Carbohydrates in Metabolism

Carbohydrates are found in a wide array of healthy and unhealthy foods bread, beans, milk, and potatoes. They also come in a variety of forms. The most common and abundant forms are sugars, fibers, and starches.

Carbohydrates are supplied in three forms:

- Starch
- Sugar
- Cellulose

Starch and sugar are the major forms of energy for humans. Metabolism of carbohydrates and sugar helps in the production of glucose.

Carbohydrate Metabolism

Carbohydrate metabolism is a fundamental biochemical process that ensures a constant supply of energy to living cells. The most important carbohydrate is glucose, which can be broken down to generate ATP, by:

Glycolysis

Krebs Cycle

Glycogenesis (glycogen building)

Gluconeogenesis

Glycogenolysis

1-Glycolysis

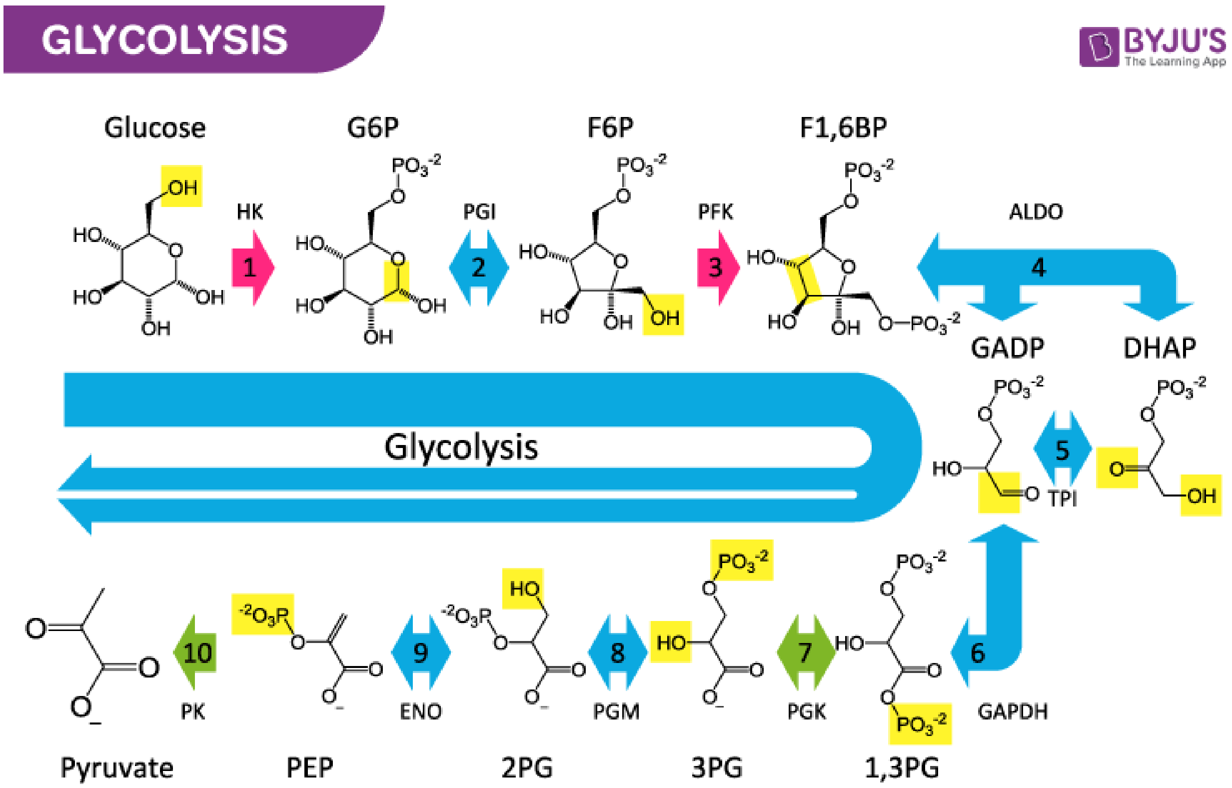
Glycolysis is breaking down a glucose molecule into two pyruvate molecules while storing energy released during this process as ATP and NADH. Nearly all organisms that break down glucose utilize glycolysis. Glucose regulation and product use are the primary categories in which these pathways differ between organisms. In some tissues and organisms, glycolysis is the sole method of energy production. This pathway is common to both anaerobic and aerobic respiration.

