6.9: STEREOCHEMISTRY OF MOLECULES WITH THREE OR MORE ASYMMETRIC CARBONS

Learning Objective

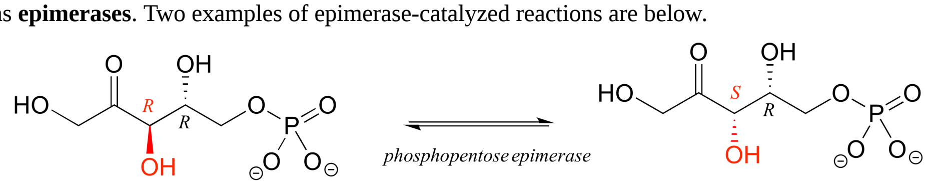
- interpret the stereoisomerism of compounds with three or more chiral centers

POSSIBLE NUMBER OF STEREOISOMERS

In general, a structure with *n* stereocenters will have 2^n different stereoisomers. (We are not considering, for the time being, the stereochemistry of double bonds – that will come later). For example, let's consider the glucose molecule in its open-chain form (recall that many sugar molecules can exist in either an open-chain or a cyclic form). There are two enantiomers of glucose, called D-glucose and L-glucose. The D-enantiomer is the common sugar that our bodies use for energy. It has $n = 4$ stereocenters, so therefore there are $2^n = 2^4 = 16$ possible stereoisomers (including D-glucose itself).

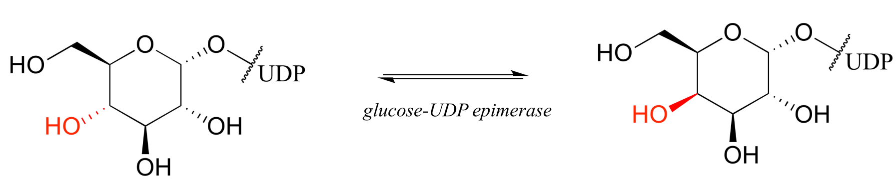
In L-glucose, all of the stereocenters are inverted relative to *D*-glucose. That leaves 14 diastereomers of D-glucose: these are molecules in which at least one, but not all, of the stereocenters are inverted relative to D-glucose. One of these 14 diastereomers, a sugar called *D*-galactose, is shown above: in D-galactose, one of four stereocenters is inverted relative to D-glucose. Diastereomers which differ in only one stereocenter (out of two or more) are called **epimers**. D-glucose and D-galactose can therefore be refered to as epimers as well as diastereomers.

The epimer term is useful because in biochemical pathways, compounds with multiple chiral centers are isomerized at one specific center by enzymes known as **epimerases**. Two examples of epimerase-catalyzed reactions are below.



ribulose-5-phosphate

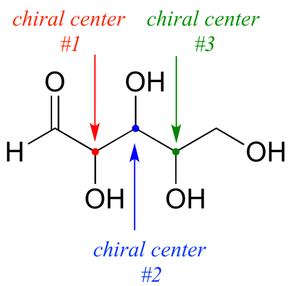
xylulose-5-phosphate



glucose-UDP

galactose-UDP

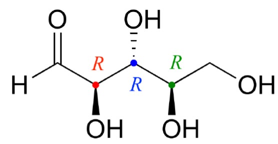
Now, let's extend our analysis to a sugar molecule with three chiral centers. Going through all the possible combinations, we come up with eight total stereoisomers - four pairs of enantiomers.



possible configurations:

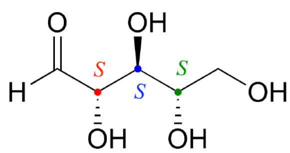
RRR RRS RSR RSS
SSS SSR SRS SRR

Let's draw the *RRR* stereoisomer. Being careful to draw the wedge bonds correctly so that they match the *RRR* configurations, we get:



RRR stereoisomer

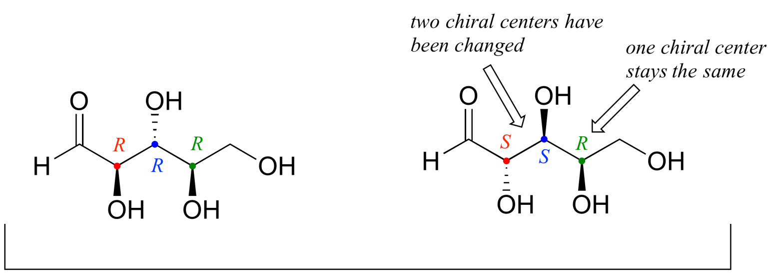
Now, using the above drawing as our model, drawing any other stereoisomer is easy. If we want to draw the enantiomer of *RRR*, we don't need to try to visualize the mirror image, we just start with the *RRR* structure and invert the configuration at *every* chiral center to get *SSS*.



SSS stereoisomer

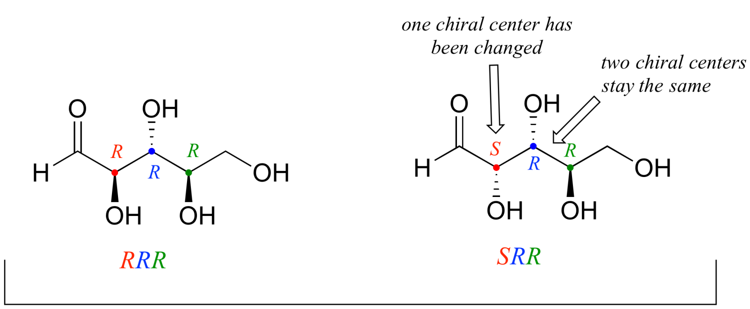
Try making models of *RRR* and *SSS* and confirm that they are in fact nonsuperimposable mirror images of each other.

There are six diastereomers of *RRR*. To draw one of them, we just invert the configuration of at least one, but not all three, of the chiral centers. Let's invert the configuration at chiral center 1 and 2, but leave chiral center 3 unchanged. This gives us the *SSR* configuration.



diastereomers

One more definition at this point: diastereomers which differ at only a single chiral center are called **epimers**. For example, *RRR* and *SRR* are epimers:



diastereomers
(epimers)

The *RRR* and *SSR* stereoisomers shown earlier are diastereomers but *not* epimers because they differ at *two* of the three chiral centers.

Example 6.9.1

1. Draw the structure of the *enantiomer* of the *SRS* stereoisomer of the sugar used in the previous example.
2. List (using the *XXX* format, not drawing the structures) all of the epimers of *SRS*.
3. List all of the stereoisomers that are diastereomers, but not epimers, of *SRS*.

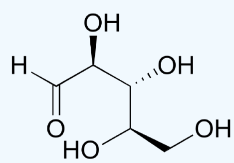
Solutions to exercises

Solution

Add text here.

Example 6.9.2

The sugar below is one of the stereoisomers that we have been discussing.



?

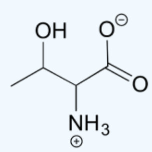
The only problem is, it is drawn with the carbon backbone in a different orientation from what we have seen. Determine the configuration at each chiral center to determine which stereoisomer it is.

Exercise 6.9.3

Draw the enantiomer of the xylulose-5-phosphate structure in the previous figure.

Exercise 6.9.4

The structure of the amino acid D-threonine, drawn without stereochemistry, is shown below. D-threonine has the (S) configuration at both of its chiral centers. Draw D-threonine, it's enantiomer, and its two diastereomers.

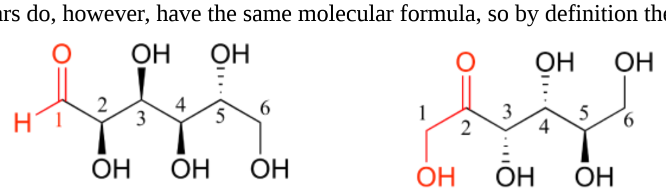


Answer

Solutions to exercises

COMPARING STEREOISOMERISM WITH STRUCTURAL ISOMERISM

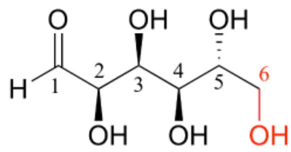
D-glucose and D-fructose are not stereoisomers, because they have different bonding connectivity: glucose has an aldehyde group, while fructose has a ketone. The two sugars do, however, have the same molecular formula, so by definition they are constitutional isomers.



