# CARBOHYDRATES

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# Specific Objectives

- Define carbohydrates
- Classification
- Biomedical importance
- General properties-reference to glucose

- Biomolecules
- Most abundant organic molecules in nature
- Contain more than one hydroxyl group (polyhydric) besides aldehyde or ketone group
- Hydrophilic

Found in many foods:

sugars, starches or fibers

# FUNCTIONS

- Main sources of energy in the body. Brain cells and RBCs are almost wholly dependent on carbohydrates as the energy source. Energy production from carbohydrates will be 4 kcal/g.
- Storage form of energy (starch and glycogen)
- Excess carbohydrate is converted to fat.
- Glycoproteins and glycolipids are components of cell membranes and receptors.
- Structural basis of many organisms: Cellulose of plants; exoskeleton of insects, cell wall of microorganisms, mucopolysaccharides as ground substance in higher organisms

General molecular formula is Cn(H2O)n.

Glucose-molecular formula $C_6H_{12}O_6$.

Polyhydroxy aldehydes or ketones or compounds which yield these on hydrolysis

# CLASSIFICATION

- Monosaccharides, Disaccharides, Polysaccharides
- Disaccharide-made-up of two monosaccharides joined by α or β glycosidic linkages. A polymer with more than 10 monosaccharide units is called polysaccharide

- Monosaccharides (simple sugars): cannot be hydrolysed further into simpler forms
- Number of carbon atoms, aldehyde (-CHO) or ketone (-CO)

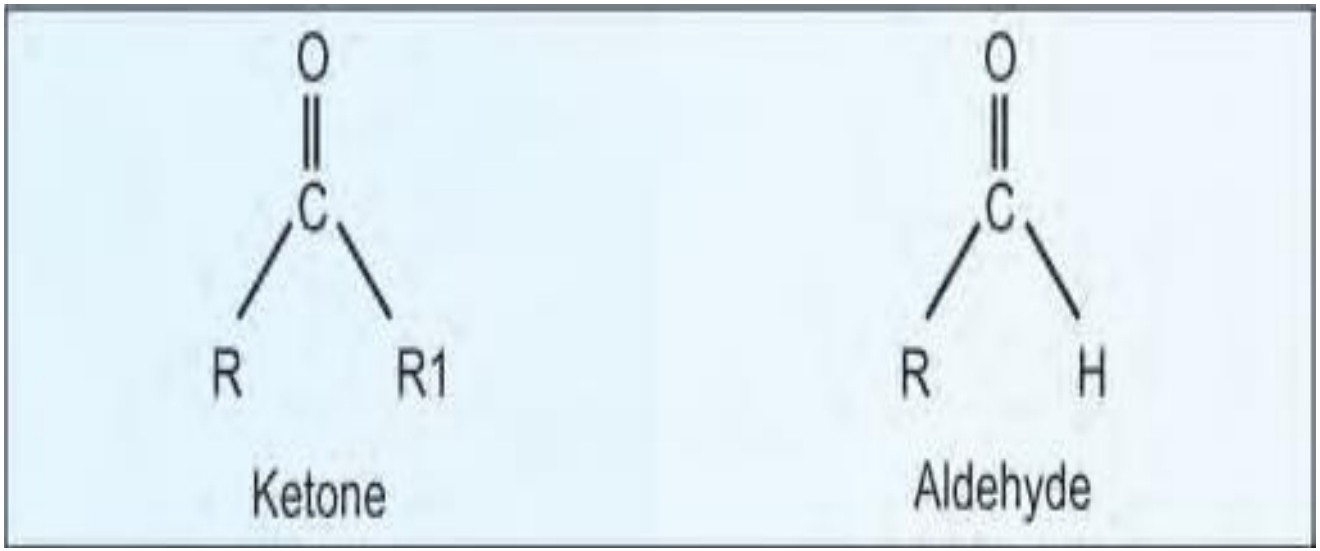



Fig: Keto group and aldehyde group

- Disaccharides- Hydrolysis yields 2 molecules of the same or different molecules of monosaccharides
- General formula: $C_n(H_2O)_{n-1}$

D and L-series

Orientation of H and OH groups around the carbon atom just adjacent to the terminal primary alcohol carbon

- Most monosaccharides occurring in mammals are D-sugars

- Maltose-2 molecules of glucose
- Lactose- glucose and galactose
- Sucrose- glucose and fructose

Wide range of functions:

Provide energy, act as storage molecules of energy, serve as cell membrane components and mediate some forms of communication between cells

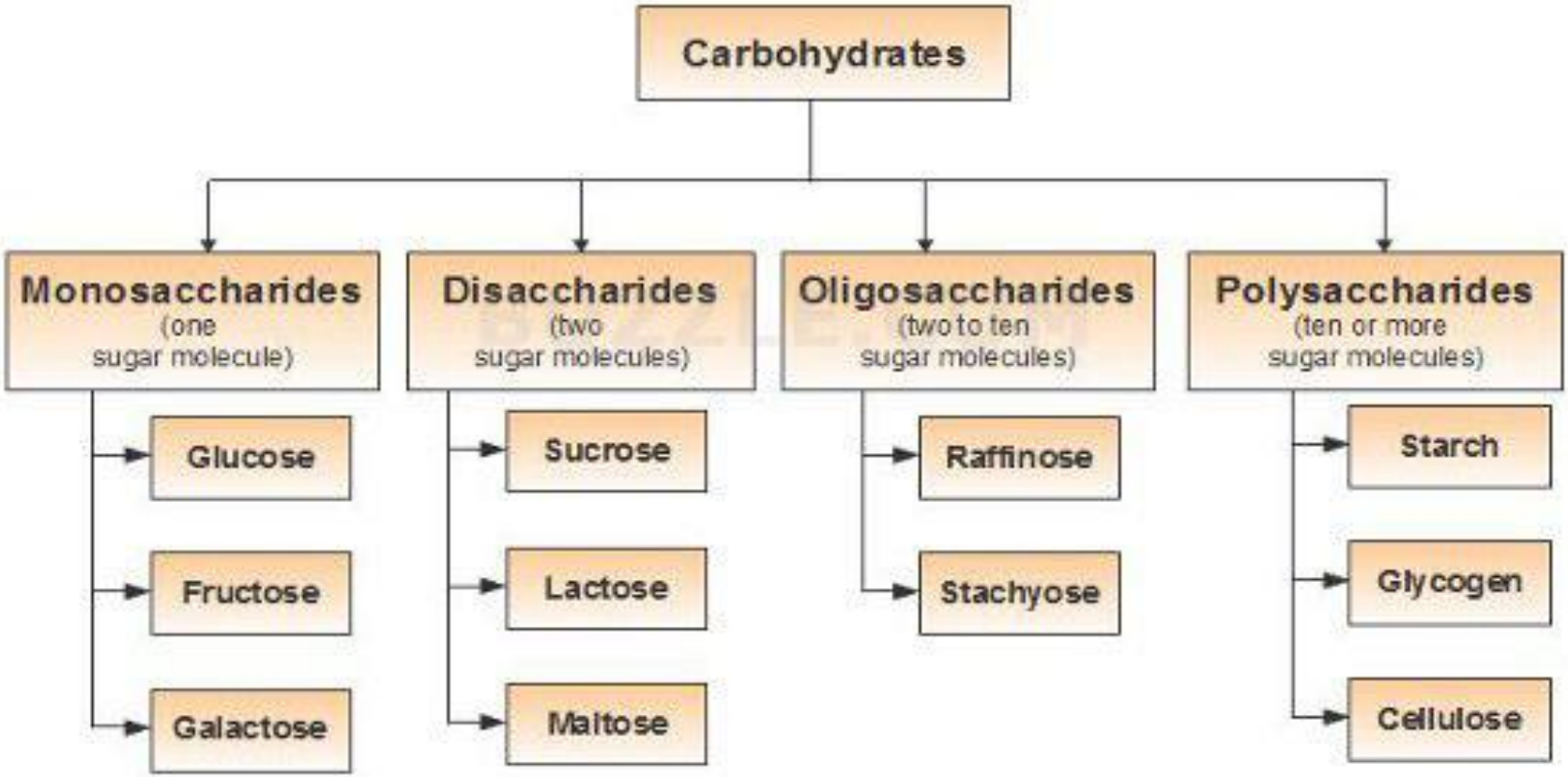
Inherited deficiency of certain enzymes in metabolic pathways:

-galactosemia, glycogen storage diseases, lactose intolerance

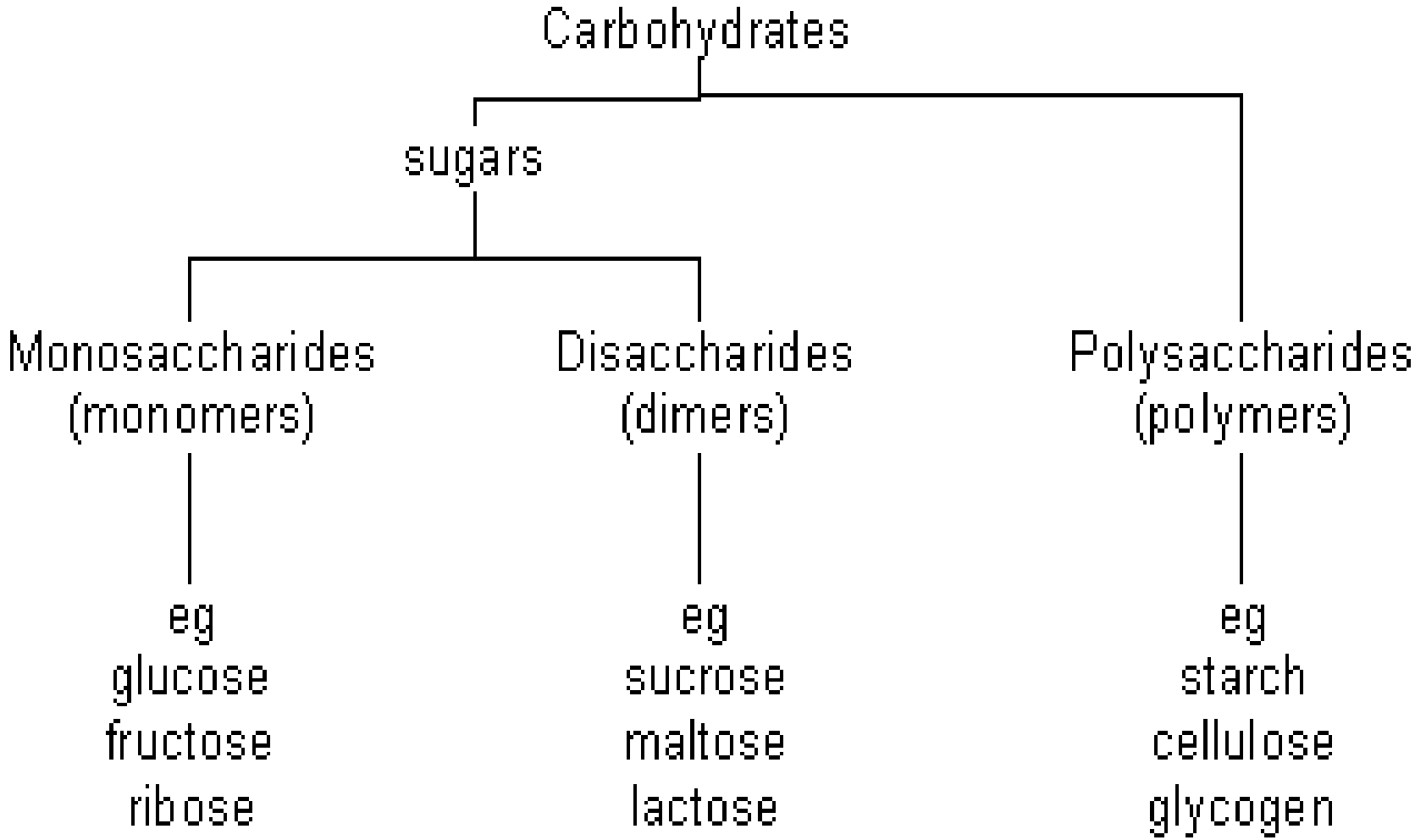
- Derangement of glucose metabolism: Diabetes mellitus