Glycolysis consists of ten steps, split into two phases. During the first phase, it requires the breakdown of two ATP molecules. During the second phase, chemical energy from the intermediates is transferred into ATP and NADH. The breakdown of one molecule of glucose results in two molecules of pyruvate, which can be further oxidized to access more energy in later processes.

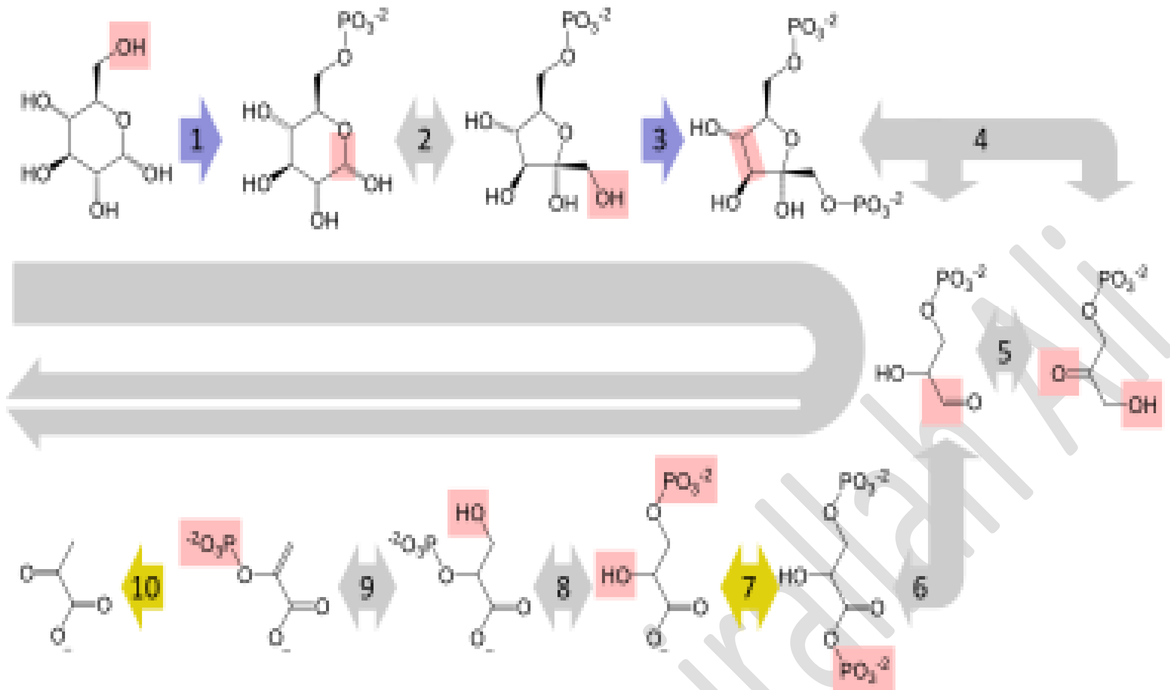
Glycolysis can be regulated at different steps of the process through feedback regulation. The step that is regulated the most is the third step. This regulation is to ensure that the body is not over-producing pyruvate molecules. The regulation also allows for the storage of glucose molecules into fatty acids. Various enzymes are used throughout glycolysis. The enzymes upregulate, downregulate, and feedback regulates the process.

Glycolysis is the metabolic pathway that breaks down (catabolism) hexose (six-carbon) monosaccharides such as glucose, fructose, and galactose into two molecules of pyruvate, two molecules of ATP, two molecules of NADH, two water (H2O) molecules, and two hydrogen ions (H+).

