



ISSN: 0976-3376

Available Online at <http://www.journalajst.com>

ASIAN JOURNAL OF  
SCIENCE AND TECHNOLOGY

Asian Journal of Science and Technology  
Vol. 08, Issue, 07, pp.5038-5043, July, 2017

## REVIEW ARTICLE

### REVIEW: CARBOHYDRATES CHEMISTRY

<sup>1</sup>Fathia, M. I. and <sup>2</sup>Mubark, E.O.

<sup>1</sup>National Center for Research/ Institute of Engineering Research and Materials Technology

<sup>2</sup>University of Khartoum, Faculty of Science department of Chemistry

#### ARTICLE INFO

##### Article History:

Received 29<sup>th</sup> April, 2017

Received in revised form

04<sup>th</sup> May, 2017

Accepted 10<sup>th</sup> June 2017

Published online 24<sup>th</sup> July, 2017

##### Key words:

Carbohydrates, Classification,  
and chemistry of carbohydrates.

Copyright©2017, Fathia and Mubark, This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

#### INTRODUCTION

Carbohydrates are organic compounds (biomolecules). They are widely distributed in plants and animals, that act as the primary biological means of storing energy (e.g., starch and glycogen) and for serving as structural component (e.g., cellulose in plants and chitin in insects), other forms being fat and protein (FINAR, 1973). They are the ultimate products of photosynthesis; an endothermic reductive process of carbon dioxide that requires (FINAR, 1973; <http://www.en.wikipedia.org/wiki/Carbohydrate> and <http://www.com.Msu.Edu/reush/Virtual Text/ Carbohydrates>) light energy and the pigment chlorophyll as the following equation illustrates:



Carbohydrates, or saccharides, are most simply defined as polyhydroxy aldehydes (aldoses) or polyhydroxy ketones (ketoses), or substances that yield these on hydrolysis (Wood, 1968). Carbohydrates are substances with general formula  $(\text{CH}_2\text{O})_n$ , which are called hydrate of carbon, because they contain hydrogen and oxygen in the same proportion as is in water (2:1) (<http://www.com.Msu.Edu/reush/Virtual Text/ Carbohydrates>, Wood, 1968 and Durrant, 2008). However, a number of compounds have been discovered which are carbohydrates by chemical behavior, but do not conform to the formula,  $(\text{CH}_2\text{O})_n$  one example of such compounds is the 2-

#### ABSTRACT

Carbohydrates are the most abundant organic compounds in the plant world. They are natural products, produced by photosynthesis processes in plants. They act as storehouses of chemical energy (glucose, starch, and glycogen), they are components of supportive structures in plants (cellulose), crustacean shells (chitin), and connective tissues in animals (acidic polysaccharides); and they are essential components of nucleic acids (D-ribose and 2-deoxy-D-ribose (DNA and RNA)) and for energy transfer (in ATP). Carbohydrates are known as sugar and they composed of monosaccharides, disaccharides and polysaccharides. The chemistry of carbohydrates most closely resembles that of alcohols, aldehydes, and ketones.

deoxyribose sugar ( $\text{C}_5\text{H}_{10}\text{O}_4$ ) which is constituent of deoxyribonucleic acid (DNA), a component of every cell. Also there are other carbohydrates containing nitrogen (amino sugar) and sulfur in addition to carbon, hydrogen, and oxygen. These compounds don't agree with the general formula  $\text{C}_n(\text{H}_2\text{O})_n$ . It is also noted that all compounds conforming to the formula  $\text{C}_n(\text{H}_2\text{O})_n$  are not carbohydrates, e.g., formaldehyde ( $\text{CH}_2\text{O}$ ) and acetic acid ( $\text{C}_2\text{H}_4\text{O}_2$ ) (ellllis, 1966). Carbohydrates are important part of balanced human diet, providing energy for life processes including growth and movement, clothing, and shelter. Excess carbohydrate intake can be converted and stored in the body as glycogen or fat (Campaigne, 1964 and [//local host/ C./Documents20% 20% setting/adil 20% Mustafa/ Desk top/ Carbohydrates.1.htm](http://local host/ C./Documents20% 20% setting/adil 20% Mustafa/ Desk top/ Carbohydrates.1.htm)).

