

## **Energy production and metabolism**

Cells need energy to sustain their lives and to maintain their systems in a reduced manner . The main source of energy on Earth is sunlight , which is converted into chemical energy by photosynthesis processes , and its products are used by other organisms to obtain energy circulating in vital systems, which is (ATP) . Energy **metabolism** refers to all the reactions involved in generating adenosine triphosphate (ATP) from nutrients, including both aerobic respiration (oxygen present), anaerobic respiration (fermentation) .

### **Metabolism is divided into :-**

\* **Catabolism:** It is the process of breaking down molecules into smaller units during metabolic reactions. The catabolism process releases ATP molecules.

\* **Anabolism:** is the process of forming large molecules from smaller units during metabolic reactions. The construction process requires the presence of ATP molecules.

## **Heterotrophic Metabolism**

Heterotrophic metabolism is the biologic oxidation of organic compounds such as glucose , to yield ATP and simpler organic (or inorganic) compound , which are needed by the bacterial cell for biosynthetic or assimilatory reactions.

Heterotrophic bacteria , which include all pathogens , obtain energy from oxidation of organic compounds . Carbohydrates (particularly glucose) , lipids , and protein are the most commonly oxidized compounds Biologic oxidation of these organic compounds by bacteria results in synthesis of ATP as the chemical energy source .

## **Cellular Respiration**

is the process by which biological fuels are oxidized in the presence of an inorganic electron acceptor such as oxygen to produce large amounts of energy, to drive the bulk production of adenosine triphosphate (ATP). Cellular respiration may be described as a set of metabolic reactions and processes that

take place in the cells of organisms to convert chemical energy from nutrients into ATP, and then release waste products .

The reactions that involved in respiration are catabolic reactions, which break large molecules into smaller ones, releasing energy (ATP). Respiration is one of the key ways a cell releases chemical energy to fuel cellular activity. The overall reaction occurs in a series of biochemical steps, some of which are redox reactions.

Nutrients that are commonly used by animal and plant cells in respiration include sugar, amino acids and fatty acids, and the most common oxidizing agent is molecular oxygen (O<sub>2</sub>). The chemical energy stored in ATP (the bond of its third phosphate group to the rest of the molecule can be broken allowing more stable products to form, thereby releasing energy for use by the cell) and then can be used to drive processes requiring energy, including biosynthesis, locomotion or transport of molecules across cell membranes.

## **Aerobic respiration**

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Aerobic respiration requires oxygen (O<sub>2</sub>) in order to create ATP. Although carbohydrates, fats, and proteins are consumed as reactants, aerobic respiration is the preferred method of pyruvate production in glycolysis, and requires pyruvate to the mitochondria in order to be fully oxidized by the citric acid cycle. The products of this process are carbon dioxide and water, and the energy transferred is used to make bond between ADP and a third phosphate group to form ATP (adenosine triphosphate), by substrate-level phosphorylation, NADH and FADH<sub>2</sub>

The potential of NADH and FADH<sub>2</sub> is converted to more ATP through an electron transport chain with oxygen as the "terminal electron acceptors". Most of the ATP produced by aerobic cellular respiration is made by oxidative phosphorylation. The energy released is used to create a chemiosmotic

potential by pumping protons across a membrane. This potential is then used to drive ATP synthase and produce ATP from ADP and a phosphate group. Biology textbooks often state that 38 ATP molecules can be made per oxidized glucose molecule during cellular respiration (2 from glycolysis, 2 from the Krebs cycle, and about 34 from the electron transport system). However, this maximum yield is never quite reached because of losses due to leaky membranes as well as the cost of moving pyruvate and ADP into the mitochondrial matrix .

Some anaerobic organisms, such as methanogens are able to continue with anaerobic respiration (Fermentation), yielding more ATP by using inorganic molecules other than oxygen as final electron acceptors in the electron transport chain. The glycolytic reactions take place in the mitochondria in eukaryotic cells, and in the cytoplasm in prokaryotic cells.

