JOURNAL OF CHEMICAL EDUCATION

Communication

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Mnemonics for the Aldohexoses That Aid in Learning Structures, Names, and Interconversion of Fischer Projection Formulas and Pyranose Chair Forms

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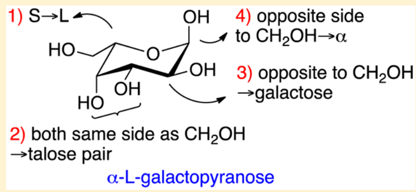
ABSTRACT: Many second−year undergraduate students have difficulty determining the names of aldohexoses from Fischer projection formulas and pyranose chair forms, and drawing structures from the names of aldohexoses. The mnemonics suggested here are useful aids in figuring out both the structures and the names of aldohexoses, and the interconversion between Fischer projection formulas and pyranose chair forms.



KEYWORDS: *Second-Year Undergraduate, Organic Chemistry, Mnemonics/Rote Learning, Misconceptions, Carbohydrates, Stereochemistry*

■ INTRODUCTION

While studying the carbohydrate chapter in second-year undergraduate organic chemistry, some students have difficulty learning the names and corresponding structural formulas of the eight D aldohexoses. The mnemonic "*all altruists gladly make gum in gallon tanks*" popularized by L. Fieser and M. Fieser[1] provides a helpful aid for memorization of the names: *allose*, *altrose*, *glucose*, *mannose*, *gulose*, *idose*, *galactose*, and *talose*.[2] Moreover, Neelakantan,[3] Klein,[4] and McGinn and Wheatley[5] proposed binary notations that help students learn carbohydrate structures.

■ MNEMONICS FOR FISCHER PROJECTION FORMULAS OF ALDOHEXOSES

A modification of Neelakantan's notation[3] is to first assign decimal numbers 0 through 7 to D-allose through D-talose, then convert the decimal numbers into binary numbers, and finally add extra zero(s) to the left of the binary number to make it a 4-digit code number, where 0 stands for OH, and 1 stands for H, both on the right side of a Fischer projection formula, as illustrated in Table 1.[6] For a given 4-digit code number, 0101, for example, the first digit 0 corresponds to the orientation of the hydroxyl group at C5 in a Fischer projection formula, the second digit 1 corresponds to the orientation of the hydroxyl group at C4 in a Fischer projection formula, and so on. After memorizing the Fiesers' mnemonic aid, one can readily draw the Fischer projection formula of any D aldohexose. For example, for D-talose, its decimal number is 7, which corresponds to code number 0111 (7 → 111 → 0111). Its Fischer projection formula should have OH, H, H, and H on the right side at C5 through C2, respectively. Furthermore, the binary system is also helpful for figuring out the stereochemistry of L aldohexoses. To get a code number for an L aldohexose, one just needs to subtract the 4-digit code number of its enantiomeric D aldohexose from 1111. For example, for L-mannose, the code number is 1111 − 0011 = 1100. Its Fischer projection formula should have H, H, OH, and OH on the right side from C5 to C2, respectively.

Once learned, this modified method is also useful for determining the names from Fischer projection formulas when applied in reverse. Two examples are illustrated in Figure 1.

■ MNEMONICS FOR PYRANOSE CHAIR FORMS OF ALDOHEXOSES

Students may find these mnemonics, which are based on Fischer projection formulas, helpful as they learn the names and structures of the aldohexoses. However, it is more common to encounter the pyranose chair forms in journal publications, poster presentations, and seminar talks. Furthermore, unlike the Fischer projection formula, the chair conformation of aldohexoses can be drawn in different orientations due to space and aesthetic considerations.[7] For most organic chemists who are not carbohydrate chemists, it may not be easy to name an aldohexose presented as a pyranose chair, probably except for glucose. It is desirable to have an aid for determining the names of all 16 aldohexoses from their pyranose chair forms. Here, a mnemonic is presented that relies on the relationship among the OH's (C1 to C5) and CH_2OH (C6). The eight names of aldohexoses can be grouped into 4 pairs in the same order as the Fiesers' mnemonic: <u>allose</u>, altrose; <u>glucose</u>, mannose; gulose, <u>idose</u>; galactose, <u>talose</u>. Each pair contains two sugars that are C2 epimers. One sugar from each pair is chosen as the reference sugar to be memorized: allose, glucose, idose, and talose. When the CH_2OH is in the equatorial position in the chair form (in case CH_2OH is in the axial position, a simple ring flip will make CH_2OH equatorial), (1) if the OH's at C4, C3, and C2 are equatorial, it is glucose; (2) if the OH's at C4, C3, and C2 are axial, it is idose (mnemonic: ax<u>i</u>al → <u>I</u> → <u>I</u>dose);[8] (3) if the OH's at C4, C3, and C2 are on the same side of the general ring plane