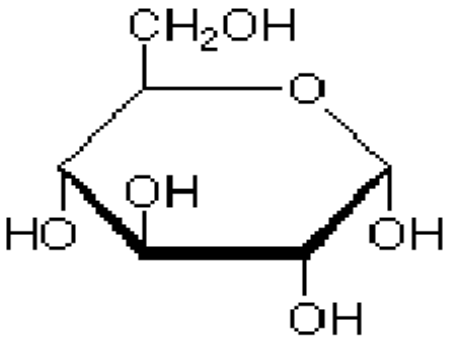
Failure of galactose and fructose metabolism due to deficient enzymes leads to turbidity of lens proteins (cataract)

Blood glucose is controlled by different hormones and metabolic processes: Diabetes if the insulin hormone is less or not functioning well-people are prone to atherosclerosis, vascular diseases and renal failure

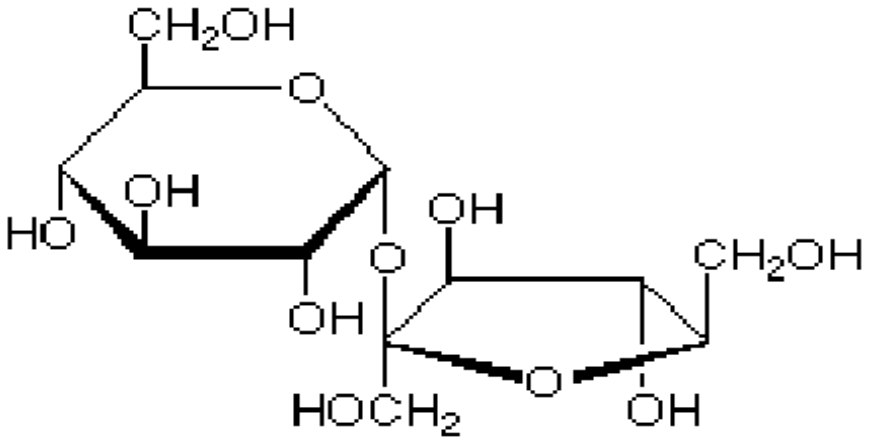

Carbohydrates
Monosaccharides
(one
sugar molecule)
Disaccharides
(two
sugar molecules)
Oligosaccharides
(two to ten
sugar molecules)
Polysaccharides
(ten or more
sugar molecules)
Glucose
Fructose
Galactose
Sucrose
Lactose
Maltose
Raffinose
Stachyose
Starch
Glycogen
Cellulose

‘Carbohydrate' comes from the atom carbon and hydrate or water, because the first carbohydrates that were discovered consisted of carbon, oxygen and hydrogen atoms

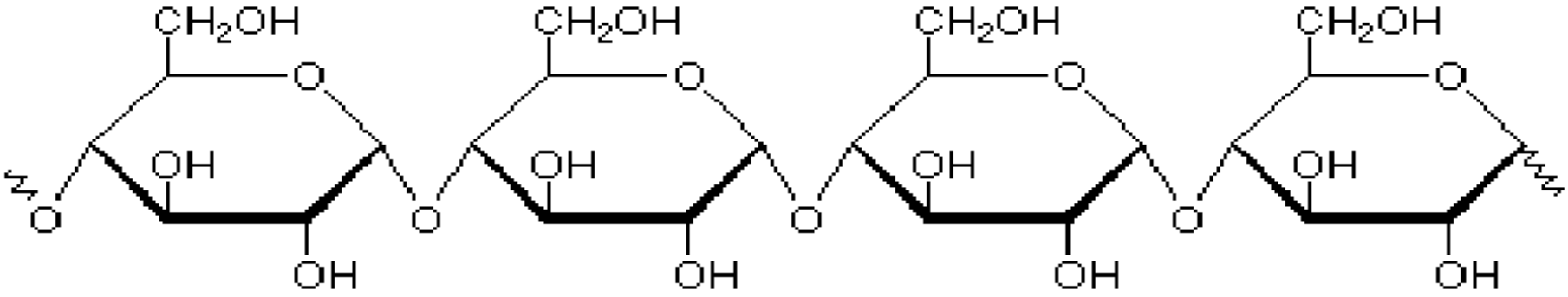

Carbohydrates
sugars
Monosaccharides
(monomers)
Disaccharides
(dimers)
Polysaccharides
(polymers)
eg
glucose
fructose
ribose
eg
sucrose
maltose
lactose
eg
starch
cellulose
glycogen




glucose (a monosaccharide)




sucrose (a disaccharide)



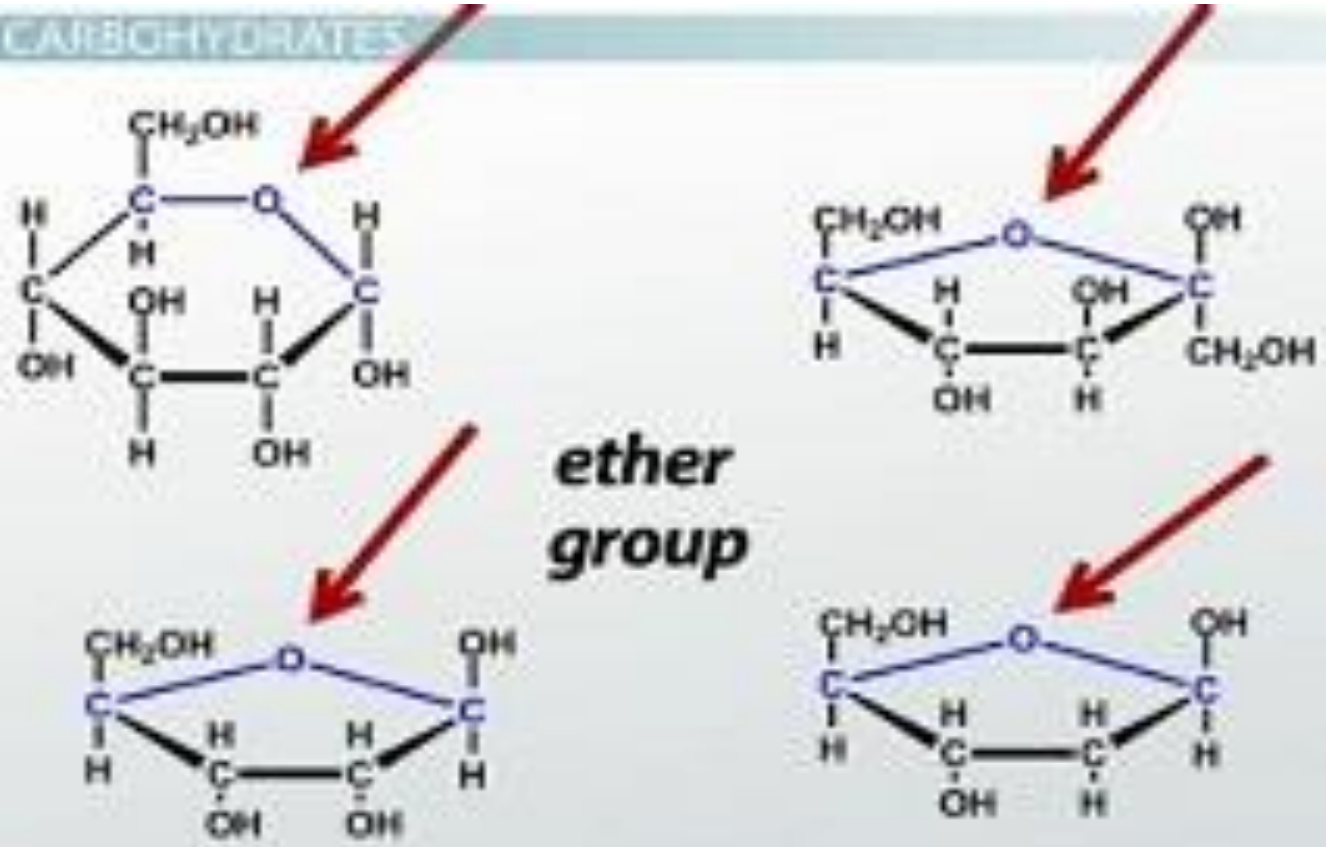

amylose (a polysaccharide/starch)

**Glucose**-the sugar that serves as fuel for our bodies.

**Fructose**-the sugar found in high-fructose corn syrup.

**Ribose**-plays an important role in holding together our genetic material.

**Deoxyribose**-very similar to ribose except that it lacks an oxygen or hydroxyl group on one of its carbons, hence 'deoxy'ribose. Important sugar that helps hold our genetic material together.


ether
group

## Monosaccharides

Formula $(CH_2O)_n$, n is between 3 and 7. Most common & important is glucose, a six-carbon sugar. Formula is $C_6H_{12}O_6$

**Monosaccharides**-simplest and smallest unit of the carbohydrates (mono = one, saccharide = sugar)

- Either aldehydes or ketones, with one or more hydroxyl groups
- Six-carbon monosaccharides, glucose (an aldohexose) and fructose (a keto hexose) have five hydroxyl groups

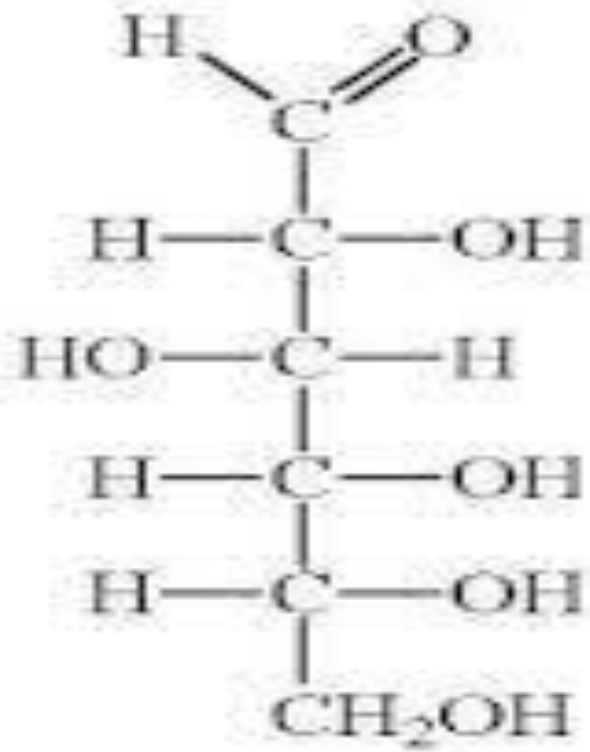
Carbon atoms, to which hydroxyl groups are attached, are often chiral centers, and stereoisomerism is common

Simple monosaccharides with four, five, six, and seven carbon atoms are called tetroses, pentoses, hexoses, and heptoses respectively

