Glucose

From Wikipedia, the free encyclopedia

Glucose (/ˈɡluːkoʊs/ or /-koʊz/; $C_6H_{12}O_6$, also known as **D-glucose**, **dextrose**, or **grape sugar**) is a simple monosaccharide found in plants. It is one of the three dietary monosaccharides, along with fructose and galactose, that are absorbed directly into the bloodstream during digestion. An important carbohydrate in biology, cells use it as the primary source of energy[3] and a metabolic intermediate. Glucose is one of the main products of photosynthesis and fuels for cellular respiration. Glucose exists in several different molecular structures, but all of these structures can be divided into two families of mirror-images (stereoisomers). Only one set of these isomers exists in nature, those derived from the "right-handed form" of glucose, denoted D-glucose. D-glucose is sometimes referred to as dextrose, although the use of this name is strongly discouraged. The term dextrose is derived from *dextrorotatory glucose*.[4] This name is therefore confusing when applied to the enantiomer, which rotates light in the opposite direction. Starch and cellulose are polymers derived from the dehydration of D-glucose. The other stereoisomer, called L-glucose, is hardly ever found in nature.

The name "glucose" comes from the Greek word *glukus* (γλυκύς), meaning "sweet". The suffix "-ose" denotes a sugar.

Contents

Function

Why glucose—and not another monosaccharide such as fructose—is so widely used in organisms is not clearly understood. One reason might be that glucose has a lower tendency, relative to other hexose sugars, to react non-specifically with the amino groups of proteins. This reaction (glycation) reduces or destroys the function of many enzymes. The low rate of glycation is due to glucose's preference for the less reactive cyclic isomer. Nevertheless, many of the long-term complications of diabetes (e.g., blindness, renal failure, and peripheral neuropathy) are probably due to the glycation of proteins or lipids.[5] In contrast, enzyme-regulated addition of glucose to proteins by glycosylation is often essential to their function. [*citation needed*] Another reason as to why glucose is the most common sugar is that it is the most conformationally stable among other possibilities.
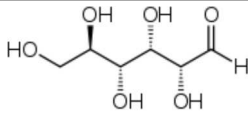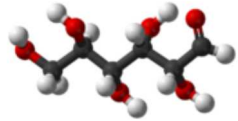
Analyte in medical blood test

Main article: Glucose test

Glucose is a common medical analyte measured in blood samples. Eating or fasting prior to taking a blood sample has an effect on the result. A high fasting glucose blood sugar level may be a sign of prediabetes or diabetes mellitus.

Energy source

Glucose is a ubiquitous fuel in biology. It is used as an energy source in most organisms, from bacteria to humans. Use of glucose may be by either aerobic respiration, anaerobic respiration, or fermentation. Glucose is the human body's key source of energy, through aerobic respiration, providing approximately 3.75 kilocalories (16 kilojoules) of food energy

D-Glucose	
Glucose C6H12O6	
Preferred IUPAC name	
D-glucose	
Systematic name	
(2*R*,3*S*,4*R*,5*R*)-2,3,4,5,6-Pentahydroxyhexanal	
Other names	
Blood sugar Dextrose Corn sugar D-Glucose Grape sugar	
Identifiers	
Abbreviations	Glc
CAS number	50-99-7 ✔
PubChem	5793
ChemSpider	5589 ✔
UNII	5SL0G7R0OK ✔
EC number	200-075-1
KEGG	C00031 ✘
MeSH	Glucose
ChEBI	CHEBI:4167 ✔
ChEMBL	CHEMBL1222250 ✔
RTECS number	LZ6600000
ATC code	B05CX01 (http://www.whocc.no/atc_ddd_index /?code=B05CX01),V04CA02, V06DC01
Beilstein Reference	1281604
Gmelin Reference	83256
3DMet	B04623
Jmol-3D images	Image 1 (http://chemapps.stolaf.edu /jmol/jmol.php?model=OC%5BC%40H%5D1OC%28O %29%5BC%40H%5D2O%28O%29%5BC%40%40H %5D%28O%29%5BC%40%40H%5D1O) Image 2 (http://chemapps.stolaf.edu /jmol/jmol.php?model=C%28%5BC %40%40H%5D1%5BC%40H%5D%28%5BC%40 %40H%5D%28%5BC%40H%5D%28%5BC%40H %5D%28O1%29O%29O%29O%29O)
SMILES	
InChI	
Properties	
Molecular formula	$C_6H_{12}O_6$
Molar mass	180.16 g mol^{-1}
Appearance	White powder
Density	1.54 g/cm^3

