Carbohydrates

Carbohydrates (CHO) are organic compounds (also called hydrated carbon) or polyhydroxy aldehydes or polyhydroxy ketones containing **carbon, hydrogen, and oxygen.** Carbohydrates are widely distributed in plants and animals; they have important structural and metabolic roles. In plants, **glucose is synthesized from carbon dioxide and water by photosynthesis.**

$$6CO_2 + 6H_2O \xrightarrow[\text{chlorophyll}]{\text{sunlight}} C_6H_{12}O_6 + 6O_2$$

Photosynthesis

Importance of Carbohydrates:

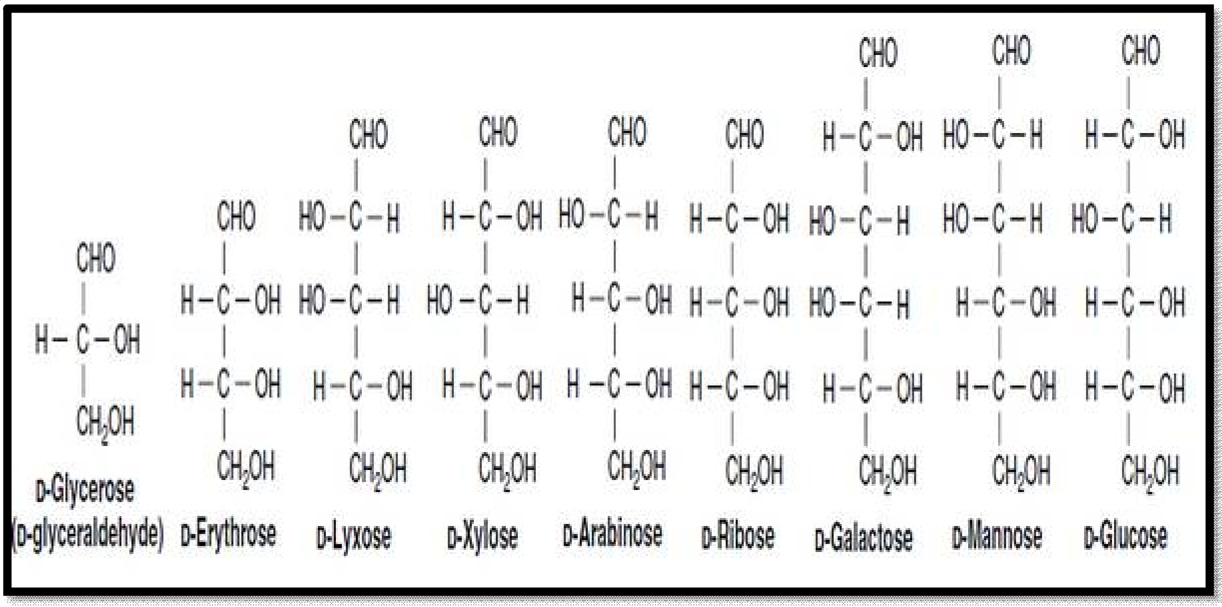
1. Act as a main source of energy and storage form of energy
2. Can be structural components of many organisms
   A. Can be cell-membrane components mediating intercellular communication
   B. Can be cell-surface antigens
   C. Can be associated with proteins and lipids
   D. Part of RNA, DNA, and several coenzymes (NAD^+, $NADP^+$, FAD, CoA)

