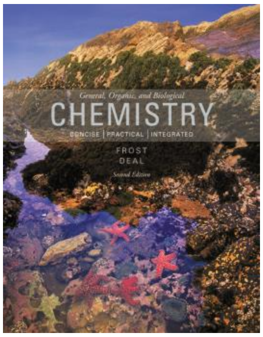

Lecture Presentation

Chapter 6

Carbohydrates

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Outline

- 6.1 Classes of Carbohydrates
- 6.2 Functional Groups in Monosaccharides
- 6.3 Stereochemistry in Monosaccharides
- 6.4 Reactions of Monosaccharides
- 6.5 Disaccharides
- 6.6 Polysaccharides
- 6.7 Carbohydrates and Blood

6.1 Classes of Carbohydrates

- The simplest carbohydrates are **monosaccharides** (*mono* is Greek for "one," *sakkhari* is Greek for "sugar").
- These often sweet-tasting sugars cannot be broken down into smaller carbohydrates.
- The common carbohydrate glucose, $C_6H_{12}O_6$, is a monosaccharide.
- Monosaccharides contain carbon, hydrogen, and oxygen and have the general formula $C_n(H_2O)_n$, where n is a whole number 3 or higher.

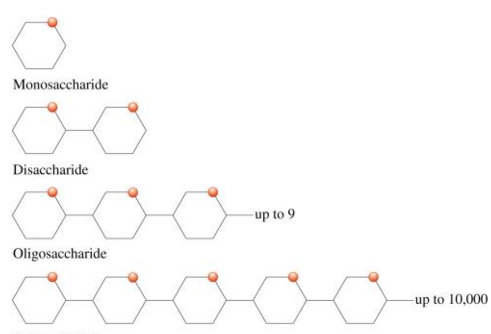
6.1 Classes of Carbohydrates

- **Disaccharides** consist of two monosaccharide units joined together.
- A disaccharide can be split into two monosaccharide units. Ordinary table sugar, sucrose, $C_{12}H_{22}O_{11}$, is a disaccharide that can be broken up, through hydrolysis, into the monosaccharides glucose and fructose.
- **Oligosaccharides**are carbohydrates containing three to nine monosaccharide units. The blood-typing groups known as ABO are oligosaccharides.

6.1 Classes of Carbohydrates

- When 10 or more monosaccharide units are joined together, the large molecules that result are **polysaccharides** (*poly* is Greek for "many").
- The sugar units can be connected in one continuous chain or the chain can be branched.
- Starch, a polysaccharide in plants, contains branched chains of glucose that can be broken down to produce energy.

6.1 Classes of Carbohydrates



6.1 Classes of Carbohydrates

FIBER IN YOUR DIET

- Dietary fibers are carbohydrates that we cannot digest with our own enzymes.
- Soluble fiber mixes with water, forming a gel-like substance in the stomach and digestive tract.
- This gives a sense of fullness and slows sugar and cholesterol absorption into the bloodstream.
- Some foods high in soluble fiber include oatmeal, legumes (peas, beans, and lentils), apples, psyllium husk, and carrots.
- Fruit pectins used in making jellies contain soluble fiber.

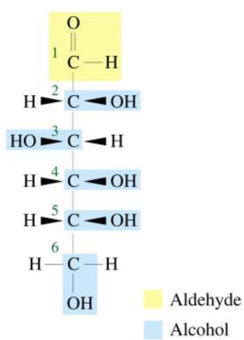
6.1 Classes of Carbohydrates

FIBER IN YOUR DIET

- Insoluble fibers do not mix with water, although they play a critical role in the digestive tract.
- Insoluble fiber has a laxative effect and adds bulk to the diet, thus preventing constipation.
- The polysaccharide cellulose is an insoluble fiber.
- Sources include whole grains, seeds, brown rice, cabbage, and vegetable skins.

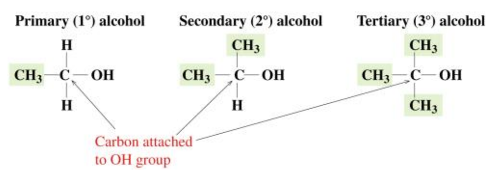
6.2 Functional Groups in Monosaccharides

- Carbohydrates are considered polyhydroxyaldehydes or polyhydroxy ketones because they contain several hydroxyl (alcohol) groups and either an aldehyde or ketone group.



