Journal of Glycobiology
ISSN: 2168-958X

Price et al., J Glycobiol 2012, 1:2
DOI: 10.4172/2168-958X.1000e105

Editorial Open Access

The Name of the – ose: An Editorial on Carbohydrate Nomenclature

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What's in a name? The term 'sugar' is usually applied to the monosaccharides, disaccharides, and lower oligosaccharides. Historically, sugars were often named after their source, for example, grape sugar for glucose, cane sugar for saccharose (later called sucrose), wood sugar for xylose, and fruit sugar for fructose (fruchtzucker, fructose). The term 'carbohydrate' (from the French 'hydrate de carbone') was originally used only for monosaccharides, because their composition can be expressed as $C_n(H_2O)_n$. Glucose was named in 1838, although much later than this Kekule suggested 'dextrose' because glucose is dextrorotatory. About the same time it was agreed that all sugars should be named with the ending '-ose'. Long before its structure was known cellulose was proposed by combination of '-ose' with 'cellule', the French word for cell.

Emil Fischer began his work on carbohydrates in 1880 and within ten years, he could assign the configurations of most known sugars, many of which he had also synthesized. It became necessary to name these various compounds, and Fischer and others proposed the triose, tetrose, pentose, and hexose terminology still in use. Fischer also classified the sugars into aldoses and ketoses, and proposed substituting the name 'fructose' for 'levulose'. Emil Fischer also introduced the classical projection formulae for sugars, with a standard orientation (carbon chain vertical, carbonyl group at, or near, the top). In 1906, Rosanoff selected the enantiomeric glyceraldehydes as the point of reference, so that any sugar derivable by chain lengthening from *D*-glyceraldehyde belongs to the *D* series; a convention that we still use today.

Up to the 1940s, carbohydrate naming conventions were made by individuals, which in some cases were accepted by the scientific community, but mostly were not. In 1939, the American Chemical Society (ACS) formed a committee to establish a systematic nomenclature for carbohydrates and sugars, based on *D* and *L* designations of stereochemistry and numbering of the carbons in the sugar chain. In 1963, the ACS and the British Chemical Society jointly published a report that led to the IUPAC Rules for Carbohydrate Nomenclature [1,2]. Based on these rules the general term 'carbohydrate' includes monosaccharides, oligosaccharides and polysaccharides as well as substances derived from monosaccharides by reduction of the carbonyl group (polyols), by oxidation of terminal groups to carboxylic acids, or by dehydration of one or more hydroxy group(s). Sugars containing an amino group, a thiol group, or similar heteroatomic groups are also included.

A well-known mnemonic for the aldohexoses is "All Altruists Gladly Make Gum In Gallon Tanks": **all**ose, **alt**rose, **gl**ucose, **ma**nnose, **gu**lose, **i**dose, **gal**actose, **ta**lose. When the Fischer projections of the *D*-aldohexoses are drawn in this order they follow a sequence. By convention based on *D*-glyceraldehyde, all *D*-series sugars have the penultimate hydroxy group to the right. With increasing chain length, a new >CH-OH is inserted at position 2 in the chain, with the new hydroxyl group drawn either to the right or left. The first *D*-hexose in the sequence, allose, has all four secondary hydroxyl groups drawn to the right. Hence, the *D*-aldohexose series conform to the following convention: *2R, 3R, 4R, 5R* (allose); *2S, 3R, 4R, 5R* (altose); *2R, 3S, 4R, 5R* (glucose); *2S, 3S, 4R, 5R* (mannose); *2R, 3R, 4S, 5R* (gulose); *2S, 3R, 4S, 5R* (idose); *2R, 3S, 4S, 5R* (galactose); and *2S, 3S, 4S, 5R* (talose). As yet there is no equivalent mnemonic for remembering the configuration of the *D*-aldopentose sugars. Perhaps I can suggest "Ribs Are X-rayed Last" for the series **rib**ose, **ar**abinose, **x**ylose, **l**yxose, so that they also conform to the above rules.

Let's just take the three most commonly occurring hexose sugars, glucose, galactose, and mannose. The IUPAC name for *D*-glucose is (*2R,3S,4R,5R*)-6-(hydroxymethyl)tetrahydro-*2H*-pyran-2,3,4,5-tetrol, although this is used only rarely. By this nomenclature, *D*-galactose is called (*2R,3S,4S,5R*)-6-(hydroxymethyl)tetrahydro-*2H*-pyran-2,3,4,5-tetrol and D-mannose is (*2S,3S,4R,5R*)-6-(hydroxymethyl)tetrahydro-*2H*-pyran-2,3,4,5-tetrol. The name 'glucose' comes from the Greek word glukus (*γλυκύς*), meaning "sweet", with the suffix "-ose" denoting a sugar. Glucose is also called dextrose, glucodin, meritose, clintose L, roferose ST, cerelose, cartose, and of course, corn sugar. Cane sugar and beet sugar are both relatively pure sucrose, which is also known as table sugar. The root of both "mannose" and "mannitol" is manna, which the Bible records as the food supplied to the Israelites during their journey through the Sinai Peninsula. Manna is a sweet secretion of several trees and shrubs, such as *Fraxinus ornus*. A sugary extract from the sap is extracted by making a cut in the bark, giving rise to the English name of the tree, and some of the vernacular names from its native area ("fresno del Maná" in Spanish, "frassino da manna" in Italian). Mannose; it is also called seminose or *d*(-) carubinose. Galactose is derived from the Greek word galaktos, meaning "milk". So nothing to do with "interstellar", except that our own galaxy is referred to as the Milky Way.