Classification of Carbohydrates

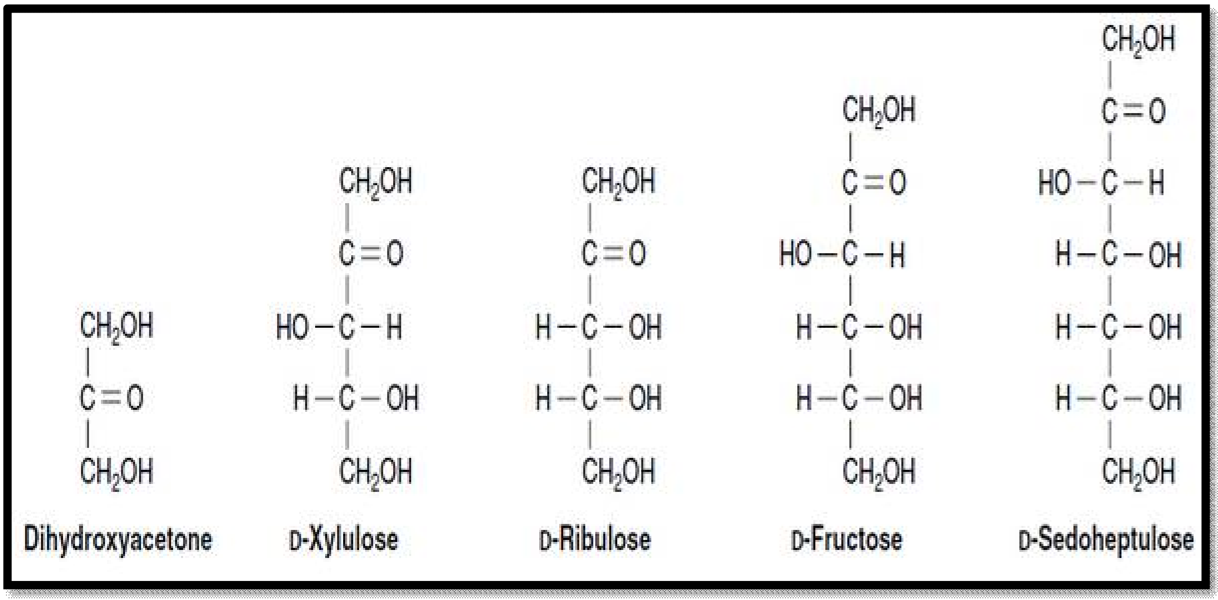
1. **Monosaccharides** are those carbohydrates that **cannot be hydrolyzed into simpler carbohydrates** i.e. it composed from one unit.
2. **Disaccharides** are condensation products of **two monosaccharide units**.
3. **Oligosaccharides** are condensation products of **two to ten monosaccharides. Example maltotriose** (a trisaccharide of glucose).
4. **Polysaccharides** are condensation products of **more than ten monosaccharide units; example starches.**

Monosaccharides

Monosaccharides are those carbohydrates that cannot be hydrolyzed into simpler carbohydrates. They may be classified as **trioses, tetroses, pentoses, hexoses, and heptoses, depending upon the number of carbon atoms**; and as aldoses or ketoses depending upon whether they have an aldehyde or ketone group. **<u>Hexoses are the most important monosaccharides found in plants</u>**. They are the first detectable sugars synthesized by plants and form the units from which most of the polysaccharides are constructed such as glucose, fructose and galactose.



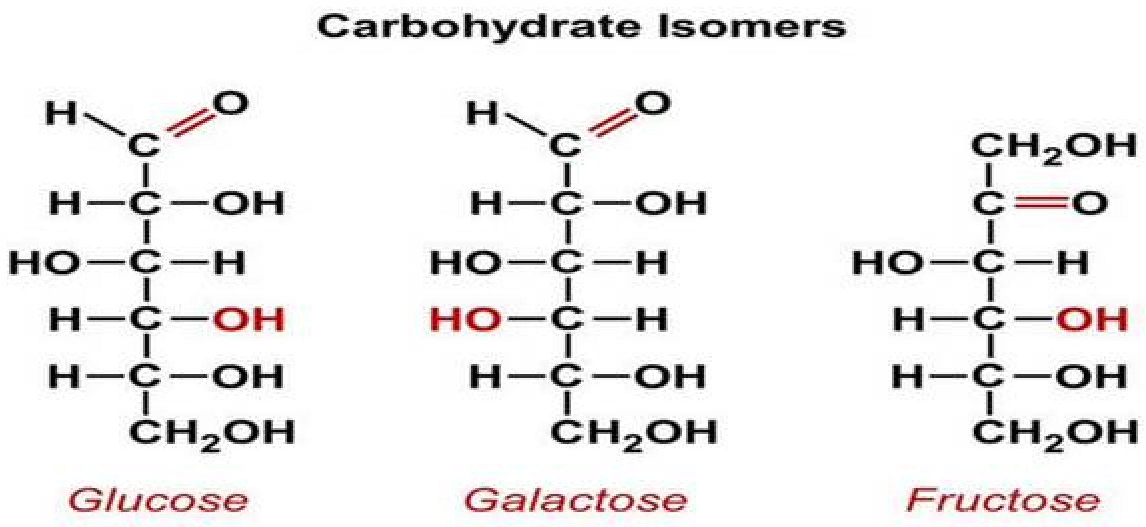
Examples of aldoses



Examples of ketoses

Isomers

Compounds that have the same chemical formula but have different structures are called **isomers**. For example, **fructose, glucose, mannose, and galactose** are all isomers of each other, having the same chemical formula, **$C_6H_{12}O_6$**.