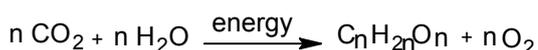
Carbohydrates are the main source of energy for mammals and are common constituent of all living plants and animals. They make up the main portion of plant tissues; stems, roots, and leaves ([//local host/ C./Documents20% 20% setting/ adil 20% Mustafa/ Desk top/ Carbohydrates. 1. htm](http://local host/ C./Documents20% 20% setting/ adil 20% Mustafa/ Desk top/ Carbohydrates. 1. htm)). The simple carbohydrates which consist of low molecular weight are called sugars, such as monosaccharides (e.g., glucose, fructose), and disaccharides; which are composed of two monosaccharide units such as sucrose, maltose, and lactose. Polysaccharides such as starch, cellulose, glycogen, and gums are in fact carbohydrates composed of repeated units of monosaccharides (glucose) with high molecular weight (FINAR, 1973; Campaigne, 1974; <http://www.elmurst.edu/chem/vchembook/541 classes, html>).

\*Corresponding author: Fathia, M. I

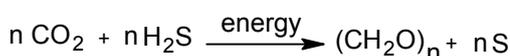
National Center for Research/ Institute of Engineering Research and Materials Technology

**Photosynthesis:** Photosynthesis is the physicochemical process by which plants, algae, and photosynthetic bacteria use light energy to derive the synthesis of organic compounds

from water and carbon dioxide (FINAR, 1973 and <http://www.life.uiue.edu/govindee/paper/gov.html>). The process of photosynthesis takes place in small organelles known as chloroplasts, which are located inside cells, which have chlorophyll in them; (the green pigment involved in photosynthesis) (FINAR, 1973 and Morrison, 1973). The photosynthetic process in all plants and algae as well as in certain types of photosynthetic bacteria involves the reduction of CO<sub>2</sub> to carbohydrates. Water is used as the electron donor in oxygenic photosynthesis as the next equation and scheme illustrated (FINAR, 1973 and <http://www.life.uiue.edu/govindee/paper/gov.html>).



Other types of bacteria (Purple bacteria, green sulfur bacteria, and green gliding bacteria) use light energy to extract (FINAR, 1973 and 111c./Document%20 and %20 settings/user/My%20Document) electrons from molecules other than water (e.g., H<sub>2</sub>S) to create organic compounds but don't produce oxygen (anoxygenic photosynthesis):



The energy harvested via the light reaction is stored by forming a chemical compound called ATP (adenine triphosphate); made of the nucleotide adenine bonded to ribose sugar. The net reaction is the transfer of electrons from the water molecule to NADP with the resultant formation of NADPH; used in the reduction of (carbon dioxide) to give rise to glucose as the following scheme (111c./Document%20 and %20 settings/user/My%20Document) suggests:

Most plants put CO<sub>2</sub> directly into Calvin Cycle. Calvin cycle is a series of chemical reactions that occurs as part of the dark reactions of photosynthesis, in which carbon is broken from gaseous carbon dioxide and fixed as organic compounds (sugars and starch as food). The Calvin cycle starts with a five-carbon sugar molecule. Thus, the first stable organic compound formed is glyceraldehydes-3-phosphate. Almost immediately, two of these join (111c./Document%20 and %20 settings/user/My%20Document) to form a glucose molecule:



The dark reaction takes place in stroma within the chloroplast and converts CO<sub>2</sub> to sugar. This reaction doesn't directly need light to occur, but it does need the products of light energy; (ATP) in addition to NADPH (111c./Document%20 and %20 settings/user/My%20Document).

