Carbohydrate Representations
Based on a Fall 2005 Chemistry 14D honors project

Some Useful Vocabulary:

➢ **Aldose**: A polyhydroxy aldehyde, i.e., a carbohydrate containing an aldehyde functional group.

➢ **Ketose:** A polyhydroxy ketone, i.e., a carbohydrate containing a ketone functional group.

➢ **Furanose:** A five-member closed chain form of a monosaccharide.

➢ **Pyranose:** A six-member cyclic form of a monosaccharide.

➢ **Fischer Projection:** A way of representing an acyclic (open chain) carbohydrate structure. Vertical lines point away from the viewer and horizontal lines point toward the viewer.

➢ **Haworth Projection:** A way of representing a cyclic (closed chain) carbohydrate. Substituents can either point up or down on this ring.

➢ **Chair Conformation:** The most stable conformation of cyclohexane that resembles a chair.

➢ **Monosaccharide:** A single sugar. A carbohydrate that cannot be broken down into a simpler carbohydrate.

➢ **Anomeric carbon:** The carbon in a cyclic sugar that is the carbonyl carbon in the open-chain (acyclic) form.

Carbohydrates are the most abundant class of bioorganic compounds in the biological world. They constitute most of Earth's biomass, from tiny structural components of cells, to food we eat for metabolic energy. To better understand the role carbohydrates play in the biological world, a basic chemical understanding of how carbohydrates are formed and represented in their simplest form is essential.

In organic chemistry, monosaccharides, the simplest carbohydrates are represented in three ways: the Fischer projection, Haworth projection, and the chair conformation of D-glucose (Figure 1). By the time you are finished reading this tutorial, you will have learned how to represent monosaccharides in these three ways.

Figure 1

D-glucose — Fischer Projection

β-D-glucose — Haworth Projection

β-D-glucose — Chair Conformation
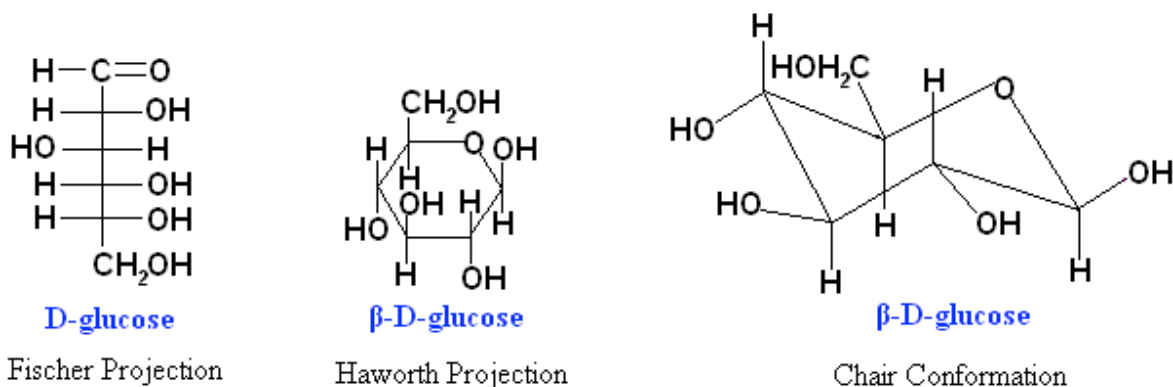
Monosaccharides, also known as saccharides, are carbohydrates that cannot be broken down into simpler carbohydrates. They can be polyhydroxy aldehydes or polyhydroxy ketones because they have either an aldehyde or a ketone group, along with –OH substituted carbons in a chain.

Polyhydroxy aldehydes are called aldoses. Polyhydroxy ketones are called ketoses. The suffix "ose" means sugar, while the prefixes "ald" and "ket" are used for aldehyde and ketone, respectively.

Classification of monosaccharides is based on the number of carbons they contain (Table 1).