## **Fermentation**

Without oxygen, pyruvate (pyruvic acid) is not metabolized by cellular respiration but undergoes a process of fermentation. The pyruvate is not transported into the mitochondrion but remains in the cytoplasm, where it is converted to waste products that may be removed from the cell . Fermentation oxidizes NADH to  $\text{NAD}^+$  so it can be re-used in glycolysis, in the absence of oxygen . In skeletal muscles, the waste product is lactic acid. This type of fermentation is called lactic acid fermentation . During anaerobic respiration ,  $\text{NAD}^+$  regenerates when pairs of hydrogen combine with pyruvate to form lactate. Lactate formation is catalyzed by lactate dehydrogenase in a reversible reaction. In yeast, the waste products are ethanol and carbon dioxide. This type of fermentation is known as alcoholic or ethanol fermentation. The ATP generated in this process is made by substrate-level phosphorylation, which does not require oxygen.

Fermentation is less efficient at using the energy from glucose: only 2 ATP are produced per glucose, compared to the 38 ATP per glucose nominally produced by aerobic respiration. Glycolytic ATP, however, is created more quickly. For prokaryotes to continue a rapid growth rate when they are shifted from an aerobic environment to an anaerobic environment, they must increase the rate of the glycolytic reactions.

**The fermentation process is divided into the following three types :**

- 1- Alcoholic fermentation : Some fungi and protozoa as well as some bacteria ferment sugar into ethanol and  $\text{CO}_2$  .
- 2- Lactic fermentation : in which pyruvate is reduced to lactic acid, which is very common in lactic acid bacteria such as *Bacillus*.
- 3- Mixed acid fermentation : It occurs in the family Enterobacteraceae .

## **Glycolysis cycle**

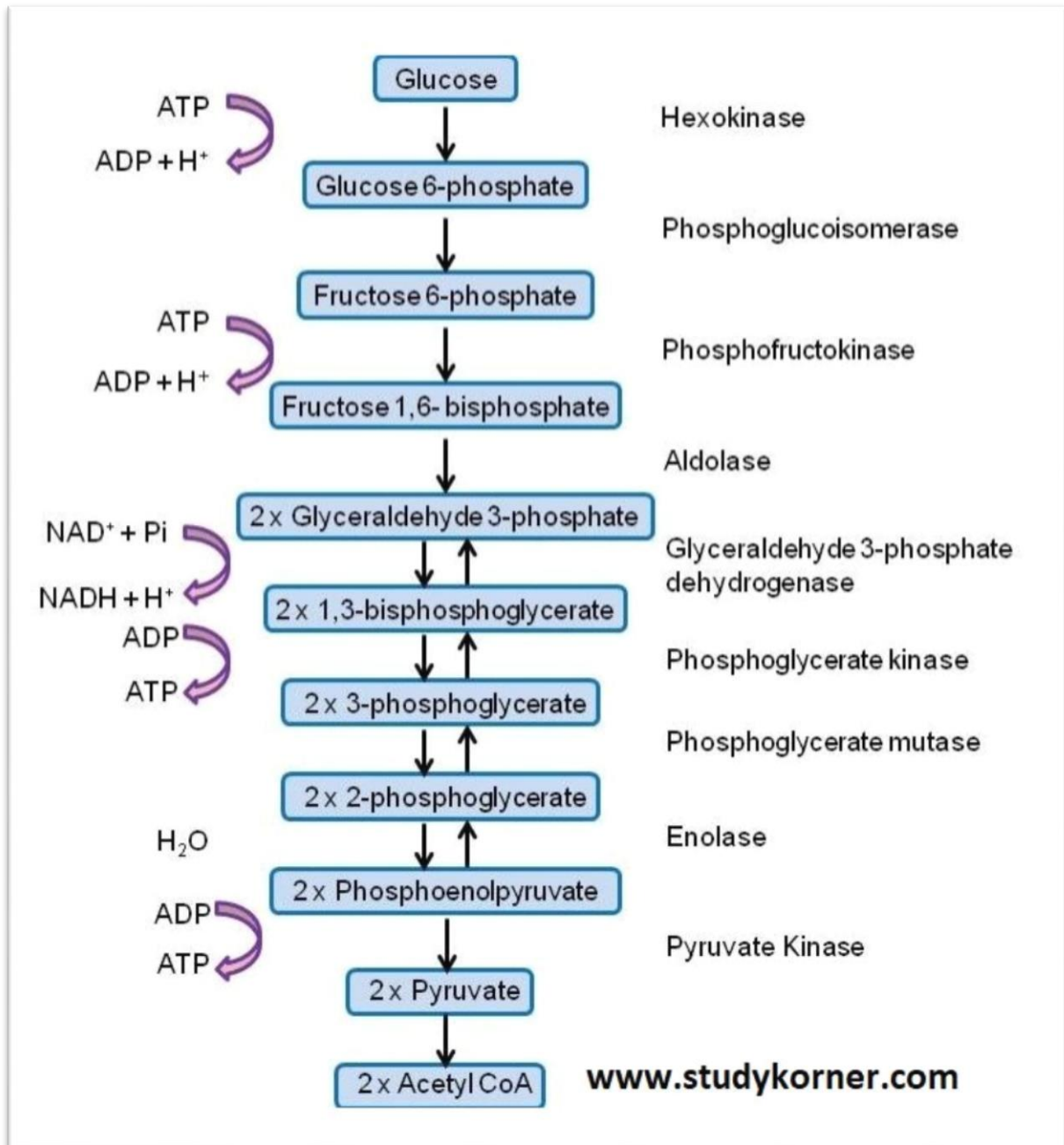
**Glycolysis** is a series of reactions that extract energy from glucose by splitting it into two three-carbon molecules called pyruvates. Glycolysis is an ancient metabolic pathway, meaning that it evolved long ago, and it is found in the great majority of organisms alive today .

