

## BIOCHEMISTRY of CARBOHYDRATES

Carbohydrates are organic compounds that contain only carbon (C), hydrogen (H), and oxygen (O).

Every carbon atom is attached to one oxygen atom. There are thousands of different carbohydrates, but they all consist of one or more smaller units called monosaccharides. All carbohydrates are made up of individual "units," which are sugars. By the ability to hydrolyze into monomers, carbohydrates fall into two groups, ethers and esters. Carbohydrates are produced in green plants by photosynthesis and serve as a major energy source in animal diets.

Carbohydrates are composed of three or more units called complex CHO.

**1. SLOW CARBOHYDRATES** = are foods rich in carbohydrates which slowly and gradually increase the level of glucose and have a low glycemic index.

**2. COMPLEX CARBOHYDRATES** = are polycondensation products of simple sugars (monosaccharide), in which, in their hydrolytic cleavage, can decompose into monomers to produce hundreds of thousands of molecules of monosaccharides.

### FUNCTIONS OF CARBOHYDRATES (CHO)

1. Carbohydrates provides energy and regulation of blood glucose.
2. It will prevent the degradation of skeletal muscle and other tissues such as the heart, liver, and kidneys.
3. It prevent the breakdown of proteins for energy.
4. Carbohydrates also help with fat metabolism. If the body has enough energy for its immediate needs, it stores extra energy as fat.
5. Carbohydrates are an important component of many industries like textile, paper, lacquers and breweries.
6. Detoxification of physiological importance is carried out to some extent with carbohydrate derivatives.
7. Agar is a polysaccharide used in culture media, laxative and food.
8. They help make up the body mass being included in all the parts of the cell and tissues.
9. Adequate storage of hepatic glycogen helps in detoxifying a normal liver.
10. Carbohydrates help clear gut and prevent constipation.

### CLASSIFICATION OF CARBOHYDRATES

1. **MONOSACCHARIDE** means one (mono) sugar (saccharide), and thus monosaccharides referred to as *Simple Sugars*. They are containing a single polyhydroxy aldehyde or polyhydroxy ketone unit (single- chain or single- ring structures), containing 3 to 7 carbon atoms; 5 and 6- carbon species are especially common. They are classified as a triose, tetrose, pentose, hexose, or heptose. Pure monosaccharides are water-soluble white, crystalline solids. They are classified into glucose, fructose, galactose, ribose, and deoxyribose. Its general formula  $C_nH_{2n}O_n$ .

The structures of many monosaccharides were first determined by Emil Fischer in the 1880s and 1890s and are still written according to a convention he developed. The Fischer projection represents what the molecule would look like if its three-dimensional structure were projected onto a piece of paper.

- **Glucose:**

Glucose also called *blood sugar or sugar of the body*, universal cellular fuel. It can be seen in fruit juices and formed in the body by hydrolysis of cane sugar, starch, lactose, and maltose. Its structure can be depicted in the form of a ring or chain. It is found in fruits, honey, and under abnormal conditions in urine.

- **Fructose**

Fructose can be seen naturally in honey, tomatoes and apples. Hydrolysis of cane sugar in the body can also give up fructose.  $C_6H_{12}O_6$  is the molecular formula for

fructose. Generally, fructose is the sweetest monosaccharide and is prepared by sucrose hydrolysis.

- **Galactose**

An element of glycoproteins and glycolipids. Sugar produced in the mammary glands, it is hydrolyzed to make the lactose of milk.

Diseases associated with carbohydrate metabolism include **Diabetes mellitus, galactosemia, glycogen storage diseases, and lactose intolerance.**

- **Mannose**

On the hydrolysis of plants gums and mannoses, mannose is obtained. mannose is a constituent of the prosthetic polysaccharide of albumins, mucoproteins and globulins. Hexoses and pentoses exist in both ring and gen chain forms.

#### ✚ **Properties of Monosaccharides**

- ✓ Most monosaccharides have a sweet taste (fructose is sweetest; 73% sweeter than sucrose).
- ✓ They are solids at room temperature.
- ✓ They are extremely soluble in water: – Despite their high molecular weights, the presence of large numbers of OH groups make the monosaccharides much more water soluble than most molecules of similar MW.
- ✓ Glucose can dissolve in minute amounts of water to make a syrup (1 g / 1 ml H<sub>2</sub>O).

2. **DISACCHARIDE** or *double sugars*, are formed when two simple sugars are joined by a synthesis reaction known as *Dehydration synthesis*. In this reaction, a water molecule is lost as the bond forms.  $C_n(H_2O)_{n-1}$  is the general formula for disaccharide. The most common disaccharides forms are lactose, maltose and sucrose. Its general formula  $C_{12}H_{22}O_{11}$ .

- **Lactose** can be found in milk or the *Milk sugar*. On hydrolysis, it produces D-galactose and D-glucose. It is a reducing disaccharide, as it has a free anomeric carbon on the glucose residue.
- **Maltose** or *Malt sugar* is formed as a transitional product of the action of amylases on starch and it contains 2 glucose residues in 1, 4 linkages. It can be seen in a detectable amount in many germinating tissues and seeds where starch is being broken down.
- **Sucrose** or *Cane sugar* is a disaccharide of fructose and glucose. The hydrolysis of sucrose to D-glucose and D-fructose is often known as inversion as it is accompanied by a net change in optical rotation from dextro to levo as the equimolar mixture is known as *invert sugar*. Certain enzymes like invertases catalyze this reaction. It is also tremendously abundant in the plants and is commonly known as *Table sugar*.
- **Trehalose** possesses two D-glucose and it is a non-reducing disaccharide like that of sucrose. It is the main sugar that can be seen in many of the insects haemolymph.

3. **POLYSACCHARIDE** (literally "many sugars"- ten or more) The final category of carbohydrates.

- are long, branching chains of linked simple sugars. Because they are large, insoluble molecules, they are ideal storage products. Another consequence of their large size is that they lack the sweetness of the simple and double sugars. There large number of monosaccharides units bonded together by **glycosidic bonds**. Three important polysaccharides, all made up of glucose units, are starch, glycogen, and cellulose.

