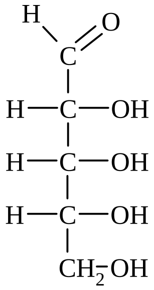
Chem 191: Biochemistry
Lecture 7 – Carbohydrates

I. Introduction

- A. Carbohydrates are one of the four major classes of biological molecules, which include:
  - 1. Carbohydrates
  - 2. Proteins
  - 3. Lipids
  - 4. Nucleic Acids
- B. Carbohydrates play many important roles.
  - 1. For biological organisms:
    - a. They are a source of chemical energy
    - b. They are a source of carbon for the biosynthesis of new molecules.
    - c. They provide a way of storing energy as glycogen and starch.
    - d. They are used for structural purposes, such as the *chitin* shells of crustaceans and the *cellulose* cell walls of plants.
  - 2. Commercially
    - a. They are used to make paper and cotton fabrics.

II. Classes of Carbohydrates

- A. Carbohydrates
  - 1. Heating produces carbon (carbo-) and water (-hydrate).
  - 2. They have a large number of functional groups.
    - a. Each carbon is involved in a functional group.
    - b. Every carbohydrate molecule is either an aldehyde or a ketone
    - c. All the carbons which are not involved in the aldehyde or ketone group have hydroxyl groups attached to them
      - i. A carbohydrate is either a *polyhydroxylated aldehyde* or a *polyhydroxylated ketone*.
    - d. Aldehydes
    - e. Ketones
    - f. Alcohols
  - 3. The example shown on page 502 in you text is the carbohydrate *ribose*.



ribose

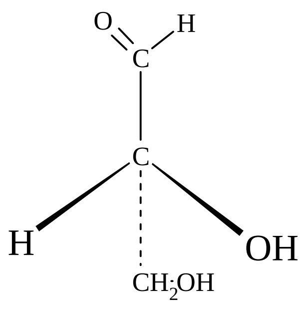
    - a. It contains 5 carbons

i. The one terminal carbon is part of an aldehyde group.
ii. The remaining 4 carbons each have a hydroxyl group.

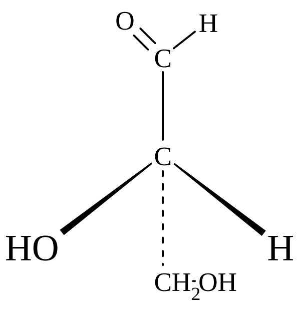
B. Classification according to sized.
1. A single carbohydrate molecule is called a **monosaccharide**.
2. Monosaccarides can join together to form *polymers*.
a. **Disaccharides** contain 2 monosaccharide units.
b. **Trisaccharides** contain 3 monosaccharide units.
c. …
d. **Oligosaccharide** contain 3-10 monosaccharide units.
e. **Polysacchrides** contain 10's to 100's of monosacchride units.s

III. Stereochemistry of Carbohydrate.

A. Carbohydrates present us with a new kind of isomer, the **optical isomer**.
1. Opical isomers are a type of stereoisomer
a. Stereoisomers have the same chemical *and* structural formulas, but a different spatial arrangement of their atoms.
i. This means that they contain the same elements, and that these elements have the same types bonds connecting them
ii. The *cis*/*trans* isomers is another example of a stereoisomer,
1) Because there is no rotation about a double bond, there are two possible spatial arrangements of groups attached to the carbon atoms that participate in the double bond.
b. A molecule has an optical isomer when its mirror image is non-superimposable on itself.
i. The non-superimposable mirror images are called **enantiomers** of one another.
c. A non-molecular example of a pair of objects that are not superimposable on one another, and which are mirror images of one another, are your left and right hands.
2. An object that can not be superimposed on its mirror image is said to be **chiral.**
a. Glyceraldehyde is an example of a molecule that is chiral.



D-glyceraldehyde



L-glyceraldehyde

- i. D and L glyceraldehyde are non-superimposable on each other.
  - 1) They are *enantiomers* of one another.
  - 2) Both D and L glyceraldehyde are *chiral* molecules.

3. Chiral organic molecules can be identified by examining the carbon atoms.
   - a. Tetrahedral carbon atoms that have 4 *different* groups attached to it are chiral.
   - b. The central carbon of glyceraldehyde has four different groups attached to it:
     - i. -CHO
     - ii. -OH
     - iii. -CH_2OH
     - iv. -H
   - c. If a molecule contains a carbon that as 4 different groups attached to it, it is a *chiral* molecule.
     - i. The carbon that makes it a chiral molecule is called a *chiral carbon*.
       - 1) It is also called an *asymmetric carbon*.

Work some examples from the Exce

B. Calculating the number of stereosomers that glucose and fructose have.

1. Each chiral carbon as two possible configurations.
   - a. If a molecule has two chiral carbons then there are 4 possible optical isomers.
     - i. There will be two pairs of enantiomers.
       - 1) Enantiomers share the same name
   - b. The number of possible optical isomers a molecule has is equal to 2^n, where *n* is the number of chiral carbons it contains.

