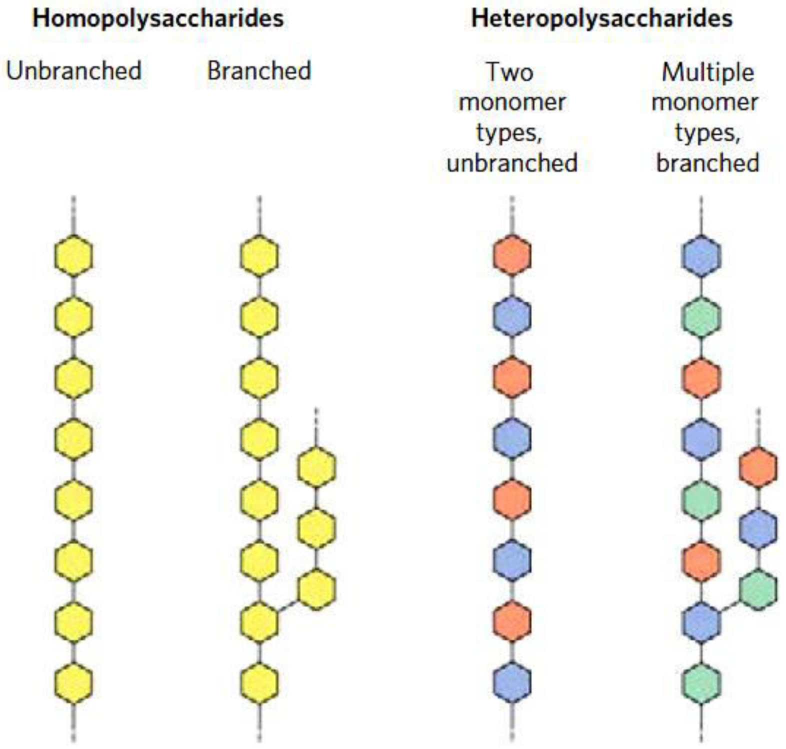
POLYSACCHARIDES

Most carbohydrates found in nature occur as polysaccharides, polymers of medium to high molecular weight (Mr .20,000). Polysaccharides, also called glycans, differ from each other in the identity of their recurring monosaccharide units, in the length of their chains, in the types of bonds linking the units, and in the degree of branching. **Homopolysaccharides contain only a single monomeric species**; **heteropolysaccharides contain two or more different kinds**. Some homopolysaccharides serve as storage forms of monosaccharides that are used as fuels; starch and glycogen are homopolysaccharides of this type. Other homopolysaccharides (cellulose and chitin, for example) serve as structural elements in plant cell walls and animal exoskeletons. Heteropolysaccharides provide extracellular support for organisms of all kingdoms. For example, the rigid layer of the bacterial cell envelope (the peptidoglycan) is composed in part of a heteropolysaccharide built from two alternating monosaccharide units. In animal tissues, the extracellular space is occupied by several types of heteropolysaccharides, which form a matrix that holds individual cells together and



provides protection, shape, and support to cells, tissues, and organs. Unlike proteins, polysaccharides generally do not have defining molecular weights. This difference is a consequence of the mechanisms of assembly of the two types of polymer. Proteins are synthesized on a template (messenger RNA) of defined sequence and length, by enzymes that follow the template exactly. For polysaccharide synthesis there is no template; rather, the program for polysaccharide synthesis is intrinsic to the enzymes that catalyze the polymerization of the monomeric units, and there is no specific stopping point in the synthetic process; the products thus vary in length.

STARCH

Occurrence: It is the most important reserve food material of the higher plants and is found in cereals, legumes, potatoes and other vegetables. More than half the carbohydrate ingested by humans is starch. Sago starch is obtained from sago palm, *Meteroxylon rumphii* ; the arrowroot from *Maranta arundinacea* and the tapioca, a starchy food, from *Manihot utillissima*. It is usually present inside the plant cells as compact insoluble granules which may be spherical, lens-shaped or ovoid, and which have a distinctly layered structure.

Chemistry: Natural starches consist of two components : amylose (15–20%), a long unbranched straight-chain component and amylopectin (80–85%), a branched chain polysaccharide. Starch from waxy corn is notable as it consists practically of amylopectin component, there being no amylose. **α-amylose** or simply amylose has a molecular weight range of 10,000 to 50,000. It may be formed in plant cells by elimination of a molecule of water from glycosidic OH group of one α-D-glucose molecule and alcoholic OH group on carbon 4 of the adjacent α-D-glucose molecule. The linkage in amylose is, thus, an α-1, 4-glucoside, like that in maltose. Enzymic hydrolysis of amylose with amylase, henceforth, yields maltose units mainly. Amylose may be considered as an anhydride of α-D-glucose units.

