Educación Química

Comunicación

The aldoses' triangle

El triángulo de las aldosas

Leonardo X. Alvarez y Bryan Fernández Solano[1]

Resumen

Una de las dificultades significativas que los estudiantes pueden encontrar al intentar aprobar un curso de Química Orgánica es la necesidad de memorizar mucha información. Esta práctica consume mucho tiempo y a veces el material memorizado se pierde durante los días siguientes a las evaluaciones. Dado a que el uso de mnemotecnias ha demostrado ser eficaz en la memorización a largo plazo, proponemos el uso del Triángulo de las Aldosas como una herramienta práctica cuando se tiene que lidiar con las estructuras de las aldopentosas, aldohexosas y cetohexosas.

Palabras clave: público en general ; segundo año de licenciatura ; bioquímica ; química orgánica ; mnemotecnia ; carbohidratos ; aldosas ; pentosas ; hexosas ; cetosas.

Abstract

One of the significant difficulties that students might find when trying to ace an Organic Chemistry course is the need to memorize a lot of information. This practice is very time-consuming and sometimes the memorized material is lost during the next few days after the evaluations. As the use of mnemonics has proven to be effective in long-term memorization, we propose the use of the Aldoses' Triangle as a handy tool when dealing with the structures of the C5, C6 aldoses, and C6 ketoses.

Keywords : general public; second-year undergraduate; biochemistry; organic chemistry; mnemonics; carbohydrates; aldoses; pentoses; hexoses; ketoses.

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[1] Laboratorio de Síntesis y Química Verde, Escuela de Química, Universidad de Costa Rica.

Introduction

Dealing with tons of memorizing in an organic chemistry or biochemistry course is time-consuming. In most cases, the students use their short-term memory only to remember things for the exam. This effort is often translated into wasted work because the "memorized" material is quickly forgotten and the memorizing exercise needs to be repeated several times during the semester. In this matter, the use of mnemonics has proven to be very helpful as a memorizing tool when teaching science (Mastropieri et al., 1988; Levin and Levin, 1990; Yeoh, 2014). In introductory organic or biochemistry courses, students are often faced with the challenge of learning the structures of the four D-Aldopentoses, the eight D-Aldohexoses and, the four D-Ketohexoses. In most cases, this is done the hard way: drawing the Fischer's projection of each one of the structures several times until memorization is achieved. This method is ineffective and due to the stress generated during the process, sometimes structures are drawn incorrectly, and exercises are not solved in the right way.

To help students to unravel this difficultly, numerous original learning aids have been published however, in most of the cases the mnemonic is devoted only to the hexoses. For example, Sattler (Sattler, 1931) proposed the use of arrows, circles, and horizontal bars to generate an easy-to-memorize code from which the structure of the desired molecule can be drawn. Despite its simplicity, the use of this tool implies the memorization of a specific code for each molecule. In the same line of thought but with greater complexity, Stewart (Stewart, 1945) suggested the use of the key phrase "ALL RIGHT" (referring to sugars that have the hydroxyl group on the right side of the vertical carbon chain) and a six-step method to associate the names of the aldoses with their structure. In this case, despite its usefulness, the use of this tool requires familiarization with each one of the steps in a specific order. For their part, Deloach and Brandon (Deloach and Brandon, 1955) recommended the use of the words GATE, LIAR, and TIM to build a pyramid that, starting from D-glyceric aldehyde, comes in handy when recalling the order of the names of the aldoses, and as a complement to this pyramid, Leary (Leary, 1955) proposed the construction of a table showing the positions of the hydroxyl groups on the different carbon atoms. This table is built by writing the names of the four pentoses in alphabetical order, by fitting names of the tetroses and hexoses to each one of them and by using the letters R and L to code for Right and Left according to the position of each one of the hydroxyl group. Once the table is completed, a code for each molecule is generated. Despite all these proposals, to our knowledge, one of the most commonly used strategies for learning the name of the Aldoses is referred to as the Fieser's mnemonic (Fieser and Fieser, 1959) which goes as : All Altruists Gladly Make Gum In Gallon Tanks. This phrase that is still cited in recent textbooks (Mcmurry, 2014; Carey, F.A. et al., 2018), becomes very helpful when the names of the eight D-Aldohexoses: Allose, Altrose, Glucose, Mannose, Gullose, Idose, Galactose, Tallose, needs to be remembered. However, it has nothing to do with their structure.