Cyclization of monosaccharides

Less than 1% of each of the monosaccharides with five or more carbons exists in the **open chain (acyclic)** form. Rather, they are predominantly found in a ring (cyclic) form, in which **the aldehyde (or keto) group has reacted with an alcohol group on the same sugar, making the carbonyl carbon (carbon 1 for an aldose or carbon 2 for a ketose) asymmetric**. Monosachharides can exist in both cyclic structures i.e. either pyrano (six membered ring) or furano (five membered ring).

Cyclization **creates an anomeric carbon** (the former carbonyl carbon), generating the α and β configurations of the sugar, for example, α-D-glucopyranose and β- D-glucopryanose. These two sugars are both glucose but are **anomers** of each other.

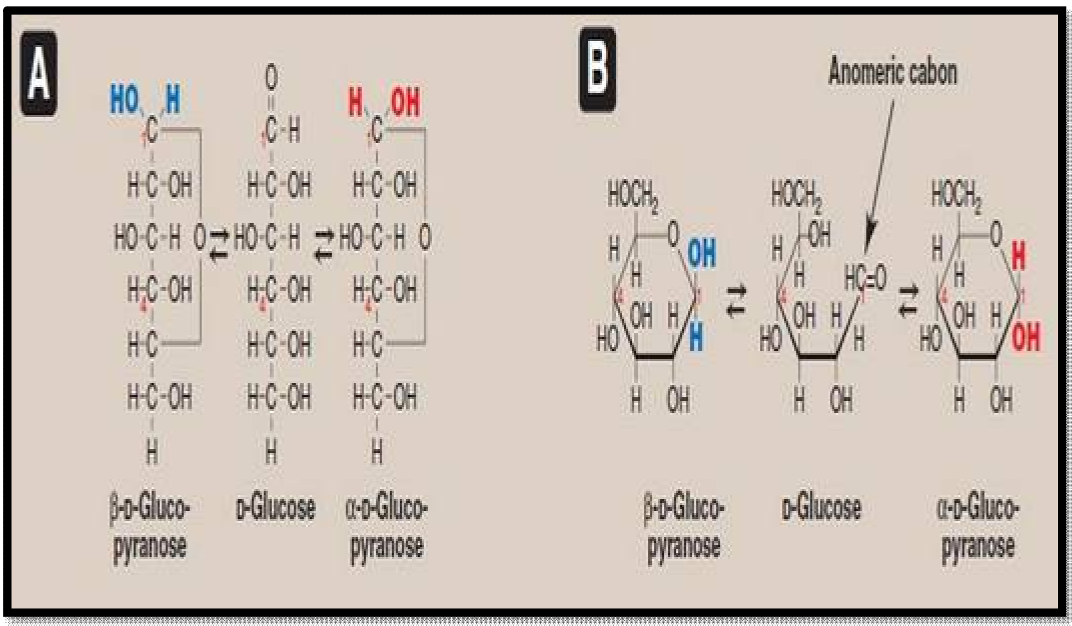


Figure A. The interconversion (mutarotation) of the α and β anomeric forms of glucose shown as modified Fischer projection formulas. B. The interconversion shown as Haworth projection formulas. Carbon 1 is the anomeric carbon.

Reducing sugars

If the hydroxyl group on the anomeric carbon of a cyclized sugar is **not linked to another compound by a glycosidic bond,** the ring can open. The sugar can act as a reducing agent, and is termed a reducing sugar.

Joining of Monosaccharides

Monosaccharides can be joined to form disaccharides, oligosaccharides, and polysaccharides. Important disaccharides include **lactose (galactose + glucose**), **sucrose (glucose + fructose),** and **maltose (glucose + glucose)**.