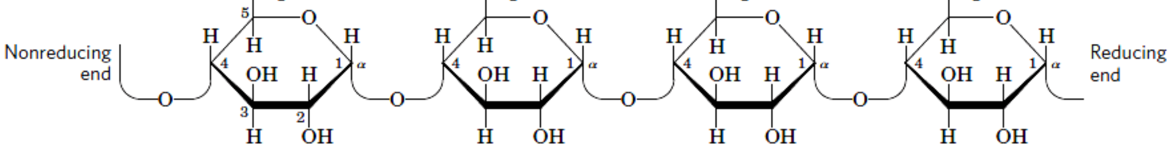


Figure: Structure of Amylose

β-amylose or isoamylose or amylopectin has a high molecular weight range of 50,000 to 1,000,000, thus indicating the presence of 300–5,500 glucose units per molecule. This possesses the same basic chain of α-1, 4-glucoside linkage like that of amylose but has, in addition, many side chains attached to the basic chain by α-1, 6-glucoside linkages, similar to those in isomaltose. It may, thus, be seen that the glucose unit, present at each point of branching, has substituents not only on carbon atoms 1 and 4 but also on carbon atom 6. In other words, these glucose units have 3 points of attachment to serve as branching points. The average chain length is about **24 glucose units**. Amylopectin, upon incomplete hydrolysis, yields the **disaccharide isomaltose**.

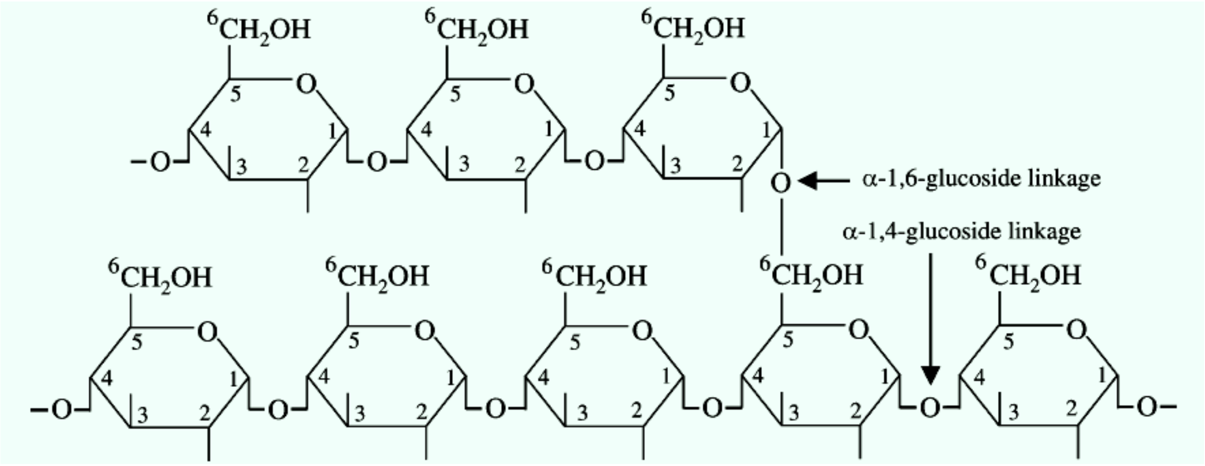


Figure: Structure of amylopectin

The detailed structure of amylopectin is still speculative. The general consensus appears to be that amylopectin is composed of 3 types of chain, A, B and C ; each chain consisting of 24 glucose units. A-chains are linked to B-chains in 1, 6, or 1, 3 manner. These B-chains are further linked to other B-chains, the terminal one of which is linked to a single C-chain, which characteristically possesses a free reducing group. There are 2 different types of combinations of these chains which explain reasonably well the properties of amylopectin : the laminated structure as proposed by Haworth in 1937 and the randomly highly-branched structure as given by Meyer in 1940.

Properties: Starch is a white soft amorphous powder and lacks sweetness. It is insoluble in water, alcohol and ether at ordinary temperature. The specific rotation of starch, $[\alpha]D_{20}$ is + 196°. The microscopic form of the starch grains is characteristic of the source of starch. Starch, on partial hydrolysis by boiling with water under pressure at about 250°C, breaks down into large fragments called **dextrins**. The resulting dextrins then confer stiffness to clothes that have been starched and ironed. Starch molecule is highly hydrated since it contains many exposed hydroxyl groups. With the result, starch, when extracted from granules with hot water, forms turbid colloidal solutions. In common with other polysaccharides, starch is a nonreducing carbohydrate since carbonyl groups of all units (except one of the two terminal ones) participate in the glycosidic linkages. The two components of starch differ in following points :

I. Amylose has a simpler structure and hence **more soluble** in water than amylopectin. Because of this difference in solubility, the two components may be separated partially by keeping starch in water for a prolonged period. When potatoes are boiled, amylose is extracted by the hot water turning it milky and opalescent. The amylopectin left behind accounts for most of the starch in boiled potatoes.