IV. Fisher projections

A. Provides a way of representing 3-dimensional information in 2-dimensions.

1. The aldehyde or ketone group is placed at the top with the carbon chain extending downward.
   - a. The hydrogen and hydroxyl groups attached to the left and right of each of the other carbons, are assumed to project outward from the the plane of the paper (board).
     - i. If the OH is on the *left*, a chiral carbon is in the L configuration.
     - ii. If the OH is on the *right*, a chiral carbon is in the D configuration.
     - iii. The chiral carbon furthest from the aldehyde or ketone group is used to designate a member of a pair of enantiomers as D or L.

B. **Optical activity**

1. Chiral molecules can be detected experimentally by using polarized light.
   - a. Dextrorotatory

            - i. Bends the plane of polarization for plane polarized light to the right (clockwise)
            - ii. A lowercase *d* is used is used in naming a chiral molelcule that bends plane polarized light to the right.
        - b. Levorotatory
            - i. Bends plane of polarization for plane polarized light to the left (counterclockwise).
            - ii. A lowercase *l* is used is used in naming a chiral molecule that bends plane polarized light tot the left.
        - c. The *l* and *d* designations do not imply whether a molecule is L or D.

V. Classifications Monosaccharides

- A. Aldoses
- B. Ketoses
- C. Hexoses
- D. Pentoses
- E. Tetroses

Fig 17.8

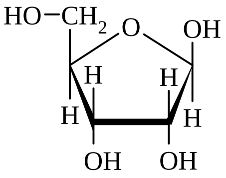
VI. Properties of Monosaccharides

- A. Physical properties
    - 1. Monosaccharides and disaccharides are called sugars because they taste sweet.
        - a. Fructose, which is found in honey and corn syrup, is the sweetest tasting sugar.
    - 2. Solids at room temperature
- B. Chemical properties
    - 1. Cyclilization
        - a. Puranose and furanose rings
            - i. Formation of hemiacetals and hemiketals.
        - b. Anomeric carbon is the one that was formerly the aldehyde or ketone.
            - i. It now becomes a chiral carbon
                - 0) The Greek letters α and β to designate the two new isomers
        - c. The different forms of D-glucose: the open chain, the α-D-glucose ring and the β-D-glucose ring are in rapid equilibrium with each other.
            - i. In a solution of D-glucose the percentage of each form present is 0.02%, 36% and 64%, respectively.
        - d. The ring-like structures are

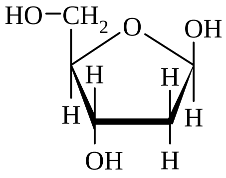
VII. Important monosaccharides

- A. Ribose and deoxyribose

1. Are used to make ribonucleic acids (RNA) and deoxyribinucleic acids (DNA), respectively.

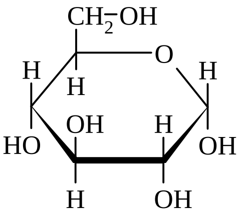


β-D-ribose



β-D-deixtribose

B. Glucose

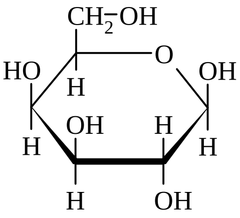


α-D-glucose

1. Is nutritionally one of the most important sugars
2. Is found in fruits
3. Is sometimes called dextrose, because the D isomer bends plane polarized light to the right (dextrorotatory)

C. Galactose

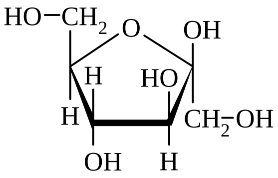
1. It is synthesized in the mammary glands and combined with glucose to form the disaccharide *lactose*.



β-D-galactose

D. Fructose

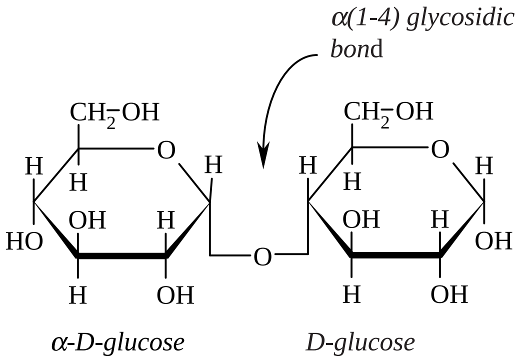
1. It is the sweetest of the common sugars
2. It is found in honey
3. It is combined with glucose to form the disaccharide *sucrose*.