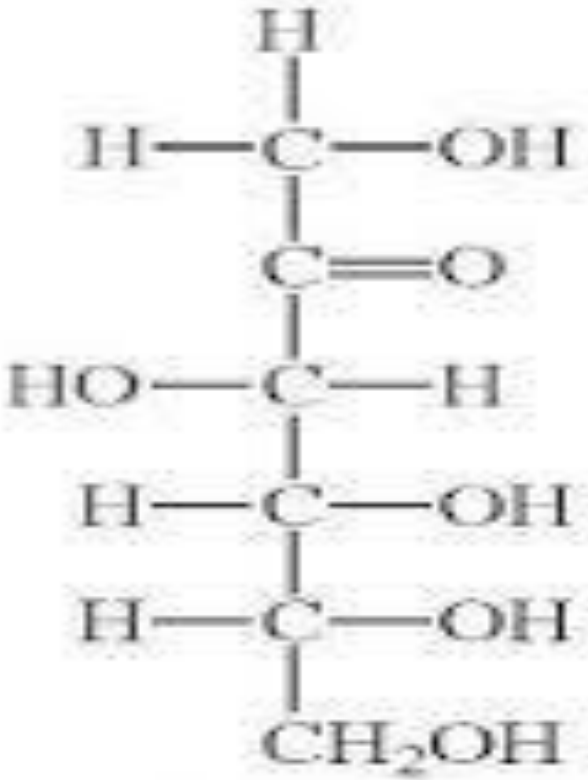
Molecules with multiple asymmetric carbons, exist as diastereoisomers, isomers that are not mirror images of each other, as well as enantiomers

In regard to these monosaccharides, the symbols, D and L designate the absolute configuration of the asymmetric carbon farthest from the aldehyde or keto group. D-Ribose, the carbohydrate component of RNA, is a five carbon aldose. D-Glucose, D-mannose, and D-galactose are abundant six-carbon aldoses

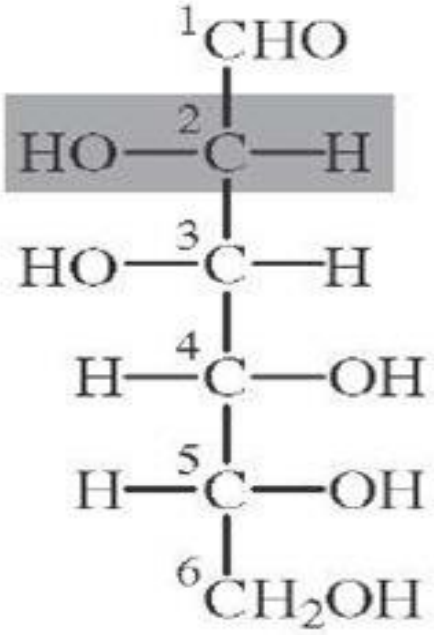
D-glucose and D-mannose differ in configuration only at C-2. Sugars differing in configuration at a single asymmetric center are called epimers. Thus, D-glucose and D-mannose are epimeric at C-2; D-glucose and D-galactose are epimers with respect to C-4.



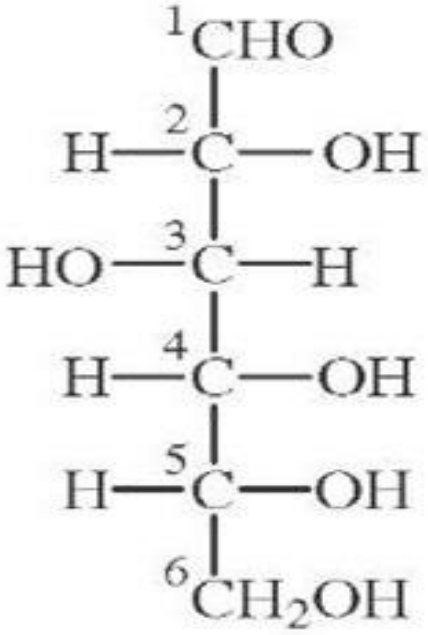

D-Glucose,
an aldohexose



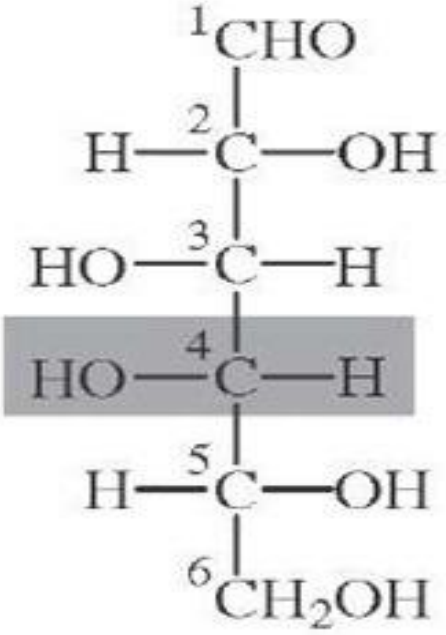

D-Fructose,
a ketohexose




D-Mannose
(epimer at C-2)




D-Glucose

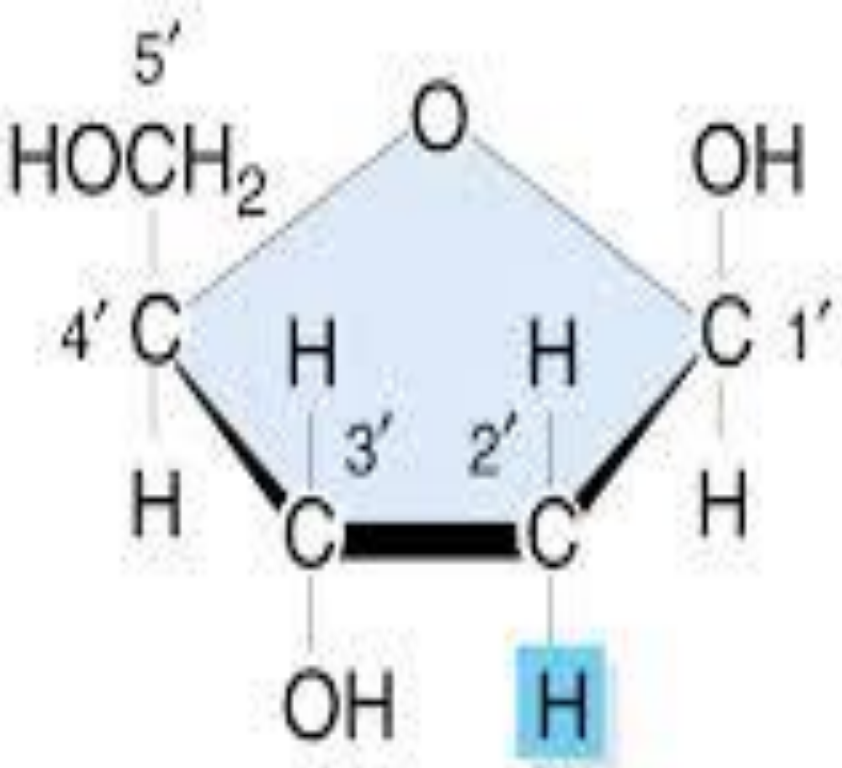



D-Galactose
(epimer at C-4)

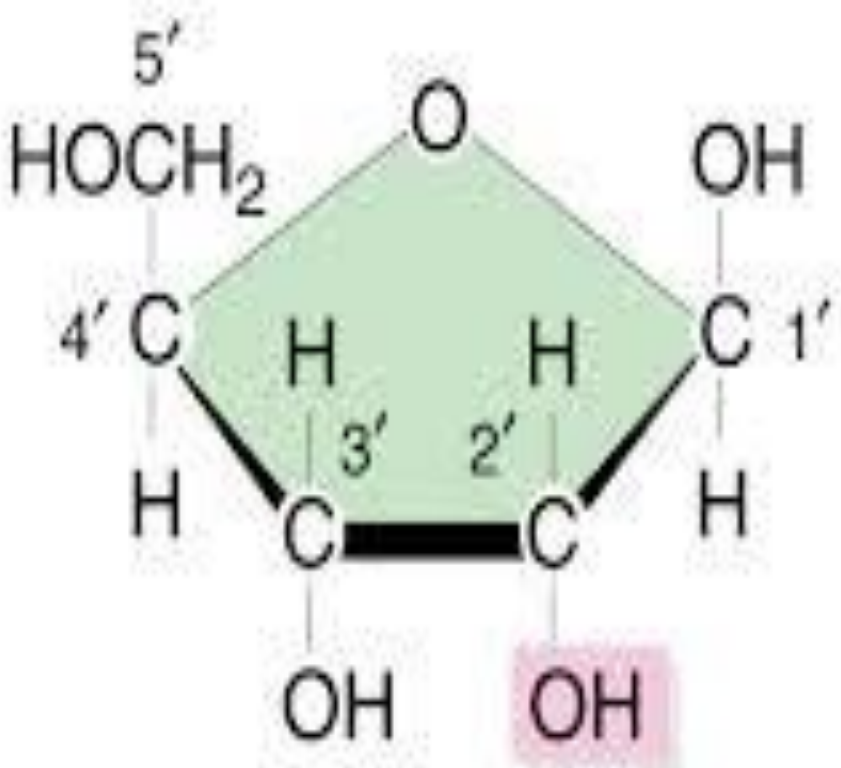
In animals, glucose is the main transport sugar in the blood. Concentration in the blood is carefully controlled

There are many monosaccharides, with the same chemical formula ($C_6H_{12}O_6$), but different structural formulae- fructose and galactose

Common five-carbon sugars (where n = 5, $C_5H_{10}O_5$) include ribose and deoxyribose (found in nucleic acids and ATP)

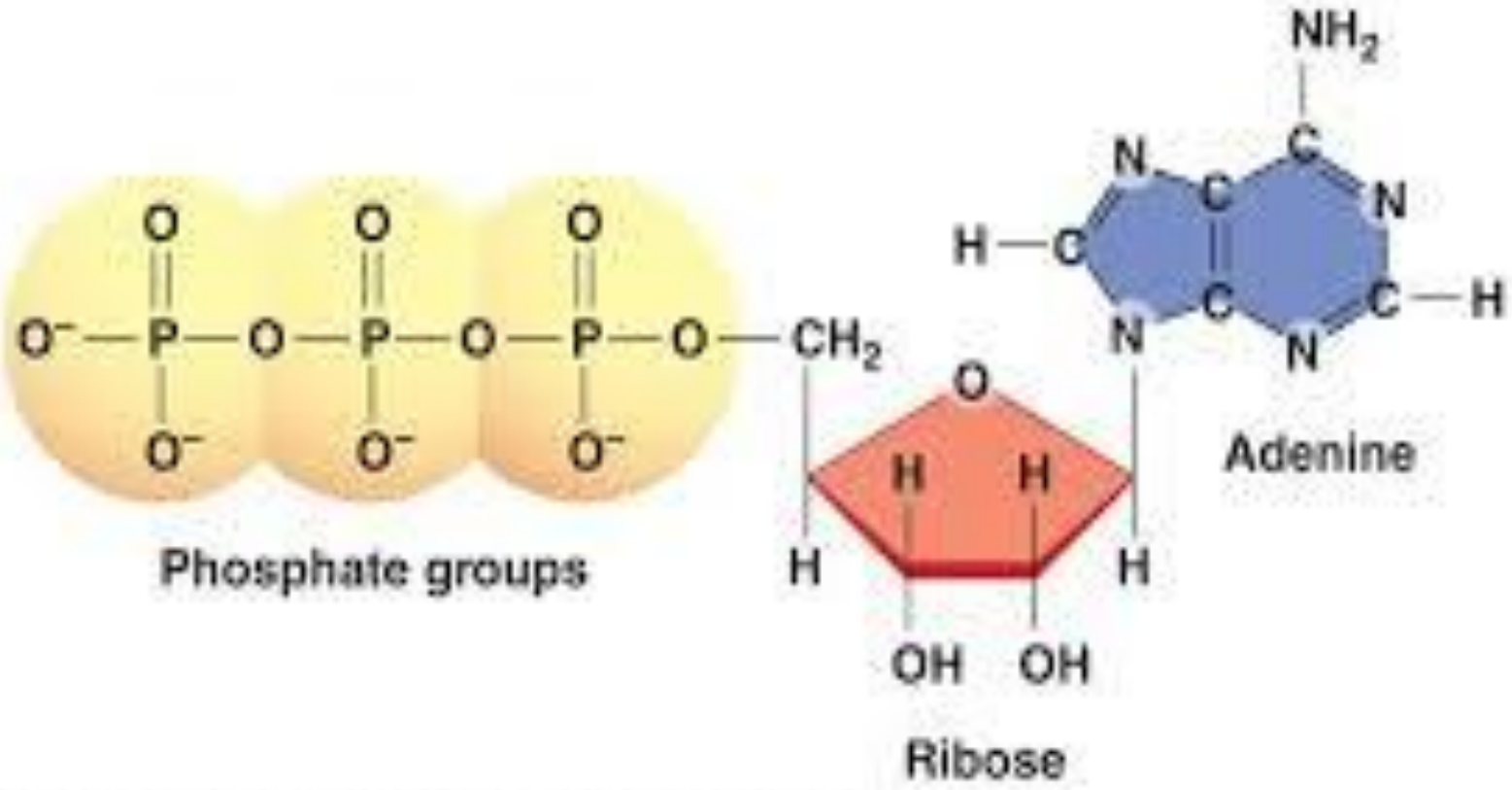



**Deoxyribose**




**Ribose**

(a) ATP consists of three phosphate groups, ribose, and adenine.



