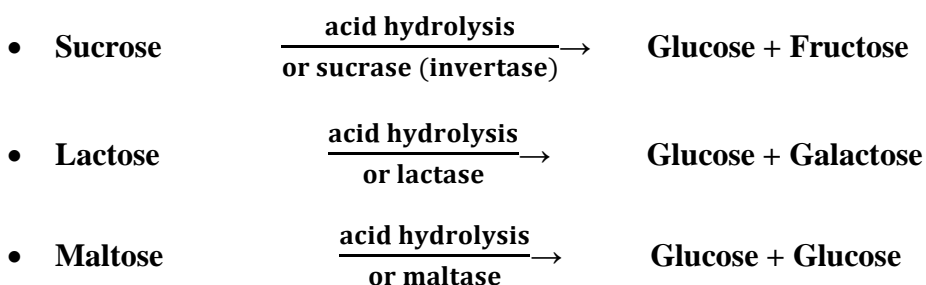


## Disaccharides

**Disaccharides** consist of two monosaccharides units linked together by covalent O-glycosidic (glucosidic) bond, e.g. sucrose, maltose, lactose, cellobios, trehalose, gentiobios, etc. **Sucrose, lactose and maltose** are the most common disaccharides; soluble in water and sweet in taste. Sucrose is the **sweetest** of the three common disaccharides. Sucrose is even sweeter than monosaccharide, but less than fructose.

Sucrose also known as '**cane sugar**' or 'table sugar' is obtained from sugar cane plant and is the most abundant disaccharide in nature. Lactose known as '**milk sugar**' is the only disaccharide, which is synthesized in humans by lactating mammary glands. Maltose, also known as '**malt sugar**' does not exist as such in nature, however, it is formed as an intermediate product during hydrolysis of starch by the action of enzymes such as salivary amylase (ptyalin), pancreatic amylase (amylpsin) and plant diastase (malt amylase).

**Disaccharides** have a general formula  $C_n(H_2O)_{n-1}$ . Disaccharides yield two constituent monosaccharides on acid hydrolysis or by the action of disaccharidases (Fig. 4.13).

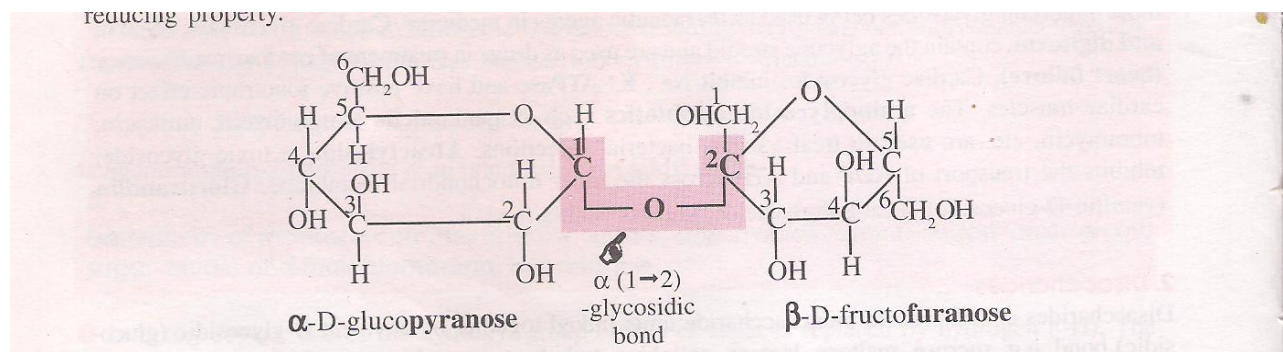


**Fig. 4.13: Disaccharides yielding constituent monosaccharides on hydrolysis.**

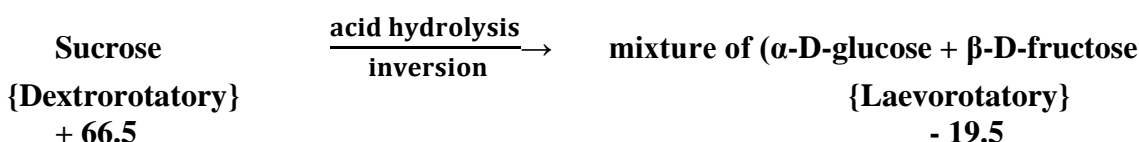
The disaccharides may be either reducing or non-reducing depending on presence or not a free carbonyl group. Reducing disaccharides contain a potentially free carbonyl group, maltose and cellobiose containing a potentially free -CHO group.(not involved in formation of O-glycosidic bond) are reducing disaccharides, whereas sucrose and trehalose lacking a free carbonyl group are non-reducing disaccharides.