To alleviate the difficulty of memorizing the Fisher projection of all the monosaccharides included in the Fieser's mnemonic, several authors have assigned numerical codes (binary or decimal) and related them to the absolute configuration of the chiral carbons in the structures. For example, and as already cited, Sattler (Sattler, 1931) generated a code for each aldose molecule using the numbers 1 and 2 depending on the number of hydroxyl groups that occur together on one side of the vertical carbon chain. Moreover, Rosenblatt (Rosenblatt, 1965) presented a didactic approach based on code word answers to four questions that generate a binary (or decimal) code for each one of the eight aldoses. In addition, Neelakantan (Neelakantan, 1969) proposed the use of decimal numbers that, when converted to their binary equivalent, can be used to assign the stereochemistry of the C-5, C-4, C-3 and C-2 atoms on each carbohydrate. Similarly, Klein (Klein, 1980) developed an educational tool for drawing and naming carbohydrates using binary numbers as stereochemistry designators, and McGinn and Weathley (McGinn and Weathley, 1990) employed a binary notation, to designate the position of the hydroxyl groups in the carbon chain. Each binary notation was then transformed into a decimal code associated with the molecular structure of the carbohydrate. Along with all the ingenious proposals mentioned above, Zheng (Zheng, 2015) suggested a modification of Neelakantan's notation to generate a code for each aldohexose. The modification consists of assigning the decimal numbers from 0 to 7 to D-allose to D-talose, and then converting the decimal number into a binary number that can be related to the Fischer projection of the molecule. He also proposed a mnemonic for the pyranose chair forms of the aldoses. More recently, a different and unique approach was presented by Arya and Kumar (Arya and Kumar, 2020). They proposed the sigma notation "$X_{6Y}s^{n,m,p}$" as an aid to drawing the Fischer projections of all 16 stereoisomers of the aldohexoses and a mnemonic to remember their structures. In the proposed sigma notation, the X stands for the first letter of the name of the aldose, the Y in the subscript can be an A or a K depending on whether the compound is an aldose or a ketose, and the numbers in the superscript represent the carbon number on which the hydroxyl group is located to the left on the Fischer projection. They also suggested that this notation is useful when using Rosanoff's projections (Rosanoff, 1906).

There are other mnemonics related to carbohydrates found on literature. For example, Garrett (Garrett, 1984) discovered a pedagogical tool to remember the glucosidic linkages configurations of maltose, cellobiose and lactose. Wilson (Wilson, 1988) offered a set of rules to determine the proper stereochemistry of carbohydrates that work for both the Haworth and the chair/boat projections. Mitschele (Mitschele, 1990) developed four rules based on a "whimsical but meaningful" set of mnemonic keys for drawing Haworth projections of α- and β- anomeric forms of monosaccharides. And Starkey (Starkey, 2000) proposed the SOS mnemonic for glucose's stereochemistry, which helped us to remember that absolute stereocenter configurations are not provided by the sugar's root names. In this matter, a while ago, we proposed a mnemonic, the Aldoses' Triangle, as a simple and helpful tool for learning the names and the structures of the D-aldopentoses and the D-aldohexoses (Castillo and Alvarez, 2015). So, to expand the application of this memory aid, in this communication, we would like to show how the Aldoses' Triangle gives fast and reliable access to the structures of the D-Ketohexoses. In the next sections, we will reintroduce the use of the triangle and its application to get the structure of the D-ketohexoses.

The Aldoses' Triangle

The Aldoses' Triangle consists of one equilateral triangle with a smaller inscribed triangle and a simple three-lined numerical code written inside. The smaller triangle contains the first two rows of the code, and the third one is enclosed in the larger triangle (Figure 1). The smaller triangle is used while working with the aldopentoses and both triangles are required when dealing with the aldohexoses.