II. Amylose is soluble **without swelling** in hot water whereas amylopectin **swells** in water.

III. Amylose is readily dispersed in water but does not form the characteristic **gel or starch paste**. However, when dispersed in sufficient concentrations, the amylopectin forms the typical **starch gel**.

IV. Amylose produces a typical **blue colour** with iodine whereas amylopectin gives a **purplish** colour with iodine. In fact, amylose is an **open, helical molecule**. The inside diameter of the helix is just large enough to accommodate an iodine molecule and it is the consequent change in the light-absorbing properties of the halogen that is responsible for the blue colour given in the starch-iodine test. By contrast, most other polysaccharides, including amylopectin, give only dull, **reddish-brown** colours.

Hydrolysis: One enzyme, α-amylase, found in the digestive tract of animals (in saliva and the pancreatic juice) hydrolyzes the linear amylose chain by attacking α (1→ 4) linkages at random throughout the chain to produce a mixture of maltose and glucose. β-amylase, an enzyme found in plants, attacks the nonreducing end of amylose to yield successive units of maltose (The prefixes α and β used with the amylases do not refer to glycosidic linkage, but simply designate these two enzymes). Amylopectin can also be attacked by α- and β-amylases, but the α (1 → 4) glycosidic bonds near the branching point in amylopectin and the **α (1 → 6) bond itself are not hydrolyzed** by these enzymes. A separate **"debranching"** enzyme, an **α (1→ 6) glucosidase can hydrolyze the bond.** at the branch point. Therefore, the combined action of α-amylase and the α (1 → 6) glucosidase will hydrolyze amylopectin ultimately to a mixture of glucose and maltose. **Starch is readily hydrolyzed by mineral acid with the final production of glucose**. The course of hydrolysis may be followed by the gradual change in colour when treated with iodine (blue → purple → red→ none) and also by the increase in concentration of reducing sugar. A compound which yields only glucose molecules on hydrolysis is called a glucosan. Hence, starch is a glucosan. If hydrolysis of starch is interrupted early, dextrins are formed. The **dextrins are white powders**, and are used for making adhesives and confectionery, for sizing paper, etc. These materials possess adhesive properties and are used as adhesives on paper products.

$$\underset{\substack{\text{Starch or Glycogen}\\\text{(insoluble)}}}{(C_6H_{10}O_5)_n} \quad + \quad \underset{\substack{(n-1)\text{ water}\\\text{molecules}}}{(n-1)\,H_2O} \quad \xrightarrow{\text{Hydrolysis}} \quad \underset{\substack{n\text{ glucose molecules}\\\text{(soluble)}}}{n(C_6H_{12}O_6)}$$

GLYCOGEN

Occurrence: It is the major reserve food in animals and is often called ‘animal starch’. Glycogen is stored in the liver and muscles of animals. It is especially abundant in the liver where it may attain up to 7% of the wet weight. It occurs in animal cells as particles much smaller than the starch grains.

Chemistry: Glycogen is a branched-chain polysaccharide and resembles amylopectin very much in structure, rather than amylose (for which there is no ‘animal’ equivalent), but has somewhat more glucose residues per molecule and about one-and-a-half times as many branching points. Also the chains are **shorter (10–20 glucose units)**, and hence the molecule is even **more highly branched** and **more compact**. These differences, however, do not alter the functional behaviour of the molecule to any significant extent. Its molecular weight is 1 − 2 × 107.

Properties: It is a white powder and is more soluble in water than amylopectin. Hence, it readily forms suspension even in cold water. Glycogen is precipitated from aqueous solutions by addition of ethyl alcohol and is fairly stable in hot alkali. It is a nonreducing sugar and gives **red colour with iodine**. The red colour, however, disappears on boiling and reappears on cooling.

Hydrolysis: On incomplete hydrolysis with α-1,4-glucanmaltohydrolase, glycogen yields maltose. However, the acids completely hydrolyze it into glucose.

INULIN

Occurrence: It is the storage form of carbohydrate in the members of the family—Compositae, such as dahlias (Dahlia sp.), artichokes (Helianthus tuberosus) and dandelions (Taraxacum officinale). Inulin is stored in the tubers of the dahlia and artichoke and in the roots of dandelion. It is also found in **onion** and **garlic**.