per gram.[6] Breakdown of carbohydrates (e.g. starch) yields mono- and disaccharides, most of which is glucose. Through glycolysis and later in the reactions of the citric acid cycle (TCAC), glucose is oxidized to eventually form CO_2 and water, yielding energy sources, mostly in the form of ATP. The insulin reaction, and other mechanisms, regulate the concentration of glucose in the blood.

Glucose is a primary source of energy for the brain, and hence its availability influences psychological processes. When glucose is low, psychological processes requiring mental effort (e.g., self-control, effortful decision-making) are impaired.[7][8][9][10]

Glycolysis

α-D-Glucose   Hexokinase   α-D-Glucose-
   6-phosphate

ATP   ADP
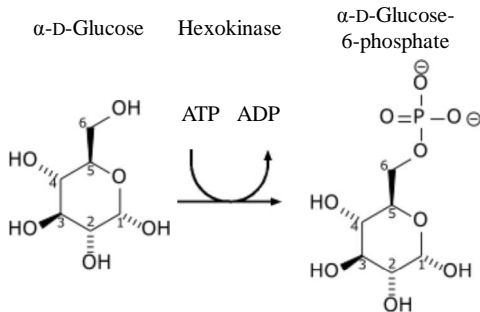
Compound C00031 (http://www.genome.jp/dbget-bin/www_bget?compound+C00031) at KEGG Pathway Database. Enzyme 2.7.1.1 (http://www.genome.jp/dbget-bin/www_bget?enzyme+2.7.1.1) at KEGG Pathway Database. Compound C00668 (http://www.genome.jp/dbget-bin/www_bget?compound+C00668) at KEGG Pathway Database. Reaction R01786 (http://www.genome.jp/dbget-bin/www_bget?rn+R01786) at KEGG Pathway Database.

Use of glucose as an energy source in cells is via aerobic or anaerobic respiration. Both of these start with the early steps of the glycolysis metabolic pathway. The first step of this is the phosphorylation of glucose by hexokinase to prepare it for later breakdown to provide energy. The major reason for the immediate phosphorylation of glucose by a hexokinase is to prevent diffusion out of the cell. The phosphorylation adds a charged phosphate group so the glucose 6-phosphate cannot easily cross the cell membrane. Irreversible first steps of a metabolic pathway are common for regulatory purposes.

In anaerobic respiration one glucose molecule produces a net gain of two ATP molecules (four ATP molecules are produced during glycolysis but two are required by enzymes used during the process).[11] In aerobic respiration a molecule of glucose is much more profitable in that a net worth of 32 ATP molecules is generated (34 gross with two being required in the process).[12]

*Click on genes, proteins and metabolites below to link to respective articles.* [§ 1]

Glycolysis and Gluconeogenesis edit
(http://www.wikipathways.org/index.php/Pathway:WP534)
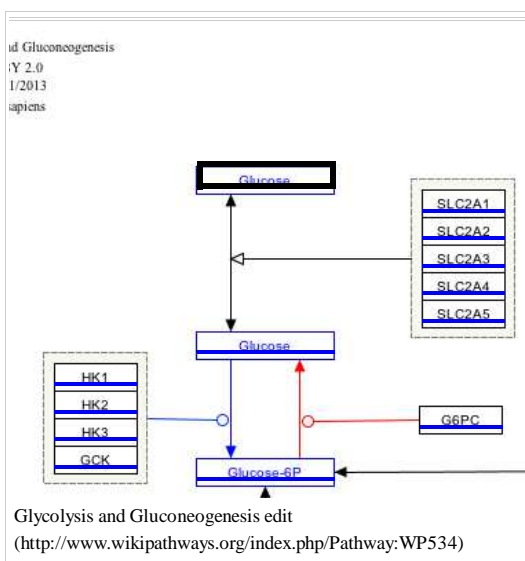
1. ^ The interactive pathway map can be edited at WikiPathways: "GlycolysisGluconeogenesis_WP534" (http://www.wikipathways.org/index.php/Pathway:WP534).

