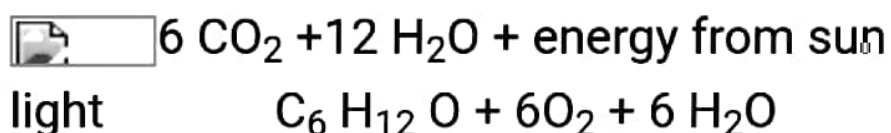


Carbohydrates

Carbohydrates include sugars, starches and cellulose. Sugars and starches serve as energy sources for cells. Cellulose is the main structural component of the walls that surround plant cells. Understanding the structure and function of each of these molecules is basic requirement for exploring how life began and how organisms work. Carbohydrates are substances which contain the elements carbon, hydrogen and oxygen and have the formula $(C H O)_n$ where the n refers to the number of "carbon hydrate" groups. Carbohydrates are widely distributed in plants and animals where they fulfill both structural and metabolic roles. In plants glucose is synthesized from carbon dioxide and water by photosynthesis and stored as starch or is converted to the cellulose of the plant framework.

In the cells of the plants:



Animals can synthesize some carbohydrate from fat and proteins, but the bulk of animal carbohydrate is derived ultimately from plants.

The sugar glucose is the most important carbohydrate. It is absorbed into the blood stream or it is converted as starch in the liver. Glucose is the major fuel of energy in the tissues of animals and a universal fuel of the fetus.

Classification of carbohydrates:

They are classified as follows:

(1) Monosaccharides: They are simple sugars that cannot be hydrolyzed into simpler carbohydrates. They may be subdivided into trioses, tetroses, pentoses, hexoses, heptoses, or octoses, depending upon the number of carbon atoms they possess and as aldoses or ketoses depending upon whether the aldehyde or ketone group is present. Examples are trioses, tetroses pentoses and hexoses.

(2) Disaccharides: They yield two molecules of mono saccharides when hydrolyzed: Examples are maltose, yielding



two molecules of glucose and sucrose, yielding one molecule of glucose and one of fructose.

(3) Oligosaccharides: They yield three to ten monosaccharide units on hydrolysis: Maltotriose is an example.

(4) Polysaccharides: They yield more than ten molecules of monosaccharides on hydrolysis. Examples of polysaccharides are starches and cellulose.

SUGARS: Solid sugars form crystals and dissolve in water to form a sweet-tasting solution. Sugars fall into two groups, monosaccharides (e.g. glucose) and disaccharides (e.g. sucrose). Disaccharides are formed from two monosaccharide molecules by a condensation reaction (the elimination of water).

Monosaccharides have the same empirical formula and those same reactive groups:

Monosaccharides contain only carbon, hydrogen and oxygen in the ratio of 1 C: 2H:



1 O, therefore the empirical formula is $(C_n H_{2n} O_n)$. Monosaccharides also have certain reactive groups present. To be a monosaccharide the molecule must contain a carbonyl group ($C=O$) and at least two hydroxyl groups

($O-H$). All monosaccharides have name ending in -ose. The carbons in a monosaccharide are always numbered. This means that a certain carbon can be referred to without drawing out the whole structural formula. The end carbon nearest the carbonyl group is always carbon 1.

THE LARGER MONOSACCHARIDES CAN EXIST AS CHAINS OR RINGS :

The simplest form of monosaccharide is a triose. A triose contains three carbons. Trioses have a backbone of three carbons, a carbonyl group and two hydroxyl groups.