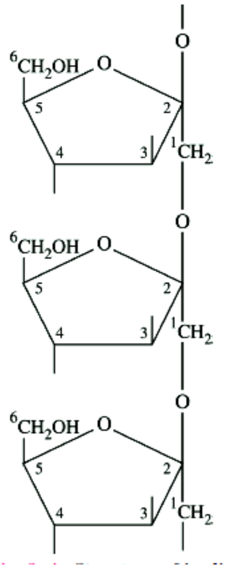


Figure: Structure of inulin

Chemistry: Inulin (Fig. 8–4) has a molecular weight of about 5,000 and consists of about 30–35 fructose units per molecule. It is formed in the plants by eliminating a molecule of water from the glycosidic OH group on carbon atom 2 of one β-D-fructose unit and the alcoholic OH group on carbon atom 1 of the adjacent β-D-fructose unit. In inulin, the fructose residues (in furanose form) are, thus, joined together in a straight chain by β-2, 1-fructosidic linkages. Inulin is, therefore, 2 → 1- β-polyfructose. On hydrolysis, however, inulin also yields a small amount of glucose besides fructose molecules. It is now thought that there are 2 glucose units in the inulin molecule, one somewhere in the centre and the other at the reducing end of the chain.

Properties: It is a white tasteless powder and is insoluble in cold water. In warm water, it easily dissolves forming a colloidal solution which does not form a gel on cooling. Inulin solution does not give any colour with iodine. It is a nonreducing sugar.

Hydrolysis: Inulin, on complete hydrolysis by dilute acids, yields D-fructose and hence it is a fructosan or levan.

CELLULOSE

Occurrence: Cellulose is not only the most abundant extracellular structural polysaccharide of the plant world but is also undoubtedly the most abundant of all biomolecules in the biosphere. It is present in all land plants, but is completely lacking in meat, egg, fish and milk. It is, however, not metabolized by the human system. Some 1015 kg of cellulose is synthesized and degraded on earth each year! It shares as much as 50% of all the carbon in vegetation. It is the most widely distributed carbohydrate of the plants, although certain tunicates also possess it. Cellulose occurs in the cell walls of plants where it contributes in a major way to the structure of the organism. Lacking a skeleton of bone onto which organs and tissues may be organized, the higher plant relies on its cell walls to bear its own weight, whether it is the smallest Wolffia flower or the tallest Sequoia tree. Cellulose is often found associated with other structural substances such as lignin. Plant residues in soil consist of 40-70% cellulose. This high cellulose content emphasizes the importance of cellulolytic organisms in the mineralization process and in the carbon cycle. It occurs in nearly pure form in cotton (94%), flax (90%) and in the wood of many plants (60%). It is not usually found in bacterial cell walls, but it is the substance which keeps the cells of Sarcina ventriculi together in large packets or bunches.

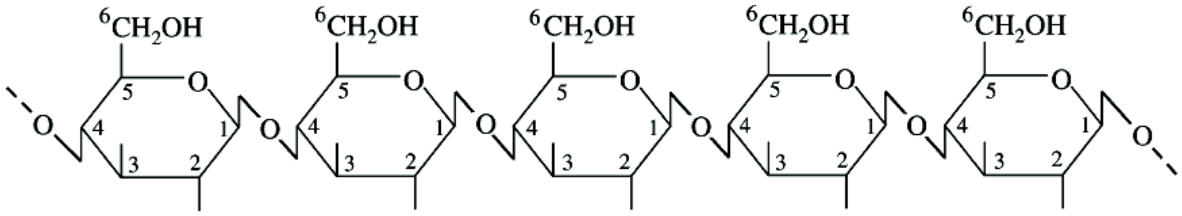


Figure: Structure of cellulose

Chemistry: The molecular weight of cellulose ranges between 200,000 and 2,000,000, thus corresponding to 1,250–12,500 glucose residues per molecule. It may be formed by taking out a molecule of water from the glycosidic OH group on carbon atom 1 of one β-D-glucose molecule and the alcoholic OH group on carbon atom 4 of the adjacent β-D-glucose molecule. It, thus, resembles in structure with amylose except that the glucose units are linked together by β-1, 4-glucoside linkages. Cellulose may, henceforth, be regarded as an anhydride of β-D-glucose units.

Properties: It is a fibrous, tough, white solid, insoluble in water but soluble in ammoniacal cupric hydroxide solution (Schweitzer's reagent). It gives no colour with iodine and lacks sweetness. Although insoluble in water, cellulose absorbs water and adds to the bulk of the fecal matter and acilitates its removal. Because of the lack of chemical reactivity, the cellulose is of no nutritive value unlike starch. However, the same characteristics have made it so useful as fibres for paper and cloth. In man, the **cellulose is not digested since it does not possess an enzyme capable of catalyzing the cleavage of**

β-glucoside bonds. Hence, it serves as an important source of "bulk" in the diet. However, the **ruminants**

(cattles, sheep, goats, camels, giraffes) and certain wood-eating insects are able to digest it because

the microorganisms, present in their digestive tract, do possess such digesting enzymes. Also certain wood-eating insects such as **termites** readily digest cellulose because their intestinal tract harbours a parasitic protozoan, Trichonympha. The latter secretes cellulase, a cellulose-hydrolyzing enzyme which enables termites to digest wood. Wood-rot fungi and bacteria also produce cellulase.