Only two polysaccharides, starch and glycogen, are of major importance to the body. *Starch* is the storage polysaccharide formed plants. We invest it in the form of "starchy" foods, such as grains products (rice and corn) and root vegetables (potatoes, carrots, beans and peas). *Glycogen* is a slightly smaller, but similar, polysaccharide found in animal tissues (largely in the muscles and the liver). Like starch, it is formed of linked glucose units.

CLASSIFIED INTO TWO TYPES: HOMOPOLYSACCHARIDES, AND HETEROPOLY SACCHARIDES.

a. Homopolysaccharides or Homoglycans are the complex carbohydrates that are formed by the method of polymerization of only one type of monosaccharide monomers. Examples: glycogen, starch and cellulose are composed of a single type of monosaccharide known as glucose.

b. Heteropolysaccharides or Heteroglycans are the complex carbohydrates that are made by the process of condensation of either one type of monosaccharide monomer or monosaccharide derivatives. Examples: agar, chitin, arbanogalactaus, peptidoglycan, arabinoxylan, etc.

- **Starch: Amylose and Amylopectin**

Starch is used for energy storage in plants. It is found in all plant seeds and tubers and is the form in which glucose is stored for later use. Starch can be separated into two principal polysaccharides: amylose and amylopectin. Although the starch from each plant is unique, most starches contain 20 to 25% amylose and 75 to 80% amylopectin.

Complete hydrolysis of both amylose and amylopectin yields only D-glucose. Amylose is composed of continuous, unbranched chains of as many as 4000 D-glucose units joined by  $\alpha$ -1,4-glycosidic bonds. Amylopectin contains chains of as many as 10,000 D-glucose units also joined by  $\alpha$ -1,4- glycosidic bonds. In addition, considerable branching from this linear network occurs. New chains of 24 to 30 units are started at branch points  $\alpha$ -1,6-glycosidic bonds.

- **Glycogen**

Glycogen acts as the energy- reserve carbohydrate for animals. Like amylopectin, it is a branched polysaccharide containing approximately  $10^6$  glucose units joined by  $\alpha$ -1,4- and  $\alpha$ -1,6- glycosidic bonds. The total amount of glycogen in the body of a well-nourished adult human is about 350g, divided almost equally between liver and muscle.

- **Cellulose**

Cellulose, most widely distributed plant skeletal; polysaccharide, constitute almost half of the cell-wall material of wood. Cotton is almost pure cellulose.

Cellulose is a linear polysaccharide of D-glucose units joined by  $\beta$ -1,4-glucose units joined by  $\beta$ -1,4-Glycosidic bonds. It has an average molecular weight of 400,000 g/mol, corresponding to approximately 2200 glucose units per molecule. The difference between cellulose and amylose can be seen by comparing the figures of amylose and cellulose. Cellulose is formed by linking  $\beta$ -glucopyranose rings, instead of the  $\alpha$ -glucopyranose rings in starch and glycogen.

The -OH substituent that serves as the primary link between  $\beta$ -glucopyranose rings in starch and glycogen is perpendicular to the plane of the six-membered ring. As a result, the glucopyranose rings in these carbohydrates form a structure that resembles the stairs of a staircase. The -OH substituent that links the  $\beta$ -glucopyranose rings in cellulose lies in the plane of the six-membered ring. This molecule therefore stretches out in a linear fashion. This makes it easier for strong hydrogen bonds to form between the -OH groups of adjacent molecules.

This, in turn gives cellulose the rigidity required for it to serve as a source of the mechanical structure of plant cells.

Cellulose and starch provide an excellent example of the link between the structure and function of biomolecules. At the turn of the century, Emil Fischer suggested that the structure of an enzyme is matched to the substance on which it acts, in much the same way that a lock and key are matched. Thus, the amylase enzymes in saliva that break down the  $\alpha$ -linkages between glucose molecules in starch cannot act on the  $\beta$ -linkages in cellulose.

Most animals cannot digest cellulose because they don't have an enzyme that can cleave  $\beta$ -linkages between glucose molecules. Cellulose in their diet therefore serves only as fiber, or roughage. The digestive tracts of some animals, such as cows, horses, sheep, and goats contain bacteria that have enzymes that cleave these  $\beta$ -linkages, so these animals can digest cellulose.

4. **OLIGOSACCHARIDE** is a carbohydrate that contains three to ten monosaccharide units covalently bonded to each other. "Free" oligosaccharides are seldom encountered in biochemical systems. They are usually found associated with proteins and lipids in complex molecules that have both structural and regulatory functions. Complete hydrolysis of an oligosaccharide produces three monosaccharide units, a hexasaccharide produces six monosaccharide units, and so on.
5. **TRISACCHARIDE** occur free in nature and contain three monosaccharide units. Carbohydrates that on hydrolysis give three molecules of monosaccharides, whether same or different. An example is Raffinose and Melezitose.
6. **TERTRASACCHARIDES** and as the name suggest this carbohydrate on hydrolysis give four molecules of monosaccharides. An example is Stachyose namely Gal, gal, glucose, & fructose.