### The chemistry of carbohydrates

The chemistry of carbohydrates most closely resembles that of alcohols, aldehydes, and ketones so they can oxidize and reduction. It is complicated by the fact that there is the functional group (OH) on almost every carbon atom. In addition, the carbohydrates may exist in either straight or a ring structure; the ring structure incorporating two additional functional groups, the hemiacetal and acetal (FINAR, 1973;

<http://www.com.Msu.Edu/reush/VirtualText/Carbohydrates>; Wood, 1968; Durrant, 2008; FINAR, 1964).

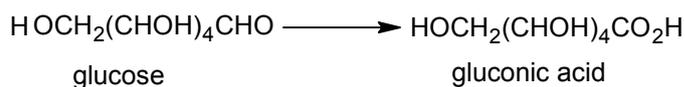
### Reactions involving the hydroxyl groups

The free hydroxyl groups of monosaccharide and polysaccharides can be acylated to yield O-acetyl derivatives; used to elucidate the structures of carbohydrates. For example, treatment<sup>5</sup> of glucose with excess acetic anhydride yields penta-O-acetyl- $\alpha$ -D-glucose:

Also hydroxyl groups of monosaccharides can be methylated. The hydroxyl group on the anomeric atom reacts with methanol to yield methyl glycosides, (which are acetals):

### Oxidation of sugars

The product(s) formed (FINAR, 1973; <http://www.en.Wikipedia.org/wiki/Carbohydrate>; <http://www.com.Msu.Edu/reush/VirtualText/Carbohydrates>; Wood, 1986; Durrant 1966 and FINAR, 1964), by oxidation of aldoses depend on the nature of the oxidizing agent used. Oxidation can be induced at either the reducing end or both ends of the chain, at individual hydroxyl groups, or conducted to induce cleavage of the carbon-carbon chain by periodic acid under controlled conditions, thus oxidation of glucose required five moles of the acid for each mole of glucose. This reagent not only oxidizes (FINAR, 1973; <http://www.en.Wikipedia.org/wiki/Carbohydrate>; <http://www.com.Msu.Edu/reush/VirtualText/Carbohydrates>; Wood, 1986; Durrant, 1966 and FINAR, 1964) 1,2-diol but also hydroxyaldehydes and hydroxyketones: Mild oxidizing reagents such as bromine water or an alkaline solution of iodine oxidize only the aldehyde groups to give aldonic acids. Glucose, thus, gives (FINAR, 1973; <http://www.en.Wikipedia.org/wiki/Carbohydrate>; <http://www.com.Msu.Edu/reush/VirtualText/Carbohydrates>; Wood, 1986; Durrant, 1966 and FINAR, 1964), gluconic acid:



Also sugars reduce (FINAR, 1973; <http://www.en.Wikipedia.org/wiki/Carbohydrate> and <http://www.wikipedia.org/wiki/Dihydroxyacetone>), Fehling's solution, Benedict's solution, and ammonical silver nitrate to give aldonic acids.

This type of oxidation is also carried out with mercuric oxide (HgO) in the presence of calcium carbonate. Also gluconic acid is manufactured by enzyme glucose oxidase; present in the fungi *Aspergillus niger* and *Penicillium chrysogenum* (FINAR, 1973).

Oxidation of aldoses with strong oxidizing reagents, such as nitric acid, produces dicarboxylic acids known as saccharic or aldaric acids. Glucose for example, gives<sup>1</sup> glucosaccharic or glucaric acid:

Oxidation of the (-CH<sub>2</sub>OH) group in aldoses, in general, gives aldouronic acids. For example, glucose is oxidized to glucuronic acid. Aldouronic acids occur in nature, e.g., D-glucuronic acid plays an important role in metabolism. D-galacturonic acid is a component of fruit pectin. D-mannuronic and L-guluronic acids occur in combined form in various seaweed and L-iduronic acid in heparin (FINAR, 1973). The general method is to protect the aldehydic group, usually as the

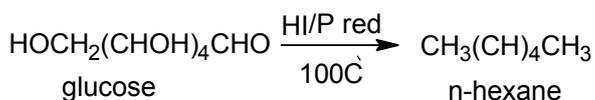
isopropylidene derivative, which is then oxidized with oxygen in the presence of Pt-C as catalyst:

Aldoses and ketoses are oxidized by periodic ( $\text{HIO}_4$ ) acid and its salts (sodium periodate) and by lead tetra-acetate with complete break down of the carbon chain. These reagents have been of inestimable value in carbohydrate chemistry. They have been employed not only as tools in structural studies but also in synthetic work. These reagents selectively oxidize  $\alpha,\beta$ -diol groups with cleavage of intervening carbon-carbon bond (Campaigne, 1974; Durrant, 2008 and FINAR, 1964). Aldohexoses and aldopentoses are completely broken down by periodic acid. For example, an aldopentose consumes (Campaigne, 1964 FINAR, 1964), four molecules of periodic acid; yielding four molecules of formic acid and one molecule of formaldehyde:

### Reduction of sugars

Reduction of aldoses (sugars in general) with sodium amalgam, sodium borohydride, catalytic hydrogenation ( $\text{Ni-H}_2$ ), or electrolytic reduction in acid solution, gives the corresponding polyhydric alcohols. For example, glucose is transformed<sup>1</sup> into sorbitol

Reduction<sup>1</sup> of glucose with concentrated hydriodic acid and red phosphorus at  $100\text{ }^\circ\text{C}$  produces 2-iso propylidene, prolonged heating finally gives n-hexane:



### Methods of ascending the sugar series

An aldose is converted (FINAR, 1973 and Morrison, 1973) into its next higher aldose, e.g., an aldopentose into aldohexose, by Kiliani reaction as follows:

1,4-aldonolactone ( $\gamma$ -lactone) may also be reduced to the corresponding aldose by sodium borohydride or lithium hydride in a mixture of tetrahydrofuran and pyridine.

There are many other methods available for stepping up the sugar. Sowden et al. (FINAR, 1973; Morrison, 1973 and FINAR, 1964) used nitromethane as follows:

### Methods of descending the sugar series

The removal of the one terminal carbon atom of the monosaccharide to give the next lower aldose can be done by a variety of methods. One of the classical methods is Ruff's degradation (FINAR, 1973; Morrison, 1973; Elllis, 1966) in which aldose is first oxidized by bromine water to the corresponding aldonic acid. When the calcium salt of this acid is treated with fenton's reagent ( $\text{H}_2\text{O}_2 + \text{FeSO}_4$ ), it is converted into the next lower aldose. The Wohl's degradation (FINAR, 1973; Morrison, 1973 and FINAR, 1964) involves the dehydration of the aldose oxime, to give the O-acetylated nitrile, followed by ammonia-induced loss of hydrogen cyanide and O-deacetylation to give the 1,1-bisacetoamido derivative from which the next lower aldose is generated by mild acid hydrolysis:

Zemplen modified Wohl's (FINAR, 1973; Morrison, 1973 and FINAR, 1964), method by using a solution of sodium methoxide in chloroform, to remove hydrogen cyanide and the acetal groups:

Also Weyygang et al. has treated<sup>1</sup> the oxime with 1-fluoro-2,4-dinitrobenzene in aqueous solution of sodium hydrogen carbonate; the product is the next lower aldose (yield 50-60%): Berezovlki et al. have showed that calcium gluconate can be oxidized with hydrogen peroxide in the presence of ferrous sulphate and barium acetate to give D-arabinose:

Weerman (FINAR, 1973), treated  $\alpha$ -hydroxy-amides and  $\alpha$ -methoxy-amides by a cold solution of sodium hypochlorite. The mildest and highest yielding chain procedure is disulphone degradation, introduced originally by Fisher et al<sup>1</sup> and further developed by Hough et al. (FINAR, 1973). The aldose is first converted into dialkyldithioacetal (mercaptal) by reaction with the appropriate alkanethiol, followed by oxidation with propionic acid to give the disulphone which then undergoes cleavage of  $\text{C}_1\text{-C}_2$  bond in dilute ammonia giving the next lower aldose as shown below:

On the other hand, (FINAR, 1973) aldoses may be descended by oxidation with lead tetra-acetate or sodium bismuthate. For example, oxidation of D-mannose by one mole of lead tetra-acetate in acetic acid gives D-arabinose as follows:

### Conversion of aldoses into ketoses

An aldose is converted into its osazone, which is then hydrolyzed with hydrochloric acid to the ozone. On reduction with zinc and acetic acid, the ozone is converted (FINAR, 1973; Morrison, 1973 and Elllis, 1966) into ketose. Glucose, for example, enters into the glycolytic pathway by phosphorylation to glucose-6-phosphate; accomplished by the enzyme hexokinase. Glucose-6-phosphate is converted to fructose-6-phosphate by phosphohexoisomerase. The process<sup>14</sup> involves an aldose-keto isomerization:

### Conversion of ketoses into aldoses

The ketose is reduced to the corresponding polyhydric alcohol, which is then oxidized to monocarboxylic acid. On warming, the acid is converted into the  $\gamma$ -lactone which on reduction<sup>1, 11</sup> with sodium amalgam in faintly acid solution is converted into the next lower aldose.

### Classification of carbohydrates

There are a variety of interrelated classification schemes. The most useful one divides carbohydrates into groups according to the number of individual simple sugar units they contain. Monosaccharides contain one single simple unit, disaccharides contain two simple units, oligosaccharides contain 3-9 single simple units, and polysaccharides contain more than nine simple sugar units. Most carbohydrates (disaccharides, oligosaccharides and polysaccharides) contain glucose as simple monosaccharide units (FINAR, 1973; Morrison, 1973; Melnilville, 1962).

The simplest carbohydrates are crystalline substances, sweet, and soluble in water. They are subdivided (FINAR, 1973; <http://www.en.Wikipedia.org/wiki/Carbohydrate>; <http://www.Msu.Edu/reush/VirtualText/Carbohydrates>; Durrant,

2008 and <http://www.tiscali.co.uk/reference/encyclopedia/hustchinson/moo01993.htm>), into two major groups:

**Monosaccharides (monosaccharoses):** these are sugars which cannot be hydrolysed into smaller molecules. Their general formula is  $C_nH_{2n}O_n$ ; where  $n$  is 2-10. Examples include glyceraldehyde, glucose, and fructose.

**Oligosaccharides:** these yield 2-9 monosaccharide molecules on hydrolysis, e.g., disaccharides, such as sucrose, lactose, and maltose. Raffinose is made up of three monosaccharide units.

Polysaccharides are more complex than sugars and most of them are non-crystalline substances, not sweet, and are insoluble in water; with general formula  $(C_6H_{10}O_6)_n$ . They yield large numbers of monosaccharides on hydrolysis. The monosaccharide units are joined together in long chains or in a branching manner (mode) by glycosidic bonds. Examples are starch, cellulose, glycogen, and plant gums.

### Monosaccharides

Monosaccharides are the simplest carbohydrates which contain 2-9 carbon atoms in the molecule. Their general formula is  $C_nH_{2n}O_n$ . The most important ones are pentoses (arabinose, xylose, and ribose) and hexoses (glucose, galactose, mannose and fructose). Pentose sugars are important constituents of nucleotides, nucleic acids, and many coenzymes (ATP, NAD, and NADP) (FINAR, 1973; <http://www.en.wikipedia.org/wiki/Carbohydrate>, Durrant, 2008; <http://www.elmurst.edu/chem/vchembook/541classes.html> and <http://www.Tiscali.Com.Uk/>).