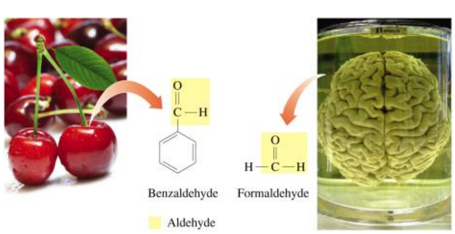
6.2 Functional Groups in Monosaccharides

- Alcohols are classified by the number of alkyl groups attached to the carbon atom bonded to the hydroxyl group.
- A **primary (1°) alcohol** has *one* alkyl group.
- A **secondary (2°) alcohol** has *two* alkyl groups.
- A **tertiary (3°) alcohol** has *three* alkyl groups.
- Monosaccharides contain primary and secondary alcohols.



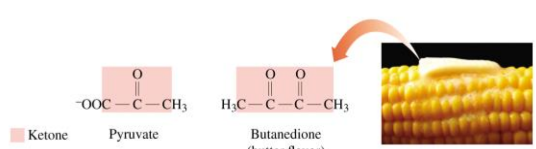
6.2 Functional Groups in Monosaccharides

- Members of the aldehyde family always have a carbonyl group with a hydrogen atom bonded to one side of the carbonyl and an alkyl or aromatic group bonded to the other.
- Monosaccharides can contain an aldehyde functional group at one end of the molecule (in addition to multiple hydroxyl groups).



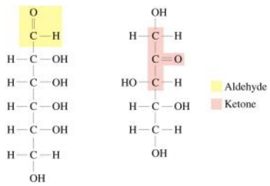
6.2 Functional Groups in Monosaccharides

- The **ketone** family of organic compounds is structurally similar to the aldehydes.
- The difference is that ketones have an alkyl or aromatic group on *both* sides of the carbonyl.
- Ketones occur in a wide variety of biologically relevant compounds.



6.2 Functional Groups in Monosaccharides

- A monosaccharide that contains an aldehyde functional group is an **aldose**, and one that contains a ketone functional group is a **ketose**.
- A monosaccharide with three carbons is a *triose*, one with four carbons is a *tetrose*, one with five carbons is a *pentose*, and one with six carbons is a *hexose*.



An aldohexose A ketopentose

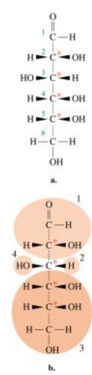
6.3 Stereochemistry in Monosaccharides

- A carbon atom with tetrahedral geometry and four different atoms or groups attached to it is chiral.
- A compound with a single chiral carbon atom can exist as two *enantiomers*.
- How many chiral carbons does a glucose molecule contain?
  - Carbon 1 is not tetrahedral, and carbon 6 does not have four different groups attached.
  - Carbons 2 to 5 are tetrahedral and have four different atoms or groups of atoms attached, so they are chiral carbons.
- Glucose has a four chiral centers.

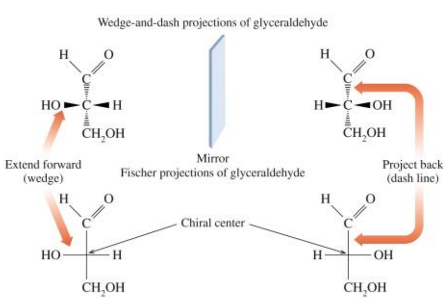
6.3 Stereochemistry in Monosaccharides

- The number of stereoisomers possible increases with the number of chiral centers present in a molecule.
- The general formula for determining the number of stereoisomers is 2^n, where *n* is the number of chiral centers present in the molecule.
- Because glucose has four chiral centers, 16 stereoisomers are possible.
- Only only one of these stereoisomers is our preferred energy source.

6.3 Stereochemistry in Monosaccharides



6.3 Stereochemistry in Monosaccharides



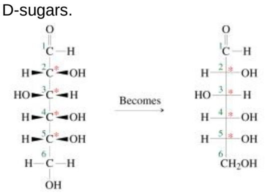
L-Glyceraldehyde D-Glyceraldehyde

6.3 Stereochemistry in Monosaccharides

- In the **Fischer projection,** *horizontal lines on a chiral center represent wedges, and vertical lines on a chiral center represent dashes*.
- A chiral carbon is not shown as a "C" on a Fischer projection but is implied at the intersection of the lines.
- This gives the viewer a quick and easy way of identifying the number of chiral centers.
- The designation of **D** or **L** is based on the Fischer projection positioning in glyceraldehyde, used as a reference molecule for this designation.