### Disaccharides of biomedical importance

**Sucrose** is also known as 'cane sugar' or 'table sugar'. Cane sugar plant, sugar beets, ripe fruits, etc. are the main dietary sources of sucrose. It is a non-reducing disaccharide composed of  $\alpha$ -D-glucose and  $\beta$ -D-fructose linked together through  $\alpha$  (1  $\rightarrow$  2) glycosidic bond (Fig. 4.14). Since in sucrose, the glycosidic bond is formed between —CHO group of  $\alpha$ -D-glucose and  $-^2CO$  group of  $\beta$ -D-fructose, the sucrose does not possess a free carbonyl group and hence it does not exhibit reducing property.



**Sugar Inversion:** Acid hydrolysis of sucrose yield D-glucose and D-fructose. Although sucrose is dextrorotatory (+6650) but the mixture of equal quantity of D-glucose and D-fructose obtained after the hydrolysis of sucrose is found laevorotatory (- 19.5°). This is because of greater laevorotation of D-fructose than the dextrorotation of D-glucose in hydrolyzed mixture. Such change of optical rotation of sucrose, from dextrorotation to laevorotation, due to hydrolysis, is called inversion.



**Fig. 4.15 inversion of sucrose**

### Biomedical significance of sucrose

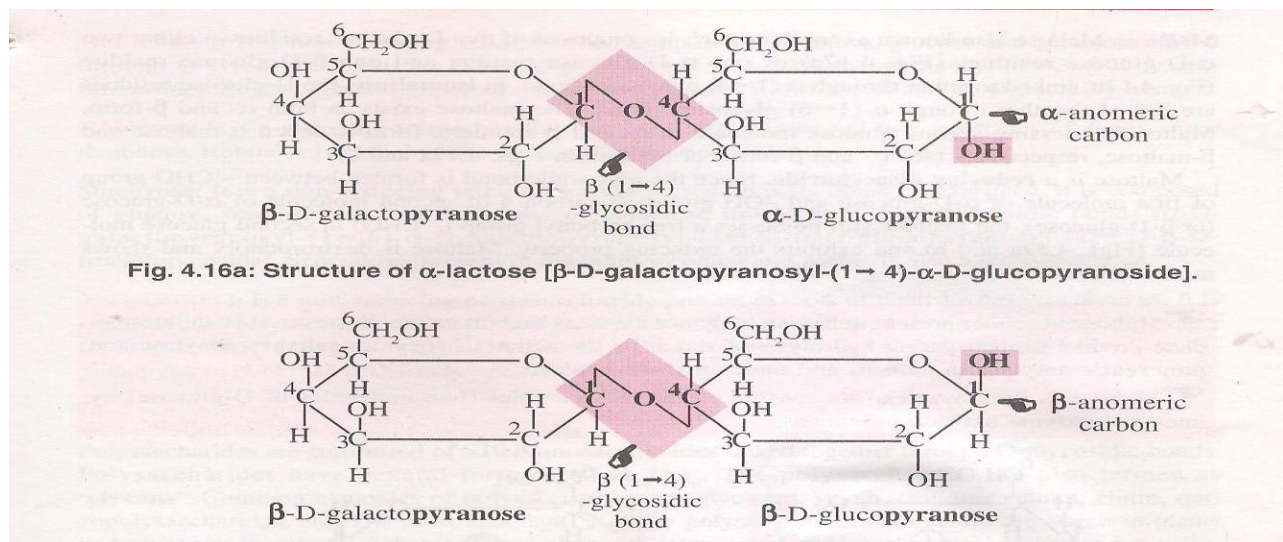
Sucrose is mostly used as table sweetener in our food items such as tea, coffee, milk, etc. in diabetic patients and obese persons, for whom sucrose has to be avoided in diet, calorie free artificial sweeteners like saccharin and aspartame are advised. Artificial sweetener saccharin is about 400 times sweeter than sucrose. Aspartame is a dipeptide in nature.

Sucrose is hydrolyzed to its constituent monosaccharides (D-glucose and D-fructose) by intestinal enzyme sucrase (also Known as invertase) in humans.