DOI: 10.1021/ed500254x
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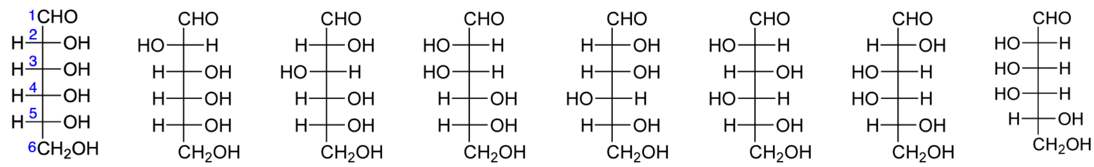
Table 1. Names and Fischer Projection Formulas for Aldohexoses

Fiesers' mnemonic	all	altruists	gladly	make	gum	in	gallon	tanks
aldohexose	allose	altrose	glucose	mannose	gulose	idose	galactose	talose
decimal #	0	1	2	3	4	5	6	7
binary #	0	1	10	11	100	101	110	111
code #	0000	0001	0010	0011	0100	0101	0110	0111
Fischer projection formulas								

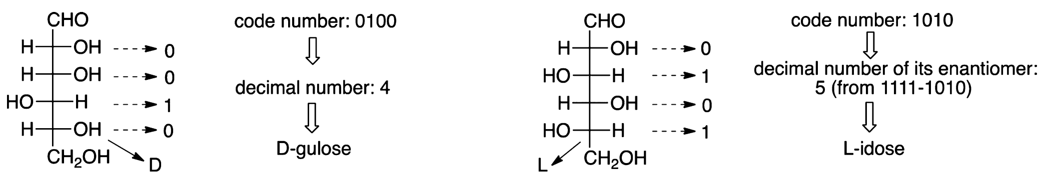


Figure 1. Determining the names from Fischer projection formulas.

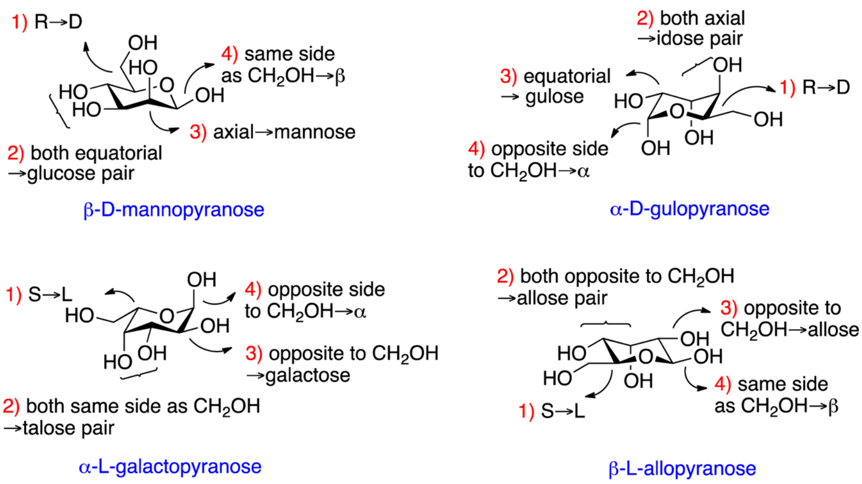


Figure 2. A four-step procedure for determining the names for hexopyranoses.