6.3 Stereochemistry in Monosaccharides

- **D-sugars** have the –OH on the chiral carbon farthest from the carbonyl C=O on the *right side* of the molecule.
- The enantiomer is the **L-sugar**, which has the –OH group on the chiral carbon farthest from the C=O on the *left side* of the projection.
- Most of the carbohydrates found in nature and the ones we use for energy are D-sugars.

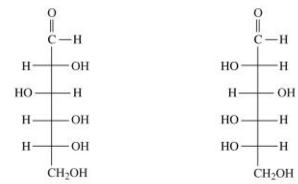


Wedge-and-dash projection D-Glucose

Fischer projection D-Glucose

6.3 Stereochemistry in Monosaccharides

- When we draw enantiomers in a Fischer projection, they are written as if there is a mirror placed between the two molecules.
- Attached atoms or groups on the right in one enantiomer appear on the left side of the other.

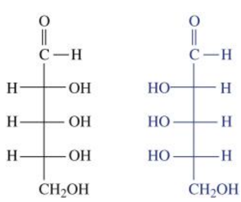


D-Glucose L-Glucose

6.3 Stereochemistry in Monosaccharides

Drawing an Enantiomer in a Fischer Projection

- Step 1: Locate the chiral centers.
- Step 2: Switch horizontal groups on the chiral centers.

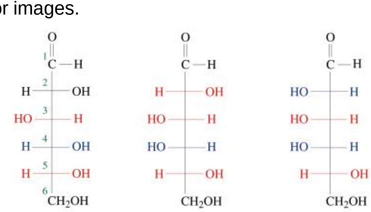


D-Ribose L-Ribose

6.3 Stereochemistry in Monosaccharides

Stereoisomers That Are Not Enantiomers

- Stereoisomers that are not enantiomers are called **diastereomers**.
- Diastereomers are stereoisomers that are not exact mirror images.



D-Glucose D-Galactose D-Talose

6.3 Stereochemistry in Monosaccharides

Important Monosaccharides: Glucose

- The most abundant monosaccharide found in nature is glucose, also called dextrose, blood sugar, or grape sugar.
- It is found in fruits, vegetables, and corn syrup.
- Diabetics have difficulty getting glucose from the bloodstream into their cells so that glycolysis can occur. This is why they must regularly monitor their blood glucose levels.
- Glucose is also a sugar unit in sucrose (table sugar), lactose (milk sugar), amylase, amylopectin, glycogen, and cellulose.

6.3 Stereochemistry in Monosaccharides

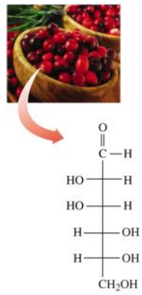
Important Monosaccharides: Galactose

- Galactose is found combined with glucose in the disaccharide lactose, which is present in milk and other dairy products.
- Galactose has a single chiral center (carbon 4) arranged opposite that of glucose.
- Diastereomers that differ in just one chiral center are **epimers**.
- The body can convert galactose into glucose with an enzyme called an *epimerase*.

6.3 Stereochemistry in Monosaccharides

Important Monosaccharides: Mannose

- **Mannose** is a monosaccharide found most notably in cranberries. It is not easily absorbed by the body.
- Mannose has been shown to be effective against urinary tract infections (UTIs). When the level of mannose builds up in the bladder, bacteria will attach themselves to the mannose in the urine and be eliminated.
- Mannose is an epimer of glucose.

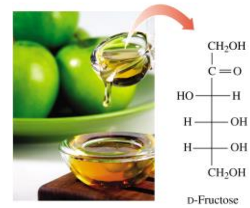


D-Mannose

6.3 Stereochemistry in Monosaccharides

Important Monosaccharides: Fructose

- The ketose fructose is also referred to as fruit sugar or levulose. It is found in fruits, vegetables, and honey.
- In combination with glucose, it gives us the disaccharide sucrose (table sugar).
- Fructose is the sweetest monosaccharide, one and a half times sweeter than table sugar.
- Even though it is not an epimer of glucose, fructose can be broken down for energy production in the body.

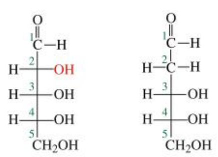


D-Fructose

6.3 Stereochemistry in Monosaccharides

Important Monosaccharides: Ribose

- The pentoses (five-carbon sugars) ribose and 2-deoxyribose are a part of nucleic acids.
- The nucleic acids are distinguished in their name by the monosaccharide they contain. *Ribo*nucleic acid (RNA) contains the sugar ribose, and *deoxyribo*nucleic acid (DNA) contains the sugar deoxyribose.
- Structurally, the only difference between the two pentoses is the absence of an oxygen atom on carbon 2 of deoxyribose.
- Ribose is also found in the vitamin *ribo*flavin and other biologically important molecules.