### Lactose

Lactose is also known as ‘milk sugar’ (Latin: *lac* means milk). It is the only disaccharide that can be synthesized in human body. It is synthesized in lactating mammary glands. Milk and milk-products are the dietary sources of lactose. **Milk contains about 5-7% lactose.**

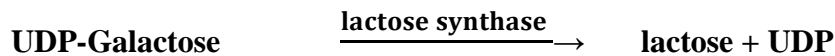
Lactose is composed of  $\beta$ -D-galactose and  $\alpha$ -D-glucose (or  $\beta$ -D-glucose) linked together through  $\beta$  (1 $\rightarrow$ 4) glycosidic bond. The lactose exists both in  $\alpha$ - and  $\beta$ -form; the lactose possessing  $\alpha$ - and  $\beta$ - anomer of D-glucose is called  $\alpha$ -lactose and  $\beta$ -lactose, respectively (see  $\alpha$ -form and  $\beta$ -form of lactose in Figs. 4.16a and b). Lactose is dextrorotatory and shows mutarotation. Lactose is a reducing disaccharide. Since the glycosidic bond is formed between — <sup>1</sup>CHO group of D-galactose and OH group on carbon-4 of D-glucose, the lactose still possesses a free carbonyl group (- CHO group) in glucose residue (Figs. 4.16a and b) and exhibits the reducing property.



**Fig. 4.16b: structure of  $\beta$ -lactose [ $\beta$ -D-galactopyranosyl-(1-4)- $\beta$ -D-glucopyranoside]**

### Biomedical Significance of Lactose

- Lactose is synthesized in lactating mammary glands from D-galactose and D-glucose by enzyme lactose synthase (also known as UDP-galactose: glucose galactosyltransferase), which catalyzes the transfer of galactose from UDP-galactose to glucose forming lactose.



- Lactose may appear in urine during advanced stage of pregnancy
- Lactose is the major dietary source of D-galactose, therefore, milk and its products are with- drawn from the diet of patients of galactosemia.
- Lactose is hydrolyzed to its constituent monosaccharides (D-galactose and D-glucose by intestinal enzyme **lactase**) in humans.
- Lactase** ( $\beta$ - galactosidase), the lactose splitting enzyme of intestinal mucosal cells, is Very active in infants but the adults suffering from lactose intolerance (a hereditary disorder) have little intestinal lactase activity. In such individuals, lactose is not digested (hydrolyzed) and remains unabsorbed in the intestinal tract resulting in diarrhea, colic pain and flatulence. Such persons should avoid milk in their diet.
- "Fearon's test, mucic acid test and osazone test can be performed to distinguish lactose from other disaccharides.
- Souring of milk results from anaerobic oxidation of lactose to lactic acid by microbes.

**Maltose:** maltose also known as 'malt sugar' is composed of two D-glucose residues' either two  $\alpha$ -D-glucose residues (Fig. 4.17:1) or one  $\alpha$ -D-glucose residue and one  $\beta$ -D-glucose residue (Fig.4.17b) linked together through  $\alpha$  (1 $\rightarrow$ 4) glycosidic bond. In isomaltose, the D-glucose residues

are linked together through or  $\alpha$ -(1 $\rightarrow$ 6) glycosidic bond. The maltose exists as both  $\alpha$ - and  $\beta$ - form. Maltose possessing second glucose molecule in  $\alpha$ - and  $\beta$ - anomeric form is called  $\alpha$ -maltose and  $\beta$ -maltose, respectively (see  $\alpha$ - and  $\beta$ -forms of maltose in Figs. 4.17a and b).

Maltose is a reducing disaccharide. Since the glycoside bond is formed between  $-^1\text{CHO}$  group on the first molecule of  $\alpha$ -D- glucose and  $-\text{OH}$  group on carbon-4 of second molecule of  $\alpha$ -D-glucose (or  $\beta$ -D-glucose), the maltose still possesses a free carbonyl group ( $-\ ^1\text{CHO}$ ) in second glucose molecule (Figs. 4.17a and b) and exhibits the reducing property.

- **Maltose** is neither present in human body nor exists as such in nature, however, it is an intermediate product formed during hydrolysis of starch by the action of enzymes **salivary amylase** and **pancreatic amylase** in humans and **malt amylase** in plants.
- **Maltose** is hydrolyzed to its constituent's monosaccharides (two molecules D-glucose) by intestinal enzyme maltase in humans.