Precursor

Organisms use glucose as a precursor for the synthesis of several important substances. Starch, cellulose, and glycogen ("animal starch") are common glucose

Melting point	α-D-glucose: 146 °C β-D-glucose: 150 °C
Solubility in water	91 g/100 mL
Thermochemistry	
Std enthalpy of formation $\Delta_f H^{\ominus}{}_{298}$	–1271 kJ/mol [1]
Std enthalpy of combustion $\Delta_c H^{\ominus}{}_{298}$	–2805 kJ/mol
Standard molar entropy $S^{\ominus}{}_{298}$	209.2 J K^{-1} mol^{-1}
Specific heat capacity, C	[2]
Hazards	
MSDS	ICSC 0865 (http://www.inchem.org/documents/icsc/icsc/eics0865.htm)
EU Index	not listed
NFPA 704	1 / 0 / 0

✗ (verify) (what is: ✓/✗?)
Except where noted otherwise, data are given for materials in their standard state (at 25 °C, 100 kPa)
Infobox references
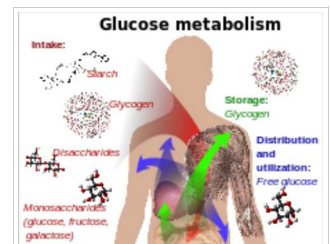
Glucose metabolism and various forms of it in the process.
-Glucose-containing compounds and isomeric forms are digested and taken up by the body in the intestines, including starch, glycogen, disaccharides and monosaccharides.
-Glucose is stored in mainly the liver and muscles as glycogen.
-It is distributed and utilized in tissues as free glucose.

polymers (polysaccharides). Some of these polymers like starch or glycogen serve as energy stores while others like cellulose and chitin (which is made from a derivative of glucose) have structural roles. Oligosaccharides of glucose combined with other sugars serve as important energy stores. These include lactose, the predominant sugar in milk which a glucose-galactose disaccharide and sucrose, another disaccharide of glucose and fructose. Glucose is also added onto certain proteins and lipids in a process called glycosylation. This is often critical for their functioning. The enzymes that join glucose to other molecules usually use phosphorylated glucose to power the formation of the new bond by breaking the glucose-phosphate bond.

Other than its direct use as a monomer, glucose can be broken down to synthesize a wide variety of other biomolecules. This is important as glucose serves both as a primary store of energy but also as a source of organic carbon. Glucose can be broken down and converted into lipids. It is also a precursor for the synthesis of other important molecules like vitamin C (ascorbic acid). Though plants and some microbes can create all the compounds they need from glucose given the necessary minerals, all animals and many microbes cannot synthesize some or

Structure and nomenclature

Glucose is a monosaccharide with formula $C_6H_{12}O_6$ or $H-(C=O)-(CHOH)_5-H$, whose five hydroxyl (OH) groups are arranged in a specific way along its six-carbon backbone.

Open-chain form

D-glucose in Fischer projection
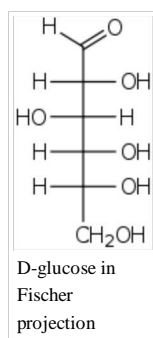
In its fleeting open-chain form, the glucose molecule has an open (as opposed to cyclic) and unbranched backbone of six carbon atoms, C-1 through C-6; where C-1 is part of an aldehyde group $H(C=O)-$, and each of the other five carbons bears one hydroxyl group -OH. The remaining bonds of the backbone carbons are satisfied by hydrogen atoms -H. Therefore glucose is a hexose and an aldose, or an aldohexose.

Each of the four carbons C-2 through C-5 is a stereocenter, meaning that its four bonds connect to four different substitutents. (Carbon C-2, for example, connects to $-(C=O)H$, -OH, -H, and $-(CHOH)_4H$.) In D-glucose, these four parts must be in a specific three-dimensional arrangement. Namely, when the molecule is drawn in the Fischer projection, the hydroxyls on C-2, C-4, and C-5 must be on the right side, while that on C-3 must be on the left side.