## GENERAL PROPERTIES OF CARBOHYDRATES

### PHYSICAL PROPERTIES OF CARBOHYDRATES

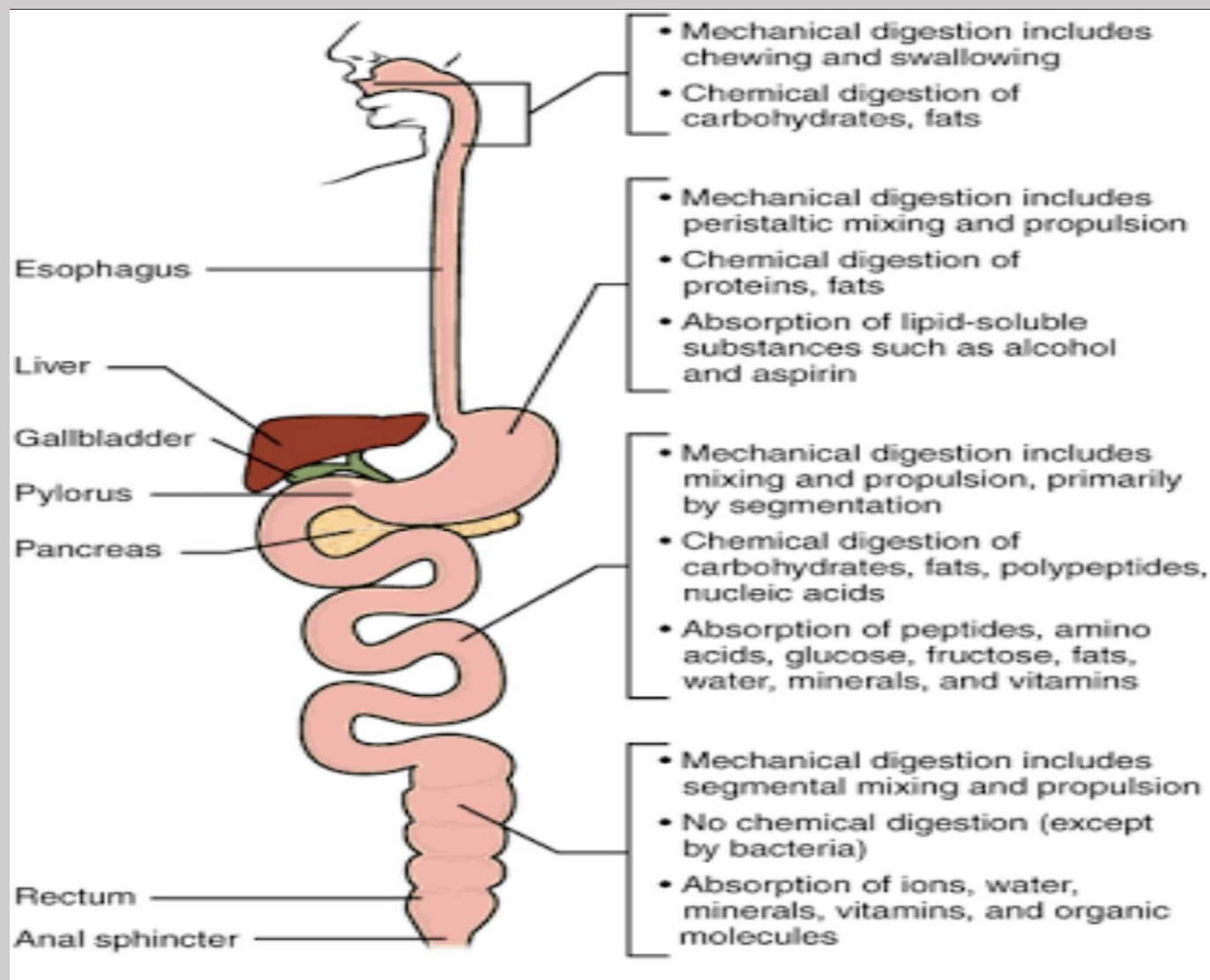
- Stereoisomerism – Compound having same structural formula but they differ in spatial configuration. Example: Glucose has two isomers with respect to penultimate carbon atom. They are D-glucose and L-glucose.
- Optical Activity – It is the rotation of plane polarized light forming (+) glucose and (-) glucose.
- Diastereo isomers – It the configurational changes with regard to C2, C3, or C4 in glucose. Example: Mannose, galactose.
- Anomerism – It is the spatial configuration with respect to the first carbon atom in aldoses and second carbon atom in ketoses.

### CHEMICAL PROPERTIES OF CARBOHYDRATES

- Osazone formation: Osazone are carbohydrate derivatives when sugars are reacted with excess of phenyl hydrazine. e.g. Glucosazone
- Benedict's test: Reducing sugars when heated in the presence of an alkali get converted to powerful reducing species known as enediols. When Benedict's reagent solution and reducing sugars are heated together, the solution changes its colour to orange-red/ brick red.
- Oxidation: Monosaccharides are reducing sugars if their carbonyl groups oxidize to give carboxylic acids.  
In the Benedict's test, D-glucose is oxidized to D-gluconic acid thus, glucose is considered a reducing sugar.
- Reduction to alcohols: The C=O groups in open chain forms of carbohydrates can be reduced to alcohols by sodium borohydride, NaBH<sub>4</sub>, or catalytic hydrogenation (H<sub>2</sub>, Ni, EtOH/H<sub>2</sub>O). The products are known as "alditols".

**DIGESTION AND ABSORPTION OF CARBOHYDRATES**

The mechanical and chemical digestion of carbohydrates **begins in the mouth**. Chewing, also known as mastication, crumbles the carbohydrate foods into smaller and smaller pieces. The salivary glands in the oral cavity secrete saliva that coats the food particles. Saliva contains the enzyme, salivary amylase. This enzyme breaks the bonds between the monomeric sugar units of disaccharides, oligosaccharides, and starches. The salivary amylase breaks down amylose and amylopectin into smaller chains of glucose, called **dextrin and maltose**. The increased concentration of maltose in the mouth that results from the mechanical and chemical breakdown of starches in whole grains is what enhances their sweetness. Only about five percent of starches are broken down in the mouth. (This is a good thing as more glucose in the mouth would lead to more tooth decay.) When carbohydrates reach the stomach no further chemical breakdown occurs because the amylase enzyme does not function in the acidic conditions of the stomach. But the mechanical breakdown is ongoing—the strong peristaltic contractions of the stomach mix the carbohydrates into the more uniform mixture of chyme. From the stomach to the small Intestine, the chyme is gradually expelled. Upon entry of the chyme into the small intestine, the pancreas releases pancreatic juice through a duct. This pancreatic juice contains the enzyme, pancreatic amylase, which starts again the breakdown of dextrin into shorter and shorter carbohydrate chains. Additionally, enzymes are secreted by the intestinal cells that line the villi. These enzymes, known collectively as disaccharidases, are sucrase, maltase, and lactase. **Sucrase** breaks sucrose into glucose and fructose molecules. **Maltase** breaks the bond between the two glucose units of maltose, and lactase breaks the bond between galactose and glucose. Once carbohydrates are chemically broken down into single sugar units they are then transported into the inside of intestinal cells.