Table 1

Number of carbons in monosaccharide	Name	Aldose Form	Ketose Form
3	Triose	aldotriose	ketotriose
4	Tetrose	aldotetrose	ketotetrose

5	Pentose	$H-C=O$ $H-^2\!\!-OH$ $H-^3\!\!-OH$ $H-^4\!\!-OH$ $^5CH_2OH$ aldopentose	$^1CH_2OH$ $^2C=O$ $H-^3\!\!-OH$ $H-^4\!\!-OH$ $^5CH_2OH$ ketopentose
6	Hexose	$H-C=O$ $H-^2\!\!-OH$ $H-^3\!\!-OH$ $H-^4\!\!-OH$ $H-^5\!\!-OH$ $^6CH_2OH$ aldohexose	$^1CH_2OH$ $^2C=O$ $H-^3\!\!-OH$ $H-^4\!\!-OH$ $H-^5\!\!-OH$ $^6CH_2OH$ ketohexose

Monosaccharides can exist in an open chain (acyclic) form, or in closed chain (cyclic) form. The open chain form of monosaccharides is illustrated with Fischer projections. A Haworth projection can be used to represent the cyclic form of monosaccharides. The five-member closed chain form of a monosaccharide is known as a furanose, while the six-member cyclic form of a monosaccharide is known as a pyranose. Often six-member monosaccharide rings can also be represented in chair conformation.

Figure 2 shows pyranose and furanose rings. Substituents have been omitted so that the ring structure can be emphasized.

Figure 2

Pyranose   Furanose
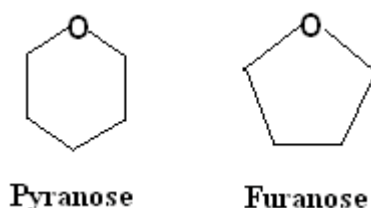
Imagine we are asked to show the Fischer, Haworth, and chair conformation of _ and _ D-glucose. How do we go about doing this? There are many things to consider; however, there are also some rules that will simplify the process. Let's walk through how this problem can be approached.

A Fischer projection shows the skeleton of the acyclic monosaccharide (Figure 3). Glucose is an aldohexose. This means that the top of the Fischer projection of glucose contains an aldehyde group and that there are six carbons in the polyhydroxy chain. In Figure 3, the structure on the right shows wedges and dashes to indicate how the sugar looks in three dimensions.
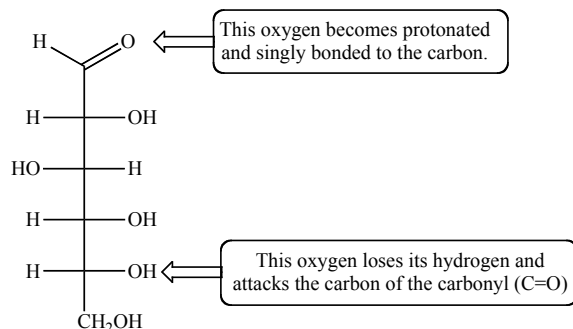
Figure 3
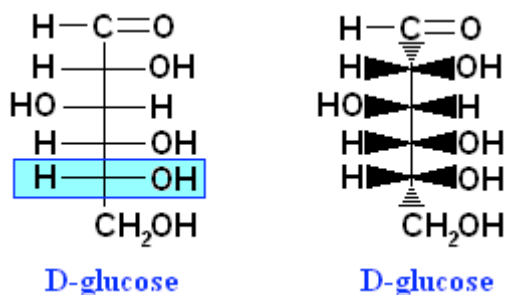
D-glucose   D-glucose

D and L Notation:

We need to make sure that the glucose is a D-glucose. We do this by looking at the monosaccharide with the ketone or aldehyde group on top; if the –OH group on the bottom-most asymmetric carbon is on the left side, the notation is L; if the –OH group on the bottom-most asymmetric carbon is on the right side, the notation is D (Figure 3).

Figure 4

This oxygen becomes protonated and singly bonded to the carbon.

This oxygen loses its hydrogen and attacks the carbon of the carbonyl (C=O)

Next, we rotate the C-5 carbon's substituents once over to put –OH on the vertical plane. This shift shows us what direction the –CH$_2$OH group with point in the Haworth projection.
A substituent on the right side of the vertical line in a Fischer projection will be pointing down in a Haworth projection. Conversely, a substituent on the left side in a Fischer projection will be pointing up in a Haworth projection. (Figure 5)