The positions of those four hydroxyls are exactly reversed in the Fischer diagram of L-glucose. D- and L-glucose are two of the 16 possible aldohexoses; the other 14 are allose, altrose, mannose, gulose, idose, galactose, and talose, each with two enantiomers, "D-" and "L-".
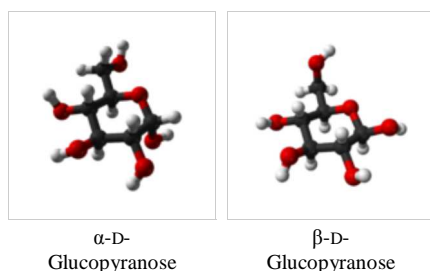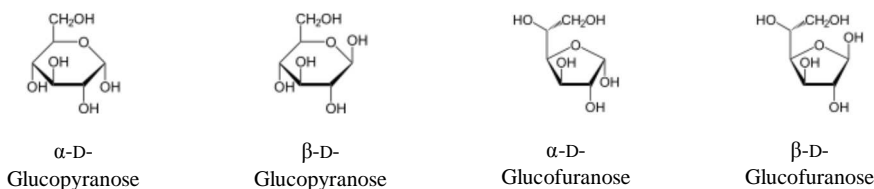
Cyclic forms

In solutions, the open-chain form of glucose (either "D-" or "L-") exists in equilibrium with several cyclic isomers, each containing a ring of carbons closed by one oxygen atom. In aqueous solution however, more than 99% of glucose molecules, at any given time, exist as pyranose. The open-chain form is limited to about 0.25% and furanose exists in negligible amounts. The terms "glucose" and "D-glucose" are generally used for these cyclic forms as well. The ring arises from the open-chain form by a nucleophilic addition reaction between the aldehyde group $-(C=O)H$ at C-1 and the hydroxyl group -OH at C-4 or C-5, yielding a hemiacetal group $-C(OH)H-O-$.

The reaction between C-1 and C-5 creates a molecule with a six-membered ring, called pyranose, after the cyclic ether pyran, the simplest molecule with the same carbon-oxygen ring. The (much rarer) reaction between C-1 and C-4 creates a molecule with a five-membered ring, called furanose, after the cyclic ether furan. In either case, each carbon in the ring has one hydrogen and one hydroxyl attached, except for the last carbon (C-4 or C-5) where the hydroxyl is replaced by the remainder of the open molecule (which is $-(C(CH_2OH)HOH)-H$ or $-(CHOH)-H$, respectively).

The ring-closing reaction makes carbon C-1 chiral, too, since its four bonds lead to -H, to -OH, to carbon C-2, and to the ring oxygen. These four parts of the molecule may be arranged around C-1 (the anomeric carbon) in two distinct ways, designated by the prefixes "α-" and "β-". When a glucopyranose molecule is drawn in the Haworth projection, the designation "α-" means that the hydroxyl group attached to C-1 and the $-CH_2OH$ group at C-5 lies on opposite sides of the ring's plane (a *trans* arrangement), while "β-" means that they are on the same side of the plane (a *cis* arrangement).

Therefore, the open-chain isomer D-glucose gives rise to four distinct cyclic isomers: α-D-glucopyranose, β-D-glucopyranose, α-D-glucofuranose, and β-D-glucofuranose; which are all chiral.

α-D-Glucopyranose

β-D-Glucopyranose

α-D-Glucofuranose

β-D-Glucofuranose

α-D-Glucopyranose

β-D-Glucopyranose

The other open-chain isomer L-glucose similarly gives rise to four distinct cyclic forms of L-glucose, each the mirror image of the corresponding D-glucose.

The rings are not planar but twisted in three dimensions. The glucopyranose ring (α or β) can assume several non-planar shapes, analogous to the "chair" and "boat" conformations of cyclohexane. Similarly, the glucofuranose ring may assume several shapes, analogous to the "envelope" conformations of

cyclopentane.