Glycolysis has ten steps , it takes place in the cytosol of a cell, and it can be broken down into two main phases: the energy-requiring phase and the energy-releasing phase .

### **Glycolysis steps**

- **Step 1.** A phosphate group is transferred from ATP to glucose, making glucose-6-phosphate . Glucose-6-phosphate is more reactive than glucose .
- **Step 2.** Glucose-6-phosphate is converted into its isomer, fructose-6-phosphate.

- **Step 3.** A phosphate group is transferred from ATP to fructose-6-phosphate, producing fructose-1,6-bisphosphate. This step is catalyzed by the enzyme phosphofructokinase, which can be regulated to speed up or slow down the glycolysis pathway.
- **Step 4.** Fructose-1,6-bisphosphate splits to form two three-carbon sugars: dihydroxyacetone phosphate (DHAP) and glyceraldehyde-3-phosphate. They are isomers of each other, but only one—glyceraldehyde-3-phosphate—can directly continue through the next steps of glycolysis.
- **Step 5.** DHAP is converted into glyceraldehyde-3-phosphate. The two molecules exist in equilibrium.
- **Step 6.** Two half reactions occur simultaneously: (1) Glyceraldehyde-3-phosphate (one of the three-carbon sugars formed in the initial phase) is oxidized, and (2)  $\text{NAD}^+$  is reduced to NADH and  $\text{H}^+$ . The overall reaction is exergonic, releasing energy that is then used to phosphorylate the molecule, forming 1,3-bisphosphoglycerate.
- **Step 7.** 1,3-bisphosphoglycerate donates one of its phosphate groups to ADP, making a molecule of ATP and turning into 3-phosphoglycerate.
- **Step 8.** 3-phosphoglycerate is converted into its isomer, 2-phosphoglycerate.
- **Step 9.** 2-phosphoglycerate loses a molecule of water, becoming phosphoenolpyruvate (PEP). (PEP) is an unstable molecule, poised to lose its phosphate group in the final step of glycolysis.
- **Step 10.** PEP readily donates its phosphate group to ADP, making a second molecule of ATP. As it loses its phosphate, PEP is converted to pyruvate, the end product of glycolysis.