Disaccharides

Those are compounds that can yield two monosaccharides molecules on hydrolysis. There are three common disaccharides, **sucrose, maltose and lactose**. All of which are isomers with the molecular formula $C_{11}H_{22}O_{11}$.

1. **Sucrose:** It is the only disaccharide that occurs **abundantly in free state in plants**. Sucrose is used as sugar at home and occurs in fruit juices, sugar cane, sugar beet, the sap of certain maples, and in many other plants. Upon hydrolysis; sucrose yields **equimolar quantities of glucose and fructose**. Sucrose is a non-reducing sugar.

2. **Maltose:** Maltose although **seldomly occurring in the free state** in nature, is produced in large quantities by the hydrolysis of starch. Upon hydrolysis, yields **2 molecules of glucose**. It is a reducing sugar.

3. **Lactose:** Lactose possesses a free functional aldehyde group and is a reducing sugar. Commercially known as milk sugar. Bacteria cause fermentation of lactose forming lactic acid. When these reactions occur, it changes the taste to a sour one. It is a reducing sugar.

Oligosaccharides are condensation products of **two to ten monosaccharides**. Example maltotriose (a trisaccharide of glucose)

Polysaccharides

Polysaccharides are formed from condensation products of **more than ten monosaccharide units.** If only one type of monosaccharide unit is present, the polysaccharide is a "homoglycan" but a "heteroglycan" if more than one kind on monosaccharide is involved.

Examples of Homoglycans:

1- Starch: composed of glucose

2- Inulin: composed of fructose

3- Dextran: polyglucagon formed from sucrose

4- Cellulose: consist of several hundred of D-glucose

Examples of Heteroglycans

1. **Gums:** They are translucent, amorphous substances that are frequently produced in higher plants as a protective after injury. They are ingredients in **dental and other adhesives and in bulk laxatives.** They are also useful as **tablet binders, gelating agents, suspending agents, stabilizers, and thickeners.**

2. **Tragacanth:** is the dried, gummy exudate from Astragalus gummifer. Tragacanth is employed pharmaceutically as a **suspending agent** for insoluble powders in mixtures, as an **emulsifying agent** for oils and resins, and as an adhesive. It is employed in **cosmetics (hand lotions) as a demulcent**.

3. **Acacia:** Acacia is the dried, gummy exudate from the sterns and branches of Acacia Senegal. Acacia is used as a **suspending agent**. It possesses useful demulcent and emollient properties and finds applications an adhesive and binder in tablet granulations.

4. **Agar:** is the dried, hydrophilic, colloidal substance extracted from Gelidium cartilagineum is used as **a laxative, suspending agent, an emulsifier**, and as a **tablet excipient and disintegrant.**

5. **Plantago seed (psyllium seed):** is the cleaned, dried, ripe seed of Plantago psyllium. Plantago seed is **a cathartic.**