Hydrolysis: Cellulose is a relatively inert material and is completely degraded only under the most drastic conditions. For example, it may be hydrolyzed to glucose when treated with conc. H2SO4 or HCl or with conc. NaOH.

Biological importance: Huge quantities of cellulose are made annually by the plants of the globe. It is estimated that every day some 50 kg of cellulose is synthesized by the plant world for each human being on the earth. Cellulose is also a very useful substance. Wood, cotton, paper and cardboard are all largely cellulose. Dried wood contains about 65% cellulose, 30% lignin and 2% pentosans. In the manufacutre of paper, wood is cooked with water, lime and SO_2 to remove lignin leaving behind the cellulose. These fibres are then spread into mats and rolled into sheets which may be coated to provide a smooth writing surface. When heavy paper is treated with H_2SO4, the translucent parchment paper is obtained. Cotton treated with alkali becomes somewhat translucent, acquires a silky lustre, and is called mercerized cotton. Rayon is made from cellulose by dissolving the material in NaOH and CS_2. The viscous material is forced through small jets into an acid solution of sodium bisulfite, regenerating the cellulose in small threads. **Cellulose nitrates** are used in explosives, lacquers, celluloid and collodion. **Cellulose acetate** is widely used in photographic film and packing materials. It may, thus, be easily visualized that the way the constituent monomeric units of various polysaccharides (glycogen, starch and cellulose, for example) are linked together has a profound bearing on the physical and chemical properties of these molecules, although the polysaccharides are made up of identical glucose units.

PECTIN

Occurrence: Pectins are found as intercellular substances in the tissues of young plants and are especially abundant in ripe fruits such as guava, apples and pears. They are components of the middle lamella found between the cell wall and adjacent cells.

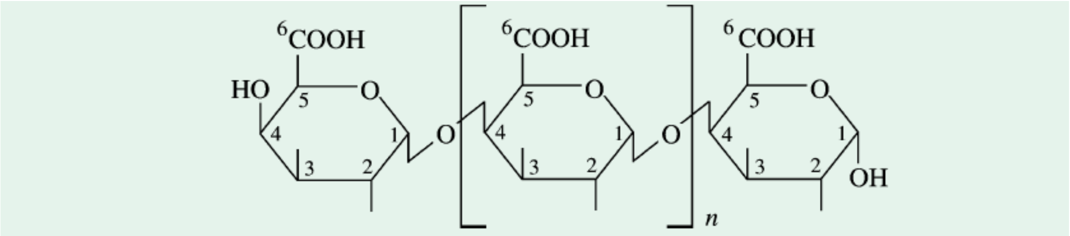


Figure: Structure of pectin

Chemistry: Pectin is a polysaccharide of α-D-galacturonic acid where some of the free carboxyl groups are, either partly or completely, esterified with methyl alcohol and others are combined with calcium or magnesium ions. Chemically, they are called polygalacturonides and have high molecular weights.

Biological properties: The importance of pectin rests not so much on their quantitative role but rather on the functional part they play in plant stability and solidity. The characteristic property of pectins is the ability of their solutions to gelate, i.e., form jellies. Pectins, along with sugar, furnish the gelling characteristics of jellies and preserves made from fruit.

CHITIN

Occurrence: Chitin is probably the most abundant polysaccharide of nature after cellulose. It is also one of the most abundant biopolymer on the earth. It is found in fungi but principally among the arthropods (crabs and insects). The armour of crabs and the exoskeleton (= cuticula) of insects consist mostly of chitin and some protein. The excellent mechanical properties of insect skeleton are due to chitin. The chitin framework of lobster and crabs shells is impregnated and hardened with calcium carbonate.

Chemistry: Chitin is closely related to cellulose. Here the alcoholic OH group on carbon atom 2 of β-D-glucose units is replaced by an N-acetylamino group. It is, thus, a linear polymer of N-acetyl-D-glucosamine units joined together by β-1, 4-glucosidic linkages. Chitin’s pronounced stability is based on the hydrogen bonding of the N-acetyl side chains. Like cellulose, chitin is indigestible by vertebrate animals.

Hydrolysis: On hydrolysis with mineral acids, chitin yields 2 final end products, namely, glucosamine and acetic acid. Glucosamine is an important component of some glycoproteins (=mucoproteins) such as mucin of saliva. Chitinases (from the gastric juice of snails or from bacteria), however, decompose the chitin to N-acetylglucosamine.