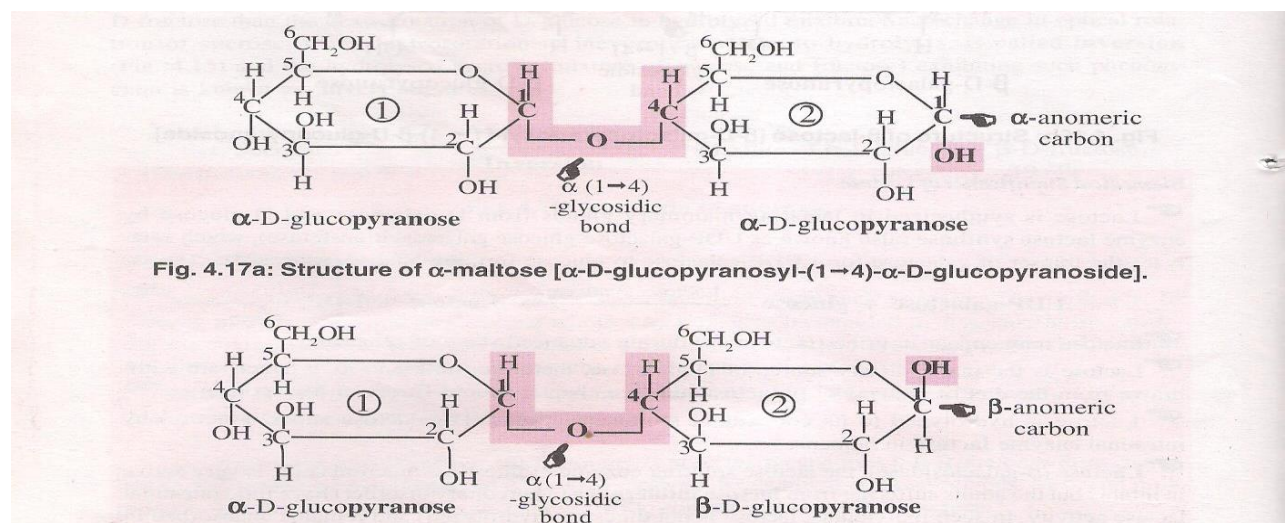


Fig. 4.17a: Structure of  $\alpha$ -maltose [ $\alpha$ -D-glucopyranosyl-(1 $\rightarrow$ 4)- $\alpha$ -D-glucopyranoside].

Fig. 4.17b: structure of  $\beta$ -maltose [ $\beta$ -D-glucopyranosyl-(1-4)- $\beta$ -D-glucopyranoside]

### 3. Oligosaccharides

These sugars (saccharides) are composed 3-10 monosaccharides, e.g. raffinose, robinose, stachyose, verbascose, etc. plant are natural source of these oligosaccharides. The oligosaccharides on hydrolysis yield their constituent monosaccharides.

**Raffinose**: It is a non-reducing trisaccharide composed of fructose, glucose and galactose linked through O-glycosidic bonds [ $\alpha$ -D-galactopyranosyl (1 $\rightarrow$ 6)- $\alpha$ -D-glucopyranosyl-(1 $\rightarrow$ 2)- $\beta$ -D fructofuranoside. Sugar beets are important source of raffinose

**Robinose**: It is a reducing trisaccharide composed of galactose and two molecules of deoxy sugar rhamnose. Robinose is carbohydrate residue of glycoside robinin.

**Stachyose:** It is a non-reducing tetrasaccharide present in plant. It is composed of glucose, fructose and two molecules of galactose linked through O-glycosidic bonds [ $\alpha$ -D-galactopyranosyl-(1 $\rightarrow$ 6)- $\alpha$ -D-galactopyranosyl-(1 $\rightarrow$ 6) -  $\alpha$ -D-glucopyranosyl-(1 $\rightarrow$ 2)- $\beta$ -D-fructofuranoside].

**Verbascose:** It is a non-reducing pentasaccharide present in plant. It is composed of glucose, fructose and three molecules of galactose linked through O-glycosidic bonds [ $\alpha$ -D-galactopyranosyl-(1 $\rightarrow$ 6)- $\alpha$ -D-galactopyranosyl-(1 $\rightarrow$ 6)- $\alpha$ -D-galactopyranosyl-(1 $\rightarrow$ 6)- $\alpha$ -D-glucopyranosyl-(1 $\rightarrow$ 2)- $\beta$ -D-fructofuranoside].

#### 4. Polysaccharides

Polysaccharides are composed of >10 monosaccharides linked together through O—glycosidic bonds. Polysaccharides have general formula  $(C_6H_{10}O_5)_n$ . The polysaccharides are also termed as '**glycane**'. Common examples of polysaccharides are glycogen, starch, cellulose, inulin, chitin, mucopolysaccharides, etc. The most abundant 'storage polysaccharides' in nature are starch in plants and glycogen in animals, whereas, most abundant 'structural polysaccharides' in nature are cellulose in plants and chitin in arthropods. The polysaccharides are of high molecular weight and are sparingly soluble in water but may form a colloidal solution in hot water. They are not sweet in taste. All polysaccharides are non-reducing. The polysaccharides are of two kinds **homopolysaccharides** and **heteropolysaccharides**.