Glycolysis cycle

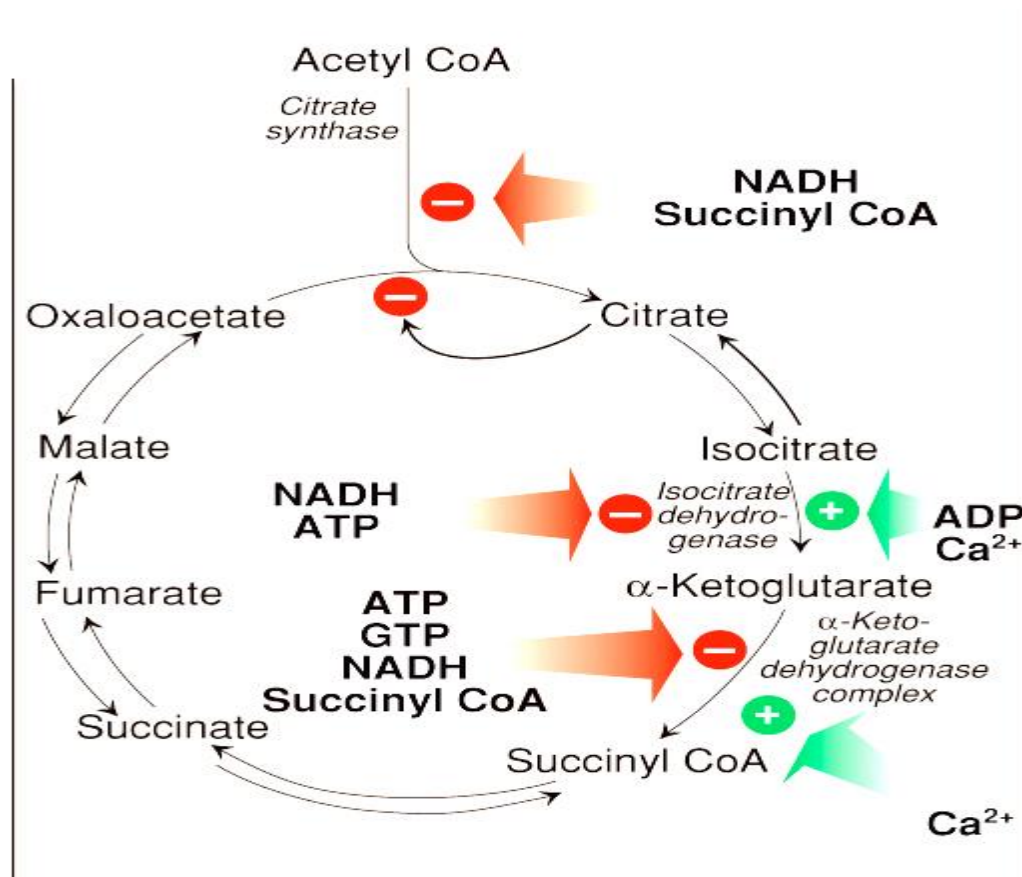
### The Transformation of pyruvate to acetyl CoA :

This is a very short step in between glycolysis and the citric acid cycle. The 3-carbon pyruvate molecule made in glycolysis loses a carbon to produce a new, 2-carbon molecule called acetyl CoA. The carbon that is removed takes two oxygens from pyruvate with it, and exits the body as carbon dioxide (CO<sub>2</sub>).

## **The citric acid cycle (krebs cycle or Tricarboxlic acid cycle)**

The citric acid cycle is called a cycle because the starting molecule, oxaloacetate (which has 4 carbons), is regenerated at the end of the cycle. Throughout the citric acid cycle, oxaloacetate is progressively transformed into several different molecules (as carbon atoms are added to and removed from it), but at the end of the cycle it always turns back into oxaloacetate to be used again. The difference in energy between the products and the reactants is the energy that is released when the reaction takes place . The released energy is captured as the electron shuttles ( $\text{NAD}^+$  and FAD) are reduced to NADH and  $\text{FADH}_2$

To start the cycle, an enzyme fuses acetyl CoA and oxaloacetate together so that citric acid is formed (6C) , This is the first molecule that is made in the cycle and is where the cycle gets its name. Enzymes then proceed to speed up (or “catalyze”) a sequence of rearrangements that convert the newly made citric acid molecule into a series of slightly different molecules , After two rounds of the citric acid cycle, we have completely oxidized one molecule of glucose to  $\text{CO}_2$  and captured its energy in a series of steps. These products from the citric acid cycle are made in the mitochondria .