When people do not have enough of the enzyme lactase, lactose is not sufficiently broken down resulting in a condition called **lactose intolerance**. The undigested lactose moves to the large intestine where bacteria are able to digest it. The bacterial digestion of lactose produces gases leading to symptoms of diarrhea, bloating, and abdominal cramps.

Lactose intolerance usually occurs in adults and is associated with race. The National Digestive Diseases Information Clearing House states that African Americans, Hispanic Americans, American Indians, and Asian Americans have much higher incidences of lactose intolerance while those of northern European descent have the least. National Digestive Diseases Information Clearing House. "Lactose Intolerance." Last updated April 23, 2012, most people with lactose intolerance can tolerate some amount of dairy products in their diet. The severity of the symptoms depends on how much lactose is consumed and the degree of lactase deficiency.

### **CARBOHYDRATE METABOLISM**

Carbohydrate metabolism is the whole of biochemical processes responsible for the metabolic formation, breakdown, and interconversion of carbohydrates in living organisms.

Carbohydrates are central to many essential metabolic pathways. Plants synthesize carbohydrates from carbon dioxide and water through photosynthesis, allowing them to store energy absorbed from sunlight internally. When animals and fungi consume plants, they use cellular respiration to break down these stored carbohydrates to make energy available to cells. Both animals and plants temporarily store the released energy in the form of high-energy molecules, such as ATP, for use in various cellular processes.

Although humans consume a variety of carbohydrates, digestion breaks down complex carbohydrates into a few simple monomers (monosaccharides) for metabolism: glucose, fructose and galactose. Glucose constitutes about 80 percent of the products, and is primary structure that is distributed to cells in the tissues, where it is broken down or stored as glycogen. In aerobic respiration, the main form of cellular respiration used by humans, glucose and oxygen are metabolized to release energy, with carbon dioxide and water as byproducts. Most of the fructose and galactose travel to the liver, where they can be converted to glucose.

Some simple carbohydrates have their own enzymatic oxidation pathways, as do only a few more complex carbohydrates. The disaccharide lactose, for instance, requires the enzyme lactase to be broken into its monosaccharide components glucose and galactose.

Carbohydrate metabolism denotes the various biochemical processes responsible for the formation, breakdown and interconversion of carbohydrates in living organisms. The most important carbohydrate is glucose, a simple sugar (monosaccharide) that is metabolized by early all known organism. Fatty acid metabolism occurs primarily in your liver, muscle and heart, in a cell organelle called the mitochondria. Just like glucose, the end-products of fatty acid metabolism are carbon dioxide, water and ATP.

Metabolic processes are constantly taking place in the body. Metabolism is the sum of all the chemical reactions that are involved in catabolism and anabolism. The reactions governing the breakdown of food to obtain energy called catabolic reactions.

Carbohydrate metabolism begins in the mouth, where the enzyme salivary amylase begins to breakdown complex sugars into monosaccharides.

- Glycolysis = degradation of glucose to pyruvate (lactate under anaerobic) generates 8 ATP.
- Citric Acid Cycle = the oxidation of acetyl CoA to Co<sub>2</sub>.
- Gluconeogenesis = the synthesis of glucose from non-carbohydrate precursors (amino acids, glycerol, etc.)
- Glycogenesis = the synthesis of glycogen from glucose.