The glucopyranose forms of glucose predominate in solution, and are the only forms observed in the solid state. They are crystalline colorless solids, highly soluble in water and acetic acid, poorly soluble in methanol and ethanol. They melt at 146 °C (295 °F) (α) and 150 °C (302 °F) (β), and decompose at higher temperatures into carbon and water.

Rotational isomers

Each glucose isomer is subject to rotational isomerism. Within the cyclic form of glucose, rotation may occur around the O6-C6-C5-O5 torsion angle, termed the ω-angle, to form three staggered rotamer conformations called *gauche-gauche* (gg), *gauche-trans* (gt) and *trans-gauche* (tg). For methyl α-D-glucopyranose at equilibrium the ratio of molecules in each rotamer conformation is reported as 57:38:5 gg:gt:tg.[13] This tendency for the ω-angle to prefer to adopt a *gauche* conformation is attributed to the gauche effect.

Physical properties

Solutions

All forms of glucose are colorless and easily soluble in water, acetic acid, and several other solvents. They are only sparingly soluble in methanol and ethanol.

Glucose 5%

The open-chain form is thermodynamically unstable, and it spontaneously isomerizes to the cyclic forms. (Although the ring closure reaction could in theory create four- or three-atom rings, these would be highly strained and are not observed.) In solutions at room temperature, the four cyclic isomers interconvert over a time scale of hours, in a process called mutarotation.[14] Starting from any proportions, the mixture converges stable ratio of α:β 36:64. The ratio would be α:β 11:89 if it were not for the influence of the anomeric effect.[15] Mutarotation is considerably slower at temperatures close to 0 °C.

Mutarotation consists of a temporary reversal of the ring-forming reaction, resulting in the open-chain form, followed by a re-forming of the ring. The ring closure step may use a different -OH group than the one recreated by the opening step (thus switching between pyranose and furanose forms), and/or the new hemiacetal group created on C-1 may have the same or opposite handedness as the original one (thus switching between the α and β forms). Thus, even though the open-chain form is barely detectable in solution, it is an essential component of the equilibrium.

Solid state

Depending on conditions, three major solid forms of glucose can be crystallised from water solutions: α-glucopyranose, β-glucopyranose, and β-glucopyranose hydrate.[16]

Optical activity

Whether in **water** or in the solid form, D-glucose is dextrorotatory, meaning that it will rotate the direction of polarized light clockwise. The effect is due to the chirality of the molecules, and indeed the mirror-image isomer, L-glucose, is levorotatory (rotates polarized light counterclockwise) by the same amount. The strength of the effect is different for each of the five tautomers.

Note that the D- prefix does not refer directly to the optical properties of the compound. It indicates that the C-2 chiral center has the same handedness as that of D-glyceraldehyde (which was so labeled because *it* is dextrorotatory). The fact that D-glucose is dextrorotatory is a combined effect of its four chiral centers, not just of C-2; and indeed some of the other D-aldohexoses are levorotatory.

Production

Metabolism of common monosaccharides and some biochemical reactions of glucose

Galactose

Galactokinase

ATP   ADP

Galactose-1-phosphate

UDP-Galactose

NAD$^+$

UDP-galactose -4-epimerase

6-Phosphoglucono -lactonase

6-Phosphogluconate

6-Phosphoglucono-δ-lactone

NADP$^+$

NADPH + H$^+$

6-Phosphopgluconate dehydrogenase

Glucose-6-phosphate dehydrogenase

NADPH + H$^+$

NADP$^+$

Glucose

P$_i$ ATP

Galactose-1-phosphate uridylyl transferase

UDP-Glucose

PP$_i$

Inorganic pyrophosphatase   2 P$_i$

CO$_2$

Ribulose-5-phosphate

Ribulose-5-phosphate epimerase

Glucose-6-phosphatase

H$_2$O

Hexokinase, Mg^{2+}

ADP

UDP-Glucose pyrophosphorylase

UTP

Glucose-1-phosphate

UDP

Glycogen synthase

Ribulose-5-phosphate isomerase

Ribose-5-phosphate

Xylulose-5-phosphate

Transketolase

Glucose-6-phosphate

Phosphogluco-mutase

Transketolase

Erythrose-4-phosphate

Phosphoglucose isomerase

Glycogen phosphorylase

P$_i$

Glycogen (less branched)