Figure 5

The numbers indicate the number of carbons.
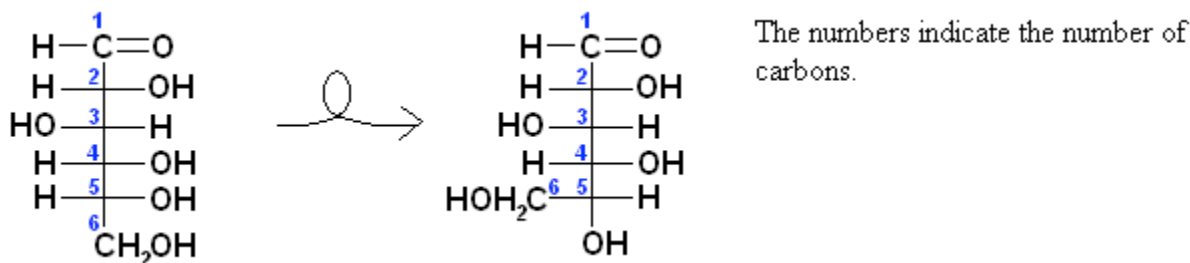
Therefore, the –CH$_2$OH group will be pointing up in the Haworth projection. Moreover, the–OH group on the C-2 will be pointing down and its –H substituent will be pointing up. And, the –OH group on the C-3 will be pointing up while its –H substituent points down, and so on.

In the next step, the carbonyl oxygen becomes protonated and singly bonded to C-1. The –OH group on C-5 becomes deprotonated and forms an O-C bond with C-1, resulting in a six-membered ring. At this point, it is important to recognize the difference between alpha (α) and beta (β) glucose (Figure 6).

The α or β configuration is determined by looking at the anomeric carbon which is the carbon that is between the two oxygen atoms of the hemiacetal or acetal. In a cyclic sugar, the anomeric carbon is the carbonyl carbon in the acyclic form. (C-1 in our case)

In an α monosaccharide, the –OH group attached to the anomeric carbon is on the right side of the Fischer projection, points down in the Haworth projection, and is axial in the chair conformation.

In a β monosaccharide, the –OH group attached to the anomeric carbon is on the left side of the Fischer projection, points up in the Haworth projection, and is equatorial in the chair conformation.

The table below summarizes the translation between Fischer projections, Haworth projections, and chair conformation. The translations for the chair conformation are used to determine α and β configurations and only concern the anomeric carbon's substituent. The Fischer and Haworth projection translations apply to all substituents on the carbon chain.
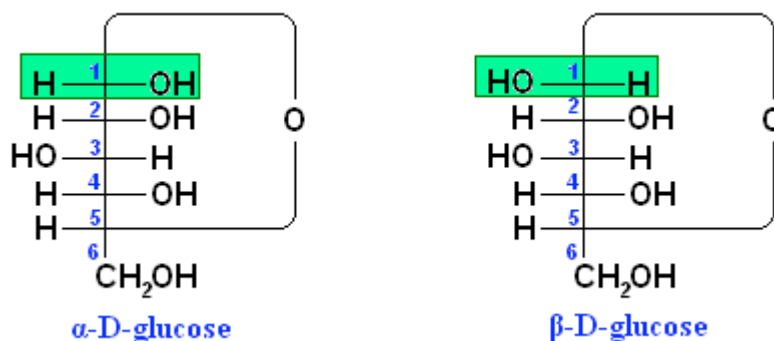
Figure 6

α-D-glucose   β-D-glucose

Table 2

Fischer Projection	Haworth Projection	Configuration	Chair Conformation
Right	Down	α	Axial
Left	Up	β	Equatorial

In β-D-glucose the anomeric carbon's –OH group is on the left. In the Haworth projection this alcohol group points up. The other substituents point up in the Haworth projection if they are on the left side in the Fischer projection, and point down if they are on the right side in the Fischer projection. (Figure 7)

Figure 7

α-D-glucose   β-D-glucose
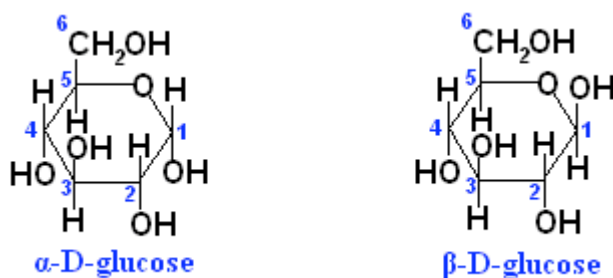
In α-D-glucose the anomeric carbon's –OH group is on the right. In the Haworth projection of α-D-glucose illustrated below the –OH group points down. Once again, the rest of the substituents also follow the translation rule from Fischer to Haworth. (Figure 7)

Take a moment to compare the Fischer and Haworth projections and notice how one form is translated to the other form.

When going from the Haworth projection to the chair conformation, the anomeric carbon's substituent that points down in the Haworth projection is going to be axial, and the substituent that points up in the Haworth projection is going to be equatorial. An axial –OH on the anomeric carbon makes the sugar an α sugar, while an equatorial –OH on the anomeric carbon makes the monosaccharide a β sugar. Besides the substituents on the anomeric carbon, everything else is drawn relative to the Haworth projection. In other words, all the other substituents are drawn pointing up if they were pointing up in the Haworth projection, and pointing down if they were pointing down in the Haworth projection. (Figure 8)

It helps to number the carbons in the monosaccharide in the Haworth projection and chair conformation to prevent any careless mistakes.