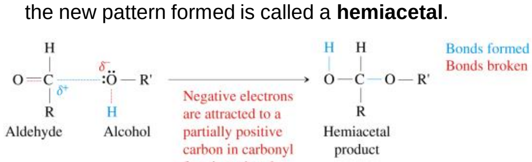
D-Ribose D-2-Deoxyribose

6.4 Reactions of Monosaccharides

- Linear structures do not show how most monosaccharides actually are structured.
- Pentoses and hexoses (5- and 6-carbon monosaccharides) bend back on themselves to form rings.
- When opposite charges on different functional groups within the monosaccharide attract strongly enough, new bonds are formed and other bonds are broken.

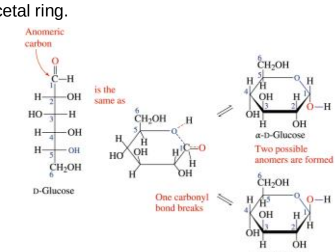
6.4 Reactions of Monosaccharides

- The carbonyl group present in aldehydes and ketones is very polar and highly reactive.
- The partially positive carbon in the carbonyl attracts the lone pairs of electrons on the oxygen of a hydroxyl that is partially negative.
- If a bond forms between this carbon and oxygen, the new pattern formed is called a **hemiacetal**.



6.4 Reactions of Monosaccharides

- Monosaccharides contain both a carbonyl and several hydroxyl (alcohol) functional groups.
- Monosaccharides exist in a ring form most of the time because the carbonyl group reacts readily with a hydroxyl to form this hemiacetal ring.



6.4 Reactions of Monosaccharides

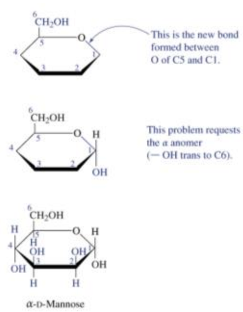
- Two structures are possible during ring formation.
- The oxygen in the hydroxyl group on carbon 5 can form its bond on either the top or the bottom side of the carbonyl.
- These two interconvertable forms are **anomers**.
- In any monosaccharide, the carbonyl carbon that reacts to form the hemiacetal in the reaction is referred to as the **anomeric carbon**.
- Note that in the ring form, the anomeric carbon is the only carbon bonded directly to two oxygen atoms.

6.4 Reactions of Monosaccharides

- The two hemiacetal anomers of D-glucose are the alpha (α) and beta (β) anomers.
- Anomers are distinguished by the positioning of the –OH group on the anomeric carbon relative to the position of the carbon outside the ring.
- In the six-member ring form of D-isomers called **pyranose**, carbon 6 (C6) is always drawn on the top side of the ring.
  - In the α anomer, the –OH on the anomeric carbon is trans to carbon 6. They are on opposite sides of the ring.
  - In the β anomer, the –OH on the anomeric carbon is cis to carbon 6. They are on the same side of the ring.

6.4 Reactions of Monosaccharides

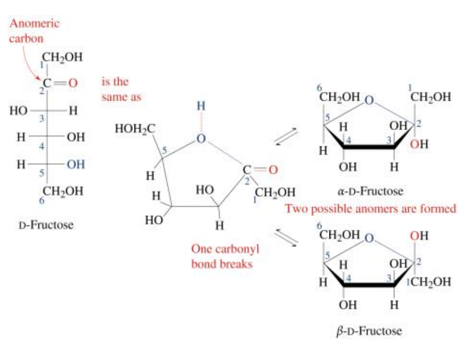
Steps I, 2, and 3 – drawing pyranose rings



6.4 Reactions of Monosaccharides

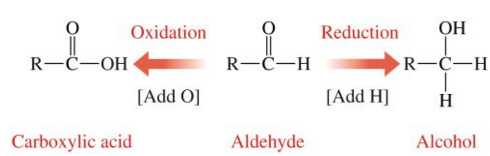
- D-Fructose contains *both* a ketone group and several hydroxyl groups.
- The –OH on carbon 5 (C5) can curl around and react with the carbonyl positioned at carbon 2 (C2), allowing two possible ring structures.
- Four carbons and an oxygen form the five-member ring called a **furanose,** and two of the carbons (C1 and C6) remain outside the ring.

6.4 Reactions of Monosaccharides



6.4 Reactions of Monosaccharides

- The carbonyl group in aldoses can also undergo organic oxidation and reduction.