Glyceraldehyde-3-phosphate

Sedoheptulose-7-phosphate

Transaldolase

Fructose-6-phosphate

Phosphomannose isomerase

$\alpha(1,4 \rightarrow 1,6)$ transglycosylase

$\alpha(1 \rightarrow 4)$ transglycosylase

Fructose

Mg^{2+}, Hexokinase (in muscle only)

ATP   ADP

P$_i$ ATP

Fructose-1,6-bisphosphatase

Phosphofructokinase, Mg^{2+}

H$_2$O   ADP

Glycogen (more branched)

Fructokinase (in liver only)

ATP   ADP

Fructose-1,6-bisphosphate

Mannose-6-phosphate   ADP

Hexokinase, Mg^{2+}

ATP

Fructose-1-phosphate

Type A aldolase

Mannose

Type B aldolase

Dihydroxyacetone-phosphate

Triose Phosphate Isomerase

Glyceraldehyde-3-phosphate

P$_i$ P$_i$

NAD$^+$ NAD$^+$

Gylceraldehyde-3-phosphate dehydrogenase

NADH + H$^+$ NADH + H$^+$

Glyceraldehyde kinase

ATP   ADP

Glyceraldehyde

NADH

NAD$^+$

Alcohol Dehydrogenase

NADH

NAD$^+$

glycerol phosphate dehydrogenase

1,3-Bisphosphoglycerate

Bisphosphoglycerate mutase

ADP   ADP

Phosphoglycerate kinase

ATP   ATP

2,3-Bisphosphoglycerate

Glycerol

ATP   ADP

Glycerol kinase

Glycerol-3-phosphate

3-Phosphoglycerate

H$_2$O

2,3-Bisphosphoglycerate phosphatase

P$_i$

Phosphoglycerate mutase

2-Phosphoglycerate

Enolase

Phosphoenolpyruvate

CO$_2$

GDP

Phosphoenolpyruvate carboxykinase

GTP

ADP

Pyruvate kinase

ATP

NAD$^+$ NADH

Lactate dehydrogenase

NAD$^+$ NADH

Pyruvate

Lactate

Oxaloacetate

HCO$_3^-$

Citric acid cycle

CO$_2$

Pyruvate carboxylase

ADP + P$_i$ ATP

Pyruvate decarboxylase

Acetaldehyde

Alcohol dehydrogenase

NADH

NAD$^+$

Ethanol

Biosynthesis

In plants and some prokaryotes, glucose is a product of photosynthesis. In animals and fungi, glucose results from the breakdown of glycogen, a process known as glycogenolysis. In plants the breakdown substrate is starch.

In animals, glucose is synthesized in the liver and kidneys from non-carbohydrate intermediates, such as pyruvate, lactate and glycerol, by a process known as gluconeogenesis.

In some deep-sea bacteria, glucose is produced by chemosynthesis.

Glucose tablets

Commercial

Glucose is produced commercially via the enzymatic hydrolysis of starch. Many crops can be used as the source of starch. Maize, rice, wheat, cassava, corn

husk and sago are all used in various parts of the world. In the United States, cornstarch (from maize) is used almost exclusively. Most commercial glucose occurs as a component of invert sugar, an approximately 1:1 mixture of glucose and fructose. In principle, cellulose could be hydrolysed to glucose, but this process is not yet commercially practical.[16]

Sources and absorption

Most dietary carbohydrates contain glucose, either as their only building block, as in starch and glycogen, or together with another monosaccharide, as in sucrose and lactose.

In the lumen of the duodenum and small intestine, the glucose oligo- and polysaccharides are broken down to monosaccharides by the pancreatic and intestinal glycosidases. Other polysaccharides cannot be processed by the human intestine and require assistance by intestinal flora if they are to be broken down; the most notable exceptions are sucrose (fructose-glucose) and lactose (galactose-glucose). Glucose is then transported across the apical membrane of the enterocytes by SLC5A1, and later across their basal membrane by SLC2A2.[17] Some of the glucose is converted to lactic acid by astrocytes, which is then utilized as an energy source by brain cells, some of the glucose is used by intestinal cells and red blood cells, while the rest reaches the liver, adipose tissue and muscle cells, where it is absorbed and stored as glycogen (under the influence of insulin). Liver cell glycogen can be converted to glucose and returned to the blood when insulin is low or absent; muscle cell glycogen is not returned to the blood because of a lack of enzymes. In fat cells, glucose is used to power reactions that synthesize some fat types and have other purposes. Glycogen is the body's "glucose energy storage" mechanism, because it is much more "space efficient" and less reactive than glucose itself.