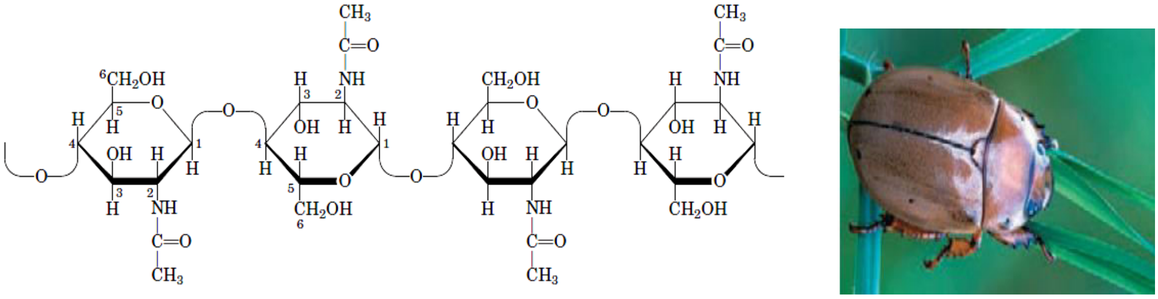


Figure: Structure of chitin and A spotted June beetle (Pelidnota punctata), showing its surface exoskeleton.

HEMICELLULOSES

Xylan and other related substances are collectively referred to as hemicelluloses. They are not structurally related to cellulose, nor do they contain the same building blocks but they are, at least partially, soluble in water or alkali. The hemicelluloses consist of either pentoses (xylose, arabinose) or hexoses (glucose, mannose, galactose) as well as uronic acids. Unrefined cereals, some fruits and vegetables and whole wheat are rich sources of hemicelluloses. They adsorb water and are partially digestible. They function as storage and supporting substances in plants. The designation ‘hemicelluloses’ has been discontinued since a large number of similar polysaccharides were discovered in fungi and bacteria. Xylan is representative of the group and is, therefore, being discussed below.

XYLAN

Occurrence: Xylan is the next most abundant and widely distributed carbohydrate after cellulose. Straw and bark consist of upto 30% xylan; residues of sugarcane also contain about 30% xylan. It also occurs in conifer wood (7–12%) and deciduous wood (20–25%). **Chemistry:** Xylan is a linear homopolymer of D-xylose (an aldopentose) in β-1→4 linkage, bearing side chains of 4–O–methylglucuronic acid and/or arabinose. Xylan can be derived from a cellulose chain by substituting hydrogen atoms for the —CH2OH groups, but its polymer size (number of units per polymer) is considerably lower (30–100).

Properties: Xylan is more rapidly degraded by a large number of microorganisms than cellulose. Many cellulose-degrading organisms (such as Sporocytophaga myxococcoides) also produce xylanase. The ability to utilize xylans is very common among fungi. Xylan is even an excellent substrate for the cultivation of mushrooms. In bacteria, xylanase is formed constitutively in some organisms (e.g., Clostridia) and in others it is inducible by xylan.

HETEROPOLYSACCHARIDES

These yield, on hydrolysis, a mixture of monosaccharides. They are numerous in both plants and animals. The ‘specific soluble sugar’ of pneumococcus type III is one of the simplest heteropolysaccharides. It contains repeating units of a mixed disaccharide consisting of glucose and glucuronic acid. Apparently, on hydrolysis, it yields equimolar amounts of glucose and glucuronic acid.

MUCOPOLYSACCHARIDES

Polysaccharides that are composed not only of a mixture of simple sugars but also of derivatives of sugars such as amino sugars and uronic sugars are called mucopolysaccharides. They are gelatinous substances of high molecular weights (up to 5 × 106). Most of these act as structural support material for connective tissue or mucous substances of the body. They serve both as a lubricant and a cementing substance. Structurally, they have a common feature. They consist of disaccharide units in which a uronic acid is bound by a glycosidic bond to the C3 of an acetylated amino acid (1 → 3 linkage). These disaccharide residues are polymerized by 1 → 4 linkages to give a linear macromolecule. The uronic and sulfuric acid residues impart a strong acidic character to these substances.

HYALURONIC ACID

Occurrence: It is the most abundant member of mucopolysaccharides and is found in higher animals as a component of various tissues such as the vitreous body of the eye, the umbilical cord and the synovial fluid of joints. The high viscosity of the synovial fluid and its role as biological lubricant is largely due to the presence of its hyaluronic acid content (about 0.03%). Frequently, it is prepared from umbilical cord.

Chemistry: Hyaluronic acid has the least complicated structure among mucopolysaccharides. It is a straight-chain polymer of D-glucuronic acid and N-acetyl- D-glucosamine (NAG) alternating in the chain. Its molecular weight approaches approximately, 5,000,000. Here, apparently two linkages are invloved, β-1 → 3 and β-1 → 4. Hyaluronic acid is an acidic substance. It is an extended left-handed helix, which is stabilized by hydrogen bonds.