### **GLYCOLYSIS**

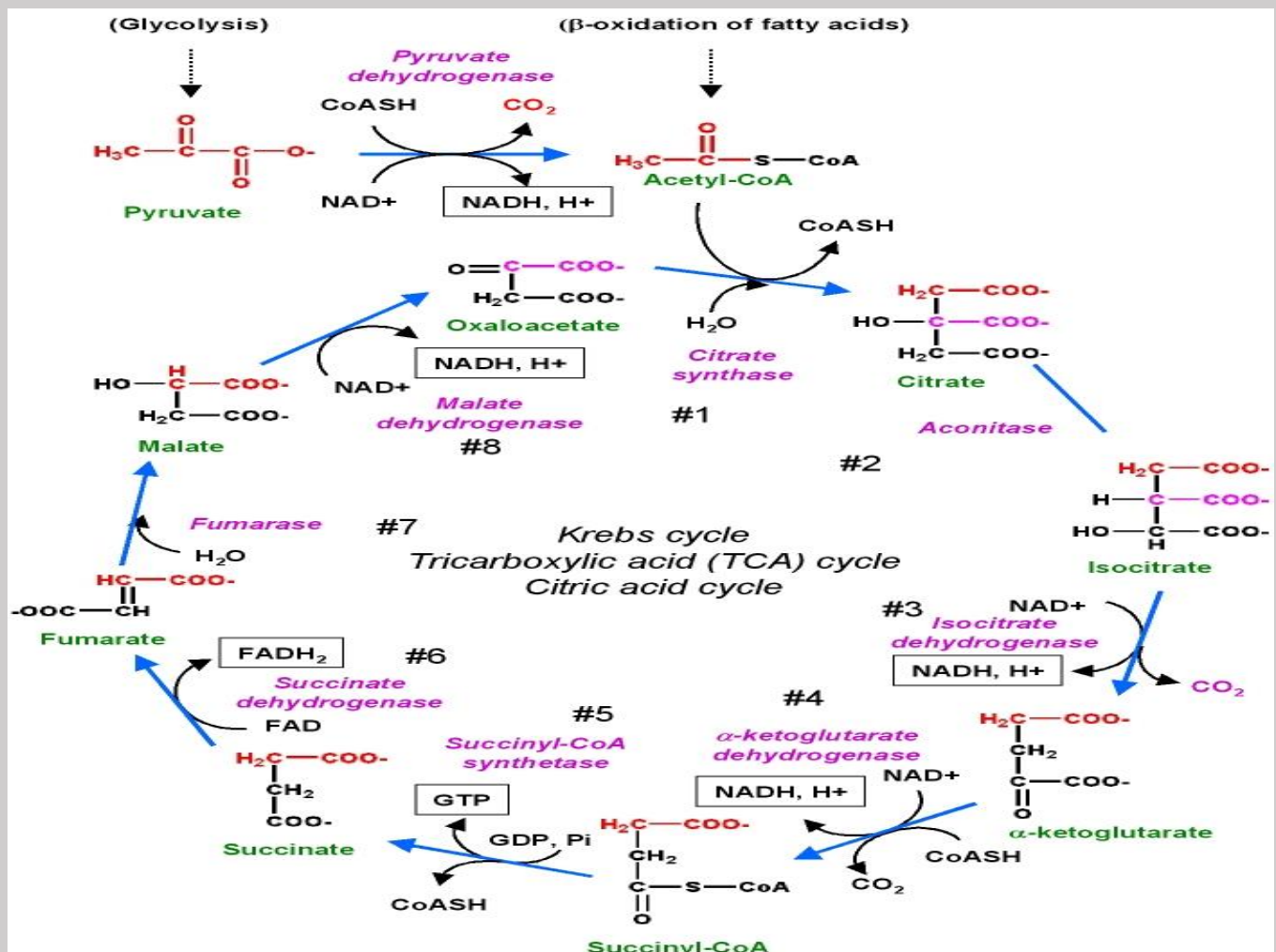
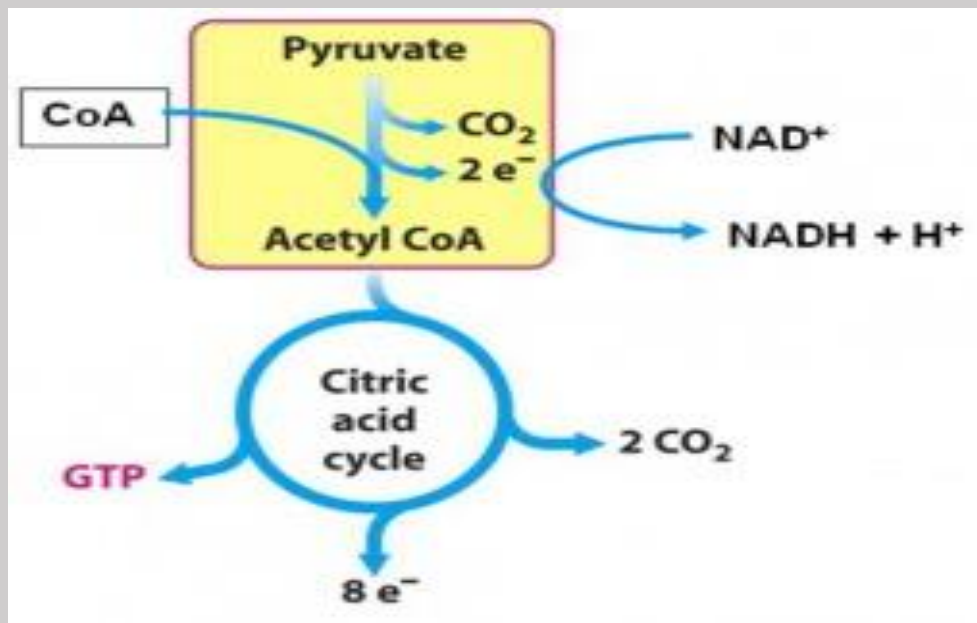
Glycolysis is the first metabolic pathway of cellular respiration and is a series of ten chemical reactions that occur in the cytosol of living cells. Glycolysis is a flexible process, in that it can function in anaerobic settings (a lack of oxygen) or aerobic settings (oxygen present), although the end products of those two conditions will be slightly different – lactate and pyruvate, respectively.

The word "glycolysis" can be separated into "glyco" and "lysis", which basically means "glucose" and "breaking/splitting". That is precisely what the process of glycolysis does – breaks down a 6-carbon sugar molecule (glucose) into two 3-carbon molecules of pyruvate, which will then go on to participate in the Krebs Cycle and the electron transport chain, in order to create more usable energy

### **KREB'S CYCLE**

The Krebs Cycle can also be called the Citric Acid Cycle (CAC) or the Tricarboxylic Acid (TCA) Cycle. This cycle takes place in the Mitochondrial matrix and is the primary step of aerobic processing within a cell. The process oxidises glucose derivatives, fatty acids and amino acids to carbon dioxide (CO<sub>2</sub>) through a series of enzyme controlled steps. The purpose of the Krebs Cycle is to collect (eight) high-energy electrons from these fuels by oxidising them, which are transported by activated carriers NADH and FADH<sub>2</sub> to the electron transport chain. The Krebs Cycle is also the source for the precursors of many other molecules, and is therefore an amphibolic pathway (anabolic and catabolic).

The sequence of reactions by which most living cells generate energy during the process of aerobic respiration. It takes place in the mitochondria, consuming oxygen, producing carbon dioxide and water as waste products, and converting ADP to energy-rich ATP.



ELECTRON TRANSPORT CHAIN

The electron transport chain is a mitochondrial pathway in which electrons move across a redox span of 1.1 V from NAD<sup>+</sup>/NADH to O<sub>2</sub>/H<sub>2</sub>O. Three complexes are involved in this chain, namely, complex I, complex III, and complex IV. Some compounds like succinate, which have more positive redox potential than NAD<sup>+</sup>/NADH can transfer electrons via a different complex—complex II. Coenzyme Q, or simply Q, can travel within membrane while Cyt C is a soluble protein. Flavoproteins are components of complexes I and II and Fe-S is present in complexes I, II, and III. The Fe atom present in Fe-S complexes helps in electron transfer by shifting from Fe<sup>2+</sup> to Fe<sup>3+</sup> states. With the help of oxidation–reduction reactions a proton gradient is created which causes phosphorylation of ADP.