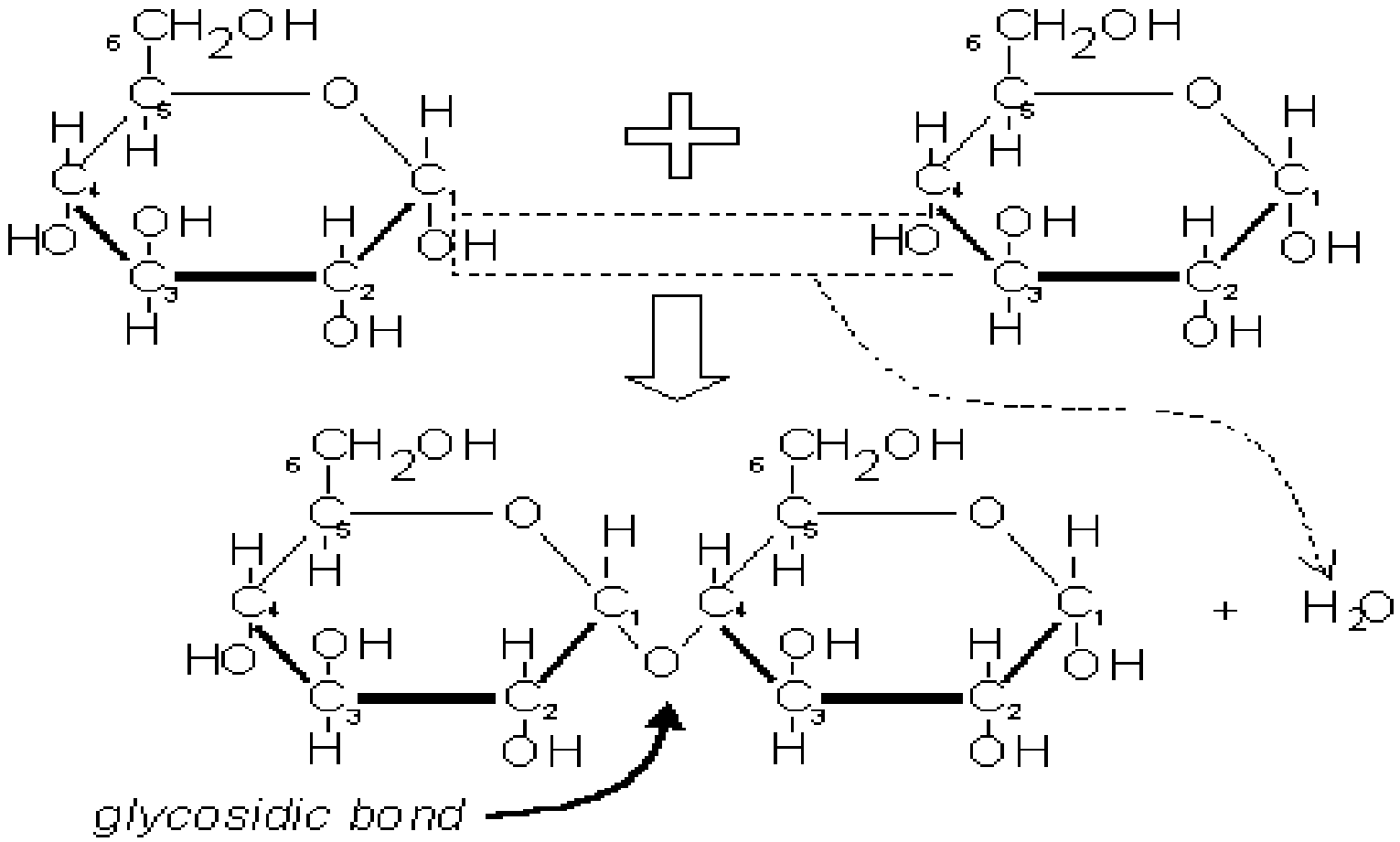
## Disaccharides

Two monosaccharides are joined together by a glycosidic bond. The reaction involves the formation of a molecule of water ($H_2O$)

Heterosaccharides

Homosaccharides

# MALTOSE



Two glucose molecules joining together to form the disaccharide, maltose. Bond is between carbon 1 of one molecule and carbon 4 of the other molecule it is called a (1-4 glycosidic bond).

- Polymerisation reactions-**condensation**
- Breakdown reactions-**hydrolysis**

Three common disaccharides:

Maltose (malt sugar) is glucose & glucose- Formed on digestion of starch by amylase. Enzyme breaks starch down into two-glucose units.

- Brewing beer starts with malt, which is a maltose solution made from germinated barley. Structure shown above

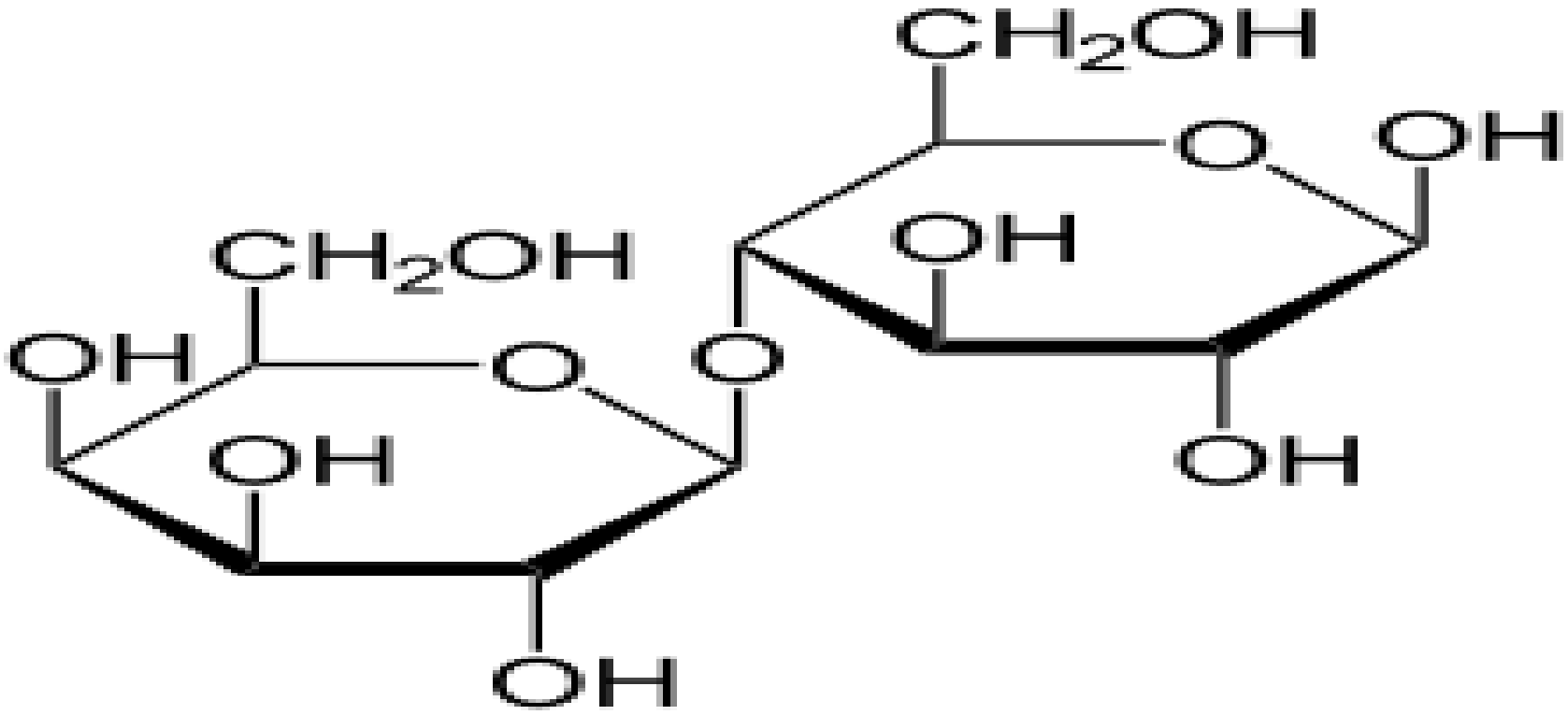
Sucrose (cane sugar) is glucose & fructose

Common in plants-less reactive than glucose-main transport sugar-common table sugar

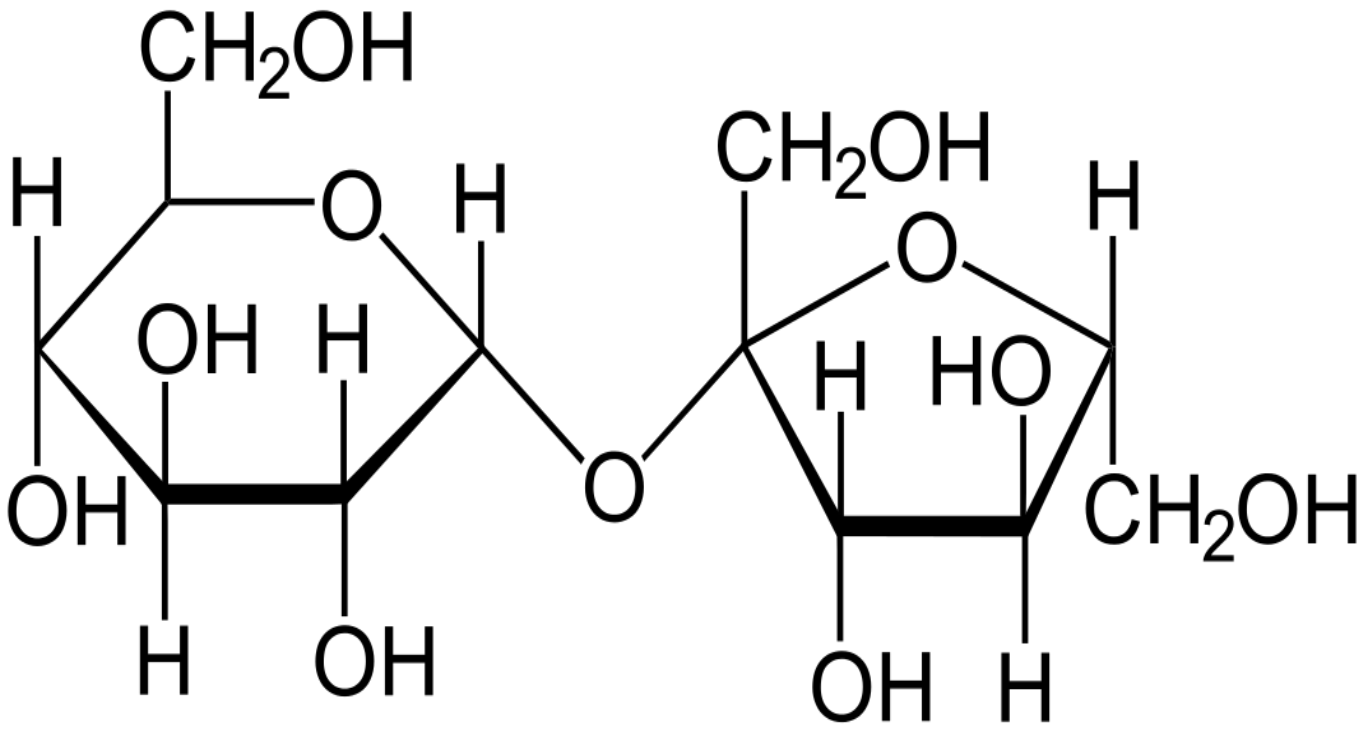
Lactose (milk sugar) is galactose & glucose