**Homopolysaccharides:** These polysaccharides are polymers of only a single kind of monosaccharides, eg. glycogen, starch, dextrans, dextrans, cellulose, inulin, chitin, etc. The polymer of glucose is called **glucans**, e.g. starch, glycogen, dextrans, cellulose, etc. of fructose is called fructans, e.g. inulin and of mannose is called mannans. Some homopolysaccharides are polymers of monosaccharide derivatives, e.g. chitin is polymer of N-acetyl-glucosamine. Homopolysaccharides may be unbranched or branched (Fig. 4.19), e.g. amylose, cellulose, inulin, chitin, etc. are unbranched polysaccharides in which monosaccharide units are linked together in a straight chain and have no branching. However, glycogen, amylopectin, dextrans, dextrans, etc. branched polysaccharides, which consist of several chains of monosaccharides branched by means of glycosidic bonds. Homopolysaccharides may be hydrolyzed by hot mineral acids (HN) in their constituent monosaccharides. Some examples of homopolysaccharides and their constituent monosaccharides are given in table 4.1.

**Heteropolysaccharides:** These polysaccharides are polymers of two or more different types of monosaccharides, e.g. mucopolysaccharides. The mucopolysaccharides are long, unbranched heteropolysaccharides generally composed of two or more different kinds of alternating monosaccharides units of amino-sugars and sugar acids (uronic acids Fig. 4.18.) Some common examples of heteropolysaccharides, mucopolysaccharides and their constituent alternating monosaccharide units are given in Table 4.2.

**Table (4.1) showing homopolysaccharides and their constituent monosaccharides**

<u>Homopolysaccharide</u>	<u>constituent monosaccharide</u>
Starch	D- glucose
Glycogen	D- glucose
Cellulose	D- glucose
Chitin	N-acetyl glucosamine
Inulin	D-fructose
Alginic acid	D- mannuronic acid

**Table (4.2) showing heteropolysaccharides and their constituent monosaccharides**

<u>Mucopolysaccharide</u>	<u>constituent alternating monosaccharide units</u>
hyaluronic acid	(D-N-acetylglucosamine-D-glucuronic acid) <sub>n</sub>
Heparin	(D-glucosamine-D-glucuronic acid/L-iduronic acid) <sub>n</sub>
Chondroitin	(D-NAcetylgalactosamine-D-glucuronic acid) <sub>n</sub>
Dermatan sulphate	(D-N-acetylgalactosamine-L-iduronic acid) <sub>n</sub>

### Homopolysaccharides of biomedical significance

#### Storage homopolysaccharides

**Starch:** It is a homopolysaccharide composed of  $\alpha$ -D-glucose. Starch is synthesized during photosynthesis in plants and is most abundant '**plant storage polysaccharide**' in nature. In plants, it is stored in cereals, grains, tubers (potatoes), roots (sugar beets), fruits, etc.

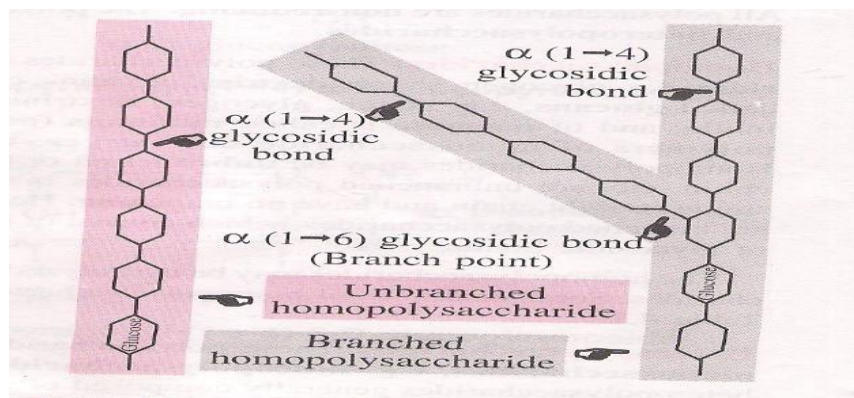
Starch contains two kinds of glucose polymer, the water soluble amylose (10-20%) and Water insoluble amylopectin (80-90%). The amylose is unbranched 'glucan' containing 300-1000  $\alpha$ -D-glucose units covalently bound by  $\alpha(1 \rightarrow 4)$  glycosidic bonds (Fig. 4.19), The unbranched chain of amylose is found helically coiled. The amylopectin is branched 'glucan' consisting of several branched chains of  $\alpha$ -D- glucose units. Each branch consists of 24-30  $\alpha$ -D-glucose units that are linked together through  $\alpha(1 \rightarrow 4)$  glycosidic bond, but the branching takes place by means of  $\alpha(1 \rightarrow 6)$  glycosidic linkage.