### GLUCONEOGENESIS

Gluconeogenesis is the biosynthesis of new glucose, (i.e. not glucose from glycogen). This process is frequently referred to as endogenous glucose production (EGP). The production of glucose from other carbon skeletons is necessary since the testes, erythrocytes and kidney medulla exclusively utilize glucose for ATP production. The brain also utilizes large amounts of the daily glucose consumed or produced via gluconeogenesis. However, in addition to glucose, the brain can derive energy from ketone bodies which are converted to acetyl-CoA and shunted into the TCA cycle. The primary carbon skeletons used for gluconeogenesis are derived from pyruvate, lactate, glycerol, and the amino acids alanine and glutamine. The liver is the major site of gluconeogenesis, however, as discussed below, the kidney and the small intestine also have important roles to play in this pathway. Synthesis of glucose from three and four carbon precursors is essentially a reversal of glycolysis.

### GLUCOGENESIS

The production of glucose by the decomposition of glycogen or from any nonglucose precursor or it is the formation of glucose within the animal body from any product of glycolysis.

**Fructolysis** refers to the metabolism of fructose from dietary sources.

Though the metabolism of glucose through glycolysis uses many of the same enzymes and intermediate structures as those in fructolysis, the two sugars have very different metabolic fates in human metabolism. Unlike glucose, which is directly metabolized widely in the body, fructose is almost entirely metabolized in the liver in humans, where it is directed toward replenishment of liver glycogen and triglyceride synthesis. Under one percent of ingested fructose is directly converted to plasma triglyceride. 29% - 54% of fructose is converted in liver to glucose, and about a quarter of fructose is converted to lactate. 15% - 18% is converted to glycogen. Glucose and lactate are then used normally as energy to fuel cells all over the body.

**Fructose** is a dietary monosaccharide present naturally in fruits and vegetables, either as free fructose or as part of the disaccharide sucrose, and as its polymer inulin. It is also present in the form of refined sugars including granulated sugars (white crystalline table sugar, brown sugar, confectioner's sugar, and turbinado sugar), refined crystalline fructose, as high fructose corn syrups as well as in honey. About 10% of the calories contained in the Western diet are supplied by fructose (approximately 55 g/day). Unlike glucose, fructose is not an insulin secretagogue, and can in fact lower circulating insulin. In addition to liver, fructose is metabolized in intestine, testis, kidney, skeletal muscle, fat tissue and brain, but it is not transported into cells via insulin-sensitive pathways (insulin regulated transporters GLUT1 and GLUT4). Instead fructose is taken in by GLUT5. Fructose in muscles and adipose tissue is phosphorylated by hexokinase.

### THE METABOLISM OF FRUCTOSE TO DHAP AND GLYCERALDEHYDE

The first step in the metabolism of fructose is the phosphorylation of fructose to fructose 1-phosphate by fructokinase ( $K_m = 0.5 \text{ mM}$ ,  $\approx 9 \text{ mg/100 ml}$ ), thus trapping fructose for metabolism in the liver. Hexokinase IV (Glucokinase), also occurs in the liver and would be capable of phosphorylating fructose to fructose 6-phosphate (an intermediate in the gluconeogenic pathway); however, it has a relatively high  $K_m$  (12 mM) for fructose and, therefore, essentially all of the fructose is converted to fructose-1-phosphate in the human liver. Much of the glucose, on the other hand, is not phosphorylated ( $K_m$  of hepatic glucokinase (hexokinase IV) = 10 mM), passes through the liver directed toward peripheral tissues, and is taken up by the insulin-dependent glucose transporter, GLUT 4, present on adipose tissue and skeletal muscle.

Fructose-1-phosphate then undergoes hydrolysis by fructose-1-phosphate aldolase (aldolase B) to form dihydroxyacetone phosphate (DHAP) and glyceraldehyde; DHAP can either be isomerized to glyceraldehyde 3-phosphate by triosephosphate isomerase or undergo reduction to glycerol 3-phosphate by glycerol 3-phosphate



dehydrogenase. The glyceraldehyde produced may also be converted to glyceraldehyde 3-phosphate by glyceraldehyde kinase or converted to glycerol 3-phosphate by glyceraldehyde 3-phosphate dehydrogenase. The metabolism of fructose at this point yields intermediates in gluconeogenic pathway leading to glycogen synthesis, or can be oxidized to pyruvate and reduced to lactate, or be decarboxylated to acetyl CoA in the mitochondria and directed toward the synthesis of free fatty acid, resulting finally in TG synthesis.

### **GALACTOSE METABOLISM**

Galactose, which is metabolized from the milk sugar, lactose (a disaccharide of glucose and galactose), enters glycolysis by its conversion to glucose-1-phosphate (G1P). This occurs through a series of steps that is referred to as the Leloir pathway, named after Luis Federico Leloir who determined the overall process of galactose utilization. (/gəˈlæktʊs/, *galacto-* + *-ose*, "milk sugar"), sometimes abbreviated **Gal**, is a monosaccharide sugar that is about as sweet as glucose, and about 65% as sweet as sucrose. It is a C-4 epimer of glucose.

The word *galactose* was coined by Charles Weissman in the mid 19th century and is derived from Greek *galaktos* (milk) and the generic chemical suffix for sugars *-ose*. The etymology is comparable to that of the word *lactose* in that both contain roots meaning "milk sugar". Lactose is a disaccharide of galactose plus glucose.

Structure and isomerismGalactose exists in both open-chain and cyclic form. The open-chain form has a carbonyl at the end of the chain. Four isomers are cyclic, two of them with a pyranose (six-membered) ring, two with a furanose (five-membered) ring. Galactofuranose occurs in bacteria, fungi and protozoa, and is recognized by a putative chordate immune lectin intelectin through its exocyclic 1,2-diol. In the cyclic form there are two anomers, named alpha and beta, since the transition from the open-chain form to the cyclic form involves the creation of a new stereocenter at the site of the open-chain carbonyl. In the beta form, the alcohol group is in the equatorial position, whereas in the alpha form, the alcohol group is in the axial position.