as CH_2OH, it is talose (mnemonic: same side → together → talose); and (4) if the OH's at C4, C3, and C2 are all on the opposite side of the general ring plane as CH_2OH, it is allose (mnemonic: opposite side → anti → allose). A general, four-step procedure for determining the name of an aldohexose presented in chair form is as follows. The first step is to assign *R*/*S* to C5; if it is *R*, that is a D sugar, and if it is *S*, that is an L sugar. The second and subsequent steps require the CH_2OH to be in the equatorial position; perform a ring flip if necessary! The second step is to identify the arrangement of the OH's at C4 and C3, which will correspond to one of the four pairs: (1) both equatorial → glucose pair; (2) both axial → idose pair; (3) both on the same side of the general ring plane as CH_2OH → talose pair; and (4) both on the opposite side of the general ring plane as CH_2OH → allose pair. The third step is to check the OH at C2, which will determine whether it is the reference sugar of the pair or the C2 epimer of the reference sugar. Finally, in order to determine anomer (α/β), one only needs to look at the spatial relationship between the OH at C1 and CH_2OH. If they are on opposite sides of the general ring plane, it is α; if they are on the same side of the general ring plane, it is β. Four examples are shown in Figure 2.

The structure of a synthetic oligosaccharide[9] is shown in Figure 3. Using the above-mentioned method, one can figure out that it contains three D-mannose units, two D-galactose units, and one protected D-glucosamine.

■ MNEMONICS FOR INTERCONVERSION OF FISCHER PROJECTION FORMULAS AND PYRANOSE CHAIR FORMS

For interconverting a Fischer projection formula of an open-chain aldohexose and one of its pyranose chair forms, a simple 2-

DOI: 10.1021/ed500254x
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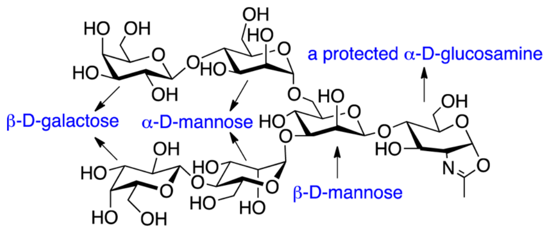

Figure 3. Deciphering a synthetic oligosaccharide.

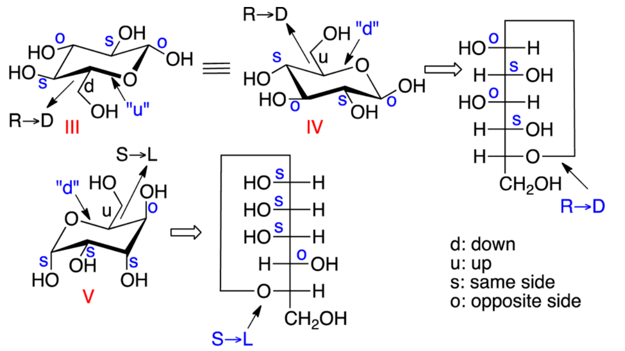

Figure 5. Converting pyranose chair forms into Fischer projection formulas.

step procedure can be followed. The first step is to decide the D/L configuration for the Fischer projection formula, where a D configuration corresponds to chair form **I**, while an L configuration corresponds to chair form **II** (Figure 4). The second step is to place OH's (C4 through C2) on the right/left side of the Fischer projection formula down/up in the chair form: a "downright uplifting" correlation.[10]

The reverse process of converting a chair form of a pyranose into a Fischer projection formula does not always work due to different drawings of pyranose chairs (cf. **III** and **V** in Figure 5). However, a general method can be applied to this conversion. For a given pyranose chair, the first step is to determine the absolute configuration of C5: If it is *R*, the C5−O bond is on the right in the Fischer projection formula; if it is *S*, the C5−O is on the left. The second step is to label the C5−O bond as "down" or "up": If the CH_2OH group is above the general plane of the ring, the C5−O bond is "down", while if the CH_2OH group is below the general plane of the ring, the C5−O bond is "up". Each of the OHs at C4 through C1 is either "up" or "down" (above or below the general plane of the ring), which is either the same as ("s") or opposite to ("o") the label assigned to the designated reference group, C5−O. The Fischer projection formula can be drawn accordingly even without knowing the names of the pyranoses (Figure 5); of course, the name of the aldohexose can be readily determined, for example with the help of the 4-digit binary code. **III** and **IV** are *β*-D-glucopyranose, and **V** is *α*-L-gulopyranose.