Monosaccharides are divided into aldoses (molecules containing an aldehydic group, and ketoses (molecules containing a ketonic group). The systematic class name also indicates the number of carbon atoms in the molecule. For example, glyceraldehyde is an aldotriose, dihydroxyacetone is a ketotriose, glucose is an aldohexose, and fructose is a ketohexose, depending on the number of carbon atoms (Wood, 1968). Monosaccharides are sweet, crystalline substances, and soluble in water. Unlike disaccharides and polysaccharides they cannot be hydrolyzed into, much, simpler constituents. They undergo oxidation very readily and therefore they are strong reducing agents. The classification of sugars as reducing or non-reducing is based on their reactivity with Tollens', Benedict's, or Fehling's reagents. If a sugar is oxidized by these reagents it is called reducing sugars. Monosaccharides, like simple aldehyde and ketone, yield additive compounds (cyanohydrin) with hydrocyanic acid, and react with hydroxylamine to form oximes. In slightly acid solution, they react with excess phenylhydrazine to form phenylosazones, which are insoluble in water and easily crystallized. Osazones are used to characterize and identify sugars. Glucose fructose and mannose yield the same osazone (FINAR, 1973; Durrant, 2008; <http://www.wikipedia.org/wiki/Glyceraldehyde>, and <http://www.wikipedia.org/wiki/Dihydroxyacetone>). The aldehydic or ketonic group in monosaccharides reacts with hydroxyl groups on a different carbon atom to form a hemiacetal or hemiketal; in which case there is an oxygen bridge between the two carbon atoms forming heterocyclic rings. The ring with five atoms is called furanose; the form with six atoms is called pyranose. The cyclic structure exists in equilibrium with the straight-chain

form; the ring structure having more optically active sites (centres) and so has both an  $\alpha$  ( $+112^\circ$ ) and  $\beta$  ( $+19^\circ$ ) forms which interconvert in solution. When either  $\alpha$  or  $\beta$  isomer of D-glucose is dissolved in water the optical rotation gradually changes and approaches a final equilibrium value of  $+52^\circ$ . This change in optical rotation is called mutarotation (FINAR., 1973 and Morrison, 1973).

Mutarotation is the term given to the change in the specific rotation of a cyclic monosaccharide as it reaches an equilibrium between its  $\alpha$  and  $\beta$  anomeric forms. All reducing sugars undergo mutarotation. When a monosaccharide is dissolved in water, the optical rotatory power of the solution gradually changes until it reaches constant value. For instance, freshly prepared solution of  $\alpha$ -D-glucose has specific rotation of  $+119^\circ$ ; when this solution is allowed to stand the specific rotation falls to  $+52.5^\circ$ . A fresh solution of  $\beta$ -D-glucose, on other hand has specific rotation of  $+19^\circ$ ; on standing it also changes to the same value ( $+52.5^\circ$ ) (FINAR., 1973 and Morrison, 1973). The equilibrium mixture in aqueous solution with specific rotation of  $+52.5^\circ$  consists of 37%  $\alpha$ - and 64%  $\beta$ - with only small amount (about 0.1%) of straight chain compound (FINAR., 1973 Durrant, 2008 and Morrison, 1973).  $\alpha$ - and  $\beta$ - forms of D-glucose are optical isomers; they are diastereomer rather than enantiomers. They also called anomers. In sugar chemistry, an anomer is a special type of epimer. It is a stereoisomer; more exactly of a saccharide (in the cyclic form) that differs only in its configuration at the hemiacetal (or hemiketal) carbon; also called the anomeric carbon (FINAR., 1973 Durrant, 2008).

### Disaccharides

The common disaccharides are dihexoses with the formula  $(C_{12}H_{22}O_{11})$ . They are composed of two monosaccharide units linked together by the glycosidic bond. The most common disaccharide is sucrose (cane or beet sugar) which is made up from one unit of glucose and one unit of fructose. Lactose (milk sugar) is made up from one unit of glucose and one unit of galactose. Maltose is made up of two glucose units (FINAR, 1974; <http://www.en.wikipedia.org/wiki/Carbohydrate>; <http://www.com.msu.edu/reush/VirtualText/Carbohydrates>; Morrison, 1973; FINAR, 1974). The disaccharides of dihexoses have shown (FINAR, 1973) that three types of combination occur in the natural compounds:

$C_1$  of one molecule is linked to  $C_6$  of the other, as for example in melibiose:

- Melibiose is disaccharide with an alpha-1,6 linkage between galactose and glucose, obtained from the trisaccharide raffinose When hydrolyzed by dilute acid it gives D-glucose and D-galactose (FINAR, 1964).
- The two monosaccharide molecules are linked (FINAR, 1964) through their reducing groups, as for example in sucrose:
- $C_1$  of one molecule is linked to  $C_4$  of the other, as in maltose for instance:

When hydrolyzed, (Wood, 1968), either by enzymes or by dilute mineral acids as catalysts, the constituents of hexoses are obtained:

Maltose and lactose reduce Fehling's solution and ammoniacal silver oxide, whilst sucrose fails to demonstrate a similar action. Maltose and Lactose also form phenylosazone; sucrose shows negative response (FINAR, 1973; Wood; 1968 and FINAR, 1964).

### Polysaccharides

Polysaccharides are polymeric carbohydrates with high molecular weight, formed of repeating units (either mono-or disaccharides) joined together by glycosidic bonds, between the hydroxyl group at C<sub>1</sub> of monosaccharide units and the hydroxyl group of C<sub>6</sub> or C<sub>4</sub> of other monosaccharide unit. Polysaccharides consist of ten to hundred to several thousand monosaccharide units joined together by  $\alpha$ - $\beta$ -glycosidic or hemiacetal linkages. Polysaccharides are synthesized by plants, animals, and humans and stored for food, structural support, or metabolized for energy. Polysaccharides are insoluble in water and alcohol, not sweet, do not act as reducing sugars; nor they form osazone with phenyl hydrazine. Their molecular weights are quite high. Because of numerous possibilities of inter-sugar linkage, polysaccharides can possess complex structure. They also form secondary structures, depending upon the conformations of sugar residues, the molecular weight, and the inter-intra chain hydrogen-bonding. The situation becomes more complicated when polysaccharides are composed of two or more kinds of monosaccharide residues.

Polysaccharides are not generally classified by their structures but according to the type of monosaccharide formed upon hydrolysis. Thus, there are three important classes of polysaccharides:

The first class is pentosans. Pentosans have the formula (C<sub>5</sub>H<sub>8</sub>O<sub>4</sub>)<sub>n</sub> which upon hydrolysis yield 5-carbon monosaccharides. These polysaccharides occur in plants such as cherry gum, corncobs, straw, and wheat. Xylans, for example, upon hydrolysis yield D-xylose and arabans give L-arabinose.

- The second class is hexosans. These polysaccharides have the formula (C<sub>6</sub>H<sub>10</sub>O<sub>5</sub>)<sub>n</sub> which yield upon hydrolysis 6-carbon monosaccharides. For instance, glycans; starch, cellulose, and glycogen, yield D-glucose units upon hydrolysis. Galactans yield galactose upon hydrolysis. Galactans occur in seed and wood. Mannans yield upon hydrolysis mannose. They are found in ivory unit, seaweed, and baker yeast.<sup>1,2,21</sup>
- The third class is complex polysaccharides which yield upon hydrolysis more than one kind of carbohydrates or sugar derivatives. Gums, which are acidic polysaccharides (e.g., gum arabic and gum tragacanth) give, on hydrolysis, arabinose, galactose, rhamnose, glucuronic acid; and mucilage which swell in water to form a gel or viscous solution. On hydrolysis, mucilage give galacturonic acid, arabinose, and xylose.
- The best known polysaccharides are starch, inulin, glycogen (reserve food stuffs in the plants or animals body), cellulose (structural material of plants), chitin (structural material in many insects). One example of structural polysaccharide in higher animals is haluronic acid. It is a mucopolysaccharide found in tissues such as eye, umbilical cord, cartilage, and skin.