Figure 8

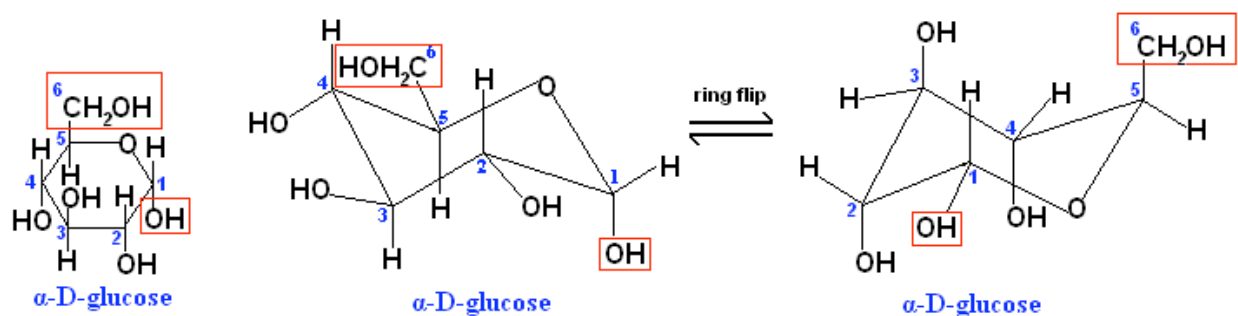β-D-glucose

β-D-glucose

α-D-glucose

α-D-glucose
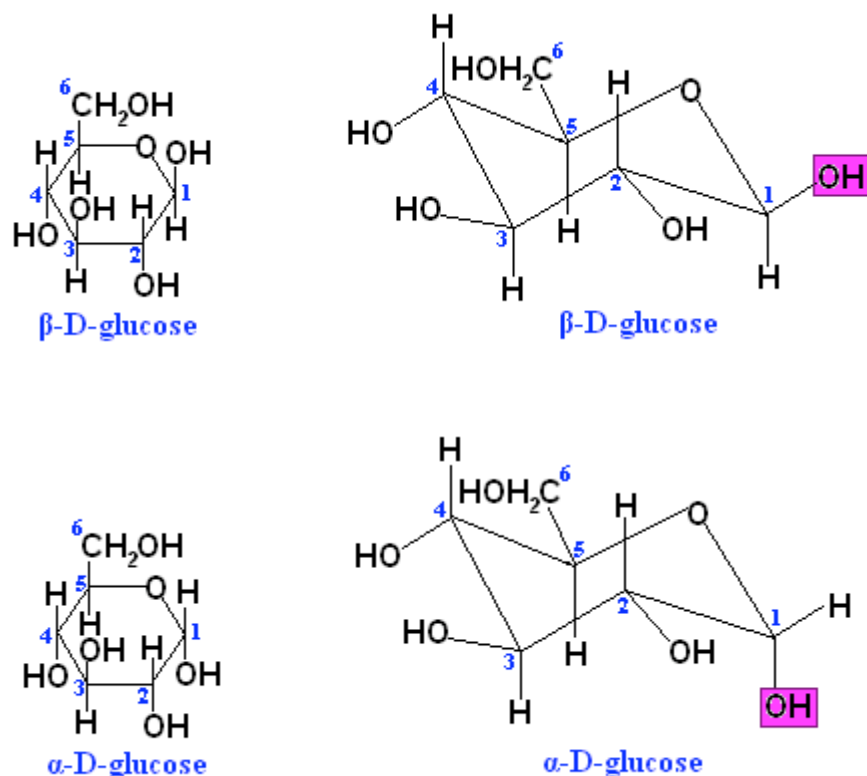
There is a shortfall in the method we have been using to determine the difference between an α and β sugar in the chair conformation. (This is also the method used in Bruice.) For example, it is true that in the chair conformational isomer that we drew that the axial –OH group of the anomeric carbon was α while the equatorial –OH group of the anomeric carbon was β. But a ring flip would make this fact untrue (Figure 9). An α-D-glucose would still be an α-D-glucose after a ring flip, but the   –OH group attached to the anomeric carbon would no longer be axial! (To learn more about ring flips, refer to your textbook and class notes)