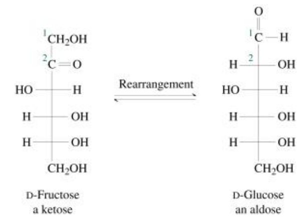
- In monosaccharides, oxidation produces sugar acid and reduction produces sugar alcohol.

6.4 Reactions of Monosaccharides

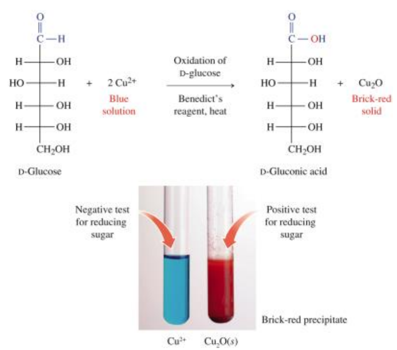
- **Benedict's test** tests for the presence of an aldose in solution.
- Cu^{2+} is soluble, coloring the initial reaction solution blue.
- An aldehyde group undergoes oxidation while reducing copper ions from Cu^{2+} to Cu^{+}.
- The resulting copper(I) oxide is not soluble and forms a brick-red precipitate in solution.

6.4 Reactions of Monosaccharides

- Because aldoses are easily oxidized, they are referred to as **reducing sugars**.
- Fructose and other ketoses are also reducing sugars, because in the presence of oxidizing agents, they can rearrange to aldoses.



6.4 Reactions of Monosaccharides



6.4 Reactions of Monosaccharides

- An aldose or ketose can also be reduced to an alcohol when the carbonyl reacts with hydrogen under the right conditions.
- Sugar alcohols are produced commercially as artificial sweeteners and are found in sugar-free foods.
- An enzyme called aldose reductase acts to reduce excessive glucose to the sugar alcohol sorbitol, which at high concentration can contribute to cataracts.

6.5 Disaccharides

Condensation and Hydrolysis—Forming and Breaking Glycosidic Bonds

•In a monosaccharide in ring form, the anomeric carbon has the most reactive –OH in the molecule (C1 in an aldose).

•When this hydroxyl reacts with a hydroxyl on another monosaccharide, a **glycosidic bond** forms.

•Glycosidic bonds join monosaccharides to each other and connect monosaccharides to any alcohol.

6.5 Disaccharides

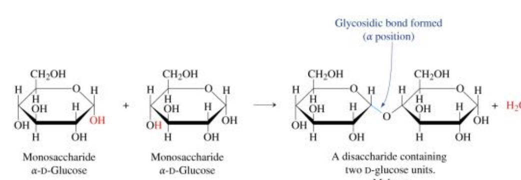


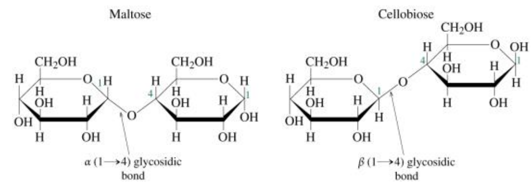
Figure 6.10 Formation of the disaccharide maltose. Two molecules of glucose are joined forming a glycosidic bond. The loss of H and OH from the glucose molecules produces a molecule of water in this condensation reaction.

6.5 Disaccharides

Naming Glycosidic Bonds

- It is necessary to specify how monosaccharides are bonded, that is, α or β.
- Because a monosaccharide has many hydroxyl groups that can undergo condensation, it is necessary to specify the carbon atoms joined by the glycosidic bond.
- The convention for naming glycosidic bonds is to specify the anomer and carbons.
- For maltose, the glycosidic bond is specified as $\alpha(1\rightarrow4)$.

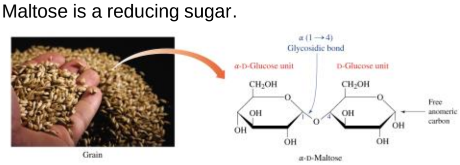
6.5 Disaccharides



6.5 Disaccharides

Three Important Disaccharides—Maltose

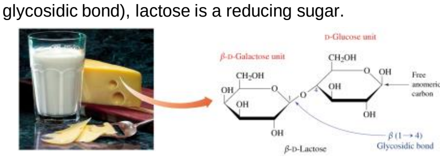
- **Maltose**, or malt sugar, is a disaccharide formed in the breakdown of starch.
- Malted barley contains high levels of maltose. The glucose in the maltose of malted barley can be converted to alcohol by yeast.
- The glycosidic bond in maltose is $\alpha(1\rightarrow4)$.
- Maltose is a reducing sugar.