Glycolysis is the process in which glucose is broken down to produce energy. It produces two molecules of pyruvate, ATP, NADH, and water. **The process takes place in the cytoplasm of a cell and does not require oxygen. It occurs in both aerobic and anaerobic organisms.**



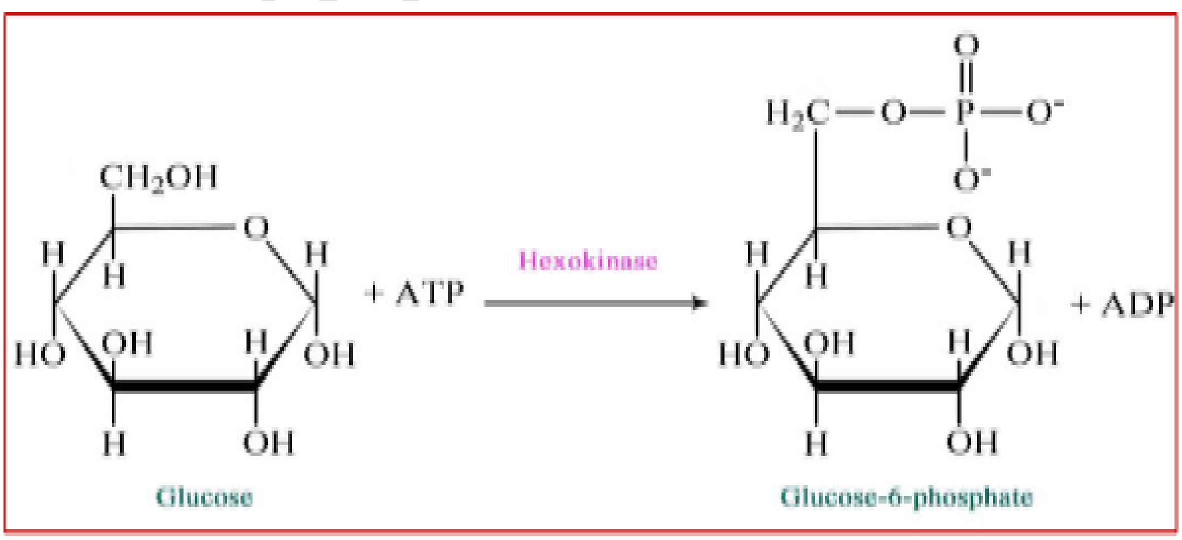
Glycolysis is the primary step of cellular respiration, which occurs in all organisms. Glycolysis is followed by the Krebs cycle during aerobic respiration. In the absence of oxygen, the cells make small amounts of ATP as glycolysis is followed by fermentation.



Step 1

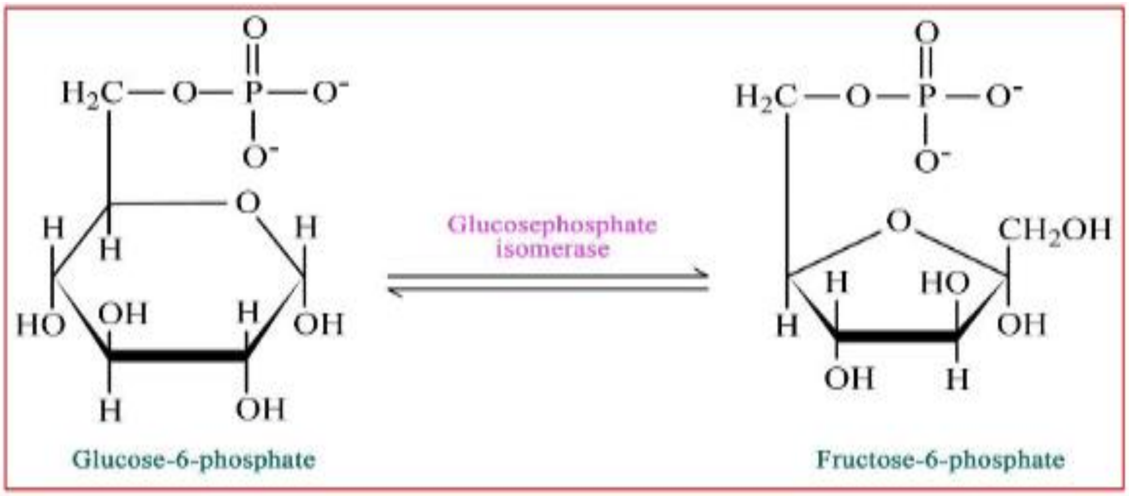
A phosphate group is added to glucose in the cell cytoplasm, by the action of enzyme hexokinase.