TCA cycle

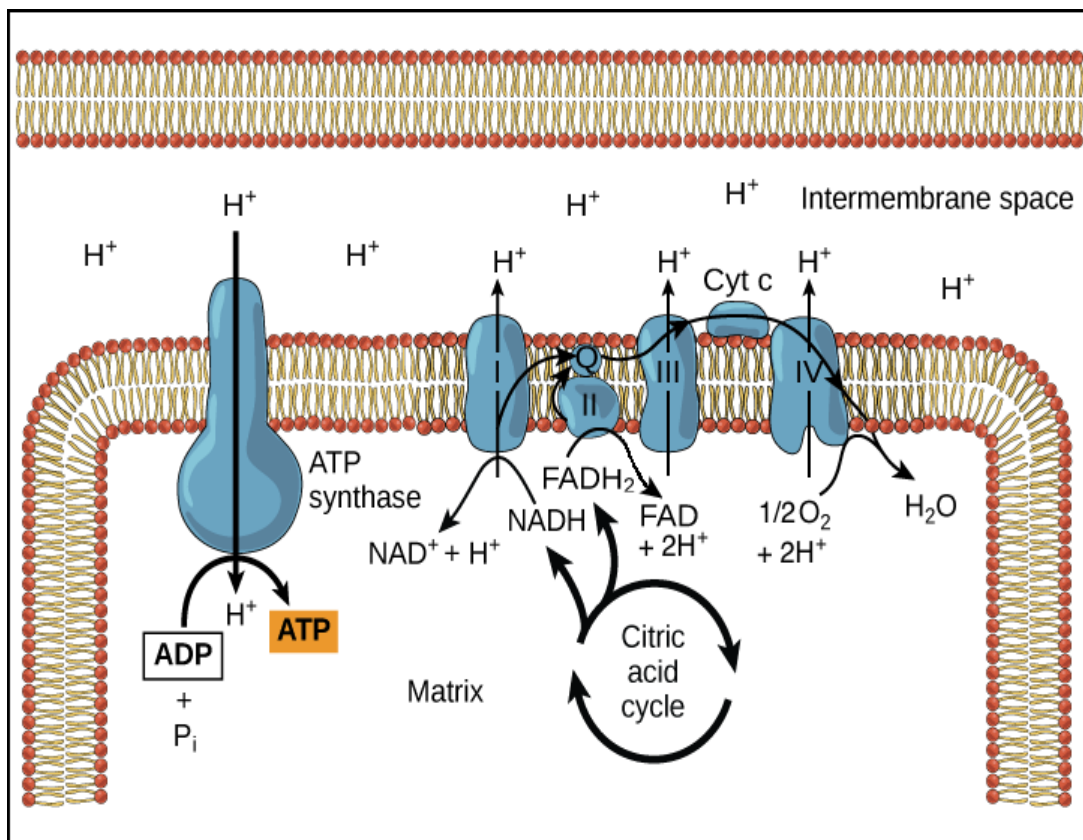
### Electron transport chain

The electron transport chain is a series of proteins and organic molecules found in the inner membrane of the mitochondria. Electrons are passed from one member of the transport chain to another in a series of redox reactions. Energy released in these reactions is captured as a proton gradient, which is then used to make ATP in a process called **chemiosmosis**. Together, the electron transport chain and chemiosmosis make up **oxidative phosphorylation**.

The key steps of this process include :

- **Delivery of electrons by NADH and FADH<sub>2</sub>**: Reduced electron carriers (NADH and FADH<sub>2</sub>) from other steps of cellular respiration transfer their electrons to molecules near the beginning of the transport chain. In the process, they turn back into NAD<sup>+</sup> and FAD, which can be reused in other steps of cellular respiration.

- **Electron transfer and proton pumping.** As electrons are passed down the chain, they move from a higher to a lower energy level, releasing energy. Some of the energy is used to pump  $H^+$  ions, moving them out of the matrix and into the intermembrane space. This pumping establishes an electrochemical gradient.
- **Splitting of oxygen to form water.** At the end of the electron transport chain, electrons are transferred to molecular oxygen, which splits in half and takes up  $H^+$  to form water.
- **Gradient-driven synthesis of ATP.** As  $H^+$  ions flow down their gradient and back into the matrix, they pass through an enzyme called ATP synthase, which harnesses the flow of protons to synthesize ATP.



**Electron transport chain**