6.5 Disaccharides

Three Important Disaccharides—Lactose

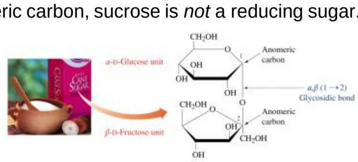
- **Lactose**, or milk sugar, is found in mammalian milk.
- Intolerance to lactose occurs in people without lactase.
- When lactose remains undigested, intestinal bacteria break it down, producing abdominal gas and cramping.
- The glycosidic bond in lactose is $\beta(1\rightarrow4)$: it occurs between C1 of a β-galactose and C4 of a glucose.
- Because the anomeric carbon on the glucose unit is free (not in a glycosidic bond), lactose is a reducing sugar.



6.5 Disaccharides

Three Important Disaccharides—Sucrose

- **Sucrose** is the most abundant disaccharide in nature: sucrose is found in sugar cane and sugar beets.
- When glucose and fructose join in an $\alpha,\beta(1\rightarrow2)$ glycosidic bond, sucrose is formed.
- Both anomeric carbons are bonded (carbon 1 of glucose and carbon 2 of fructose). Because there is no free anomeric carbon, sucrose is *not* a reducing sugar.



6.5 Disaccharides

TABLE 6.1 Relative Sweetness of Sugars and Artificial Sweeteners

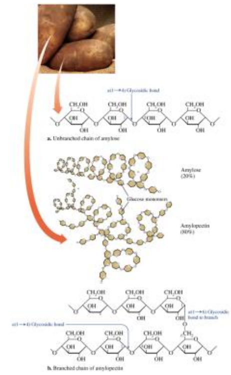
Sweetener	Sweetness Relative to Sucrose (= 100)	Description
Simple Sugars		
Fructose	140–175	Fruit sugar, a monosaccharide that is a component of sucrose
Invert sugar (Hydrolyzed sucrose)	120	Found in honey
Sucrose	100	Table sugar, a disaccharide containing glucose and fructose
Xylitol	100	A sugar alcohol, used in sugar-free products
Glucose	75	Dextrose, a monosaccharide that is a component of sucrose and lactose
Erythritol	70	A sugar alcohol used in sugar-free products
Sorbitol	36–55	A sugar alcohol used in sugar-free products
Maltose	32	A disaccharide of glucose
Galactose	30	A monosaccharide that is a component of the disaccharide lactose
Lactose	15	Milk sugar, a disaccharide containing galactose and glucose
Other Sweeteners		
Sucralose (Splenda®)	60,000	Chlorinated disaccharide
Saccharin	45,000	An organic substance initially discovered as a by product of research on dyes
Stevia (found in Truvia™)	25,000	Natural sweetener containing nonhydrolyzable glucosides found in the leaves of the plant *Stevia rebaudiana*
Aspartame (Nutrasweet®)	18,000	Contains two amino acids, aspartic acid and phenylalanine

6.6 Polysaccharides

Storage Polysaccharides: Amylose and Amylopectin

- Starch is a glucose storage polysaccharide that accumulates in small granules in plant cells.
- Starch is a mixture of amylose and amylopectin.
  - **Amylose,** which makes up about 20% of starch, is made up of 250 to 4000 D-glucose units $\alpha(1\rightarrow4)$ bonded in a continuous chain. Long chains of amylose tend to coil.
  - **Amylopectin** makes up about 80% of plant starch. It also contains D-glucose units connected by $\alpha(1\rightarrow4)$ glycosidic bonds. About every 25 glucose units along a linear glucose chain, a second glucose chain branches off through an $\alpha(1\rightarrow6)$ glycosidic bond.
- When we eat starch, our digestive system breaks it down into glucose units for use by our bodies.

6.6 Polysaccharides



6.6 Polysaccharides

Storage Polysaccharides: Glycogen

- **Glycogen** is the storage polysaccharide found in animals.
- Most glycogen stores are located in the liver and in muscles.
- Glycogen is identical in structure to amylopectin except that $\alpha(1\rightarrow6)$ branching occurs about every 12 glucose units.
- Glycogen is in the liver to maintain constant glucose levels in the blood when sugars are not being consumed.
- The large amount of branching in this molecule allows for quick hydrolysis when glucose is needed.