### **PENTOSE PHOSPHATE PATHWAY**

The main molecule in the body that makes anabolic processes possible is NADPH. Because of the structure of this molecule it readily donates hydrogen ions to metabolites thus reducing them and making them available for energy harvest at a later time. The Pentose phosphate pathway is also called the phosphogluconate pathway and or the Hexose monosphate shunt . A process that breaks down glucose-6-phosphate into NADPH and pentoses for use in downstream biological processes. The pentose phosphate pathway (PPP) is also responsible for the production of Ribose-5-phosphate which is an important part of nucleic acids. Finally the PPP can also be used to produce glyceraldehyde-3-phosphate which can then be fed into the TCA and ETC cycles allowing for the harvest of energy.

#### **Importance**

The pentose phosphate pathway is the major source for the NADPH required for anabolic processes. There are three distinct phases each of which has a distinct outcome. Depending on the needs of the organism the metabolites of that outcome can be fed into many other pathways. Gluconeogenesis is directly connected to the pentose phosphate pathway. As the need for glucose-6-phosphate increases so does the activity of gluconeogenesis.

#### **Process**

The enzymes reasonable for catalyzing the steps of the PPP are found most abundantly in the liver (the major site of gluconeogenesis) more specifically in the cytosol. The cytosol is where fatty acid synthesis takes place which is a NADPH dependent process.

3 Distinct Phases

Oxidation phase

Isomerization phase

Rearrangement phase

**GLYCOGEN METABOLISM** Glycogen is a readily mobilized storage form of glucose. It is a very large, branched polymer of glucose residues that can be broken down to yield glucose molecules when energy is needed.

A large branched polysaccharide that is the main storage form of glucose in animals and humans.

Important energy reservoir.

Made and stored in the cells of liver and muscles that are hydrated with the four parts of water.

Acts as the secondary long term energy storage.

#### **Significance**

Glycogen is important because the glucose from glycogen is readily mobilized and is therefore a good source of energy for sudden strenuous activity.

Process

Glycogen degradation and synthesis are relatively simple biochemical processes. Glycogen degradation consists of three steps:

- (1) The release of glucose 1-phosphate from glycogen,
- (2) The remodeling of the glycogen substrate to permit further degradation,
- (3) The conversion of glucose 1-phosphate into glucose 6-phosphate for further metabolism.

### **GLYCOGENESIS**

The biological process of forming glycogen from glucose, the simplest cellular sugar. The body creates glycogen through the process of glycogenesis to store these molecules for use later, when the body does not have readily available glucose. Glycogen is not the same as fat, which is stored for long term energy. Glycogen stores are often resorted to between meals, when the blood glucose concentration has dropped. In this case, the cells of the body resort to their stores of glycogen, undergoing the reverse process from glycogenesis. This process is called glycogenolysis.

PROCESS

To start the process, the cell must have an excess of glucose. Glucose is the starting molecule, and is modified through the process of glycogenesis. Through the modifications, it gains the ability to be stored in long chains. The process starts when the cell receives a signal from the body to enter glycogenesis. These signals could come from a number of different routes, and are discussed in a later section. When glucose enters the glycogenesis process, it must be acted on by a number of enzymes as seen in the image below.

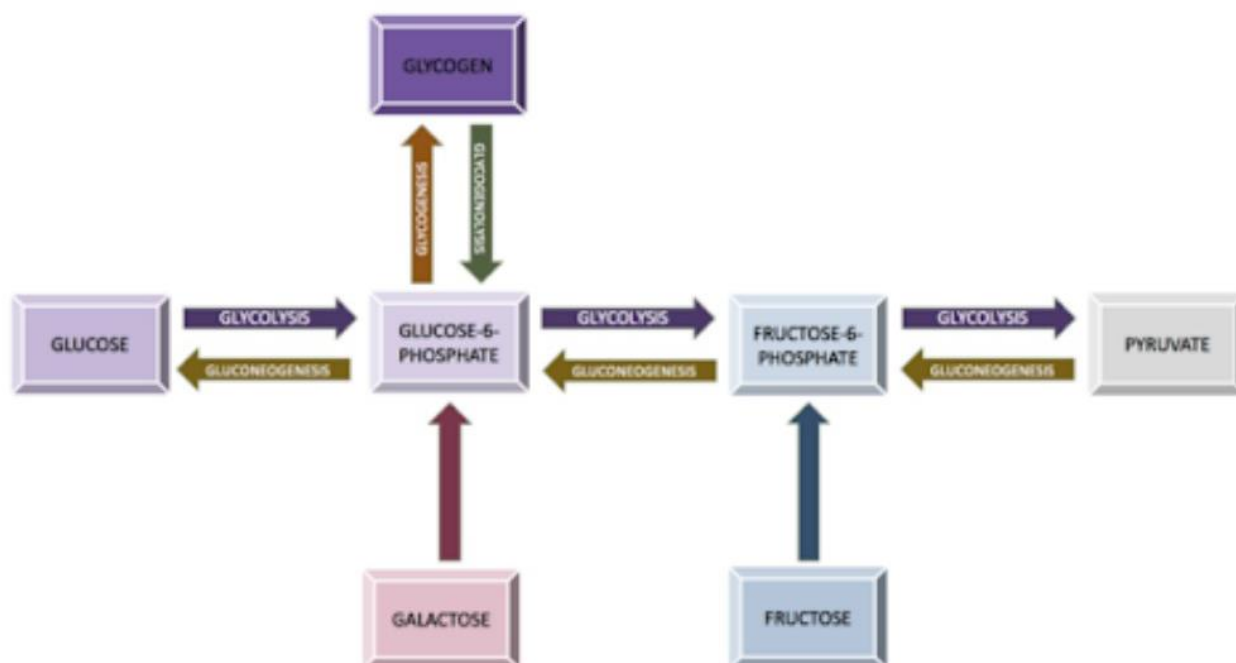
First, the glucose molecule interacts with the enzyme glucokinase, which adds a phosphate group to the glucose. In the next step of glycogenesis, the phosphate group is transferred to the other side of the molecule, using the enzyme phosphoglucomutase. A third enzyme, UDP-glucose pyrophosphorylase, takes this molecule and creates uracil-diphosphate glucose. This form of glucose has two phosphate groups, as well as the nucleic acid uracil. These additions aid in the next step, creating a chain of molecules.