Found only in mammalian milk-main source of energy for infant mammals

LACTOSE



# SUCROSE



# Polysaccharides

Relatively complex

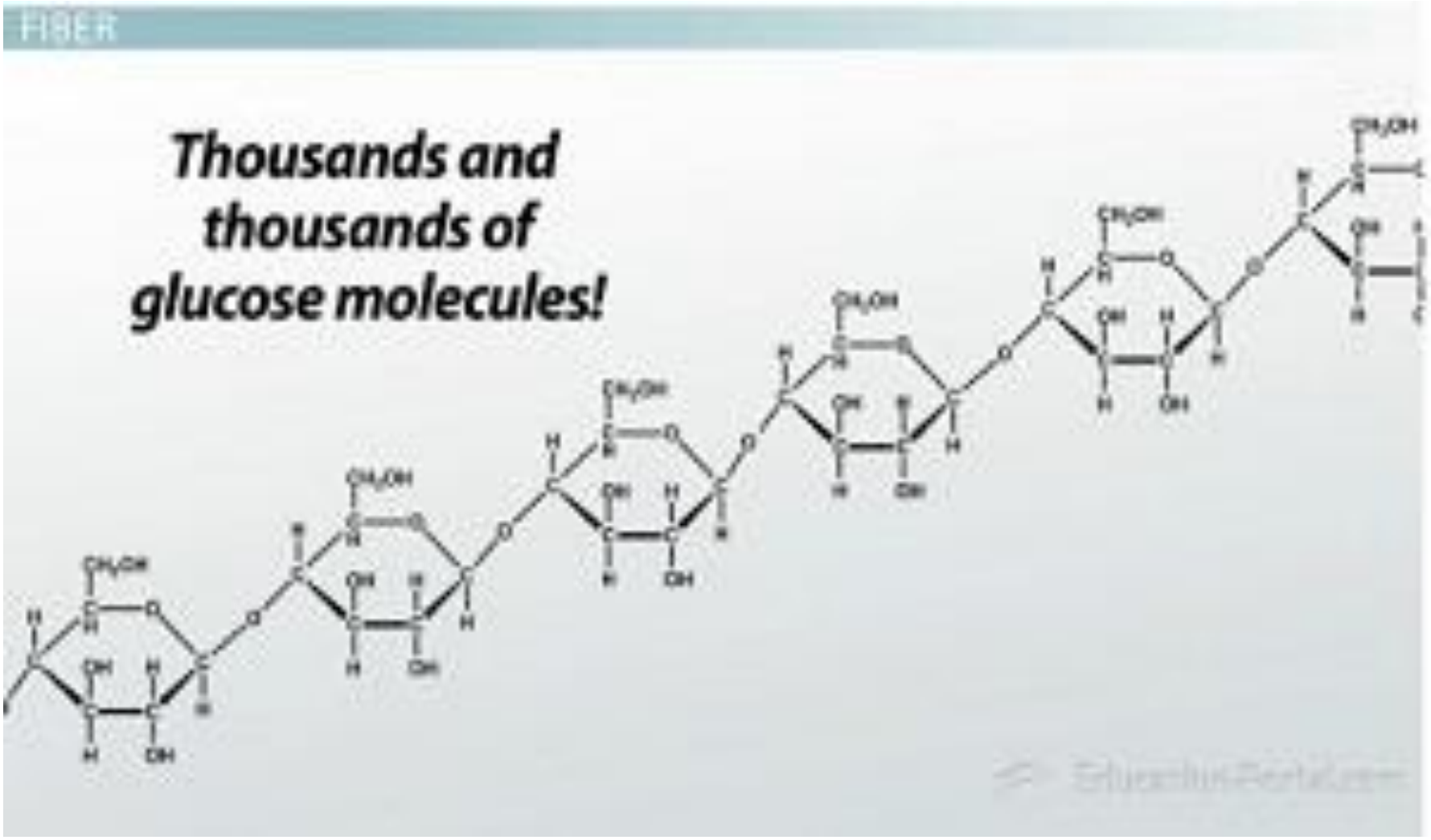
Polymers made-up of many monosaccharides joined together by glycosidic bonds. Very large, often branched, amorphous macromolecules. Insoluble in water and have no sweet taste.

Starch, glycogen and structural polysaccharides such as cellulose and chitin

General formula of $C_n(H_2O)_{n-1}$

(where n, can be any number between 200 and 2500)

# POLYSACCHARIDES



# FUNCTIONS

- Multiple
- Necessary to incorporate in meals

**Metabolic/Nutritional**:

The biological breakdown of carbohydrates (often spoken of as "combustion") supplies the principal part of the energy that every organism needs for various processes

Note: Glucose-only sugar used by the body to provide energy for its tissues

→Digestible polysaccharides, disaccharides and monosaccharides must eventually be converted into glucose or a metabolite of glucose by various liver enzymes

→Significant importance to proper cellular function, blood glucose levels must be kept relatively constant

Liver-regulating the level of blood glucose

- During food consumption: Pancreatic beta (β) cells sense the rise in blood glucose
- Secrete the hormone, insulin

Insulin leads to:

- uptake of glucose
- synthesis of glycogen, a glucose storage polymer

- Glucagon is secreted into the bloodstream by pancreatic alpha (α) cells upon sensing falling levels of blood glucose

Glucagon:

- Inhibits the uptake of glucose by muscle and other cells
- Promotes the breakdown of glycogen in the liver in order to release glucose into the blood

Glucagon also promotes gluconeogenesis-a process involving the synthesis of glucose from amino acid precursors

- Other hormones: Epinephrine and cortisol (etc yet to be discovered)

- Direct absorption of monosaccharides from the blood stream
- Fructose and galactose converted to glucose by the liver