Figure 9



ring flip

α-D-glucose

α-D-glucose
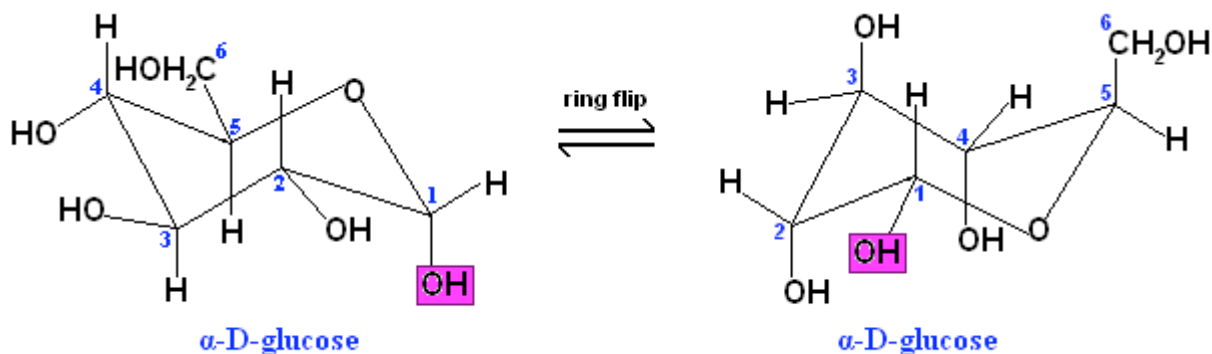
The method we have been using works, but only when the chair conformational isomer is drawn so that the anomeric carbon is at the bottom right corner. However, a less restricted method that is always true exists. As long as the primary alcohol, CH_2OH, and the anomeric –OH group are on opposite sides of the ring, as in the trans isomer, it is α. Moreover, if the primary alcohol and the anomeric –OH group are on the same side of the ring as in the cis isomer, it is β. For example, in the illustration below, notice that when CH_2OH points up, the anomeric –OH group points down (opposite side of the pyranose). This is the trans isomer, and thus an α-pyranose. (Figure 10)

Figure 10

α-D-glucose   α-D-glucose   α-D-glucose

In β-glucose, or any β monosaccharide, the pyranose would be the cis isomer. Thus, when CH_2OH points above the plane of the ring, the anomeric –OH group will point up as well. Conversely, when the CH_2OH points down, the anomeric –OH group will also point down. (Figure 11)

Figure 11

β-D-glucose   β-D-glucose   β-D-glucose
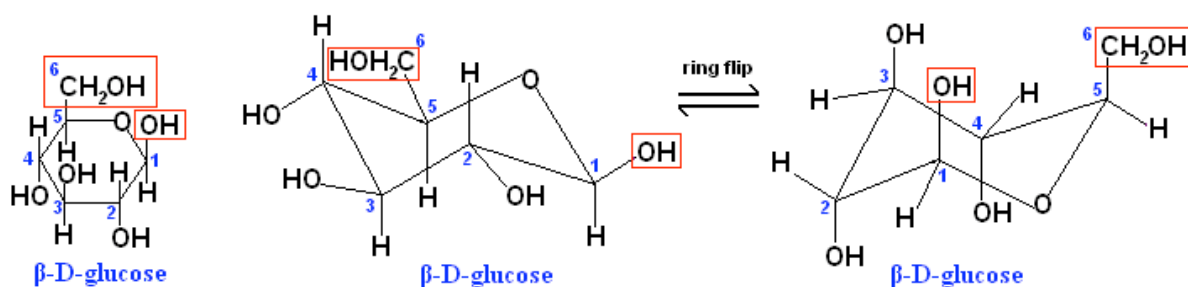
To get a better understanding of this concept, build models with your molecular model building kit.

The cyclic monosaccharides in this example are pyranoses because they have a six-membered ring. α-D-glucose can also be called α-D-glucopyranose. You may be asked specifically to form another type of cyclic sugar, such as a furanose. In that case the –OH that becomes deprotonated and attacks the carbonyl carbon may be different than the one from the last stereocenter. (Figure 12)