A special enzyme, glycogenin, takes the lead in this part of glycogenesis. The UDP-diphosphate glucose can form short chains by binding to this molecule. After around 8 of these molecules chain together, more enzymes come in to finish the process. Glycogen synthase adds to the chain, while glycogen branching enzyme helps create branches in the chains. This leads to a more compact macromolecule, and thus more efficient storage of energy.

The enzymes within cells are prone to actively using glucose as quickly as possible. To save energy for times of no food intake, organisms must have a back-up source. When the cells have depleted all their glucose and are not receiving more from the body, they can turn to their stores of glycogen. Muscle cells, for example, commonly use glycogenesis to provide energy while exercising, because the blood glucose concentrations are not sufficient. The idea of “carbo-loading” (eating carbs and sugar before and athletic event) is based on the idea that cells will undergo glycogenesis and store as much glycogen as possible. Thus, when they need the energy during the exercise, it is readily available from glycogenolysis.

Glycogenesis is used to create glycogen from glucose, storing the energy within the bonds for future use.

A second function of glycogenesis is that of water conservation and management. A glucose molecule is a polar sugar molecule which is not tightly packed. The process of glycogenesis produces molecules which are less polar and much more compact than glucose. This means that a cell can store many glucose molecules in a single glycogen molecule, and upset the water balance less. Every salt and sugar within the cytoplasm takes a certain amount of water to surround and suspend. If cells stored only glucose for later, they would soon need more water than the volume of the cells could hold, and would burst. Glycogen reduces this, but also takes water to store.



### GLYCOGENOLYSIS

Is the breakdown of the molecule glycogen into glucose, a simple sugar that the body uses to produce energy. Glycogen is essentially stored energy in the form of a long chain of glucose, and glycogenolysis takes place in muscle and liver cells when more energy needs to be produced. The opposite of glycogenolysis is glycogenesis, which is the formation of glycogen from molecules of glucose.

#### **Function**

Glycogenolysis breaks down glycogen into glucose. Specifically, the process of glycogenolysis forms one molecule of glucose-6-phosphate, leaving the remaining chain of glycogen with one less molecule of glucose. This process is repeated many times so that multiple glucose molecules can be removed from the chain. Glucose molecules are removed via phosphorylation, which is the breaking down of a molecular acid.

#### **Difference between glycogenesis and glycolysis**

Glycogenolysis is the biochemical breakdown of glycogen to glucose whereas glycogenesis is the opposite, the formation of glycogen from glucose. Glycogenolysis takes place in the cells of muscle and liver tissues in response to hormonal and neural signals. In particular, glycogenolysis plays an important role in the adrenaline-induced fight-or-flight response and the regulation of glucose levels in the blood. The reverse process, glycogenesis, the formation of glycogen from glucose, occurs in liver and muscle cells when glucose and ATP are present in relatively high amounts. In the synthesis of glycogen, one ATP is required for every glucose unit incorporated into the polymeric branched structure of glycogen. The glucose (in the form of glucose-6-phosphate) is synthesized directly from glucose or as the end product of gluconeogenesis.

Glucose – A simple sugar that has an important role in metabolism and energy production.

Glycogen – A molecule that has long chains of glucose; glucose is stored in the form of glycogen.

Glycogenesis – The formation of glycogen by putting together glucose molecules; it is the opposite of glycogenolysis.

Adenosine triphosphate (ATP) – The main molecule used for energy in cells.

### CLINICAL SIGNIFICANCE OF CARBOHYDRATES

#### Significance of carbohydrates

Carbohydrates are the most abundant biomolecules in nature, having a direct link between solar energy and the chemical bond energy in living organisms.

Source of rapid energy production, structural building blocks of cell and a component of several metabolism pathways. It is also a recognition of cellular phenomenon, such as cell recognition and binding.

Sugar and starch are important production in the economy of mankind. They are extensively used as foods and pharmaceuticals.

#### **Diabetes Mellitus**

Diabetes mellitus is a disease that prevents your body from properly using the energy from the food you eat. Diabetes occurs in one of the following situations:

The pancreas (an organ behind your stomach) produces little insulin or no insulin at all. Insulin is a naturally occurring hormone, produced by the beta cells of the pancreas, which helps the body use sugar for energy.

-Or-

The pancreas makes insulin, but the insulin made does not work, as it should. This condition is called insulin resistance.

Your body is made up of millions of cells. To make energy, the cells need food in a very simple form. When you eat or drink, much of your food is broken down into a simple sugar called glucose. Glucose provides the energy your body needs for daily activities.

The blood vessels and blood are the highways that transport sugar from where it is either taken in (the stomach) or manufactured (in the liver) to the cells where it is used (muscles) or where it is stored (fat). Sugar cannot go into the cells by itself. The pancreas releases insulin into the blood, which serves as the helper, or the "key," that lets sugar into the cells for use as energy.

When sugar leaves the bloodstream and enters the cells, the blood sugar level is lowered. Without insulin, or the "key," sugar cannot get into the body's cells for use as energy. This causes sugar to rise. Too much sugar in the blood is called "hyperglycemia" (high blood sugar).

#### TWO MAIN TYPES OF DIABETES: TYPE 1 AND TYPE 2:

Type 1 diabetes occurs because the insulin-producing cells of the pancreas (beta cells) are damaged. In type 1 diabetes, the pancreas makes little or no insulin, so sugar cannot get into the body's cells for use as energy. People with type 1 diabetes must use insulin injections to control their blood glucose. Type 1 is the most common form of diabetes in people who are under age 30, but it can occur at any age. Ten percent of people with diabetes are diagnosed with type 1.

In type 2 diabetes (adult onset diabetes), the pancreas makes insulin, but it either doesn't produce enough, or the insulin does not work properly

#### **Glycogen Storage Disorder**

Glycogen storage disorder are abnormal group of inherited disorder characterized by deposition of an abnormal type or quantity of glycogen in the tissue. They are mainly due to the deficiency to one of the enzyme glycogenolysis or glycogenesis.