6.6 Polysaccharides

Structural Polysaccharides: Cellulose

- **Cellulose** contains $\beta(1\rightarrow4)$-bonded glucose units.
- This change in bond configuration completely alters the overall structure of cellulose compared with that of amylose.
- Whereas amylose coils, the β-bonded chain of cellulose is straight.
- Many of these straight chains of cellulose align next to each other, forming a strong, rigid structure.
- We cannot digest cellulose, but it is still an important part of our diet because it assists with digestive movement in the small and large intestine.

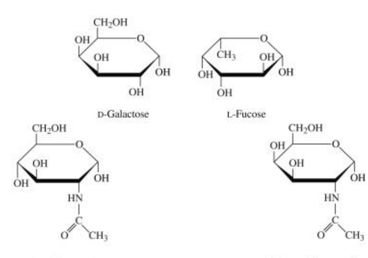
6.6 Polysaccharides

Structural Polysaccharides: Chitin

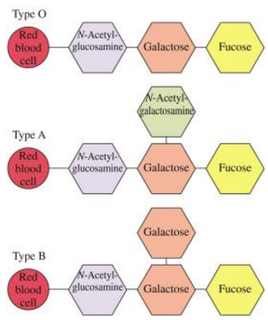
- **Chitin** is made up of a modified β-D-glucose called *N*-acetylglucosamine with $\beta(1\rightarrow4)$ glycosidic bonds.
- Like cellulose, chitin is a strong material with many uses, one of which is a surgical thread that biodegrades as a wound heals.
- Chitin is present in many insects' exoskeletons and serves to protect them from water. Because of this property, chitin can be used to waterproof paper.
- When ground, chitin becomes a powder that holds in moisture, and it can be added to cosmetics and lotions.

6.7 Carbohydrates and Blood

- Red blood cells have a number of chemical markers bonded to the cell, including the ABO blood markers, which contain three or four monosaccharides.



6.7 Carbohydrates and Blood



6.7 Carbohydrates and Blood

- The body can only recognize its own carbohydrate set (A, B, or O) and will try to destroy what it considers a foreign blood type.
- Because the trisaccharide on the cells of O-type blood is present on cells of *all* blood types (A, B, and AB), no blood type recognizes the O carbohydrate set as foreign.
- The AB blood type is considered the universal acceptor blood type: AB blood contains all possible ABO combination types, so any blood type transfused will be accepted by the body.

6.7 Carbohydrates and Blood

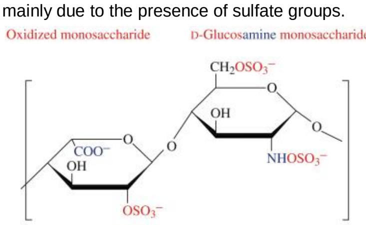
TABLE 6.2 Compatibility of ABO Blood Groups

Blood Group	Can Receive Blood Types	Can Donate to Blood Types
A	A,O	A, O
B	B, O	B, O
AB[a]	A, B, AB, O	Cannot donate to other blood types
O[b]	O	A, B, AB, O (all types)

[a]AB universal acceptor.
[b]O universal donor.

6.7 Carbohydrates and Blood

- **Heparin** is a polysaccharide that prevents clotting.
- Heparin is a highly ionic polysaccharide of many repeating disaccharide units known as a **glycosaminoglycan.**
- These molecules all have highly charged repeating disaccharide units, mainly due to the presence of sulfate groups.



Heparin's repeating disaccharide

Chapter Six Summary

6.1 Classes of Carbohydrates

- Carbohydrates are classified as monosaccharides (simple sugars), disaccharides (two monosaccharide units), oligosaccharides (three to nine monosaccharide units), and polysaccharides (many monosaccharide units).
- The simplest carbohydrates are the monosaccharides, with a molecular formula of $C_n(H_2O)_n$.
- Edible carbohydrates that cannot be broken down by the body's enzymes are classified as either soluble or insoluble fibers based on their ability to mix with water.

Chapter Six Summary

6.2 Functional Groups in Monosaccharides

- Monosaccharides contain several alcohol (hydroxyl) groups and either an aldehyde or ketone functional group.
- Alcohols can be primary, secondary, or tertiary depending on the number of carbons attached to the alcohol carbon.
- Aldehydes and ketones are carbonyl-containing functional groups.
- Because of the functional groups present, monosaccharides can be called aldoses or ketoses and referred to as polyhydroxyaldehydes and polyhydroxyketones.

Chapter Six Summary

6.3 Stereochemistry of Monosaccharides

- Monosaccharides can be drawn linearly in a representation called the Fischer projection that highlights their chiral centers.
- Most carbohydrates found in nature are the D-isomer.
- Stereoisomers that have multiple chiral centers can be related to each other as either enantiomers (mirror images of each other) or diastereomers (not enantiomers).
- Some important monosaccharides are glucose, galactose, mannose, fructose, deoxyribose, and ribose.