In this, a phosphate group is transferred from ATP to glucose forming glucose,6-phosphate.



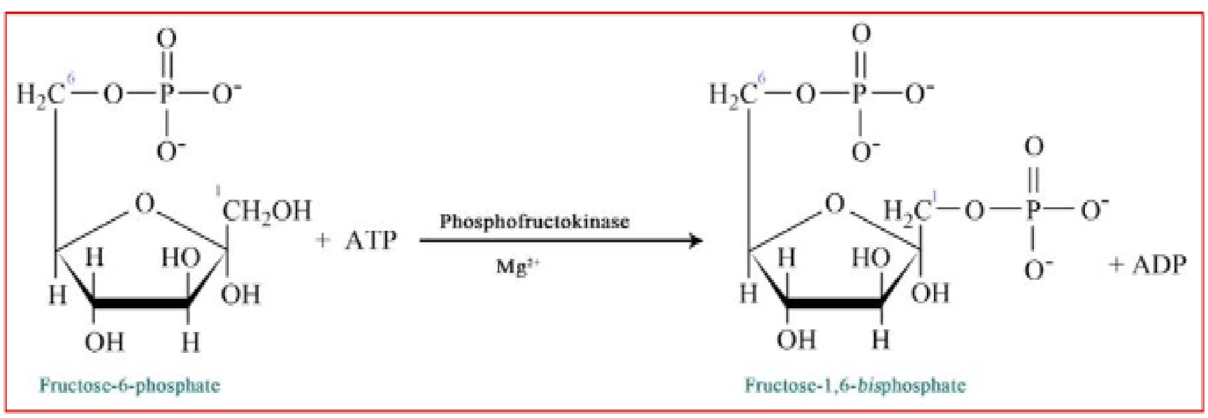
Step 2

Glucose-6-phosphate is isomerized into fructose 6-phosphate by the enzyme glucose phosphate isomerase.



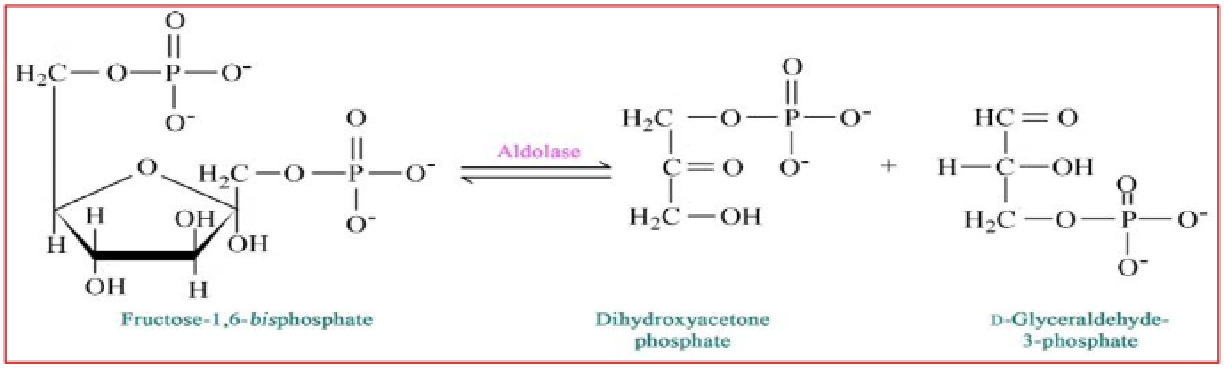
Step3

The other ATP molecule transfers a phosphate group to fructose 6-phosphate and converts it into fructose 1,6-bisphosphate by the action of the enzyme phosphofructokinase.