#### Biomedical significance of starch

**Iodine** gives a **deep blue color** with **amylose**. Formation of a coordination complex between helically coiled amylose and iodine molecules is responsible for the deep blue color, which disappears by heating. The **amylopectin** gives **reddish-violet color** with **iodine**. These observations form the basis of **Iodine test** for carbohydrates. Enzymes that hydrolyze starch are known as amylases. There are of two types of amylases:

**(i)  $\alpha$ -amylase:** It includes the salivary amylase (ptyalin) and pancreatic amylase (amylapsin) of mammals.  $\alpha$ -amylase randomly hydrolyzes  $\alpha(1 \rightarrow 4)$  glycosidic bonds in starch to yield maltose, maltotriose and dextrins.

**(ii)  $\beta$ -amylase:** It includes the amylases from malt.  $\beta$ -amylase (also termed as malt amylase) hydrolyzes amylose completely to maltose.  $\beta$ -amylase also splits maltose molecules from the ends of the branches of amylopectin until its action is blocked at branching point, i.e. at  $\alpha$  (1-6) glycosidic bond. The action of  $\beta$ -amylase on starch yields dextrans and maltose. Starch is a major dietary component.



**Glycogen:** It is a branched homopolysaccharide composed of  $\alpha$ -D-glucose. Glycogen is synthesized in liver and muscles and is most abundant ‘**animal storage polysaccharide**’ (also known as animal starch’) in nature.

Similar to amylopectin, the glycogen is also a branched ‘glucan’ consisting of several branched  $\alpha$ -D-glucose units. Each branch consists of about 10-12  $\alpha$ -D-glucose units that are linked together by  $\alpha$ (1 $\rightarrow$ 4) glycosidic bonds, but the branching takes place by means of  $\alpha$ (1-6) glycosidic linkage (Fig. 4.19). Glycogen gives a red colour with iodine. Glycogen is synthesized from its monomer  $\alpha$ -D-glucose residues during glycogenesis in liver and muscles; both store glycogen as ‘fuel reserve’. A normal adult liver contains about 6-8% glycogen.

### Structural homopolysaccharides

**Cellulose:** it is an unbranched homopolysaccharide composed of 10,000-15,000  $\beta$ -D- glucose units linked together by  $\beta$  (1 - 4) glycosidic bonds. It is most abundant ‘plant structural polysaccharides’ in nature. The cellulose is major component of cell walls of all plants. Woods contain 40-50% cellulose content and cotton is almost pure cellulose (97-99%). Cellulose insoluble both in cold and hot water. Cellobiose, a reducing disaccharide, is formed as an intermediate product during hydrolysis of cellulose.

### Biomedical significance of cellulose

- Due to lack of enzyme **cellulase**, cellulose cannot be digested in humans, therefore it has no dietary importance for calories. However, Cellulose contributes to major portion of roughage (dietary fibers) in vegetarian diet.
- Most mammals cannot digest cellulose, however, ruminants (sheep, goats, horses, cow, etc.), can digest cellulose with the help of cellulase-producing bacteria present in their extra

compartment of gastrointestinal tract (i.e. rumen); actually, these bacteria secrete enzyme cellulase, which digest cellulose.

**Chitin:** It is an unbranched homopolysaccharide composed of  $\beta$ -D-N-acetyl-glucosamine units linked together by  $\beta$  (1  $\rightarrow$  4) glycosidic bonds. It is most abundant 'animal structural polysaccharide' in nature. Chitin is major component of exoskeleton of nearly a million species of arthropods. It is insoluble in both cold and hot water. Chitin cannot be digested by vertebrate animals.

### **Other homopolysaccharides**

**Inulin:** Inulin is an unbranched homopolysaccharide composed of D-fructose units. It is found in bulbs of onion and garlic. Inulin is slightly soluble in cold water but readily soluble in hot water.