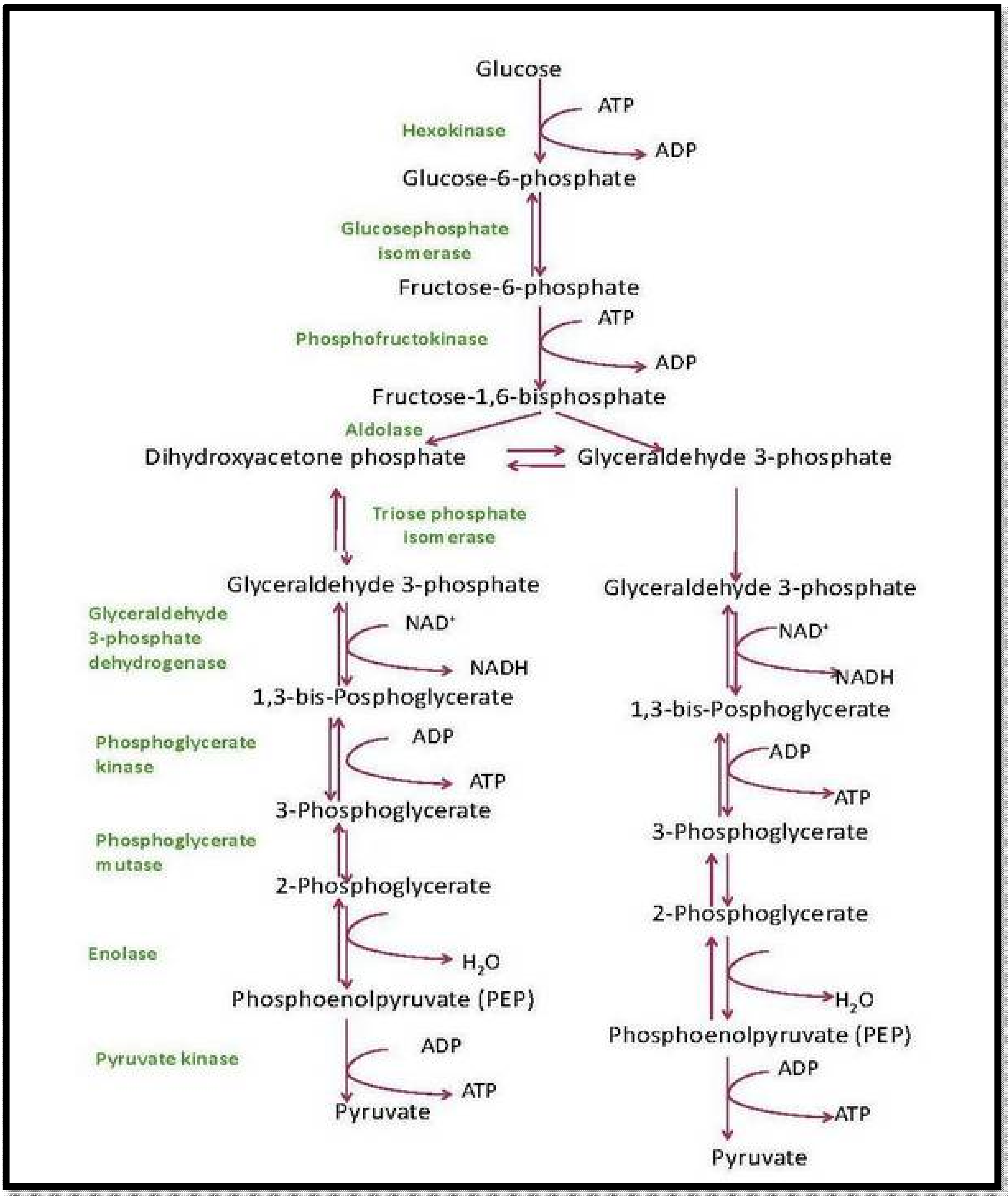
6. **Pectin:** Pectin is a purified carbohydrate product obtained from the dilute acid extract of the inner portion of the rind of citrus fruits or from apple. Pectin is classified as **a protectant and a suspending agent** and is an ingredient in many **antidiarrheal formulations**.

Carbohydrate utilization

Storage carbohydrate such as the **starch of plants or glycogen of animals** is made available for energy production by a process which involves conversion of **glucose to pyruvate** by **glycolysis** and then the **pyruvate converted to acetyl-coenzyme A**, then will pass to **the tricarboxylic acid cycle** (TCA). As a result of this, the energy rich **carbohydrate is oxidized to CO_2 and H_2O**. Coenzymes in TCA will carry the liberated hydrogen atoms to the cytochrome system in which the energy is liberated in stages, with the formation of ATP from ADP. The hydrogen combines with oxygen to form water.

1-Embden-Meyerhof scheme (pathway) of glycolysis:

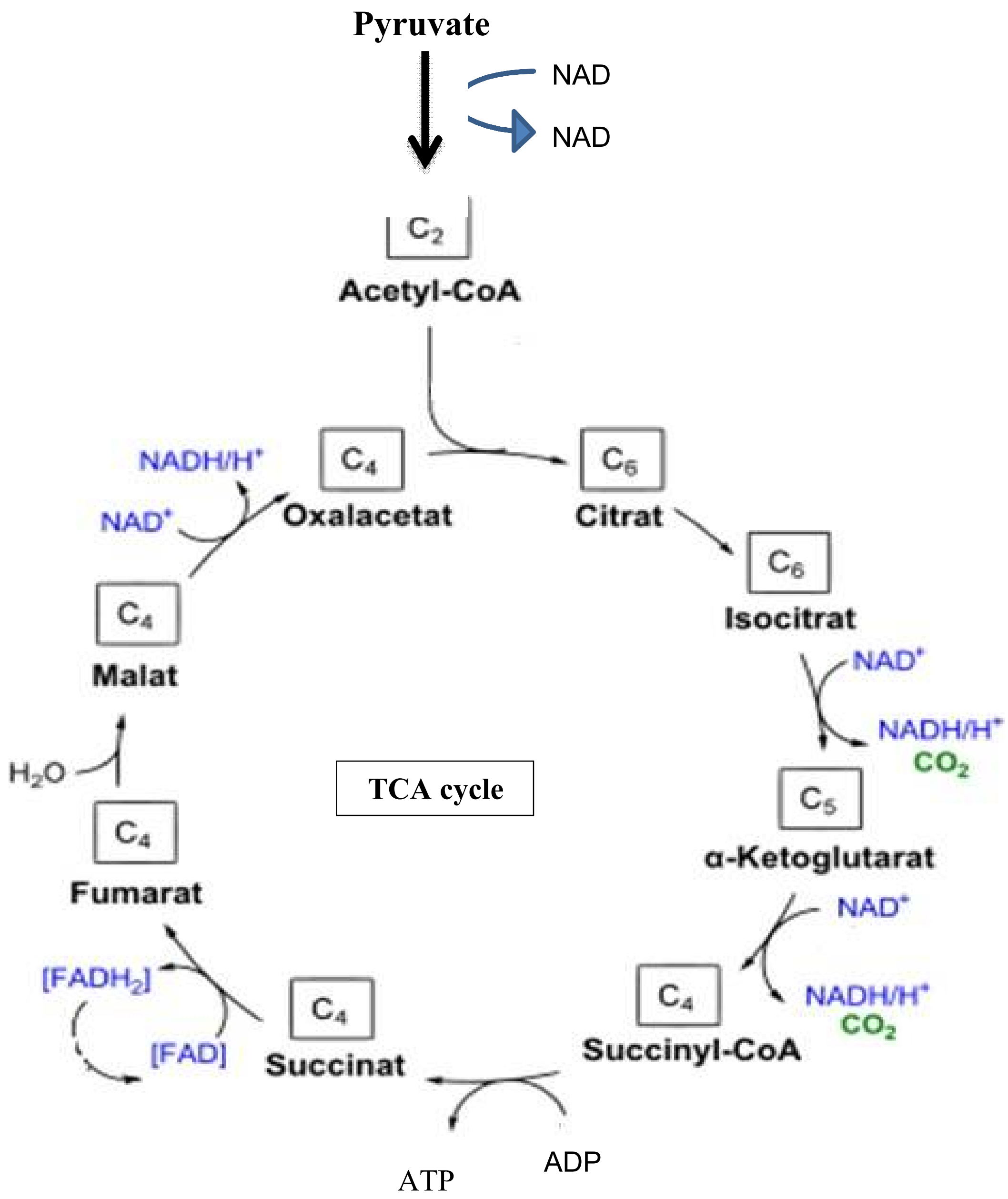
One molecule of glucose can give rise to two molecules of pyruvate, then each of which is converted to acetyl-coenzyme A and CO_2.



This yields 2 NADH molecules and 2 ATP molecules from the glycolytic pathway per glucose.

1-Tricyclic acid cycle:

TCA cycle represent the oxidation of one acetyl-coenzyme A to two molecules of CO_2 giving rise to 12 molecules of ATP (1 ATP = 8 Kcal).

