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Glucose—Chemical Properties, Synthesis, and Correlation with Biology

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Abstract

Glucose, also known as dextrose, is one of the most famous and important organic compounds. Its molecule structures and functional groups are worth to explore because they determine the efficacy, functions, and reactivities of glucose molecule. Glucose's structure and isomers are complex, and they determine the some of the properties of glucose molecule. Our prediction of glucose's reactivity suggests that glucose's chemical property has a close relation with the function groups it contains. There are various methods to synthesis glucose, including photosynthesis and extraction. Organisms' blood contains glucose; thus, glucose is a kind of material that vital to metabolism. Glucose also joins in organisms' respiration process. Our research may generate a profound effect on organic chemistry because glucose is one of the most important organic compounds, and the prediction and description of glucose may reveal the truth that glucose is worth for people to do some research.

Keywords

Glucose; Organic Chemistry; Reactivity; Structure; Biology; Synthesis.

1. Introduction

Glucose molecule has been discovered for more than two-hundred years. German chemist Andreas Marggraf [1] separated glucose from raisins for the first time in 1747. After forty-five years after the separation of glucose, Johann Tobias Lowitz discovered glucose in grapes. In 1838, Jean Baptiste Dumas gave this new molecule a name- glucose, which derived from the Greek word glykys, means "sweet".

Following the naming of glucose, a series of great discover about glucose was made. Friedrich August Kekulé purposed a new name (dextrose, meaning that as an optical isomer is rotating plane polarized light to the right) for glucose. Otto Meyerhof discover the connection between glucose and metabolism in 1922.

2. Structure & Isomers

Glucose molecule has the molecule formula $C_6H_{12}O_6$. There are two important glucose's stereoisomers: D-glucose and L-glucose. D-glucose and L-glucose are enantiomers, which means they are mirror imagine of one and other.

Fischer Projection of D-glucose and L-glucose. The difference between two isomers is the position of alcohol (R-OH) group. When the OH group lies towards right side, it called as D-configuration, and if it is on the left side, it would be left configuration.

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There are enormous differences between D-glucose and L-glucose because of the difference in structure. First, D-glucose is abundant in nature. In contrast, L-glucose is less abundant in nature. The most important difference between them is the direction when they rotate under plane polarized light. Optical rotation, also known as polarization rotation, is the rotation of the orientation of the plane of polarization about the optical axis of linearly polarized light as it travels through certain materials [3]. The rotation of D-glucose is clockwise, toward the right (dextrorotary, d-rotary) [4]. The rotation of L-glucose is anticlockwise, toward the left (levorotary, l-rotary).

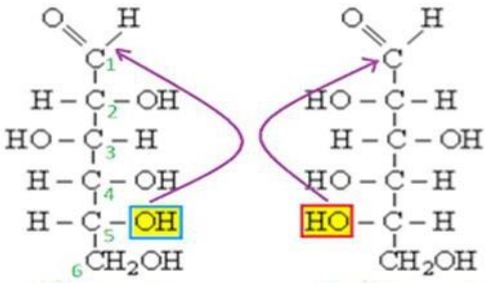
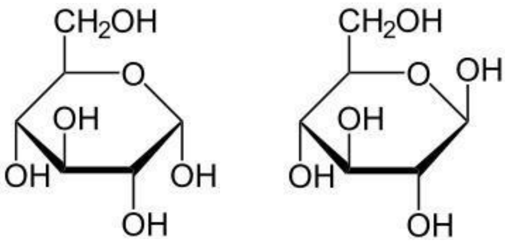


Figure 1. Difference between D-glucose and L-glucose. Download from the website Quora.com [2].

glucose, also known as dextrose, can be found in fruits, honey, and fruit juices. The D-glucose exists in two forms: α-D-glucose and β-D-glucose. The only difference between them is the direction of alcohol functional group (R-OH).



α-D-glucose β-D-glucose

Figure 2 Structure of α-D- glucose and β-D-glucose.

The designation "α" means the -OH functional group and the CH_2OH functional group are in the opposite side of the ring's plane (a trans arrangement). The designation "β" means the -OH functional group and the CH_2OH functional group are in the same site of the ring's plane (a cis arrangement). When the α-D-glucose molecules are joined chemically, a polymer starch is formed. When the β-D-glucose molecules are joined chemically, a polymer cellulose is formed [5]. Figure 3 illustrates the structures of polymer starch and cellulose structure.