History

Because glucose is a basic necessity of many organisms, a correct understanding of its chemical makeup and structure contributed greatly to a general advancement in organic chemistry. This understanding occurred largely as a result of the investigations of Emil Fischer, a German chemist who received the 1902 Nobel Prize in Chemistry as a result of his findings.[18] The synthesis of glucose established the structure of organic material and consequently formed the first definitive validation of Jacobus Henricus van't Hoff's theories of chemical kinetics and the arrangements of chemical bonds in carbon-bearing molecules.[19] Between 1891 and 1894, Fischer established the stereochemical configuration of all the known sugars and correctly predicted the possible isomers, applying van't Hoff's theory of asymmetrical carbon atoms.

See also

- 2,5-Dimethylfuran, a potential glucose-based biofuel
- Caramelization
- Fludeoxyglucose (18F)
- Glucose transporter (GLUT): GLUT1, GLUT2
- Glycated hemoglobin
- Peritoneal dialysis
- Sugars in wine
- Trinder glucose activity test

References

1. ^ Ponomarev, V. V.; Migarskaya, L. B. (1960), "Heats of combustion of some amino-acids", *Russ. J. Phys. Chem. (Engl. Transl.)* **34**: 1182–83.
2. ^ Boerio-Goates, Juliana (1991), "Heat-capacity measurements and thermodynamic functions of crystalline α-D-glucose at temperatures from 10K to 340K", *J. Chem. Thermodynam.* **23** (5): 403–9, doi:10.1016/S0021-9614(05)80128-4 (http://dx.doi.org/10.1016%2FS0021-9614%2805%2980128-4).
3. ^ Clark, D.; Sokoloff, L. (1999), *Basic Neurochemistry: Molecular, Cellular and Medical Aspects*, Lippincott, pp. 637–670
4. ^ "dextrose" (http://www.m-w.com/dictionary/dextrose), *Merriam-Webster Online Dictionary*, retrieved 2009-09-02.
5. ^ *High Blood Glucose and Diabetes Complications: The buildup of molecules known as AGEs may be the key link* (http://forecast.diabetes.org/magazine/features/high-blood-glucose-and-diabetes-complications), American Diabetes Association, 2010, ISSN 0095-8301 (//www.worldcat.org/issn/0095-8301)
6. ^ "Chapter 3: Calculation of the Energy Content of Foods – Energy Conversion Factors" (http://www.fao.org/docrep/006/Y5022E/y5022e04.htm), *Food energy — methods of analysis and conversion factors*, FAO Food and Nutrition Paper 77, Rome: Food and Agriculture Organization, 2003, ISBN 92-5-105014-7.
7. ^ Fairclough, Stephen H.; Houston, Kim (2004), "A metabolic measure of mental effort", *Biol. Psychol.* **66** (2): 177–90, doi:10.1016/j.biopsycho.2003.10.001 (http://dx.doi.org/10.1016%2Fj.biopsycho.2003.10.001), PMID 15041139 (//www.ncbi.nlm.nih.gov/pubmed/15041139).
8. ^ Gailliot, Matthew T.; Baumeister, Roy F.; DeWall, C. Nathan; Plant, E. Ashby; Brewer, Lauren E.; Schmeichel, Brandon J.; Tice, Dianne M.; Maner, Jon K. (2007), "Self-Control Relies on Glucose as a Limited Energy Source: Willpower is More than a Metaphor", *J. Personal. Soc. Psychol.* **92** (2): 325–36, doi:10.1037/0022-3514.92.2.325 (http://dx.doi.org/10.1037%2F0022-3514.92.2.325), PMID 17279852 (//www.ncbi.nlm.nih.gov/pubmed/17279852).