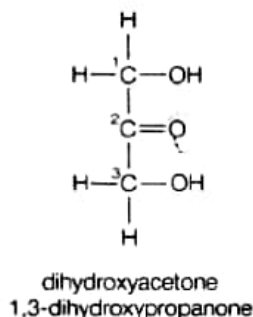
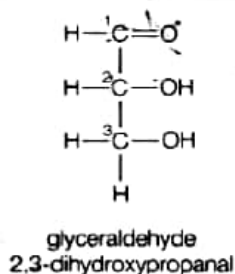


Fig 1.16

and two hydroxyl groups. Figure 1.16 shows two important trioses, glyceraldehyde and dihydroxyacetone. Glyceraldehyde and dihydroxyacetone are structural isomers of each other. As can be seen from Fig 1.16 glyceraldehyde has a carbonyl group at the end of the molecule, this makes it an **aldose** (a sugar with an aldehyde group), while dihydroxyacetone has a carbonyl group away from the ends of the molecule, this makes it a **ketose** (a sugar with a ketone group). Trioses exist only as chains; they are too short to form rings.

All naturally occurring sugars are originally made from trioses. Glyceraldehyde contains a carbon joined to four different groups and can therefore form two stereoisomers, L-glyceraldehyde and D-glyceraldehyde (Fig 1.17). All aldoses in organisms are made from D-glyceraldehyde and are therefore called D-aldoses. All ketoses are made from dihydroxyacetone. While dihydroxyacetone cannot form stereoisomers, the tetrose (four-carbon sugar) formed from it can, as it contains a carbon joined to four different groups (Fig 1.18). All ketoses are formed from the D version of this sugar, and are therefore D-ketoses.

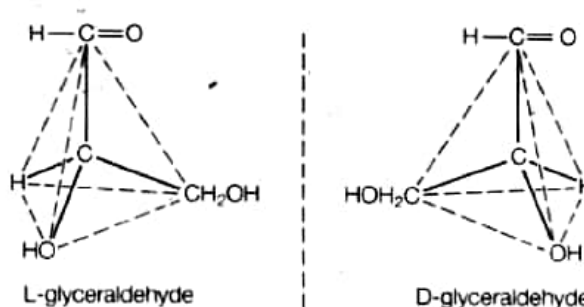


Fig 1.17*

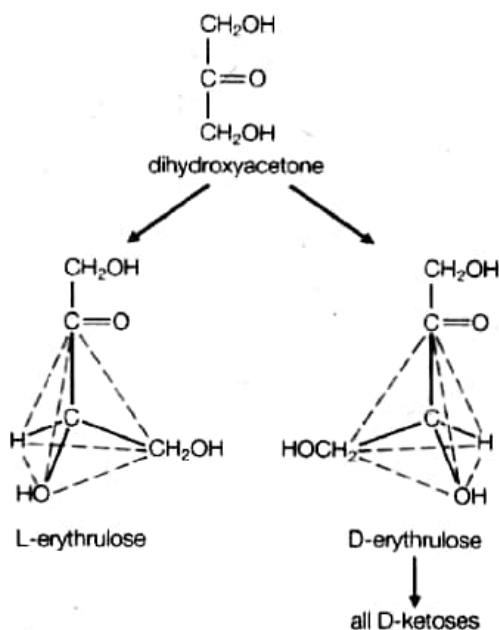


Fig 1.18

Hexoses, monosaccharides with six carbon atoms (hex = 6), all have the same simple formula, $\text{C}_6\text{H}_{12}\text{O}_6$. As all hexoses have the same simple formula they are all isomers of each other. Figure 1.19(a) shows some common hexoses, including glucose and fructose. Each hexose has a backbone of six carbons in a chain, a carbonyl group and at least two alcohol groups. Some of the hexoses, for example glucose, have the carbonyl group at the end of the molecule and are therefore aldoses, while other hexoses, for example fructose, have the carbonyl group on carbon 2, away from the end of the molecule, and are therefore ketoses.

Hexoses exist in two forms, a straight chain form (Fig 1.19(a)) and a ring form (Fig 1.19(b)). To form a ring the carbonyl group reacts with one of the hydroxyl groups elsewhere in the chain. The carbons are still numbered as they were in the straight chain form, and carbon 1 is always drawn on the right hand side (Fig 1.19(b)). Two types of rings can be formed: a ring of six atoms called a **pyranose** ring and a ring of five atoms called a **furanose** ring. The pyranose ring is the more stable ring form for aldoses, for example glucose and galactose, while the furanose ring form is more stable for ketoses, for example fructose and sorbose (Fig 1.19(b)).