The *α*/*β* configuration for aldohexoses, by definition, is about the spatial relationship between the anomeric reference atom (O at C5) and the exocyclic oxygen atom at the anomeric center (C1) in the Fischer projection formula. If they are formally *cis*, it is the *α* anomer; if they are formally *trans*, it is the *β* anomer. According to this definition, in the pyranose chair forms of aldohexoses, an informal method for assigning *α* and *β* is as follows. If the CH_2OH group and OH at C1 are *trans*, it is the *α* anomer; while if the CH_2OH and the OH at C1 are *cis*, it is the *β* anomer. It should be noted that the *α*/*β* description is not simply defined as axial/equatorial or up/down for OH at C1 in the chair form, or the same absolute configurations for the anomeric center and the reference center, common misconceptions by students.

CONCLUSION

In summary, the mnemonics suggested here could serve as useful aids to decide both the structures and the names of aldohexoses, and the interconversion of Fischer projection formulas and pyranose chair forms.

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Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

The President's Fund for Faculty Advancement Award of Hunter College is gratefully acknowledged. I would also like to thank the reviewers whose valuable comments and suggestions resulted in improvement of this manuscript.

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(2) Fiesers' mnemonic also finds a place in modern organic textbooks; see for examples: (a) Carey, F. A. *Organic Chemistry*, 7th ed.; McGraw-Hill: New York, 2008; pp 1028−1029. (b) McMurry, J. E. *Organic Chemistry*, 8th ed.; Cengage Learning: United States, 2011; p 1010.

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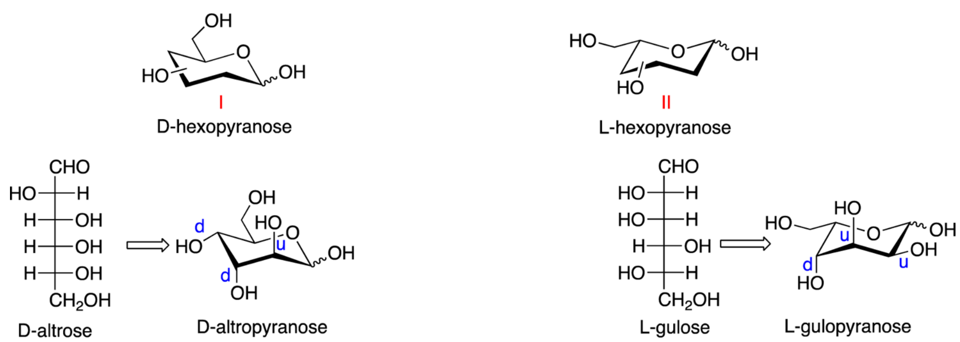

Figure 4. A "downright uplifting" conversion of Fischer projection formulas to pyranose chair forms.

DOI: 10.1021/ed500254x
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(5) McGinn, C. J.; Wheatley, W. B. Binary Representation in Carbohydrate Nomenclature. *J. Chem. Educ.* **1990**, *67* (9), 747−748.

(6) It is advantageous to assign decimal numbers 0 through 7 to the eight D aldohexoses since it is faster to convert them into binary numbers compared to Neelakantan's original assignment of 8 through 15 to the D family aldohexoses. Moreover, by defining 0 as OH and 1 as H on the right side of a Fischer projection formula, a student can readily generate a Fischer projection formula by writing 0 or 1 on the right side at C5 to C2, respectively, on the basis of the 4-digit code number because 0 resembles O and 1 resembles the first stroke of H.

(7) For different drawings of chair pyranoses, see: Ostash, B.; Yan, X.; Fedorenko, V.; Bechthold, A. Chemoenzymatic and Bioenzymatic Synthesis of Carbohydrate Containing Natural Products. *Top. Curr. Chem.* **2010**, *297*, 105−148.

(8) The capital letter I resembles the three axial lines in chair form of idose.

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DOI: 10.1021/ed500254x
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