythrocytes (of type A blood)

The last monosaccharide (at the non-reducing end) in this carbohydrate chain determines the ABO classification. In type A, the chain terminates in N-acetyl-D-galactosamine. In type B it terminates in D-galactose and in type O, the last sugar is missing completely, while type AB contains both N-acetylgalactosamine as well as D-galactose as the terminal sugars, as shown:



Last sugar in type AB in NaGal as well as Gal as shown:

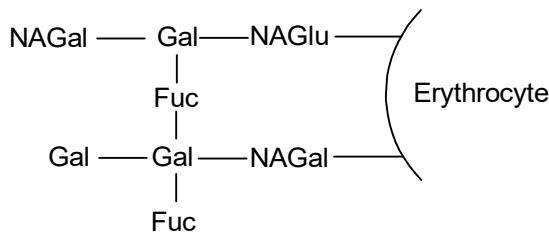
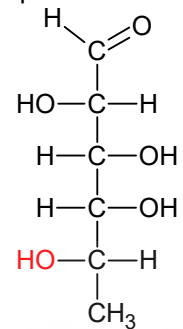


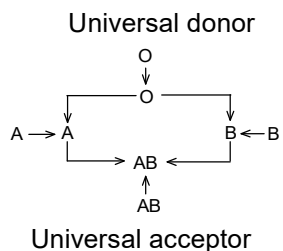
Fig. 3.7: Carbohydrate composition of erythrocytes

Antigens are foreign substances that invade the body and antibodies are substances that counteract them

L-Fucose is an uncommon carbohydrate, where -CH₂OH group is replaced by a -CH₃ group.



The ABO grouping is very important in blood transfusion. Blood from individuals of the same type can be mixed without clumping (agglutination) of erythrocytes. However, if serum of type A blood is mixed with type B blood or vice versa, the erythrocytes will clump. The following transfusion possibilities exist.



SAQ 7

How does type a blood differ from type O blood?

3.6 SUMMARY

- Disaccharides and polysaccharides have glycosidic bonds, which hold the monosaccharide units together.
- The different disaccharides can be distinguished by the nature of sugars present and the position and orientation of the glycosidic bond.
- Starch and glycogen, the chief storage polysaccharides, are branched glucose polymers with α -1,4 linkages in the chains and α -1,6 linkages at branch points.
- Cellulose the most important structural polysaccharides of plants is a linear polymer of D-glucose with β -1, 4 linkages.
- Starch and glycogen are easily hydrolysed by acids and enzymes, while cellulose is resistant to acids and is hydrolysed only by cellulase.
- Complex polysaccharides are important as components of intercellular ground substances and may exist either free or complexed with proteins.
- The glycosaminoglycans-hyaluronic acid, chondroitin sulphate, keratin sulphate and heparin are high molecular weight polymers consisting of uronic acids, and sulphated or amino substituted acetyl sugars.
- Glycosaminoglycans are excellent shock absorbers and lubricating compounds in tissues.
- The glycoproteins on the external surface of the erythrocyte membranes are important as blood group antigens.

5.7 TERMINAL QUESTIONS

1. Name the storage polysaccharides present in animals and plants. Indicate the structural differences between them.
2. Why is maltose a reducing sugar and sucrose a non-reducing sugar?
3. Why is cellulose insoluble in water and why is it not used as an energy source by human beings?
4. Give the structure of sucrose, lactose and maltose. What are the sources of these common disaccharides?
5. How is the classification of polysaccharides related to their composition and function?