# Figure 12

D-glucose   α-D-glucose   α-D-glucofuranose
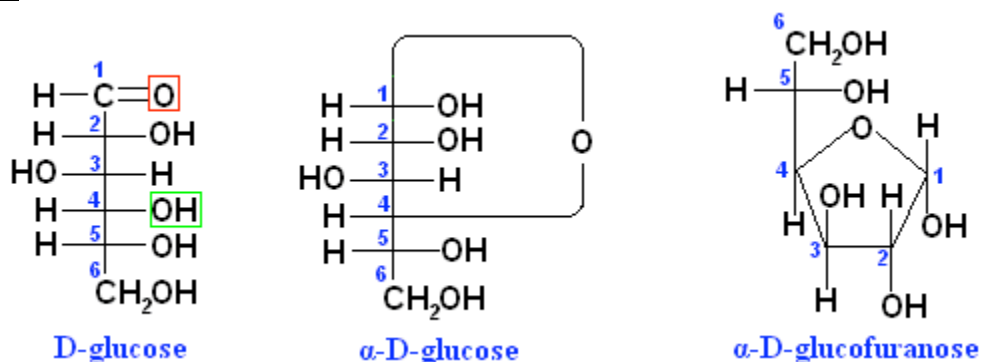
As long as all the rules are applied consistently, the transition from Fischer projection to Haworth projection to chair conformation will be a simple one. The chair conformation can only be done with pyranoses. The following are some practice problems to help you strengthen this skill.

Practice Problems *Solutions start on page 10.*

1. Make a table with the Fischer, Haworth, and chair conformation (when applicable, i.e. when a six-membered ring exists) for each of the following sugars: (a) b-D-galactose, (b) a-D-ribose, and (c) b-D-fructose.

1. Draw the Haworth projection of as a β-pyranose anomer of the sugar given below:
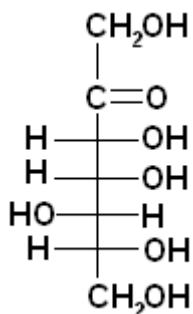
1. Draw the chair conformation of α-D-glucopyranose.

1. The following questions apply to the sugar **A.**
   (a) Is this sugar a ketose or an aldose?
   (b) Draw an arrow pointing to the anomeric carbon.
   (c) Box the OH group attached to C-4.
   (d) Is this the α or β anomer?

Sugar **A**
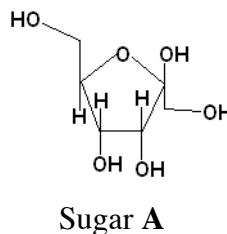
Practice Problem Solutions

1.   Fischer projection   Haworth projection   Chair conformation

(a)

(b)   Furanoses do not have chair
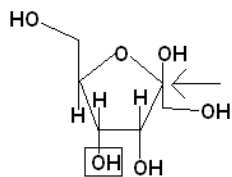   conformations

(c)   Furanoses do not have chair
                                                                                         conformations

Hydrogens can be omitted from Haworth projections to avoid cluttering, but do not draw a stick instead of a hydrogen atom. As in all bond-line or "stick" structures, a stick that is only attached to one other atom represents a methyl group.

            Correct Haworth projection   Too many methyl groups!

1.

1.
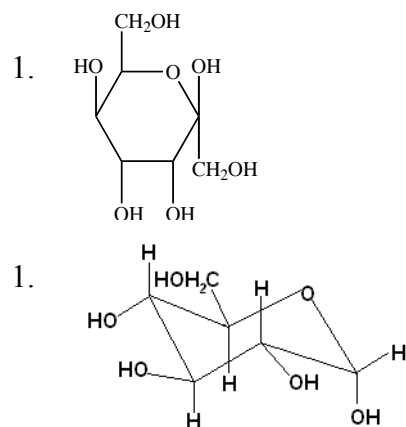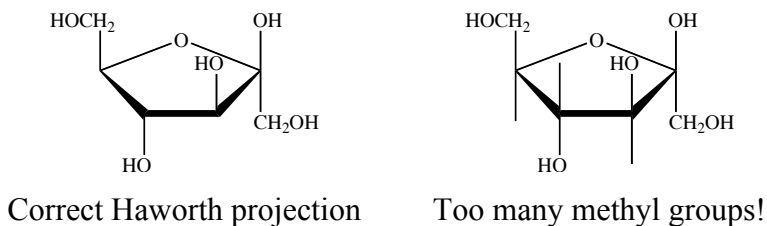
1. (a) Ketose.

(b)-(d)

Works Cited
1. Lecture Notes and practice problems from Professor William Nguyen. (Summer 2004, 14C)

2. Bruice, Organic Chemistry, Fourth Edition.

3. 14C Thinkbook for Fall 2004, Professor Hardinger.

4. I want to thank Professor Hardinger and Mark Smuckler for helping me edit this tutorial.