Chapter Six Summary

6.4 Reactions of Monosaccharides

- A hydroxyl group and the carbonyl functional group of a linear monosaccharide can react to enclose the hydroxyl's oxygen in a ring.
- Because the carbonyl group is a planar structure, this reaction produces two possible ring arrangements about the anomeric carbon termed the α and the β anomer when a ring is formed.
- The anomeric carbon of carbohydrates (C1 of an aldose) is highly reactive and can undergo both oxidation to a carboxylic acid and reduction to an alcohol.
- Monosaccharides are considered reducing sugars because their anomeric carbon can react to reduce another compound in a redox reaction.

Chapter Six Summary

6.5 Disaccharides

- Carbohydrates form glycosides when an anomeric carbon reacts with a hydroxyl on a second organic molecule.
- This condensation results in formation of a glycosidic bond.
- Glycosidic bonds are named by designating the anomer of the reacting monosaccharide and the carbons that are bonded, for example, $\alpha(1\rightarrow4)$.
- Some important disaccharides formed through condensation reactions are maltose, lactose, and sucrose.
- Monosaccharides and disaccharides make up simple sugars, many of which are sweet to the taste.
- The sweetness of carbohydrates and other carbohydrate substitutes is indexed relative to the sweetness of sucrose.

Chapter Six Summary

6.6 Polysaccharides

- Polysaccharides consist of many monosaccharide units bonded together through glycosidic bonds.
- Glucose can be stored as a polysaccharide called starch in plants and glycogen in animals.
- Starch consists of two polysaccharides: amylose, a linear chain of glucose, and amylopectin, a branched chain of glucose.
- Glycogen is also a branched polysaccharide of glucose, but it contains more branching than does amylopectin.
- Two polysaccharides that are structurally important in nature are cellulose in plants (wood) and chitin in arthropods (exoskeleton) and fungi (cell wall).

Chapter Six Summary

6.6 Polysaccharides

- Cellulose is a linear chain of glucose, but in cellulose the glycosidic bonds are $\alpha(1\rightarrow4)$, whereas in starch they are bonded $\alpha(1\rightarrow4)$.
- Chitin is also a linear chain of a modified glucose, *N*-acetylglucosamine bonded $\beta(1\rightarrow4)$.
- Both these structural polysaccharides form strong, water-resistant materials when the linear chains are aligned with each other.

Chapter Six Summary

6.7 Polysaccharides and Blood

- Carbohydrates are also used as recognition markers on the surfaces of cells and in other bodily fluids.
- The ABO blood groups are oligosaccharides of which one of the carbohydrate units is L-fucose, one of the few L-sugars found in nature.
- These ABO oligosaccharides are found on the surface of red blood cells. The A and B blood groups look like the O blood group except that they contain an additional monosaccharide. For this reason, the O blood type is the universal donor.
- Heparin is a polysaccharide consisting of a repeating disaccharide containing an oxidized monosaccharide and a glucosamine. Heparin functions in the blood as an anticoagulant and is commonly found as a coating on medical tubing and syringes used during blood transfusions.

Chapter Six Study Guide

6.1 Classes of Carbohydrates
- Classify carbohydrates as mono-, di-, oligo-, or polysaccharides.
- Distinguish soluble and insoluble fiber.

6.2 Functional Groups in Monosaccharides
- Distinguish primary, secondary, and tertiary alcohols.
- Recognize and draw the functional groups alcohol, aldehyde, and ketone.

Chapter Six Study Guide

6.3 Stereochemistry of Monosaccharides
- Distinguish D and L stereoisomers of monosaccharides.
- Draw Fischer projections of linear monosaccharides.
- Define enantiomer, epimer, and diastereomer.
- Draw enantiomers and diastereomers of linear monosaccharides.
- Characterize common monosaccharides.

Chapter Six Study Guide

6.4 Reactions of Monosaccharides
- Draw the cyclic α and β anomers from linear monosaccharide structures.
- Draw oxidation and reduction products of aldoses.

6.5 Disaccharides
- Locate and name glycosidic bonds in disaccharides.
- Distinguish condensation and hydrolysis reactions of simple sugars.
- Characterize common disaccharides.

6.6 Polysaccharides
- Identify polysaccharides by glycosidic bond and sugar subunit.

Chapter Six Study Guide

6.7 Polysaccharides and Blood
- Predict ABO compatibility.
- Describe the structure and role of heparin.