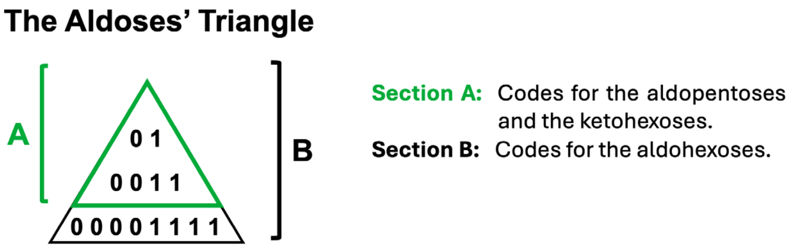
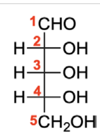
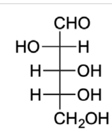
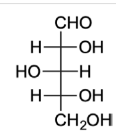
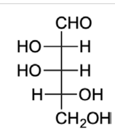


FIGURE 1. The Aldoses' Triangle. The first two rows on the smaller triangle are used to generate a specific code for each one of the D-aldopentoses or D-ketohexoses. The three rows codify the structures of the D-aldohexoses.

Before using the code, a simple detail that needs to be accounted for is that the hydroxyl groups oriented to the left in the Fischer's projection of the carbohydrate are going to be coded with a number 1 and the hydroxyl groups oriented to the right are going to be coded by a zero. The numbers in the triangle are used to build a matrix whose size depends on the number of chiral carbons in the sugar molecule. For example, in the case of the D aldopentoses, the matrix has four columns (one for each molecule) and three rows (one for each chiral atom). One of these rows (the last one) will be easily completed with zeroes because all the aldopentoses of the D-series have the hydroxyl group on carbon 4 oriented to the right in the Fischer's projection (Table 1). So, to fill the matrix, the digits on the first row of the triangle (zero, one) are written repeatedly to complete the four columns in the first row of the grid. Then the digits in the second row of the triangle are used to complete the second row of the matrix. Once the grill completed, the structures of each one of the D-Aldopentoses can be easily drawn just by decoding the numbers (Figure 2).

TABLE 1. Matrix codifying the structures of the D-aldopentoses.

Name	*D-ribose*	*D-arabinose*	*D-xylose*	*D-lyxose*
C-number		**Code**		
2	0	1	0	1
3	0	0	1	1
4	0	0	0	0
Structure				

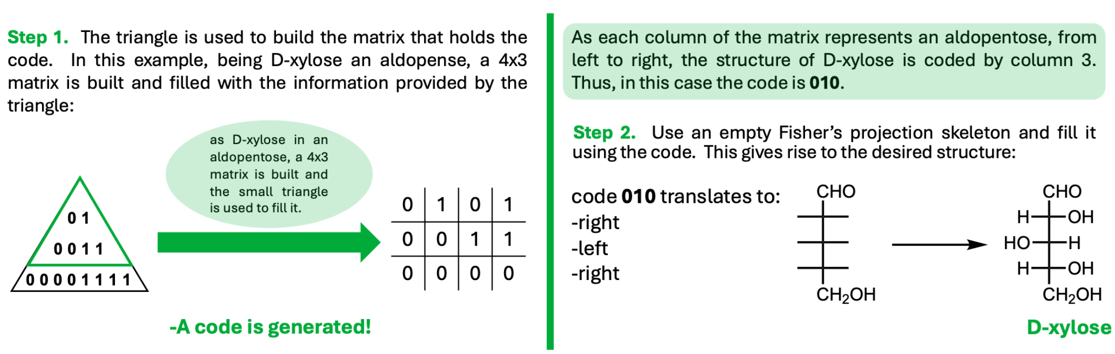


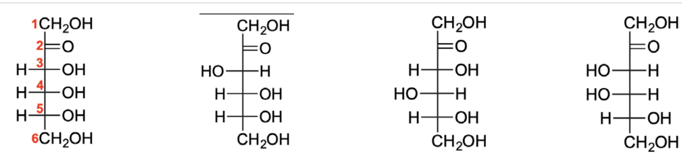
FIGURE 2. The Aldoses' Triangle in action : getting the code and drawing the structure of D-xylose.

It is important to notice that the binary codes generated here are not coincident with others previously reported. In this respect, the Klein System of Nomenclature for Carbohydrates showed 001 for D-arabinose (Klein, 1980) while we propose 100 for the same D-aldopentose (see table 1).

Drawing the Structures of the D-Ketohexoses

With respect to the D-ketohexoses, the Aldoses' Triangle can also come in handy when any of the structures of the four natural D-ketohexoses need to be drawn. As we are dealing with the 6-carbon ketoses, carbons C1, C2, and C6 are non-chiral, so there is no need to create a code for them. So, as before, the smaller triangle is used to build a matrix codifying the three chiral atoms on each one of the molecules. In this case, the codified carbons are C3, C4, and C5. Once again, as we are working with carbohydrates from the D series, for carbon 5, the digit that completes the table is a zero (Table 2). Once the table is completed, the structure of any one of the D-ketohexoses can be easily drawn (Figure 3).