Facilitated diffusion

The glucose molecule is generally too large

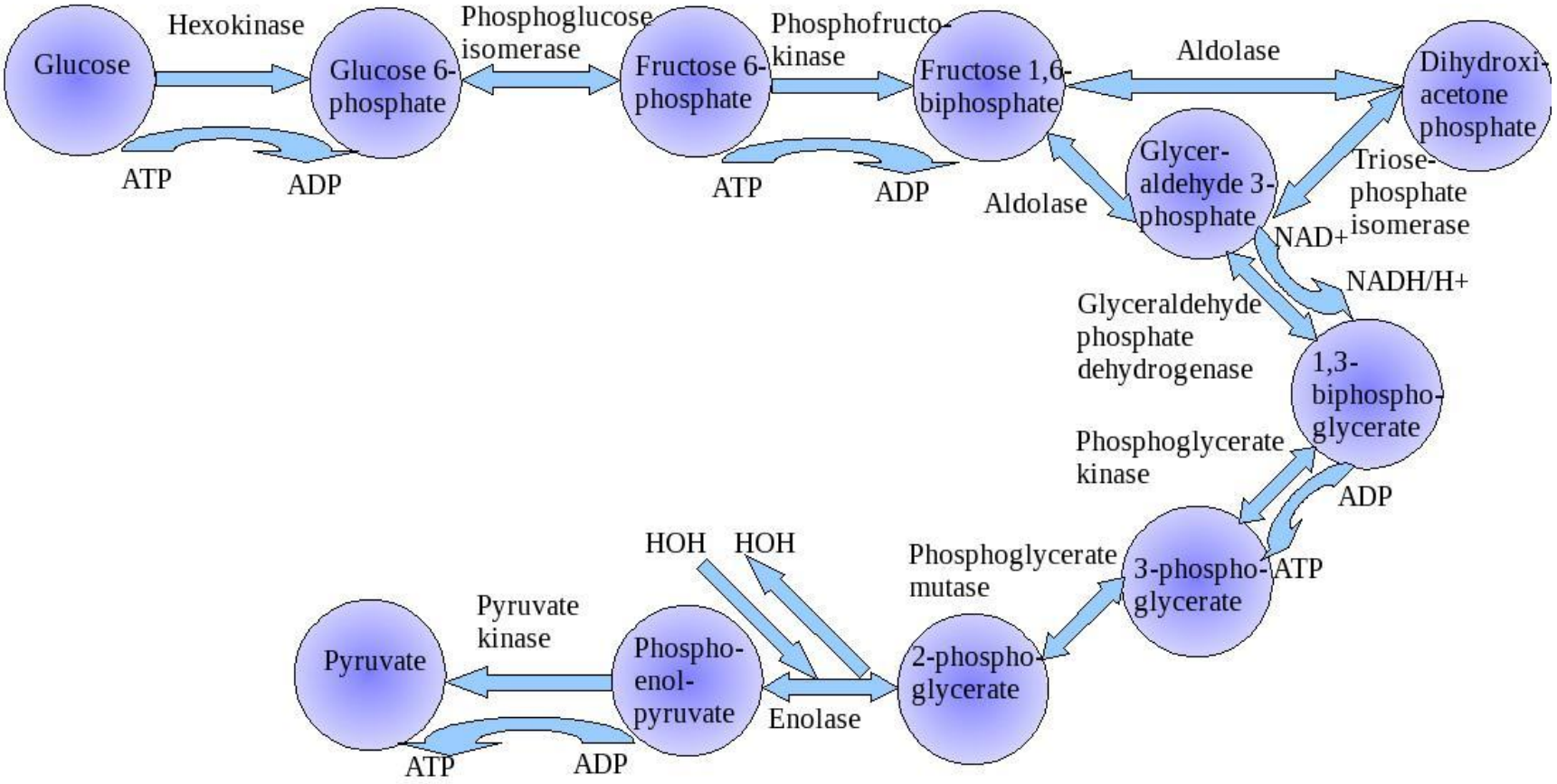
Need for a Facilitator

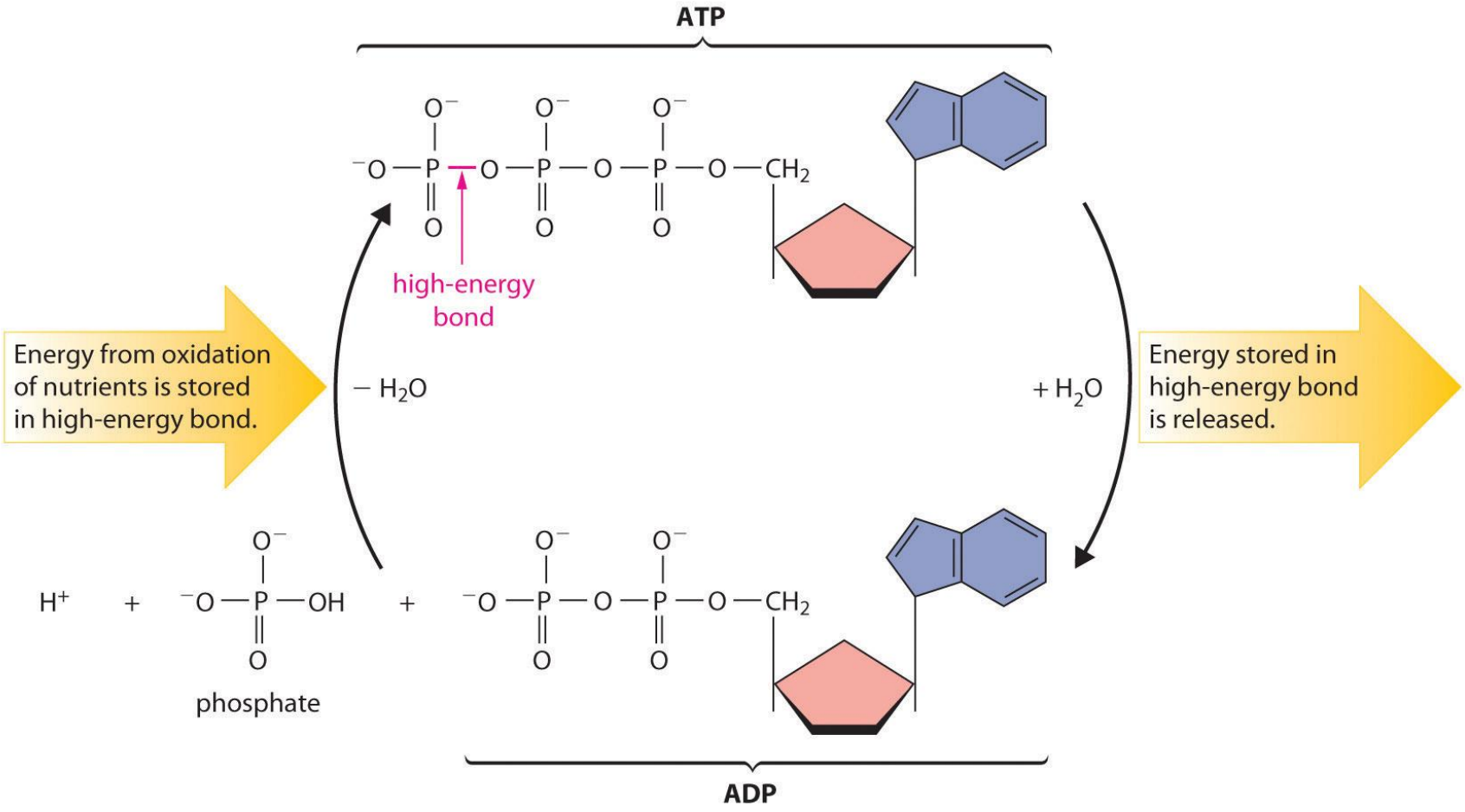
No energy required- passive transport

Active transport-low concentration to high concentration-energy is required

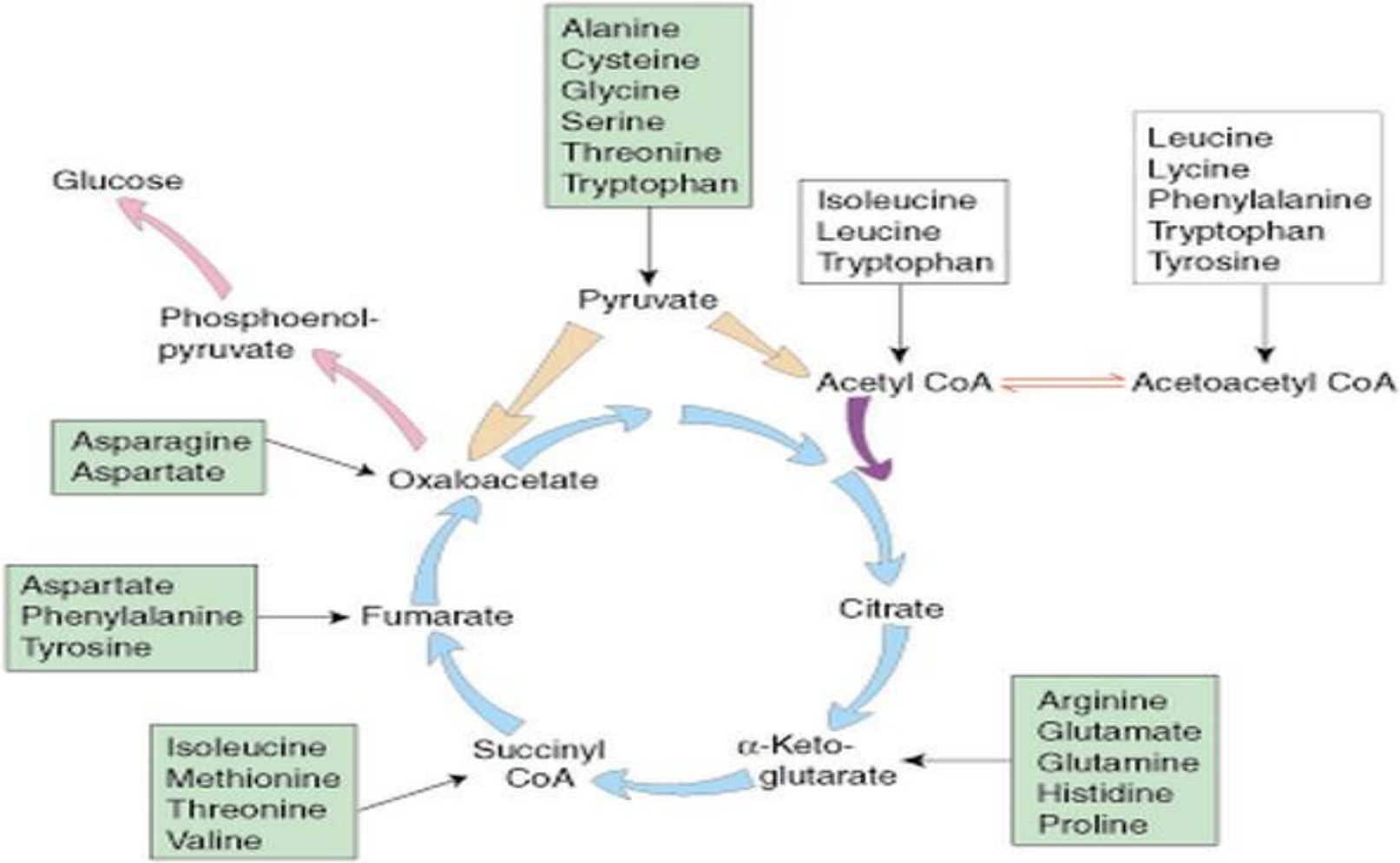
- Glycolysis
- Formation of ATP
- Formation of NADH

# GLYCOLYSIS


Glucose
Hexokinase
Glucose 6-phosphate
ATP
ADP
Phosphoglucose isomerase
Fructose 6-phosphate
Phosphofructo-kinase
ATP
ADP
Fructose 1,6-biphosphate
Aldolase
Dihydroxi-acetone phosphate
Aldolase
Glycer-aldehyde 3-phosphate
Triose-phosphate isomerase
NAD+
NADH/H+
Glyceraldehyde phosphate dehydrogenase
1,3-biphospho-glycerate
Phosphoglycerate kinase
ADP
ATP
3-phospho-glycerate
Phosphoglycerate mutase
HOH
HOH
2-phospho glycerate
Enolase
Phospho-enol-pyruvate
Pyruvate kinase
Pyruvate
ATP
ADP


ATP
high-energy bond
Energy from oxidation of nutrients is stored in high-energy bond.
− H2O
+ H2O
Energy stored in high-energy bond is released.
H+
phosphate
ADP

# GLUCONEOGENISIS



Carbohydrate metabolism: subject of biochemical and medical research for a long time

Major role-in promoting health fitness, form a major part of food and help a great deal in building body strength, by generating energy

Serve as excellent energy providers, the other two being fats and proteins

Energy generation-sugars and starch-perfect fuels that enable us to carry out our physical activities efficiently and effectively

# Dietary Fiber

- Fiber-bowel function

Dietary fibers such as cellulose, hemicellulose, pectin, gum and mucilage - degraded into fatty acids and gases by the large intestine

Fatty acids produced:

- Fuel for the large intestine or absorbed into the bloodstream

# Dietary fiber-essential for proper intestinal health

High fiber intake reduces the risk of developing obesity by increasing the bulk of a meal without yielding much energy

Diabetics can also benefit from consuming a regular amount of dietary fiber. Once in the intestine, it slows the absorption of glucose to prevent a sudden increase in blood glucose levels

A relatively high intake of fiber will also decrease the absorption of cholesterol- compound that is thought to contribute to atherosclerosis or scarring of the arteries

Serum cholesterol may be further reduced by a reduction in the release of insulin after meals

Since insulin is known to promote cholesterol synthesis in the liver, a reduction in the absorption of glucose after meals through the consumption of fiber can help to control serum cholesterol levels

Dietary fiber intake may help prevent colon cancer by diluting potential carcinogens through increased water retention, binding carcinogens to the fiber itself and speeding the passage of food through the intestinal tract so that cancer-causing agents have less time to act

Carbohydrates add on to the taste and appearance of food item-making the dish tempting and mouthwatering.

Sometimes used as flavors and sweeteners

Carbohydrates are found in different foods, which if eaten, also pave way for consuming other essential nutrients