9. ^ Gailliot, Matthew T.; Baumeister, Roy F. (2007), "The Physiology of Willpower: Linking Blood Glucose to Self-Control", *Personal. Soc. Psychol. Rev.* **11** (4): 303–27, doi:10.1177/1088868307303030 (http://dx.doi.org/10.1177%2F1088868307303030), PMID 18453466 (//www.ncbi.nlm.nih.gov/pubmed/18453466).
10. ^ Masicampo, E. J.; Baumeister, Roy F. (2008), "Toward a Physiology of Dual-Process Reasoning and Judgment: Lemonade, Willpower, and Expensive Rule-Based Analysis", *Psychol. Sci.* **19** (3): 255–60, doi:10.1111/j.1467-9280.2008.02077.x (http://dx.doi.org/10.1111%2Fj.1467-9280.2008.02077.x), PMID 18315798 (//www.ncbi.nlm.nih.gov/pubmed/18315798).
11. ^ *Medical Biochemistry at a Glance @ Google books* (http://books.google.co.uk/books?id=9BtxCWxrWRoC&pg=PA52), Blackwell Publishing, 2006, p. 52, ISBN 978-1-4051-1322-9
12. ^ *Medical Biochemistry at a Glance @ Google books* (http://books.google.co.uk/books?id=9BtxCWxrWRoC&pg=PA50), Blackwell Publishing, 2006, p. 50, ISBN 978-1-4051-1322-9
13. ^ Kirschner, Karl N.; Woods, Robert J. (2001), "Solvent interactions determine carbohydrate conformation", *Proc. Natl. Acad. Sci. USA* **98** (19): 10541–45, doi:10.1073/pnas.191362798 (http://dx.doi.org/10.1073%2Fpnas.191362798), PMC 58501 (//www.ncbi.nlm.nih.gov/pmc/articles/PMC58501), PMID 11526221 (//www.ncbi.nlm.nih.gov/pubmed/11526221)
14. ^ McMurry, John E. (1988), *Organic Chemistry* (2nd ed.), Brooks/Cole, p. 866, ISBN 0534079687.
15. ^ Juaristi, Eusebio; Cuevas, Gabriel (1995), *The Anomeric Effect*, CRC Press, pp. 9–10, ISBN 0-8493-8941-0.
16. ^ *a b* Fred W. Schenck "Glucose and Glucose-Containing Syrups" in Ullmann's Encyclopedia of Industrial Chemistry 2006, Wiley-VCH, Weinheim. doi: 10.1002/14356007.a12_457.pub2 (http://dx.doi.org/10.1002%2F14356007.a12_457.pub2)
17. ^ Ferraris, Ronaldo P. (2001), "Dietary and developmental regulation of intestinal sugar transport" (http://www.biochemj.org/bj/360/0265/bj3600265.htm), *Biochem. J.* **360** (Pt 2): 265–76, doi:10.1042/0264-6021:3600265 (http://dx.doi.org/10.1042%2F0264-6021%3A3600265), PMC 1222226 (//www.ncbi.nlm.nih.gov/pmc/articles/PMC1222226), PMID 11716754 (//www.ncbi.nlm.nih.gov/pubmed/11716754).
18. ^ *Emil Fischer* (http://nobelprize.org/nobel_prizes/chemistry/laureates/1902/fischer-bio.html), Nobel Foundation, retrieved 2009-09-02.
19. ^ Fraser-Reid, Bert, "van't Hoff's Glucose", *Chem. Eng. News* **77** (39): 8.

External links

- International Chemical Safety Card 0865 (http://www.inchem.org/documents/icsc/icsc/eics0865.htm)

Retrieved from "http://en.wikipedia.org/w/index.php?title=Glucose&oldid=557051355"
Categories: Glycolysis | Glucose | Chemical pathology | Nutrition | Starch | Sweeteners | World Health Organization essential medicines

- This page was last modified on 27 May 2013 at 18:18.
- Text is available under the Creative Commons Attribution-ShareAlike License; additional terms may apply. By using this site, you agree to the Terms of Use and Privacy Policy.
  Wikipedia® is a registered trademark of the Wikimedia Foundation, Inc., a non-profit organization.