### Conclusion

The presented work contains everything about classification, structure and chemistry of carbohydrate. Carbohydrates are the most abundant biomolecules on earth. In general, carbohydrates are white solids, sparingly soluble in organic solvents, but soluble in water. They are widely distributed in plants and animals. They are the first products formed in photosynthesis and are defined as optically active polyhydroxy aldehydes or ketones or those substances that yield such compounds on hydrolysis. Many, but not all, carbohydrates have the empirical formula (CH<sub>2</sub>O)<sub>n</sub> (e.g. glucose: C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>; sucrose: C<sub>12</sub>H<sub>22</sub>O<sub>11</sub>). But certain carbohydrates do not correspond to this formula (e.g. rhamnose: C<sub>6</sub>H<sub>12</sub>O<sub>5</sub>; rhamnohexose: C<sub>7</sub>H<sub>14</sub>O<sub>6</sub>; digitoxose: C<sub>6</sub>H<sub>12</sub>O<sub>4</sub>) while some of the noncarbohydrates (e.g. formaldehyde: CH<sub>2</sub>O; acetic acid: C<sub>2</sub>H<sub>4</sub>O<sub>2</sub>; lactic acid: C<sub>3</sub>H<sub>6</sub>O<sub>3</sub>; inositol: C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>) correspond to the above formula. Apart from carbon, hydrogen and oxygen, some of the carbohydrates are found to contain nitrogen, phosphorus or sulphur.

### Acknowledgements

This work was supported by the National Center of Research/ Institute of Engineering Research and Material Technology. Also supported by University of Khartoum/ Faculty of Science/ Department of Chemistry.

### REFERENCES

- Wood, C.W., A. K. Holiday, and R.J.S Beer, M.A., D. Phill. Organic Chemistry, An Introductory, and Text, 1968, p 273-279.
- Campaigne, E. Elementary Organic Chemistry. PRENICE. HALL, INC. Englewood Cliffs., N. J. 1964, p 250-286.
- Haslam Pergamon Press, E. Comprehensive Organic Chemistry, Biological compounds, Vol. 5, p 687-718.
- file: //local host/ C:/Documents20% 20% setting/ adil 20% Mustafa/ Desk top/ Carbohydrates. 1. htm.
- file:111c,/Document%20and%20settings/user/My% 20 Document.
- Ellis, G. P. Bsc., PhD. (London), F.R.I.C. London Butterworths. Modern Text Book of Organic Chemistry, 1966, p 283-403.
- <http://www.com.Msu.Edu/reush/ Virtual Text/ Carbohydrates>.
- <http://www.en.Wikipedia.org/wiki/ Carbohydrate>.
- <http://www.tiscali.co.uk/reference/encyclopedia/hustchinson/mooo1993.htm>.
- <http://www.elmurst.edu/chem/vchembook/541 classes,html>.
- <http://www.Tiscali.Com.Uk/> -
- <http://www.wikipedia.org/wiki/ Dihydroxyacetone>.
- <http://www.wikipedia.org/wiki/ Glyceraldehyde>.
- <http://www.life.uiue.edu/govindee/paper/gov.html>
- FINAR., I.L. 1964. Org. Chem., V. 2, Third Edition, 1964, p 176-241.
- Jonh Read. An Introduction to Organic Chemistry. 1958, p 212-227.
- L FINAR. Organic Chemistry, V.1. Six edit. 1973.
- Melnilville L. Wolfrom, R. Stuart Tipson. Advances in Carbohydrate Chemistry. Academic Press, New York and London. 1962, V. 17, p 120-196.
- Sturat Tipson, R. 1973. Derek Horton, Advances in carbohydrate chemistry and Biochemistry, Academic

- Press, New York, San Francisco, London Vol. 32, 1973, p 253-263.
- Durrant, R.J., M.A., PhD. Organic Chemistry, p 332-335.
- Morrison, R.T., R.N. Boyd. Org. chem., New York. 1973, p 1068-1128.
- Robert, A. Murray, Daryl K. Granner, Peter A. Mayes, Victor W, Rodwell, Harper's Biochemistry, 23 ed., p 130-218.

\*\*\*\*\*