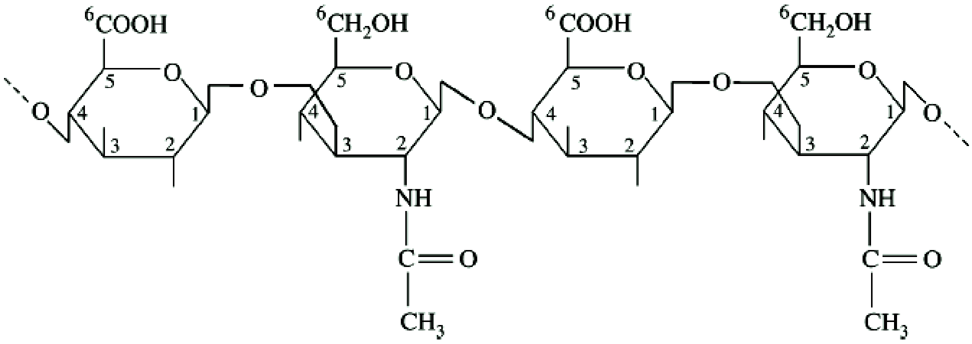


Figure: structure of Hyaluroic acid.

Hydrolysis: Hyaluronic acid, upon hydrolysis, yields an equimolar mixture of D-glucuronic acid, D-glucosamine and acetic acid. It is noteworthy that hyaluronic acid is split swiftly by the enzyme hyaluronidase. The enzyme brings about depolymerization of hyaluronic acid (leading to a drop in its viscosity) and cleavage to smaller fragments. Hyaluronidase is a 'spreading factor' of skin and connective tissue. The depolymerization effect allows any foreign bodies (such as pigments, pathogenic bacteria) to penetrate the tissue, since the cementing substance is being dissolved. The enzyme also has a physiologic role in fertilization. The sperm is rich in hyaluronidase and hence can advance better in the cervical canal and finally fertilize the ovum.

CHONDROITIN

Occurrence: Chondroitin is of limited distributioin. It is found in cartilage and is also a component of cell coats. It is a parent substance for two more widely distributed mucopolysaccharides, chondroitin sulfate A and chondroitin sulfate B.

Chemistry: Chondroitin is similar in structure to hyaluronic acid except that it contains galactosamine rather than glucosamine. It is, thus, a polymer of β-Dglucuronido- 1, 3-N-acetyl-D-galactosamine joined by β- 1 → 4 linkages.

Hydrolysis: On hydrolysis, chondroitin produces equimolar mixture of D-glucuronic acid, D-galactosamine and acetic acid.

CHONDROITIN SULFATES

Occurrence: The two chondroitin sulfate A and C are widely distributed and form major structural components of cartilage, tendons and bones. They are very often associated with collagen and probably with other proteins too.

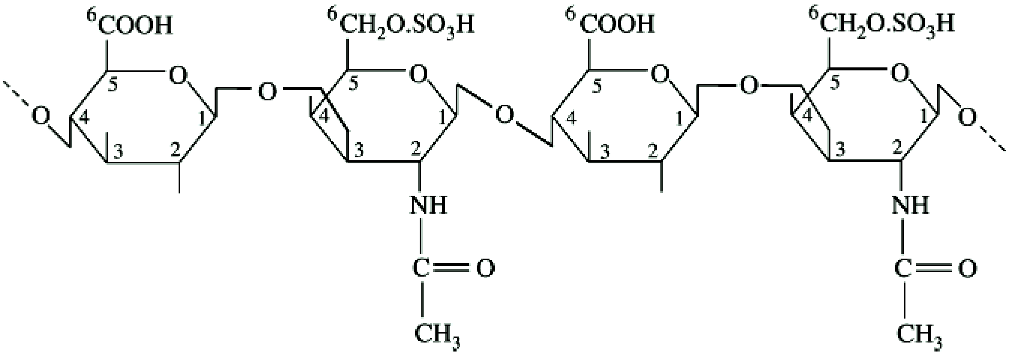


Figure: Structure of chondroitin sulphate C.

Chemistry: Chondroitin sulfates may be regarded as derivatives of chondroitin where, in the galactosamine moiety, a sulfate group is esterified either at carbon 4 as in chondroitin sulfate A or at carbon 6 as in chondroitin sulfate C. The two linkages involved in both types of chondroitin sulfate would, obviously, be the same. These are β-1 → 3 and β-1 → 4.

Hydrolysis: On hydrolysis, chondroitin sulfates A and C yield approximately equivalent amounts of D-glucuronic acid, D-galactosamine, acetic acid and sulfuric acid.