Fat-9 calories per gram

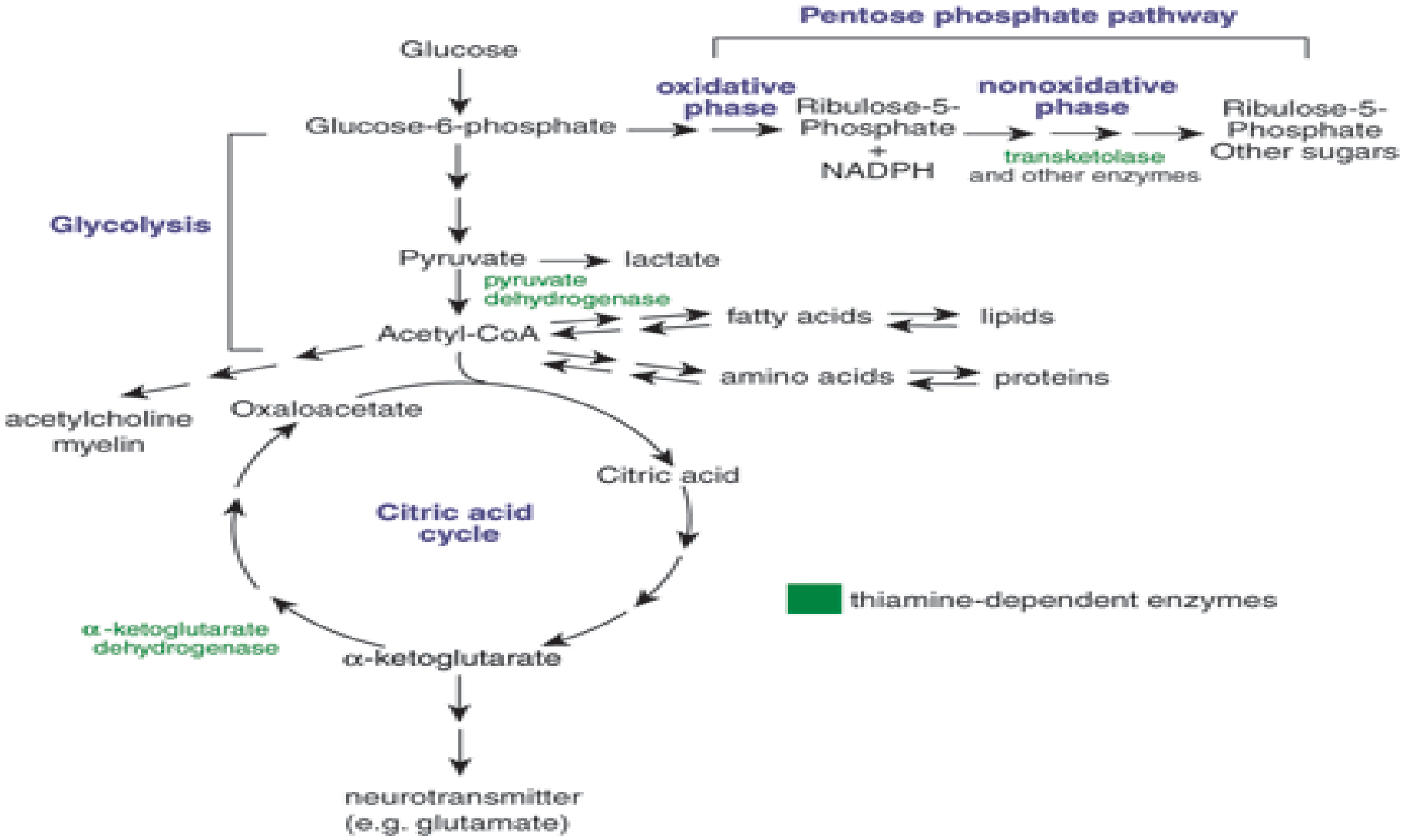
Carbohydrate-4 calories per gram

Protein-4 calories per gram but longer route

50-80% of diet energy supplied by carbohydrates

**Protein-sparing action:**

Carbohydrates are mainly fulfilling the major part of the energy needs, thus sparing protein for tissue building and repairing


Pentose phosphate pathway
Glucose
oxidative phase
nonoxidative phase
Glucose-6-phosphate
Ribulose-5-Phosphate
+
NADPH
transketolase
and other enzymes
Ribulose-5-Phosphate
Other sugars
Glycolysis
Pyruvate
lactate
pyruvate dehydrogenase
Acetyl-CoA
fatty acids
lipids
amino acids
proteins
acetylcholine
myelin
Oxaloacetate
Citric acid
Citric acid cycle
thiamine-dependent enzymes
α-ketoglutarate dehydrogenase
α-ketoglutarate
neurotransmitter
(e.g. glutamate)

**Essential for Fat Oxidation:**

Carbohydrates are essential for oxidation of fats. The common expression that 'fat burns in the fire of carbohydrates' is used to emphasize that in absence of carbohydrates, fats cannot be oxidised by the body to yield energy

Recent studies have shown that oxaloacetic acid, a breakdown product of carbohydrate is essential for the oxidation of acetate, which is the breakdown product of fats

In the absence of oxaloacetic acid, acetate is converted into ketone bodies, which accumulate in the body and the person suffers from 'Ketosis'- a toxic condition of the body

Ketosis occurs in diabetes, where cells cannot utilise carbohydrates and in starvation, where cells must use fat stores in the body as a source of energy

The first physiological demand of the body is the need for energy, which must be satisfied before the nutrients are used for other functions. So, this function of carbohydrates to spare protein for its primary purpose of body building and repair of tissues is an important one

# Gastro-intestinal function:

Carbohydrates play an important role in the gastro-intestinal functions of mammals. Lactose promotes the growth of certain desirable bacteria in the small intestine which brings about the synthesis of certain B-complex vitamins. Lactose also enhances the absorption of calcium. Cellulose (see previous slide on dietary fiber)

**Structural:**

The structural diversity possible by linking the different, common sugars is immense: Far greater than that of proteins, which largely consist of 22 amino acids linked by a single type of peptide bond

Linkages between sugars can occur through a glycoside linkage between the anomeric, first carbon of a sugar in either α or β configuration with any of a variety of hydroxyl groups on the adjacent sugar

**Communication:**

Glycoconjugates-Carbohydrates covalently linked with:

proteins, peptides, lipids and saccharides

Process of glycosylation

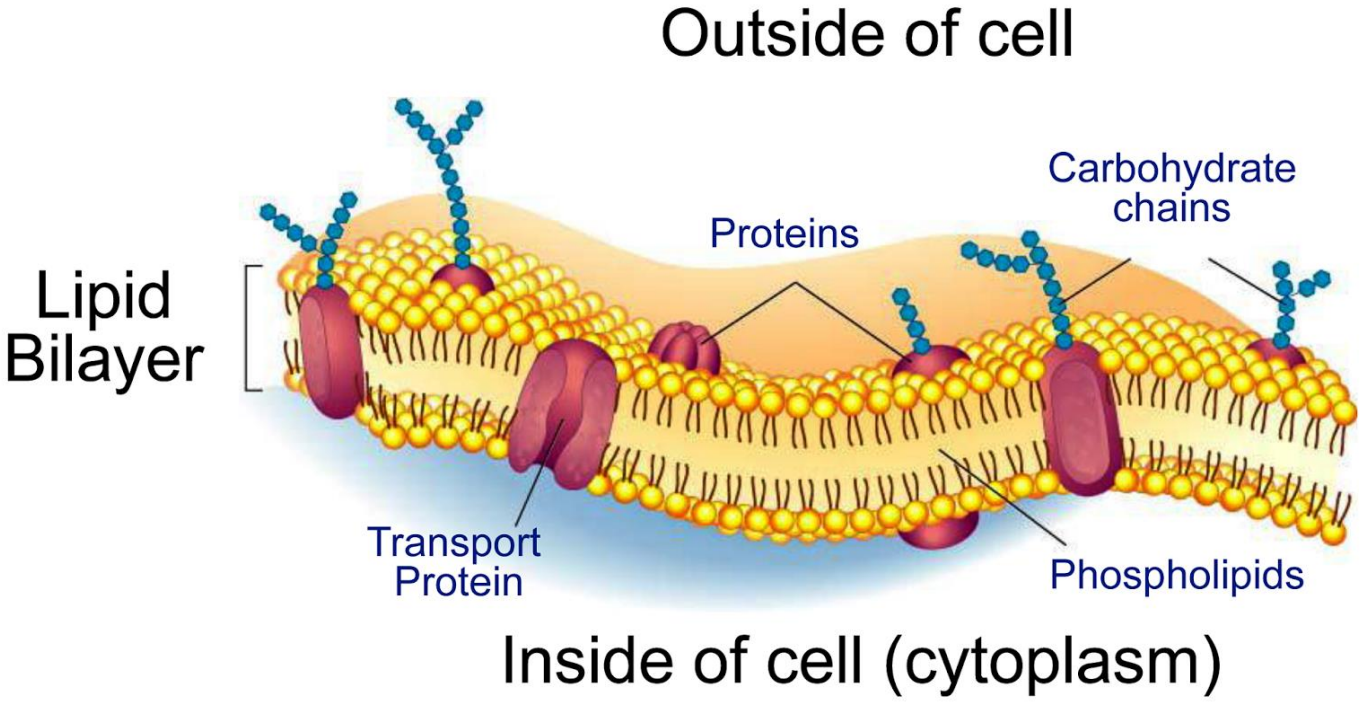
Glycosylation -reaction in which a carbohydrate, i.e. a glycosyl donor, is attached to a hydroxyl or other functional group of another molecule

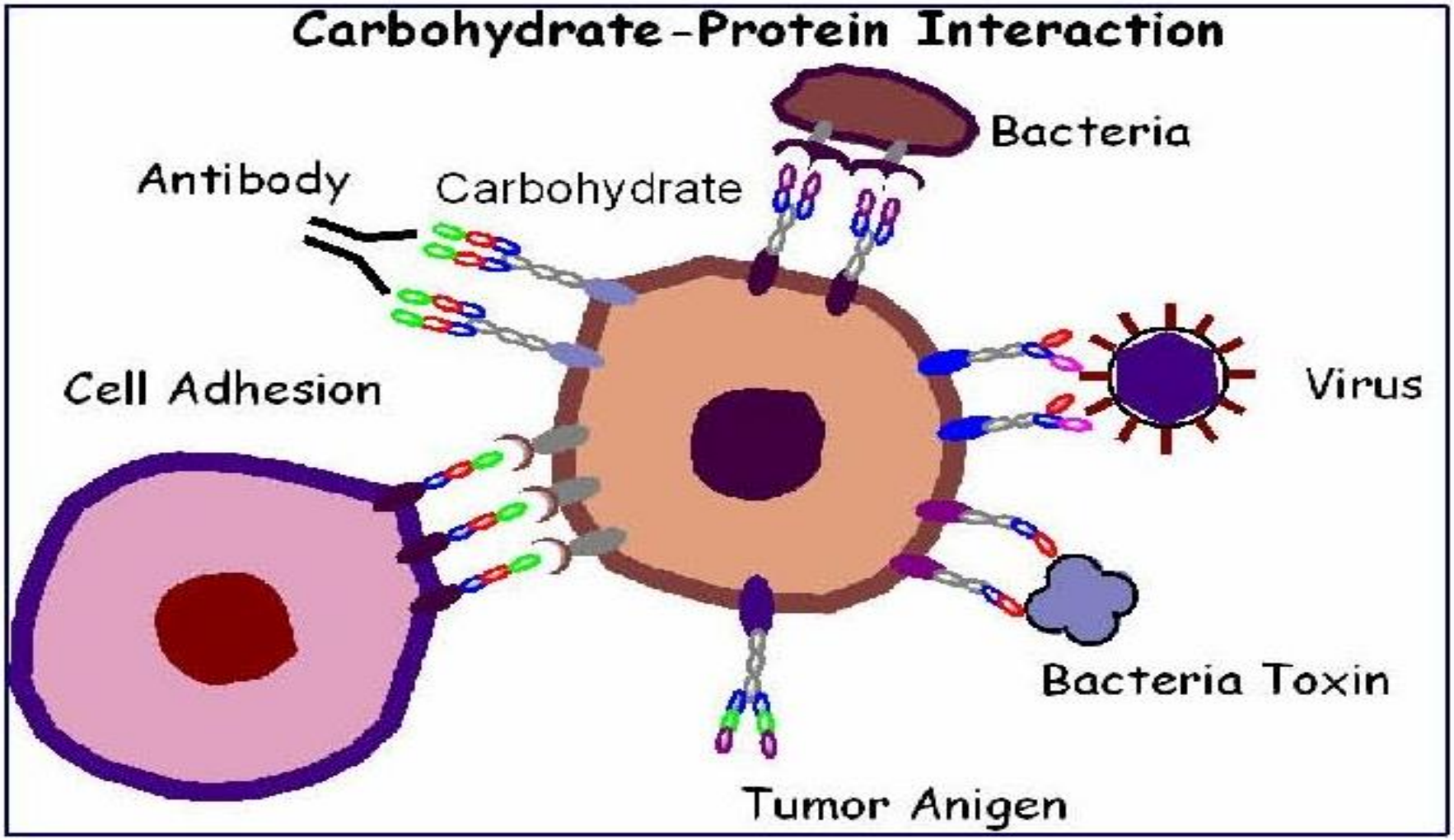
Cells recognize one another because of the saccharides attached to cell surfaces