TABLE 2. Matrix codifying the structures of the D-ketohexoses.

Name	*D-psicose*	*D-fructose*	*D-sorbose*	*D-tagatose*
C-number		**Code**		
3	0	1	0	1
4	0	0	1	1
5	0	0	0	0
Structure				

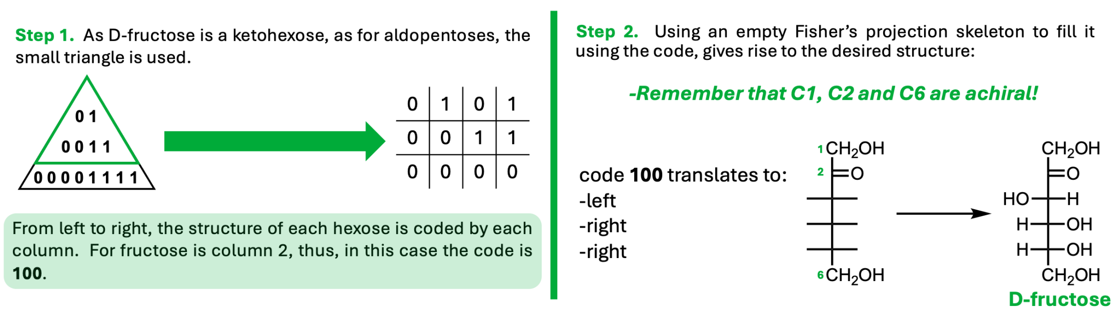


FIGURE 3. Using The Aldoses' Triangle to draw the Fisher's projection for the structure of D-fructose.

As it can be seen from what's shown in the last two sections, the use of the Aldoses' Triangle requires little to no memorization, and its application readily gives access to the structures of the four D-aldopentoses and the four D-ketohexoses. The application of the triangle for the structures of the D-aldohexoses can be found in the original paper (Castillo and Alvarez, 2015).

Many mnemonics and binary codes have been proposed previously, especially for the eight aldohexoses, still it is of great importance to mention that our proposal does not generate the same codes found in literature. For D-talose we can find some binary codes as 1001 shown by Rosenblatt (Rosenblatt, 1965), or 0111 suggested by Klein (Klein, 1980) and later by Zheng (Zheng, 2015), but by using the Aldoses' Triangle we can obtain 1110 as the code for the latter aldohexose mentioned. Of course, there is the probability of having coincident codes, on the graphical abstract we can see that for D-galactose the code generated by the Aldoses' Triangle is 0110 which is exactly the same proposed by Zheng for this same sugar, but it is not the same as 0011 presented by Rasenblatt almost sixty years ago, so we would like to mention that this mnemonic is not a mere repetition of what we can find previously published. Finally, the mnemonic proposed here generate a code which gives us a structure of the sugar, and this could be complemented with some other applications reported in the literature. Once the Fischer projection is obtained by the Aldoses' Triangle, we can convert it to its corresponding angular line representation as proposed by Moreno (Moreno, 2012). On the other hand, we can use the simple paper model proposed by Mak (Mak, 2018) to cyclize monosaccharides from Fischer to Haworth projections, as well as the "push–pivot–pull" mnemonic described by Butler (Butler, 2021) to generate the Natta (zigzag) projection or staggered bond-line structure from the corresponding Fischer projection, or with the Arrow–Rotation–Method (ARM) developed by Hallal and Tlais (Hallal and Tlais, 2023) to interconvert zigzag structures and Fischer projections.

Conclusions

We have shown that the simple mnemonics presented as the Aldoses' Triangle is very helpful in building a simple code that can be correlated with the Fischer's projections of the structures of the aldopentoses, the aldohexoses and the ketohexoses. This code can be built in a couple of minutes and provides a very fast and reliable method for drawing the structures of the 16 important monosaccharides. It provides new binary codes and does not repeat what has been published previously. This mnemonic generates rapidly a structure that could serve as a starting point for the use of methods for interconverting Fischer's to Natta's or Haworth's projections.

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