Once a ring has formed the hydroxyl groups attached to the carbons in the ring will point up from the plane of the ring, or down from the plane of the ring. This is one way in which stereoisomers are formed. Glucose forms isomers of this type: the ring can form with the hydroxyl group on carbon 1 pointing down (this is α -glucose), or pointing up (this is β -glucose) (Fig 1.20).

Pentoses, monosaccharides with five carbon atoms (pent = 5), have the simple formula $\text{C}_5\text{H}_{10}\text{O}_5$, a carbonyl group and at least two hydroxyl groups. Pentoses exist in a chain form and a ring form. Figure 1.21 shows the structural formulae of two important pentoses, ribose and deoxyribose, in both the straight chain and the ring form. Both deoxyribose and ribose are stable in the furanose ring form.

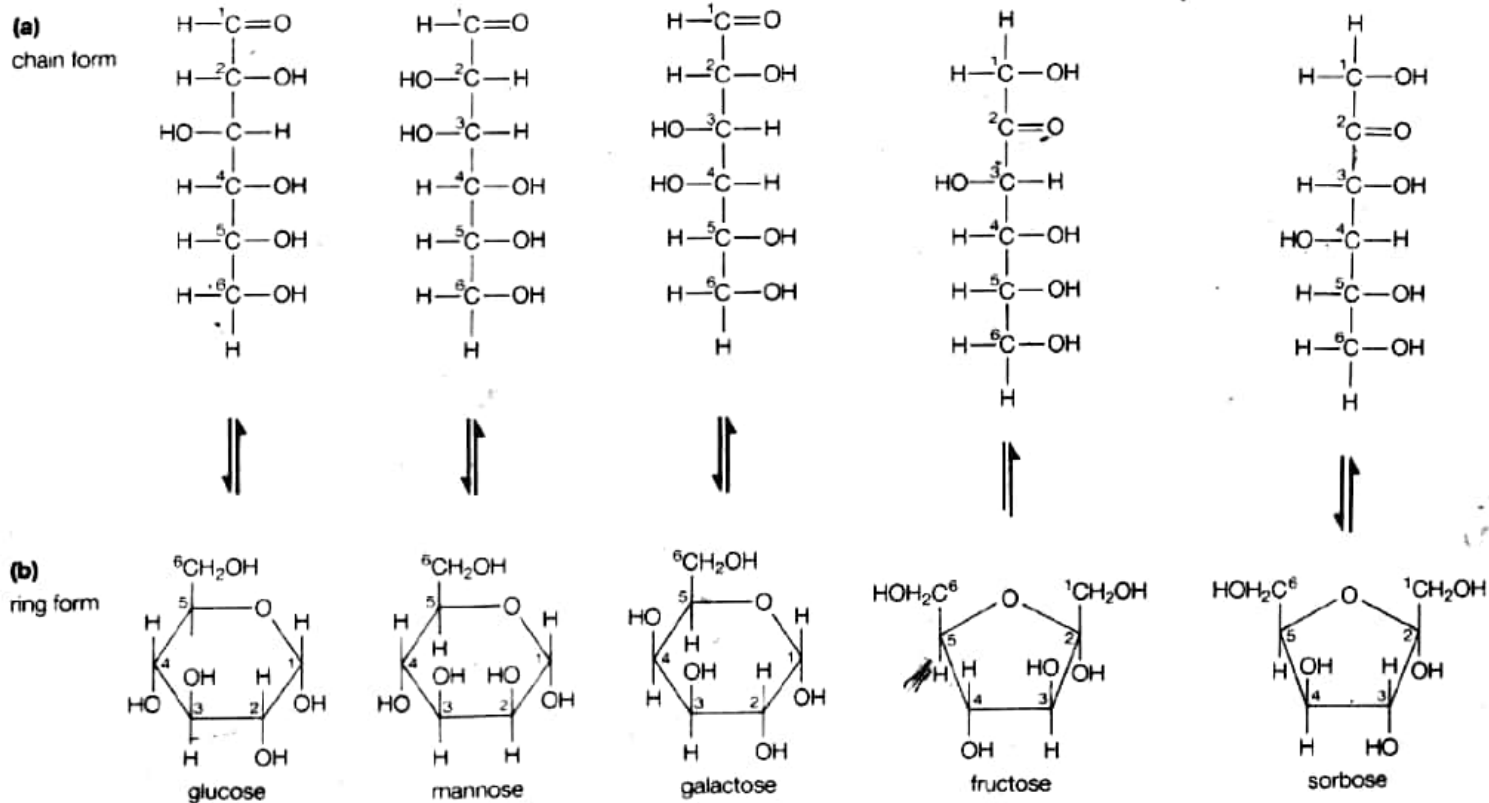
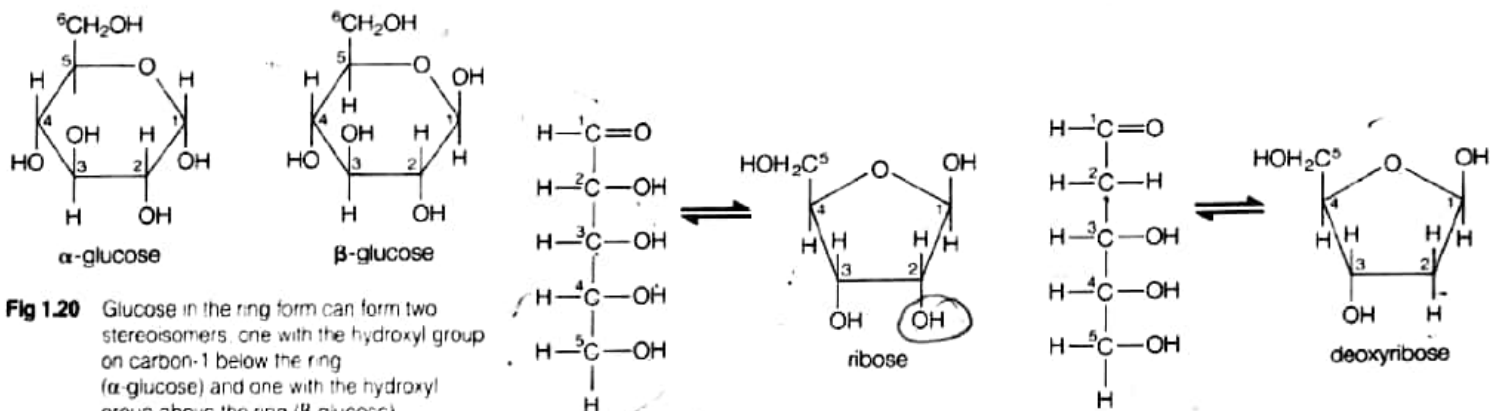
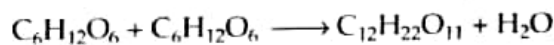