### **Biomedical significance of inulin**

- Inulin does not give characteristic color with iodine.
- Inulin is source for commercial production of fructose.
- In plants inulinase hydrolyzes inulin. Inulinase is found absent in humans. Since inulin cannot be digested in gastrointestinal tract in humans, it has no dietary importance.

**Dextrans:** Dextrans (molecular weights ranging from 70-400 kD) are branched homopolysaccharides composed of several branched chains of  $\alpha$ -D-glucose units linked together by  $\alpha$ (1  $\rightarrow$  4),  $\alpha$ (1  $\rightarrow$ 6) and  $\alpha$ (1 $\rightarrow$ 3) glycosidic bonds. Dextrans are synthesized when various strains of *Leuconostoc- mesenteroides* (non-pathogenic gram-positive cocci) are allowed to grow in sucrose solution. The dextrans are synthesized by exocellular enzymes released by the microbes in sucrose medium, which serves as a source of  $\alpha$ -D-glucose.

**Dextrins:** Similar to amylopectin, dextrins are branched homopolysaccharides composed of  $\alpha$ -D-glucose units linked together through  $\alpha$  (1 $\rightarrow$ 4) and  $\alpha$  (1 $\rightarrow$ 6) glycosidic bonds. Dextrins do not exist in nature; however, they are derived by partial hydrolysis of starch. Limit dextrins and maltose formed by action of salivary and pancreatic amylases on starch. Dextrins give characteristic color with iodine, e.g. purple and red colors are obtained.

**Agar:** It is a homopolysaccharide composed of sulphated galactose units. Both D- and L- isomers of galactose are suggested to be present in agar. Agar is obtained from seaweeds. Agar is odorless and tasteless and has ability to absorb lot of water.

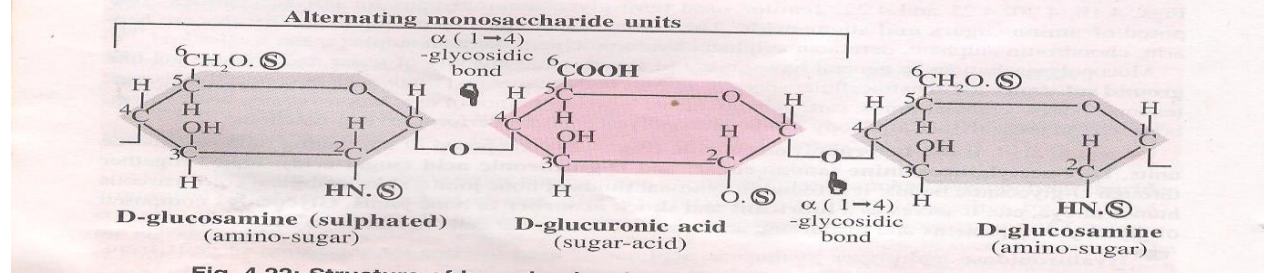
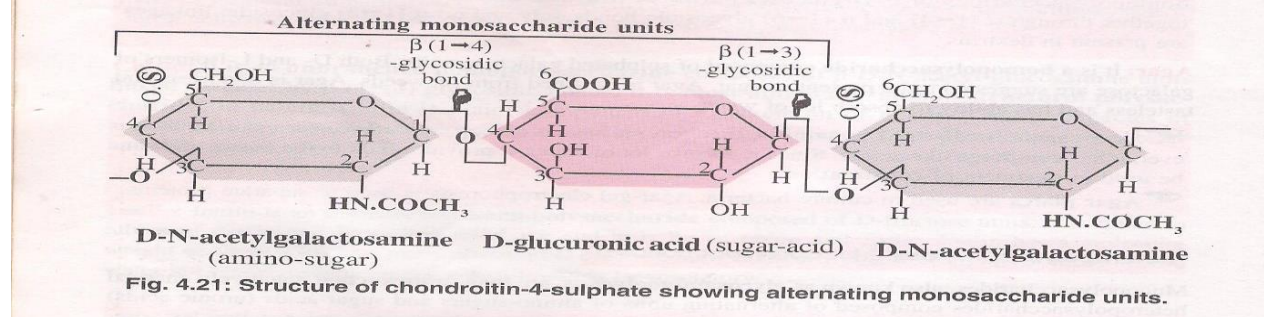
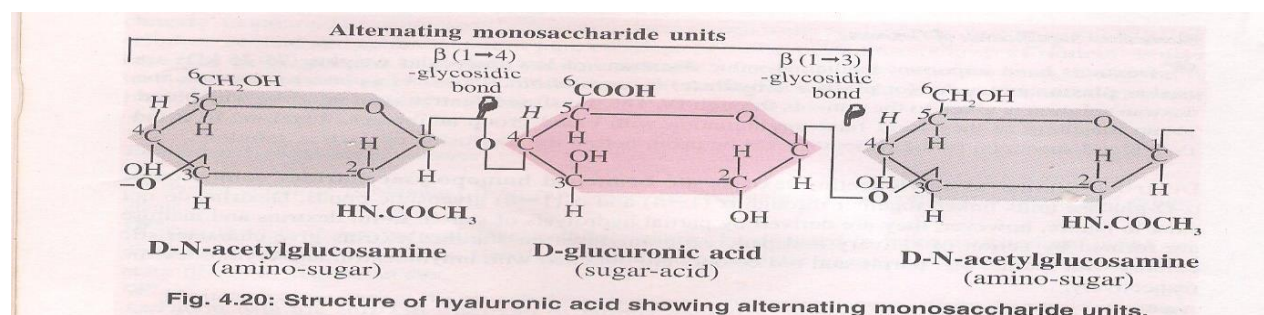
Agar cannot be digested in humans; therefore, it has no dietary importance for calories. However, it has roughage like action. Since it absorbs lot of water, it provides bulk to the faeces and may be used in treatment of constipation.