DERMATAN SULFATE

Dermatan sulfate is a mucopolysaccharide structurally similar to chondroitin sulfate A except that the D-glucuronic acid is replaced by L-iduronic acid (the two uronic acids differ in configuration only at C5). The two linkages involved are α-1 → 3 and β-1 → 4. Dermatan sulfate is also known by its conventional name, chondroitin sulfate B. This is, however, a misnomer since dermatan sulphate differs from both chondroitin sulfate A and C in the composition of their repeating disaccharide unit.

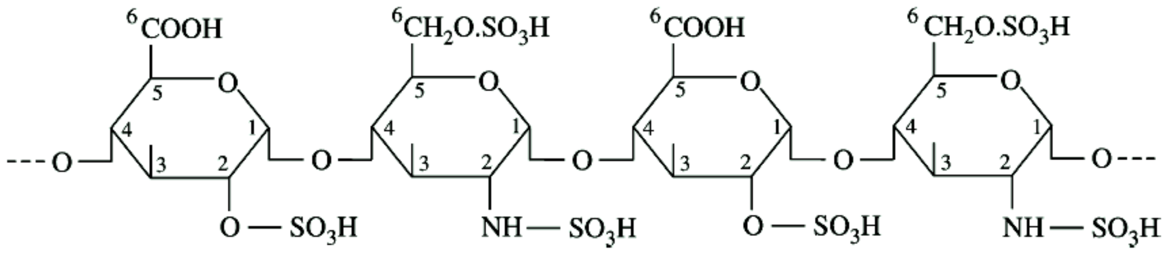
KERATOSULFATE

Keratosulfate differs from other mucopolysaccharides in that the uronic acid component is replaced by D-galactose. Here, the second acetylated amino sugar component (which is N-acetyl-D-glucosamine in this case) is esterified by a sulfate group at carbon 6. Although, the two alternating linkages involved are β-1 → 4 and β-1 → 3, in this case the linkage between the repeating disaccharide units is β-1 →3 rather than β-1 → 4.

HEPARIN

Occurrence: Related to the sulfated mucopolysaccharides is heparin. It is present in liver, lung, arterial walls and, indeed, wherever mast cells are found, possibly for the purpose of neutralizing biogenic amines (e.g., histamine).

Chemistry: Heparin (Fig. 8–14) is a heteropolysaccharide composed of D-glucuronic acid units, most of which (about 7 out of every 8) are esterified at C2 and D-glucosamine-N-sulfate (= sulfonylaminoglucose) units with an additional O-sulfate group at C6. Both the linkages of the polymer are alternating α-1 → 4. Thus, the sulfate content is very high and corresponds to about 5– 6 molecules per tetrasaccharide repeating unit. The relative positions of the sulfate residues may also vary. Its molecular weight ranges between 17,000 and 20,000. Heparin acts as an anticoagulant. It prevents coagulation of blood by inhibiting the prothrombinthrombin conversion. This eliminates the effect of thrombin on fibrinogen. The heteropolysaccharides described above contain two different sugars in their repeating units or monomers. However, there are many heteropolysaccharides which contain more than 2 carbohydrates in their repeating units. Vegetable ‘gums’ and agar-agar are two notable examples.



Vegetable 'gums': These contain as many as 4 different monosaccharide units. Most common of these are D-glucuronic acid, D-mannose, D-xylose (the second most abundant sugar in the biosphere) and L-rhamnose.

Agar-agar: It is a gelatinous polysaccharide produced by certain marine red algae (= rhodophycean members) such as species of Gelidium, Gracilaria, Gigartina, Eucheuma, Campylaephora, Ahnfeltia, Hypnea, etc. Japan is the major producer of agar-agar. It consists of D- and L-galactose, predominantly with 1 → 3 bonds and always contains some amount of sulfuric acid. On hydrolysis, it yields D- and L-galactose in a ratio of 9 : 1. It forms highly viscous gels and has melting point between 90 and 100°F. At lower temperature, it solidifies. It is insoluble in cold but soluble in hot water. Agar-agar is of great value in the preparation of foodstuffs, particularly as articles of diet for invalids. It is used extensively in biological laboratories as the base material for the preparation of culture media, especially for bacteria and fungi. It is also used in the preparation of some medicines, and in cosmetics and leather industry. It is largely used as a solidifying agent in desserts, as a laxative and as a sizing material for textiles. It also finds application as an emulsifier in dairy products. Agaragar is not utilized by man and hence adds to the bulk of the feces and helps in its propulsion. A wide variety of heteropolysaccharides are found in animals and microbes. These, on hydrolysis, yield various types of monosaccharides. These more complex polysaccharides are found bound to proteins (glycoproteins) and lipids (glycolipids). Carbohydrates occur in them as an oligosaccharide moiety.