Fig 1.19 Five common hexoses in straight chain and ring forms.



Two monosaccharide molecules can be joined to make a disaccharide molecule

Monosaccharides react to make disaccharides, forming a bond between two monosaccharide molecules by eliminating a molecule of water



This type of reaction, where a bond is formed by the elimination of a water molecule, is called a **condensation** reaction. The bond formed during the condensation reaction between monosaccharide molecules is called a **glycosidic bond**. This bond is formed between the carbonyl group on one monosaccharide and a hydroxyl group on the other monosaccharide. A 1 \rightarrow 4 glycosidic bond is from carbon 1 of one monosaccharide to carbon 4 of the second monosaccharide (Fig 1.22(a)), while a 1 \rightarrow 2 glycosidic bond is from the carbon 1 of one monosaccharide to carbon 2 of the second monosaccharide (Fig 1.22(b)). Three common disaccharides and the types of glycosidic bonds found in those molecules are listed in Table 1.5.

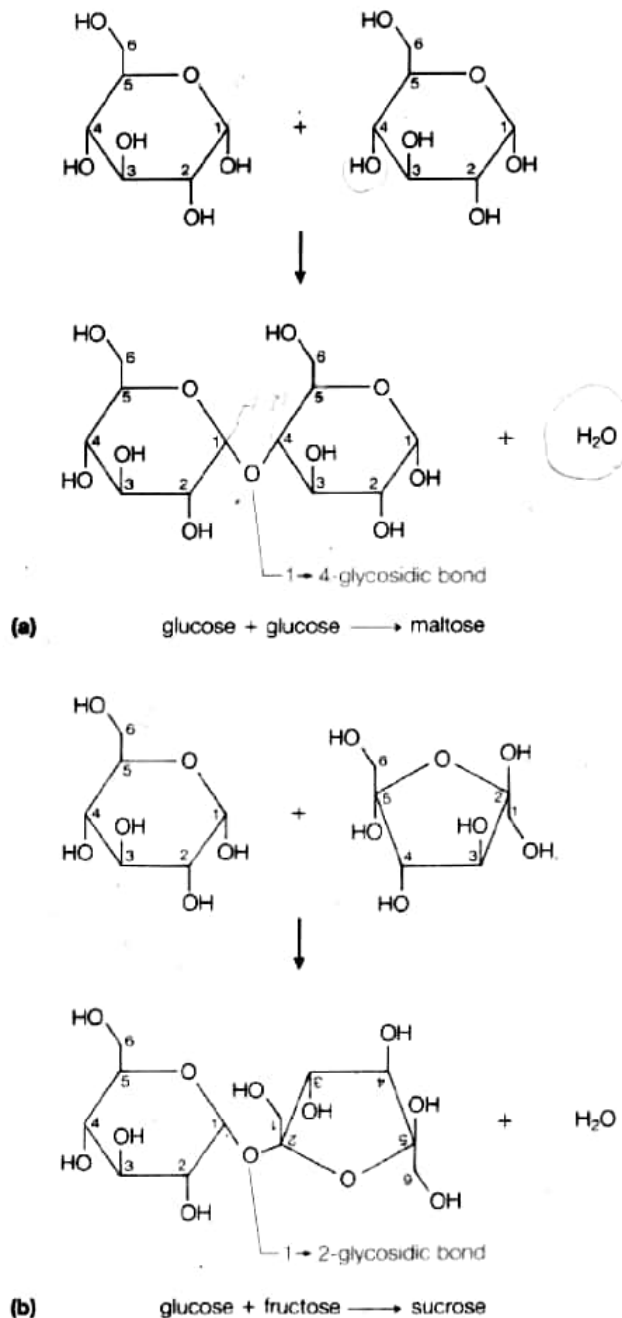


Fig 1.22 Monosaccharides react together in a hydrolysis reaction to form a disaccharide

Table 1.5

| Disaccharide | Monosaccharides | Type of bond |
|--------------|---------------------|----------------|
| maltose | glucose & glucose | 1→4 glycosidic |
| lactose | glucose & galactose | 1→4 glycosidic |
| sucrose | glucose & fructose | 1→2 glycosidic |

Sugars have many roles in organisms

Sugars are an important source of energy for all organisms. Plants use the energy of the sun to synthesise hexoses which can be transported to other cells and oxidised to release energy. Animals and fungi obtain sugars from other organisms and oxidise them to release energy. The trioses glyceraldehyde and dihydroxyacetone are important intermediates in the process by which cells release energy from hexoses. You can read more about the processes by which organisms release the energy in sugars in Chapter 8.

Polysaccharides and nucleic acids are polymers. A polymer is a long macromolecule formed by linking many small molecules, the monomers, in a chain.