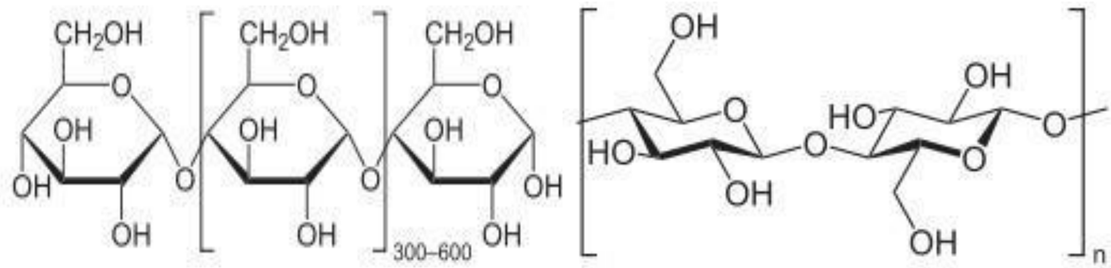


Figure 3 Polymer starch's structure and polymer cellulose's structure.

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Polymer Starch has a spiral structure and polymer cellulose looks like a linear chain.

The differences in their shape are caused by the difference in their bond angles. From the three-dimension models of α-D-glucose and β-D-glucose, we can see the difference in their shape clearly. polymer starch and polymer cellulose's 3D model are shown in figure 4.

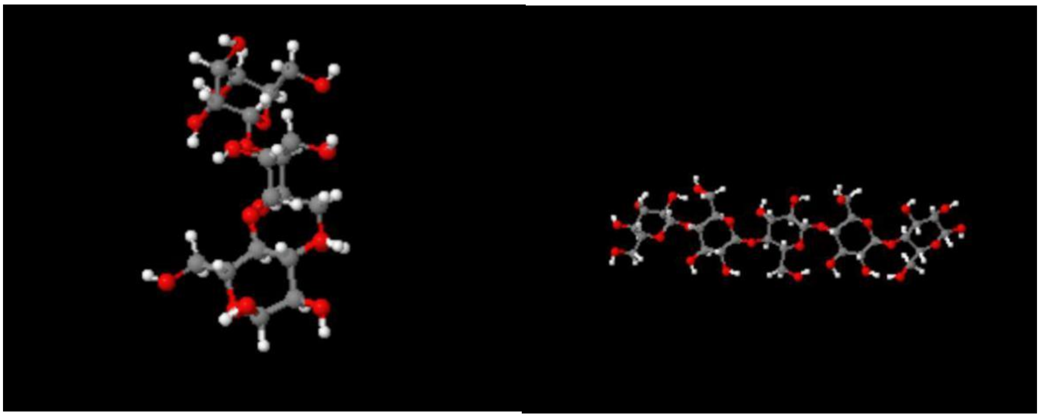

Figure 4 Image of 3D model of polymer starch and polymer cellulose. Produce via *JSmol.*

L-glucose is an enantiomer of D-glucose and it is indistinguishable in taste from

D-glucose. It does not occur naturally in higher living organisms, but people can synthesis it under laboratory conditions [6]. Although L-glucose and D-glucose are similar in their physical properties, there are still some differences between them. One of the biggest differences between those two kinds of glucose is that D-Glucose rotates plane polarized light clockwise whereas L-Glucose rotates plane polarized light anticlockwise. Scientists still can not find the answer to explain why L-glucose is rare. One possible explanation is that L-glucose can not form stable ring isomers [7]. Although L-glucose can not be absorbed by human, it is significant in helping diabetic because this can provide them some sweet.

3. Prediction of reactivity

To predict the reactivity of glucose, we first need to examine glucose molecule contain what functional groups.

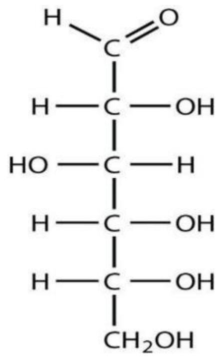

Figure 5 structure of glucose molecule as a straight chain. Download from the website https://chemistry.stackexchange.com/questions/57927/why-is-it-important-that-glucose-s-third-oh-group-points-to-the-left

From this graph we noticed that there are five alcohol functional groups (R-OH) and an aldehyde functional group (CH=O).

The reason for alcohol functional group can from hydrogen bonds with other molecules is that the huge differences in electronegativity between oxygen and hydrogen. Since the hydrogen ion is

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partially positive (δ^+), it may from a strong chemical bond with other polar molecules. Furthermore, the unusual high boiling point for glucose (527.1±50.0 °C at 760 mmHg) [8] is also cause by hydrogen bonds. Another important feature of organic compounds contain alcohol is that alcohol can react with acid functional group (R-COOH), and this reaction is called the "esterification reaction". Esterification reaction is the reaction between carboxylic acids and alcohol to produce ester and water [9]. And this is the reason why glucose can react with organic acid.