**Agar plates** are used to culture bacteria. **Agar gel electrophoresis** is used to separate proteins.



**Heteropolysaccharides**, also known as glycosaminoglycans, are long, unbranched negatively charged heteropolysaccharides composed of alternating units of amino-sugars and sugar—acids (uronic acids). The common examples of mucopolysaccharides are heparin, chondroitin sulphate, dermatan sulphate, hyaluronic acid, etc. mucopolysaccharides in general have ability to absorb large quantity of water and produce gel-like.

**Hyaluronic acid:** It is a heteropolysaccharide (Fig. 4.20) composed of alternating monosaccharide D-N-acetylglucosamine (amino-sugar) and D-glucuronic acid (sugar-acid), linked together through O-glycosidic bonds. It is found in synovial fluids of bone joints, skin, umbilical cord, etc. It serves as a lubricant and shock absorber in bone joints



**Chondroitin sulphate:** It is a heteropolysaccharide (Fig. 4.21) composed of alternating monosaccharide units, D-N-acetylgalactosamine (amino-sugar) and D-glucuronic acid (sugar-

acid) linked together through O-glycosidic bonds. It is most abundant mucopolysaccharide in human body. Chondroitin sulphate is of three types, A, B and C and is present in ground substance of connective tissues, tendons, cartilage, bones, teeth, blood vessels, heart valve, etc.

**Heparin:** It is a heteropolysaccharide (Fig. 4.22) composed of alternating monosaccharide units, D-glucosamine (amino-sugar) and D-glucuronic acid (sugar-acid) linked together through O-glycosidic bonds. D-glucosamine and D-glucuronic acid residues may also be sulphated. It is produced by mast cells that line arteries in liver, lung, spleen, thymus, skin, etc.

Heparin has a molecular weight of about 20 kD. It is a natural blood anticoagulant. Binding of heparin to plasma antithrombin causes inhibition of thrombin activity, which prevents the conversion of fibrinogen to fibrin and hence stops blood to clot. Patients with inherited deficiency of antithrombin have tendency of blood clot formation.

**Proteoglycans:** These are conjugated proteins, composed of extracellular 'core' protein and glycosaminoglycans. As compared to glycoproteins and mucoproteins, the amount of carbohydrates covalently attached to 'core' protein may be very high (up to 95%) in proteoglycans. These are important constituents of extracellular ground substances. Proteoglycans along with other extracellular proteins like collagen, elastin, etc. give the whole extracellular matrix strength and resilience.

**Peptidoglycans:** **The bacterial cell wall** is composed of peptidoglycans that are heteropolysaccharide of alternating monosaccharide units— N-acetylglucosamine and N-acetylmuramic acid linked together through  $\beta(1\rightarrow4)$  glycosidic bonds and peptide chains. The linear chains of heteropolymer of N-acetylcetylglucosamine and N-acetylmuramic acid are arranged parallel side by side and are cross-linked by short peptide chains. In bacterial cell wall, all the heteropolysaccharide chains are held together through peptide chains forming a cell coat that envelopes the bacterial cell membrane. The exact composition and structure of heteropolysaccharide and peptide chains vary with bacterial species and between Gram-negative and Gram -positive bacteria.