

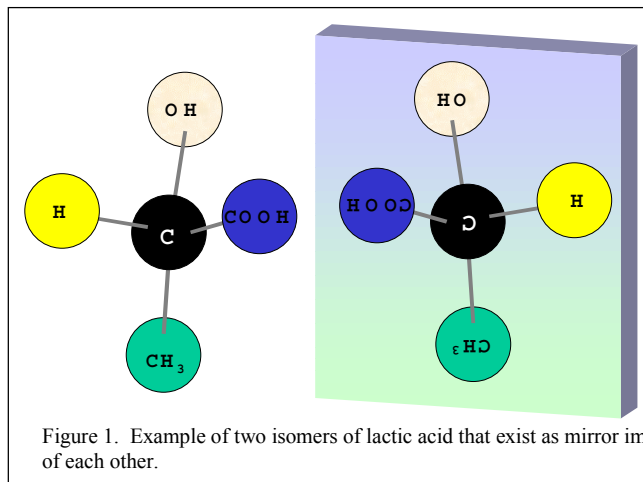
Calf Notes.com by Dr. Jim Quigley Primer on Calf Nutrition Series

Primer Number 102 – Structure and Function of Carbohydrates

Introduction. Carbohydrates are a widely diverse group of compounds that are ubiquitous in nature. More than 75% of the dry weight of the plant world is carbohydrate in nature - particularly cellulose and lignin. Chemically, carbohydrates are molecules that are composed of carbon, along with hydrogen and oxygen - usually in the same ratio as that found in water (H₂O). Typical carbohydrates are composed of strings or chains of monosaccharides - that is, chains of individual sugars. A monosaccharide (mono = one, saccharide = sugar) is the smallest carbohydrate unit. The type of monosaccharides in the chain, length of the chain, and method of linking all determine the composition of the carbohydrate.

A listing of some of the saccharides include:

- Monosaccharides - single molecules, usually with 5 or 6 carbons
 - pentoses - sugars with 5 carbons, including arabinose, xylose, ribose
 - hexoses - sugars with 6 carbons, including glucose, fructose, galactose, mannose
- Disaccharides - sugars containing 2 monosaccharides
 - sucrose - glucose + fructose
 - maltose - glucose + glucose
 - lactose - glucose + galactose
- Trisaccharides - combinations of three monosaccharides
- Polysaccharides - combinations of a large number of monosaccharides into complex three-dimensional forms. Examples include:
 - glycogen - three dimensional strings of glucose that is produced by the liver and stored in liver and muscles. Glycogen serves as a glucose reserve for animals. In ruminants, glycogen provides a critical glucose reserve. Due to microbial fermentation in the rumen, mature ruminants do not absorb significant amounts of glucose from the digestive tract.
 - starch - three dimensional strings of glucose stored in plants. Like glycogen, starch is one of the glucose reserves used in plants. It is highly digestible by animals and is a ready source of glucose.
 - cellulose - Linear chains of glucose produced by plants. The glucoses in cellulose are linked together differently than starch, that changes the properties of the molecule. Cellulose cannot be digested by enzymes produced by mammals. However, some bacteria do produce cellulase, the enzyme that breaks down cellulose.



- lignin - the polysaccharide that comprises the woody parts of plants. Cobs, hulls, and the woody portions of trees and shrubs all contain this complex carbohydrate. Lignin is largely indigestible and is therefore unavailable to animals. Some classify lignin in a separate category of compounds due to the complexity of the chemical structure.

An important consideration in understanding sugars is that the sugars can bend (or rotate) a source of polarized light in one of two directions - when the light is bent in a clockwise (or right) direction (dextrorotatory) and in a counterclockwise (left) direction (levorotatory).

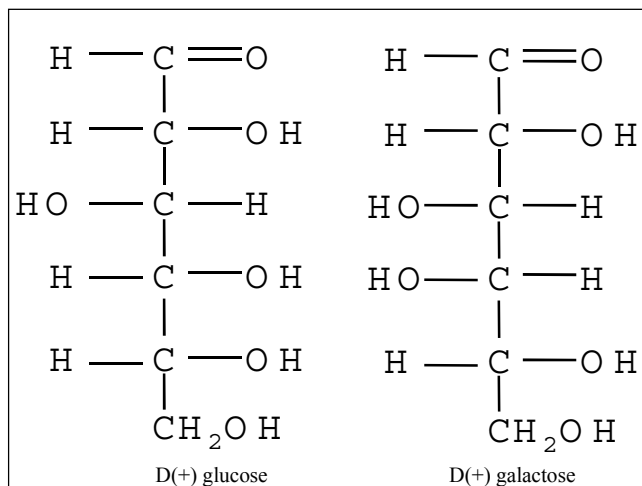
Dextrorotatory substances are often denoted by a + sign, and levorotatory substances are often denoted by a - sign. The model of lactic acid (Figure 1) is an example of how these two otherwise similar molecules exist. The situation is similar to two gloves - one for the right hand and the other for the left hand. In addition to the "+" and "-" notation for sugars, many sugars are denoted as "D" and "L", which are abbreviations for dextrorotatory and levorotatory, respectively. However, not all "D" sugars are "+" and not all "L" sugars are "-", so it's necessary to include both letters and symbols in referring to sugars.