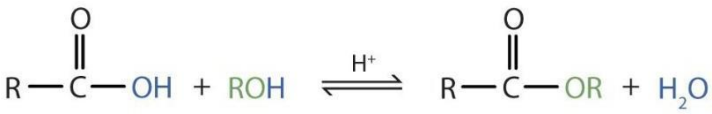

Figure 6 Mechanism of esterification reaction. This image is download from the website The LibreTexts libraries. [10]

Aldehyde functional group is a polar functional group. As the image below this text shows that the carbon may have a partially positive charge (δ^+) and the oxygen may have a partially negative charge (δ^-)

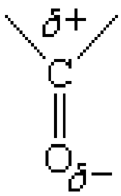

Figure 7 Download from the website https://www.britannica.com/science/aldehyde/Properties-of-aldehydes

As a result of the polarity of aldehyde functional group, glucose molecule can attach to a molecule of the same substance or different substance [11].

The polarity of aldehyde also affects the physical properties of substances. Hydrocarbon compounds usually have a low melting or boiling point because they are usually non-polar. In contrast, the melting or boiling point of a carbonyl-containing compound are usually higher. For example, butane (C_4H_{10}) has a lower boiling point than acetone (C_3H_6O) though they have the same molecule mass.

When the glucose molecule is in ring form, it contains ether (R-O-R) functional group. Because the oxygen is bonded to two different carbon atoms, ethers are generally less reactive than other oxygen-containing compounds. In this reason, ether functional group probably will not affect glucose's reactivity and other chemical properties.

4. Synthesis of glucose

4.1 Natural synthesize of glucose

The researchers used a mathematical mode called a "molecular clock" (amino acids change with each other over time in almost certain proportions, or they were replaced at the same rate per unit of time) [12] to calculate evolutionary events based on gene mutation. On the basis of confirming the age of red algae fossils, they concluded that, about 1.23 billion years ago, eukaryotes began to evolve chlorophyll that allows photosynthesis, which means that the natural synthesize of glucose has existed around1.23 billion years.

PHOTOSYNTHESIS

CO_2 (carbon dioxide) + H_2O (water) ----sunlight $C_6H_{12}O_6$ (glucose)+ O_2 (oxygen)

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This equation shows how the plants and algae change the sunlight, water and carbon dioxide into energy (glucose) and oxygen with the use of chlorophyll and other photosynthetic pigments [13]. The importance of such method is that the inorganic matters are converted into the organic matters, the solar energy is turned into chemical energy and the amount of carbon dioxide in the atmosphere is well controlled.

4.2 Industrial synthesize of glucose

Since 1960, almost all glucose extraction in the world has been enzymatic (Saussure first demonstrated the mechanism of starch hydrolysis in 1914. Langloiscg discovered the mildew solution principle in 1942. Kroyer first invented hydrolysis in 1954). At present, the glucose extraction around the world is mainly from starch, but from the current problem of food, leading to the problem of choosing which food as the extracted raw materials.

4.2.1. Extraction from corn starch

By using the specificity of enzyme action, it is possible to directly liquefy corn with amylase, and the liquid is then sugared by the enzyme to produce syrup of glucose. The amylase and sugaring enzyme process saves the starch making process. The price of the raw material is cheap. The process of such production cycle is short.

Alpha-amylase glycosylase activated carbon
↓ ↓ ↓
Corn → grinding →mixing → liquefaction → filtration → sugared → decolorization
→ filtration → Ion exchange → concentration → crystallization → drying → grinding → sieving
→ PRODUCT

Through the above process, it can be seen the double mold method can reduce the production investment, simplify the process and improve the utilization rate of raw materials. However, corn, as a necessity, this extraction is not a long-term solution.

4.2.2. Extraction from potato starch

Under the food shortage, some people use the rich potato resources in Inner Mongolia to produce starch and glucose. It is also based on the approach of double enzymatic hydrolysis method.

Use potato starch as raw material. First mix the starch and water together to prepare slurry. After that, add the enzyme into the slurry to liquefy the slurry. Then, kill the active enzyme in the solution gained in the last step. And, adjust the pH value of this solution to about 7. Then, add enzyme into the solution to make the solution sugared. Kill the active enzyme once again. The final step is to filter the solution to remove the impurities and take off its color. And, then what need to do is concentrating the liquid to get the product - glucose.