Monosaccharides and disaccharides are also used as the starting material for the synthesis of other biologically important molecules in cells. Monosaccharides are the monomers from which polysaccharides are made, for example α -glucose forms starch while β -glucose forms cellulose. Some polysaccharides, such as starch, act as energy storage molecules while others, such as cellulose, are structural materials. The pentoses ribose and deoxyribose form part of the monomers that are joined together to form nucleic acids. Nucleic acids are used to store and express the genetic information in cells. You can read more about polysaccharides and nucleic acids in Chapter 2.

Sugars contain a carbonyl group, $C=O$. A carbonyl group at the end of a molecule is called an aldehyde group and an aldehyde group can be oxidised to a carboxylic group, $COOH$. This means that an aldehyde group can act as a reducing agent. Sugars containing an aldehyde group can act as reducing agents and are therefore called reducing sugars. As can be seen in Fig 1.23 glucose contains an aldehyde group and is thus a reducing sugar.

Sugars that do not, at first sight, contain an aldehyde group can also act as reducing sugars. This is because a carbonyl group on carbon 2, one away from the end, can change places with a hydroxyl group on the end carbon, giving an aldehyde group that can act as a reducing agent. This is shown for fructose in Fig 1.23. Most hexoses have their carbonyl group on carbon 1 or a carbonyl group on carbon 2 and a hydroxyl group on carbon 1, and are therefore reducing sugars.

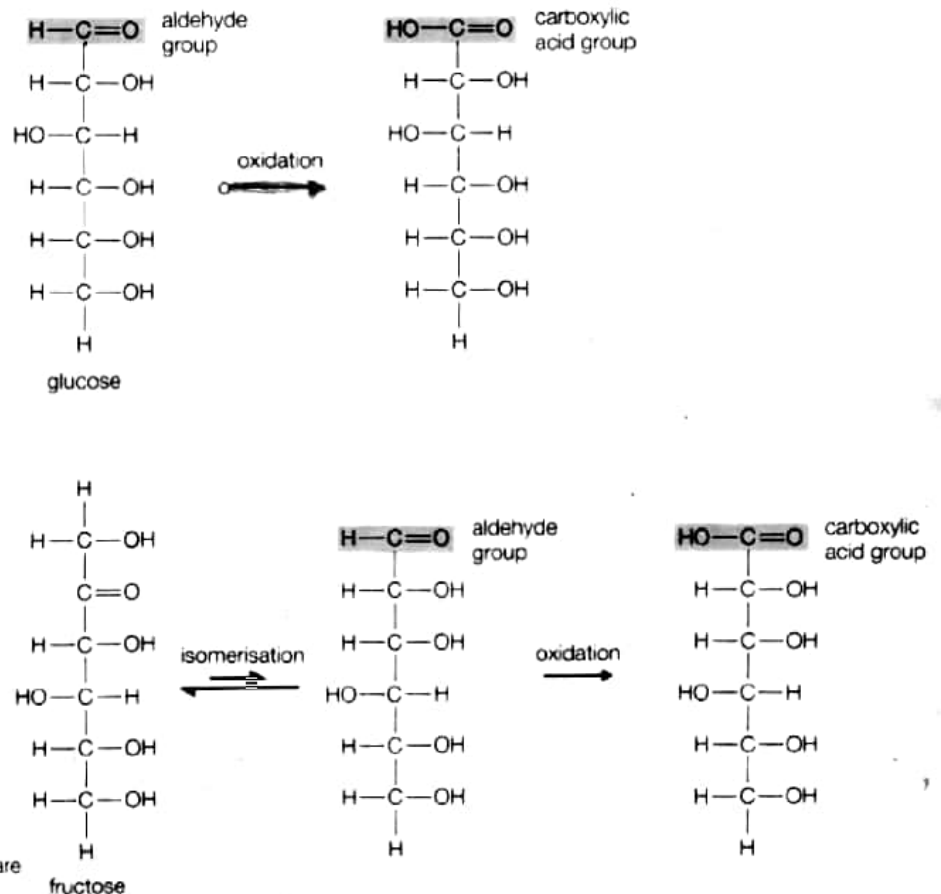


Fig 1.23 Monosaccharides that can be oxidised are called reducing sugars.