Some of the more important pentoses and hexoses are noted in the table below:

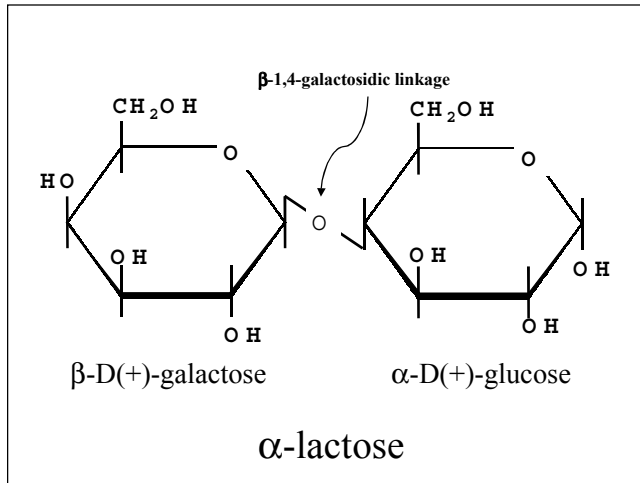
Sugars generally don't exist in nature in linear chains as indicated in figure 2. Instead, they normally exist in a ring structure, which may be in an alpha or beta form, depending on how the ring is formed.

Sugar	Sources	Importance
Pentoses		
D-ribose	Nucleic acids	Structural component of DNA, RNA, ATP, NAD, NADP
D-ribulose	Formed in metabolism	Intermediates in metabolic processes
D-arabinose	Gum arabic	No known function
D-xylose	Wood gums	No known function
Hexoses		
D-glucose	Hydrolysis of starch, lactose, fruit juice	The primary sugar of the body and used in tissues
D-galactose	Hydrolysis of lactose	Converted to glucose
D-mannose	Hydrolysis of plant mannosans and gums	A constituent of albumins, globulins & mucoproteins
D-fructose	Fruit juices, honey, hydrolysis of cane sugar	Converted to glucose in liver & intestine

The most common carbohydrate in the diet of preruminant calves is lactose. Lactose is a disaccharide composed of glucose and galactose (see figure) and is the primary sugar in milk. Commercial milk replacers also provide significant lactose, which is usually derived from whey or whey fractions. A typical calf milk replacer will contain approximately 40% lactose on an air-dry basis. On the other hand, whole milk contains approximately 4.9% lactose ÷ 12.5% DM in milk = 39.2% on a dry basis.



The two monosaccharides in lactose (glucose and galactose) are combined into a disaccharide using a specific type of chemical linkage.



This linkage (β -1,4-galactosidic linkage) joins the two monosaccharides to form one disaccharide. There are other types of chemical linkages (α -1,4- linkage) which is used to join other disaccharides together.

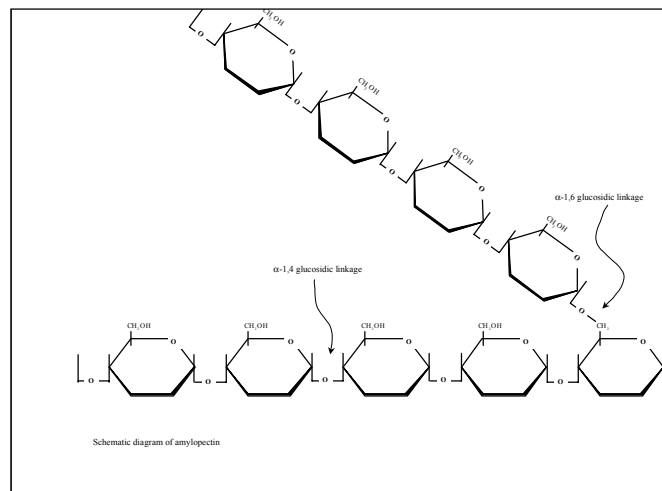
Polysaccharides are very large molecules, consisting of very large, sometimes complex structures of monosaccharides. Polysaccharides include starch, cellulose and lignin.

Starch is comprised of large strings of glucose molecules. There are many types of starches with different overall structures. However, the two major units of starch are amylose and amylopectin. Amylose is composed of linear chains of glucose joined by α -1,4-glucosidic linkages. Some data suggest that amylose is not actually linear, but may be coiled in structure. Amylose may range from a few hundred to several thousand glucose units in length. Amylopectin on the other hand, is comprised of glucose molecules connected into branched structures by α -1,6-glucosidic linkages. These linkages allow amylopectin to branch into far more complex structures than simple linear chains of glucose. Most commercial starches (potato, corn) contain approximately 25% amylose, with the remainder as amylopectin.

Starch is comprised of large strings of

Cellulose is the primary structural component of plants. It is found primarily in the cells walls and is a primary component of the fiber component of animal feeds. The structure of cellulose is similar to that of amylose in starch – that is, linear chains of glucose, except that the glucose molecules are joined by β -1,4-glucosidic linkages. This linkage is the reason that humans (and preruminant calves) cannot digest cellulose. Cattle digest cellulose because rumen bacteria contain the enzyme cellulase, which can hydrolyzing this linkage.

Lignin is actually a class of compounds that provides the woody structure to cell walls. Most scientists do not consider lignin to be carbohydrate. The characteristics of lignin vary depending on the plant species, maturity and method of determination. However, lignin is clearly important to nutrition, as it is the component that limits digestibility of fiber sources such as hay and silage.



Plant cell walls are complex arrangements of cellulose, hemicellulose and lignin. This contributes significantly to the overall digestibility of the fiber. The proportion of each

component depends on species and age of the plant. Chemical determination of structural carbohydrates of plants normally includes determination of acid or neutral detergent fiber.

Newborn dairy calves do not possess the rumen microbial population to ferment cellulose and hemicellulose to volatile fatty acids that can be used for energy. Development of ruminal function and establishment of bacterial populations are important to allowing calves to utilize these carbohydrate sources.