The mechanism of potato starch producing process is to use biological enzymes to break down large carbohydrates into small ones. The obtained glucose syrup has high sugar content, few solids, pure and clean color, high reducing sugar concentration and is superior to the glucose extracted form corn starch.

5. Correlation to biology

5.1 Blood glucose

The sugar in the blood is called blood glucose, and in most case it is glucose. Most of the energy required for cell activity in the comes from glucose, so blood sugar must be maintained at a certain level in order to maintain the needs of organs and tissues in the body. The normal blood glucose concentration in human body is 3.9 - 6.1 mmol/L. Sugar is one of the essential nutrients for human bodies. People could gain some simple sugar like glucose, which enters the blood and are transported to cells through the body as a source of energy, from grains, fruits and vegetables by the digestive system. Part of the glucose that can not be consumed will be converted into glycogen which is stored in the liver and muscles. If the amount of unconsumed part excesses the limit of liver and muscles,

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the excess will turn itself into fat. When the food is digested, sugar stored in the liver and muscles becomes the source of sugar, which maintains the normal concentration of blood sugar. After using up all the sugar stored in liver and muscles, fat will be also broken down for energy, almost ten percent of the fat is glycerol which can be converted into sugar. Other parts of fat can also be oxidized to produce energy, but the metabolic pathways are not the same as glucose.

5.2 Respiration

Cellular respiration is a process that glucose and oxygen are turned into water, carbon dioxide, and energy (ATP, the primary energy carrier in living organisms [14]) [15]. There are two types of cellular respiration: aerobic respiration reaction and anaerobic respiration reaction.

Aerobic respiration reaction is a process that glucose ($C_6H_{12}O_6$) is oxidized, and oxygen (O_2) is reduced to produce water (H_2O). The overall equation for aerobic

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{Cellular respiration}} 6CO_2 + 6H_2O + ATP$$

Figure 8 Download from the website https://www.khanacademy.org/science/high-school-biology/hs-energy-and-transport/hs-cellular-respiration/a/hs-cellular-respiration-review

respiration is shown below.

ATP, which is the abbreviation for adenosine triphosphate, is an energy-carrying molecule found in the cell of all organisms. Energy is contained in the bonds between phosphate. When the bonds are broken, the energy is released.

Anaerobic respiration, also known as “fermentation”, is the decomposition of glucose without oxygen [16]. French chemist Louis Pasteur in 19th century noticed the decomposition of glucose driven by microorganisms in the absence of air. People are using this reaction to produce various products like wine and beer.

Industrial fermentation is a process that human beings use fermentation to produce various biochemical products. The process is beginning with suitable organisms and careful controlled conditions. The products produced by this process include vitamin B_{12}, butyl alcohol ($C_4H_{10}O$), lactic acid ($C_3H_6O_3$). Industrial fermentation can bring the society a lot of advantages. Besides producing biomass, industrial fermentation can also help people produce extracellular metabolites and intracellular components [20].

Figure 9. People in South Dakota are using starch from corn to produce ethyl alcohol (C_2H_5OH) via fermentation. Picture download from the website of Britannica, shot by Jim Parkin

6. Conclusion

For glucose molecule’s structure, the most important thing to know is the relation between L-glucose and D-glucose. Although the differences between those two stereoisomers are small, organisms

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always have some difficulties in digesting L-glucose. It is important to notice that human beings are capable to digest L-glucose. However, excess intake of L-glucose can cause many health problems like Parkinson's disease (Parkinson's disease (PD) is a neurodegenerative disorder that affects predominately dopamine-producing (dopaminergic) neurons in a specific area of the brain called substantial nigari) [17]. For the designation α and β, they simply represent the trans and cis arrangement.

The two most important functional groups for glucose molecule is alcohol (R-OH) and aldehyde (CH=O). Alcohol makes glucose capable to react with organic acid. Having high boiling point and soluble in water. Aldehyde makes glucose capable to attach with molecule of same and difference substances. Ether is not a polar functional group, so it probably not affects glucose's reactivity and any chemical properties.

Research shows that glucose has been synthesized 1.23 billion years ago. Human can also synthesis glucose under laboratory conditions from extracting starch from corn and potato. Those two methods are cheap and quick.

Glucose has a close relation with biology. Glucose is essential nutrients for human and the normal blood glucose concentration in human body is 3.9 - 6.1 mmol/L. Cellular respiration is a process that consumes glucose and provides energy for organism. In temporary society, people use fermentation (anaerobic respiration) to produce a lot of organic compounds.

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In the process of writing this paper, all team members made great contributions, so we use the alphabetic rule to rank the writers.

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