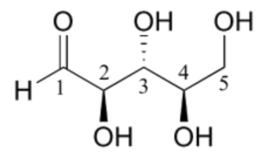
D-glucose D-fructose

(constitutional isomers)

D-glucose and D-ribose are not isomers of any kind, because they have different molecular formulas.



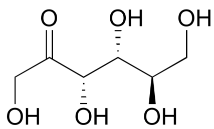
D-glucose



D-ribose

(not isomers)

<u>Exercise 5</u>: Identify the relationship between each pair of structures. Your choices are: not isomers, constitutional isomers, diastereomers but not epimers, epimers, enantiomers, or same molecule



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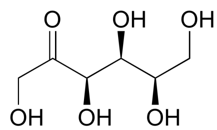
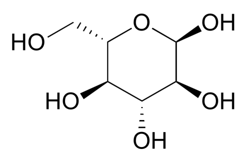


D-fructose

D-sorbose



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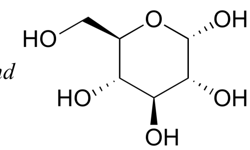

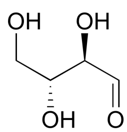

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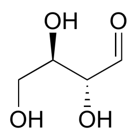

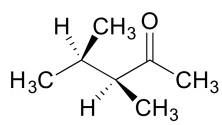

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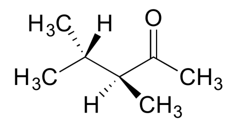
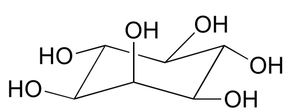
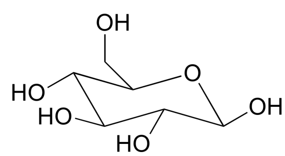




inositol

and



glucose

<u>Exercise 6</u>: Identify the relationship between each pair of structures. *Hint* - figure out the configuration of each chiral center.

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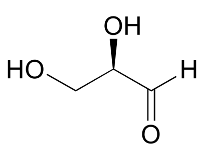

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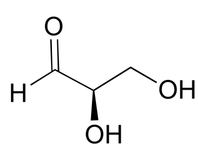

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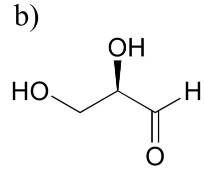

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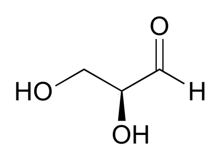

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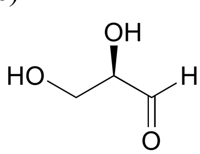

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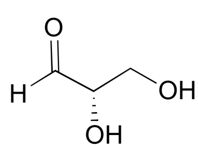

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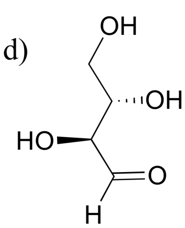

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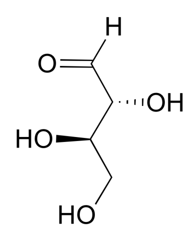
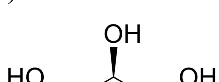


e)



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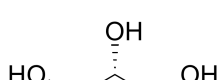

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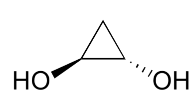

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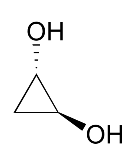

Solutions to exercises

Kahn Academy video tutorial on stereoisomeric relationships

Organic Chemistry With a Biological Emphasis by Tim Soderberg (University of Minnesota, Morris)