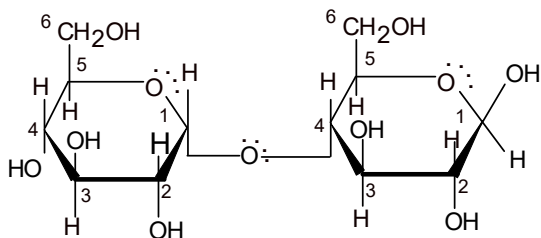
3.8 ANSWERS

Self Assessment Questions

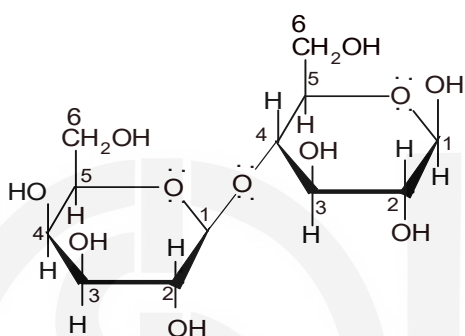
1. 4. In a disaccharide, the constituent monosaccharide units are held by acetal linkages, known as glycosidic bonds. These are formed between C-1-OH of one sugar unit and usually the C-4 or C-6-OH of another sugar molecule. These bonds can be α or β glycosidic bonds, depending on the

starting hemiacetal. The resulting disaccharide does have one anomeric carbon left as such and the $-OH$ group on it can have α and β orientation, i.e., the disaccharide can be in α or β anomeric forms.

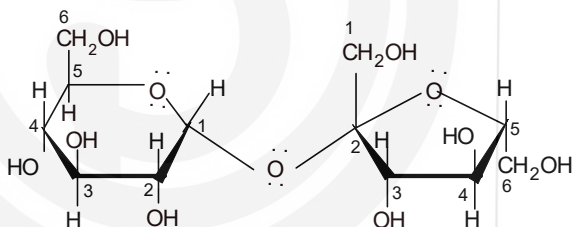
2. a) D-glucose and D-fructose; b) two molecules of D-glucose; c) D-glucose and D-galactose.
3. a) Maltose



b) Lactose



c) Sucrose



4. a)
5. a)
6. In polysaccharides, the anomeric carbon of the constituent sugar units is not free to mutarotate, as it is linked in a glycosidic bond with another sugar molecule.
7. In type A blood the last monosaccharide in the carbohydrate chain is *N*-acetyl-D-galactosamine, whereas in type O blood it is missing.

Terminal Questions

1. Glycogen and starch are the reserve polysaccharides in animals and plants respectively. While starch is mixture of the linear polymer amylose (made of glucose units linked by α -1, 4'- glycosidic linkages) and branched polymer amylopectin (which consist of short α -1, 4' glucose chains linked by α -1,6 glycosidic bonds and the branching is not extensive). Glycogen is similar to amylopectin in structure excepting that the branching is more frequent (at every 8-10 glucose units).

2. Although maltose is a glycoside, the second glucose units have an –OH group on its anomeric carbon atom and its ring can open to give an aldehyde and hence acts as a reducing sugar. Sucrose, on the other hand has its –D-glucose unit condensed with the anomeric hydroxyl of β -D-fructose. Since either unit possesses an anomeric hydroxyl or the rings cannot open to give an aldehyde, the sugar is non-reducing.
3. Cellulose molecules are insoluble in water, due to their size and structure. In cellulose, glucose units are linked to each other by β -1, 4 linkages to form large linear polymers. Human beings do not possess the enzyme required to hydrolyse this bond. Amylase present in human saliva and pancreatic juice are suited for the hydrolysis of α -1, 4 glucosidic bonds only. Hence, the glucose present in cellulose is unavailable to human beings as an energy source.
4. Structures of maltose, lactose and sucrose are given in section 2.4. Sucrose is the major disaccharide present in sugarcane, lactose is present in milk and maltose is a product obtained during incomplete (enzymatic) hydrolysis of starch, glycogen or dextrans and is present naturally in barley malt.
5. Polysaccharides can be classified on the basis of their composition as homopolysaccharides (starch) and heteropolysaccharides (Peptidoglycan of cell wall). Functionally, two types of polysaccharides are distinguished, namely, storage polysaccharides like starch and glycogen, and structural polysaccharides, like cellulose and chitin.