The word molasses comes from the Portuguese word melaço, which ultimately comes from mel, the Latin word for "honey". This, of course, is also the root derivative for the sugars melibiose and melezitose. Sweet sorghum syrup is called "molasses" or "sorghum molasses" in some regions of the U.S., but the term molasses more properly refers to a different sweet syrup made as a byproduct of the sugarcane or sugar beet production. And interestingly, the word syrup itself comes from Arabic sharab, meaning beverage, via the Latin word 'syrupus'.

Rather confusingly, fructose is also called corn sugar, so in that case what is 'high-fructose corn syrup'? The USDA designates a variety of high-fructose corn syrups (HFCS). HFCS 55 is approximately 55% fructose and 42% glucose, and mainly used in soda drinks. HFCS 42 is 42% fructose and 53% glucose and used in processed foods. HFCS 90, approximately 90% fructose, is mainly used to blend with HFCS 42 to make HFCS 55. How important is standardizing the nomenclature for sugars anyway? Fructose, or fruit sugar (from Latin fructus, meaning fruit), is a simple ketose monosaccharide and was discovered by French chemist Augustin-Pierre Dubrunfaut in 1847. The previous

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Received June 13, 2012; **Accepted** June 15, 2012; **Published** June 17, 2012

Citation: Price NPJ (2012) The Name of the –ose: An Editorial on Carbohydrate Nomenclature. J Glycobiol 1:e105. doi:10.4172/2168-958X.1000e105

year the same gentleman had also discovered mutarotation, when he noticed that the specific rotation of aqueous sugar solution changes with time. Fructose is found as a free monosaccharide in honey, tree and vine fruits, flowers, berries and most root vegetables, but primarily as a component of sucrose. The primary reason that fructose is used commercially in foods and beverages, besides the low cost, is its relatively high sweetness. It is the sweetest of all naturally occurring carbohydrates, and is about 1.73 times sweeter than sucrose. However, it is the 5-ring furanose form of fructose that is sweeter. The 6-ring pyranose form is less sweet, and curiously warming fructose leads to conversion into the pyranose form.

Allos is the Greek for "other" or "different", hence the naming of allose. Similarly altrose is derived from the *alter* which is the Latin word for "other". Idose may be derived from the Greek, eidos, meaning shape or form, or from contraction of the Latin word idem (Latin, 'the same') and gulose, referring to the similar stereochemistry of gulose and idose. Talose is an unnatural aldohexose monosaccharide that is soluble in water and slightly soluble in methanol. There are suggestions that the name 'talose' derives from the automaton of Greek mythology named Talos, but quite why is unclear. Certainly there is no relationship to the word "tallow", which is a rendered form of beef or mutton fat. Idose is also not found in nature, but its uronic acid, iduronic acid, is a component of dermatan and heparan glycosaminoglycans. "Id" is Freud's personality structure which contains the libido, and acts according to the "pleasure principle".

The origin for xylose, 1890–95, is from the Greek xýl for wood, plus –ose. Xylan, and hence xylose, of course, is known as the wood sugar, and is a major component of hemicelluloses. *D*-Ribose was first reported in 1891 by Emil Fischer, and is a C-2 carbon epimer of the sugar *D*-arabinose. Arabinose is named for its source, gum Arabic, and ribose may be named as a transposition of the name of arabinose. However, ribose may also arise from the German ribonsäure, equivalent to 'ribon' meaning ribbon, because it was initially recovered from RNA. As for the deoxysugars, rhamnose is from the Greek "rhámn" thorn bush. Rhamnose is isolated from the plant buckthorn (Rhamnus) in the Rhamnaceae family. The plant species are named after Rhamnus, a Greek archaeological site at the abandoned city in Attica, Greece. Interestingly, Rhamnus is also the name of a main-belt asteroid discovered in 1988, and of a mountain in Antarctica. Fucose, which we had to be so careful of pronouncing correctly when I was a student, is derived from the brown algae genus Fucus, that is especially rich in the sulfated polysaccharide fucoidan, and which is >95% composed of sulfated esters of fucose,

The community of carbohydrate research scientists is looking forward with anticipation to the high impact that the Journal of Glycobiology will have on our field. Whether we write *D*-mannose, *R*-mannose, or (*2S,3S,4R,5R*)-6-(hydroxymethyl)tetrahydro-2*H*-pyran-2,3,4,5-tetrol, which is the IUPAC name for *D*-mannopyranose, is clearly of great importance. Maintaining the correct nomenclature is essential. Let's make sure that we are all describing the same sugars. "What's in a name? That which we call an -ose by any other name would smell as sweet."

Acknowledgements

Thanks to my ARS-USDA colleagues Drs. Ken Doll and Joseph Rich. Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the US Department of Agriculture. USDA is an equal opportunity provider and employer.

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