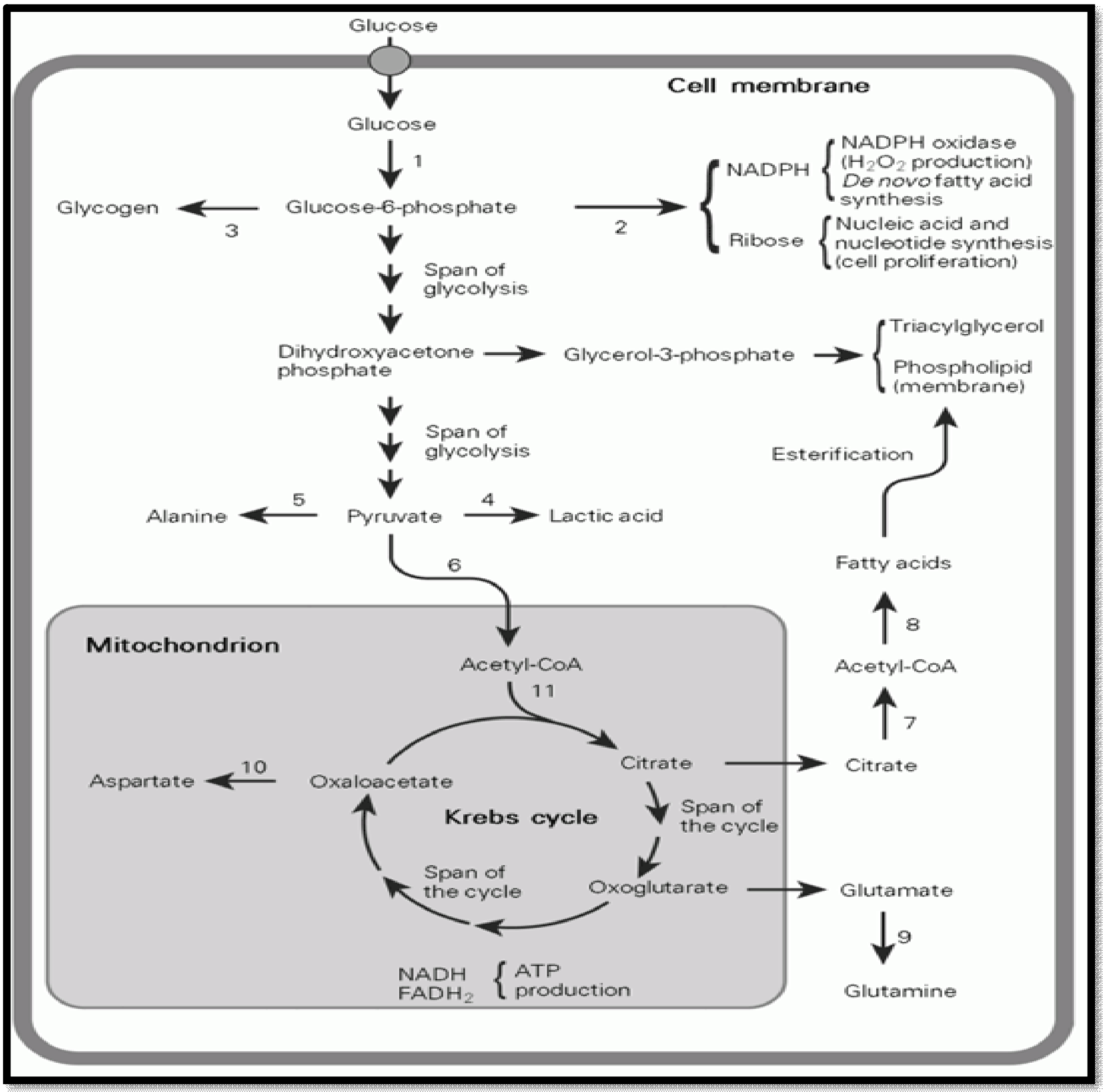


The overall reaction for the metabolism of one molecule of glucose in terms of ADP and ATP is:

$$\underset{\text{Glucose}}{C_6H_{12}O_6} + 6O_2 + 38ADP + 38\ P\ (\text{inorganic}) \longrightarrow 6H_2O + 6CO_2 + 38ATP$$

In the cytoplasm		
Glycolysis:	2 ATP	→ 2 ATP
In the mitochondria		
From glycolysis:	2 NADH → 6 ATP	→ 6 ATP*
From respiration:		
Pyruvic acid → acetyl CoA:	1 NADH → 3 ATP	(× 2) → 6 ATP
Krebs cycle:	1 ATP 3 NADH → 9 ATP 1 FADH$_2$ → 2 ATP	(× 2) → 24 ATP
Total:		38 ATP

The overall scheme:

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