β-D-fructose

VIII. Disaccharides

- A. Disaccharides are sugars composed of two monosaccharides joined by a glycosidic bond.
  - 1. The -OH of the hemiacetal or hemiketal on the one monosaccharide reacts with an -OH from another monosaccharide.
    - a. The -OH can be either a hydroxyl group or the -OH from the hemiacetal or hemiketal on the other monosaccharide.
    - b. The reaction leads to the release of a water molecule
- B. The glycosidic bond connecting the monosaccharides can be easily hydrolyzed (broken) with mild acid and heat or using enzymes (biological catalysts).
- C. The most important nutritional disaccharides are *maltose*, *lactose* and *sucrose*.
- D. Maltose
  - 1. Glucose α(1-4) Glucose

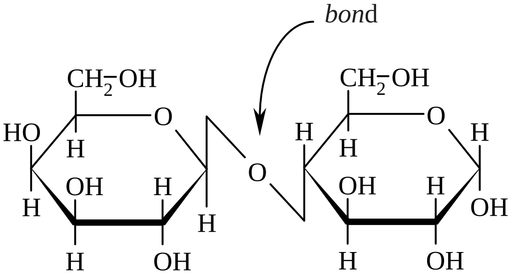


D-maltose

  - 2. The -OH from the hemiacetal of D-glucose in it α configuration combines with the -OH from the hydroxyl group on the forth carbon of a second D-glucose to form the glycosidic bond.
    - a. This is called a *α(1-4)* glycosidic bond.
  - 3. Maltose is produced from the break down of starch when seeds germinate.
    - a. If the seeds are roasted soon after they germinate the process is called malting and the resulting product will have high concentrations of maltose.
    - b. This process is used the production of beers, ales, and malt liquors. Yeast are used to convert the maltose to ethanol and carbon dioxide.
  - 2. Lactose is still considered a reducing sugar
    - a. Eventhough the D-glucose on the left is no longer capable of reducing Cu^{2+}, the D-glucose on the right, which still contains a hemiacetal group, can open up the expose an aldehyde group.

B. Lactose

1. Galactose β(1-4) Glucose



β(1-4) glycosidic bond

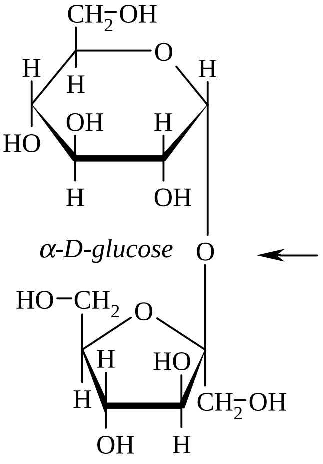
β-D-galactose *D-glucose*

D-lactose

2. The -OH from the hemiacetal of D-galactose in it β configuration combines with the -OH from the hydroxyl group on the forth carbon of D-glucose to form the glycosidic bond.
   a. This is called a *β(1-4)* glycosidic bond.
3. Lactose is called "milk sugar" because it is found in milk.
4. Individuals who have the condition called *lactose intolerance* lack the ability to break the glycosidic bond connecting the galactose to the glucose monosaccharides.
5. Lactose is still considered a reducing sugar
   a. Eventhough the D-galactose is no longer capable of reducing Cu^{2+}, the D-glucose on the right, which still contains a hemiacetal group, can open up the expose an aldehyde.

C. Sucrose

1. Glucose α1-β1 Fructose



D-sucrose

α-D-glucose

α1-β2 glycosidic bond

β-D-fructose

2. The -OH from the hemiacetal of D-glucose in it α configuration combines with the -OH from the hemiketal of D-frucose in its β configuration to form the glycosidic bond.

        - a. This is called a *α1-β2* glycosidic bond.
    - 2. Sucrose is also called table sugar.
    - 3. Sucrose is not a reducing sugar
        - a. This is because both the hemiacetal of the D-glucose and the hemiketal of the D-frucose are involved the formation of the glycosidic bond.
            - i. Both monosaccharides are locked in their closed ring form.

II. Polysaccharides

- A. Starch
    - 1. Is a polymer that contains hundreds to thousands of glucose monosaccharide connected together
        - a. The amylose form is unbranched and the glucose monosaccharides are connected by *α(1-4)* glycosidic bonds.
        - b. The amylopectin form is branched; in addition to long chains of glucose monosaccharides connected by *α(1-4)* glycosidic bonds, every 24-30 monosaccharide units along the chain there is an additional *α(1-6)* glycosidic bond.
            - i. Amylopectin is therefore a branched polymer.
        - c. Glucose α(1-4) glucose (amylose unbranched)
    - 2. Starch is found in plants and is a storage form of glucose.
- B. Glycogen
    - 1. Glycogen is similar to amylopectin but more highly branched (every 8 - 12 units).
    - 2. It is found in animals, primarily in the muscles and liver, and is also a strorage form of glucose to be used for energy purposes
- C. Cellulose
    - 1. Celluose is also a polymer of glucose
        - a. Like amylose it is unbranched, but the glucose monosaccharides are connected instead by *β(1-4)* glycosidic bonds.
    - 2. This gives cellulose markedly different physical and chemical properties than starch or glycogen.
        - a. It is a very linear polymer and is quite insoluble, unlike starch or glycogen.
    - 3. Can only be digested a few microorganisms, making it quite resistant go biological degradation.
    - 4. Cellulose is used primarily by plants for structural purposes.