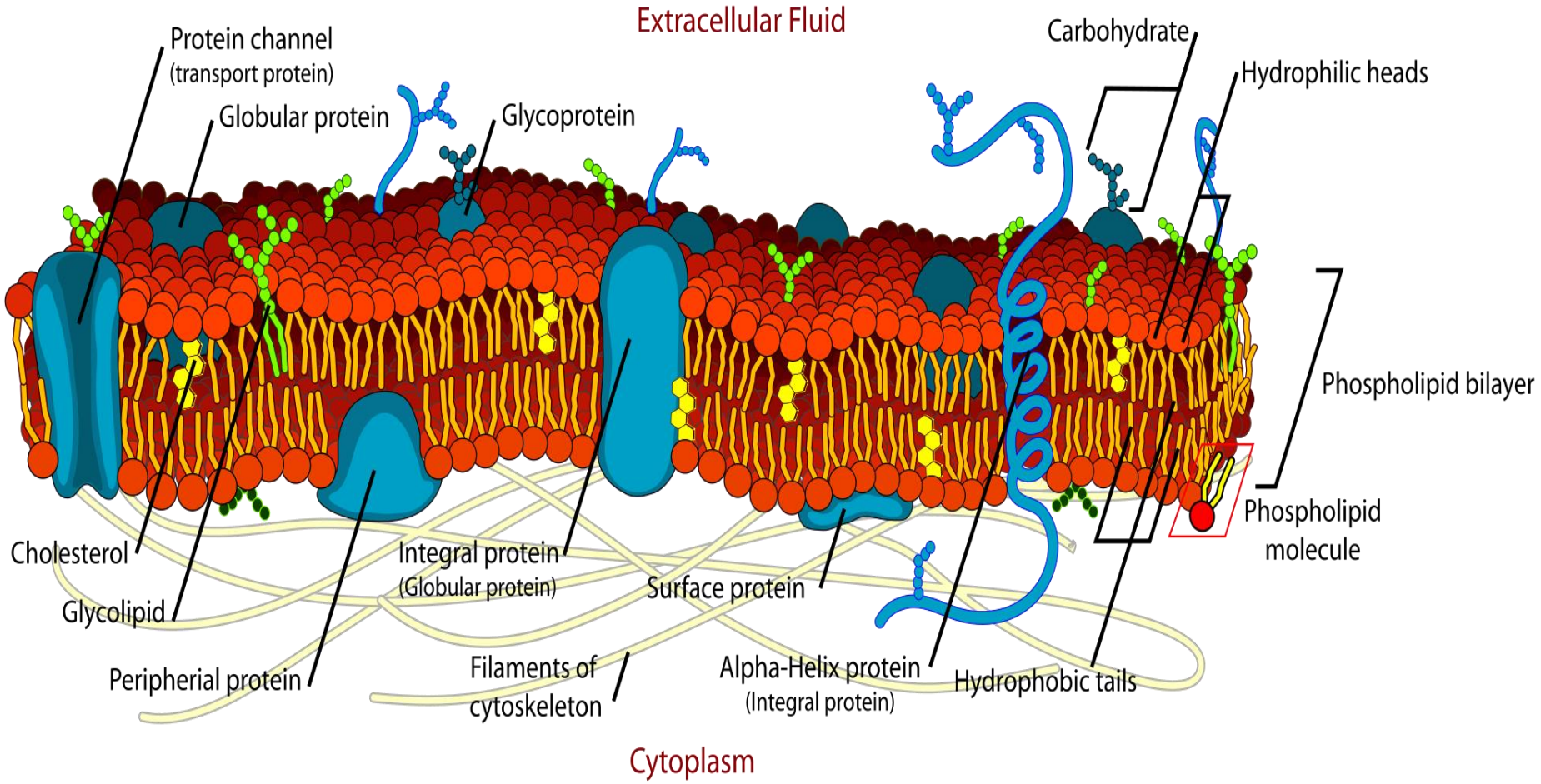
Oligosaccharides associated through covalent links to lipids and/or proteins

The lipid or protein part is integrated into the cell membrane structure, with the saccharide part towards the external membrane surface

# Structure of the Cell Membrane




Carbohydrate-Protein Interaction
Bacteria
Antibody
Carbohydrate
Cell Adhesion
Virus
Bacteria Toxin
Tumor Anigen


Extracellular Fluid
Protein channel
(transport protein)
Globular protein
Glycoprotein
Carbohydrate
Hydrophilic heads
Phospholipid bilayer
Phospholipid
molecule
Cholesterol
Glycolipid
Peripherial protein
Integral protein
(Globular protein)
Filaments of
cytoskeleton
Surface protein
Alpha-Helix protein
(Integral protein)
Hydrophobic tails
Cytoplasm

Membrane carbohydrates (2-10% of the membranes) are on the extracellular surface bound to lipids or proteins of the membrane, forming glycoconjugates that serve as docking sites in cell recognition, adhesion and receptor action

Sugars include mainly:

glucose, galactose, mannose, fucose, N-acetyl galactosamine and N-acetyl glucosamine

# GLYCOCONJUGATES

- Carbohydrate derivatives:
  - One or more carbohydrate chains linked covalently to a peptide bond chain, protein or lipid

- Proteoglycans
- Peptidoglycans
- Glycoproteins
- Glycolipids

# TYPES

**Proteoglycans**: Glycosaminoglycan moiety forms the greater fraction of the molecule (typically a proteoglycan consists of 95 % of carbohydrates) and is the main site of biological activity, providing multiple binding sites

Found mainly in the extracellular matrix-major components of connective tissue

**Glycoproteins**: Membrane bound glycoproteins participate in a wide range of cellular phenomena, including cell recognition, cell surface antigenicity, etc.

Majority of the molecule consists of proteins; -one or more oligosaccharides attached to a protein-usually are branched and do not have serial repeats

Rich in information, forming highly specific sites for recognition and high affinity binding by other proteins

- **Glycolipids**: are membrane lipids in which the hydrophilic head groups are oligosaccharides
- As in glycoproteins, glycolipids act as specific sites for recognition by carbohydrate binding proteins

The four types of human RBC have different oligosaccharides (antigens) in their cell membranes

Blood groups depend on the gangliosides (a kind of sphingolipid) in the surface of the red blood cell

# DERIVATIVES

Various sugar derivatives:

Essential participants in various reactions. Some of them participate in the transformations of simple sugars to other simple sugars or sugar derivatives

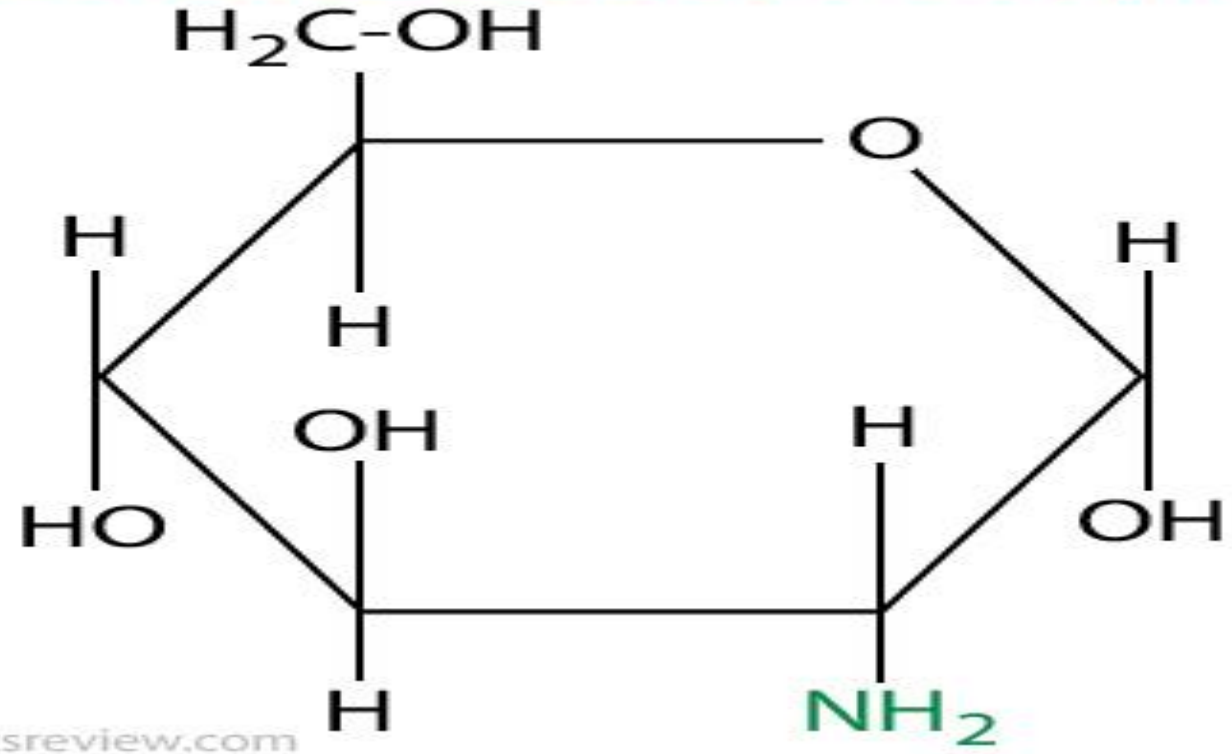
## Derivatives of Monosaccharide

Number of reactions to form biologically important derivatives

Three common types of monosaccharide derivatives: amino sugars, carboxylic acid sugars and sugar alcohols

- Amino sugars and N-acetylated sugars
  - Glucosamine- produced in the body from the sugar glucose and the amino acid glutamine
  - used as a precursor in the biochemical synthesis of glycosylated proteins and lipids.
  - stimulates the synthesis of proteoglycans, glycosaminoglycans (more commonly referred to as mucopolysaccharides) and collagen. It therefore plays a role in the formation of cartilage and the cushioning synovial fluid between the joints; hence it’s "chondroprotective"

# Glucosamine



- Supplementary glucosamine can be an important source of this vital amino sugar for those with reduced capacity to produce glucosamine, such as the elderly.
- acts as an immune modulator with antitumor and antiviral properties, as well as it has some activity against HIV. Oral glucosamine is commonly used for the treatment of osteoarthritis. Since glucosamine is a precursor for glycosaminoglycans, and glycosaminoglycans are a major component of joint cartilage, supplemental glucosamine may help to rebuild cartilage and treat arthritis. Deficiencies or malfunctions in the ability to metabolize this sugar have been linked to diseases of the bowel and bladder. Glucosamine has been shown to help repair the mucosal-lining defensive barrier called the glycosaminoglycan layer (GAG). Defects in the GAG layer have been implicated in Crohn's disease, ulcerative colitis, and interstitial cystitis.
- One of the most striking effects of glucosamine is its ability to reduce the progression of experimental cancers. Reductions in blood levels of Glucosamine have been found in those with colon cancer. Distribution of the sugar is also altered when other cancerous tissues are present. It has been found that, with some of the other essential sugars, glucosamine is also vital to learning.
- Retinal tissue from human eye donors showed that glucosamine preferred the photoreceptor layer of the retina, suggesting that this sugar is needed in transplantation

# DISEASES

- Diabetes mellitus
- Galactosemia
- Glycogen storage diseases
- Lactose intolerance

**These conditions are associated with carbohydrate metabolism. Look them up**

# SUMMARY

Source of energy- Leave the proteins free to be used as building blocks of the body

Carbohydrates are the singular source of energy for the brain! They also play an important role in the regulation of the nervous system

High fiber carbohydrates prevent bowel irregularities like constipation and prevent development of diseases such as diabetes, cancer and heart diseases

# SUMMARY

Certain carbohydrates promote development of healthy bacteria in the digestive system

Polysaccharides make up the structural complex of cellulose in plants and the chitin present in arthropods, besides storing energy as glycogen in liver and muscle cells, and starch in plants