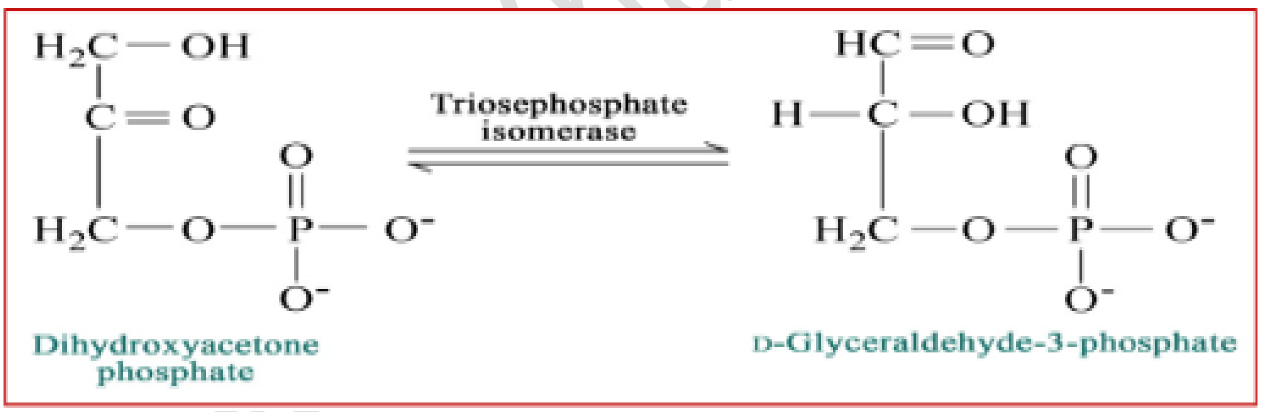
Step 4

The enzyme aldolase converts fructose 1,6-bisphosphate into glyceraldehyde 3-phosphate and dihydroxyacetone phosphate, which are isomers of each other.



Step 5

Triose-phosphate isomerase converts dihydroxyacetone phosphate into glyceraldehyde 3-phosphate which is the substrate in the successive step of glycolysis.

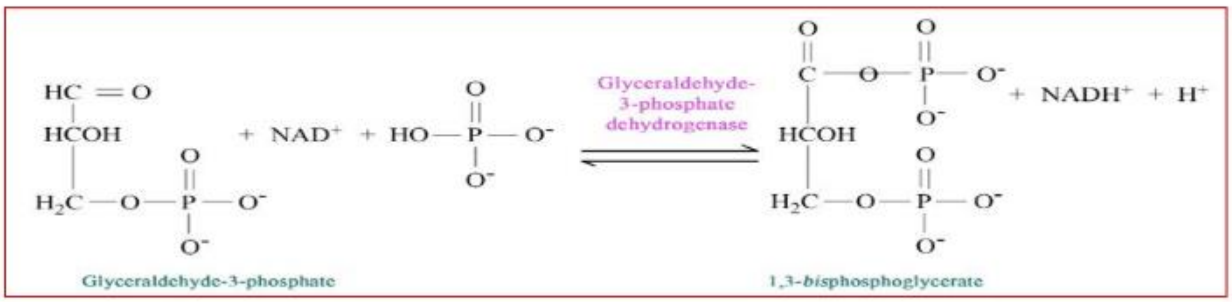


Step 6

This step undergoes two reactions:

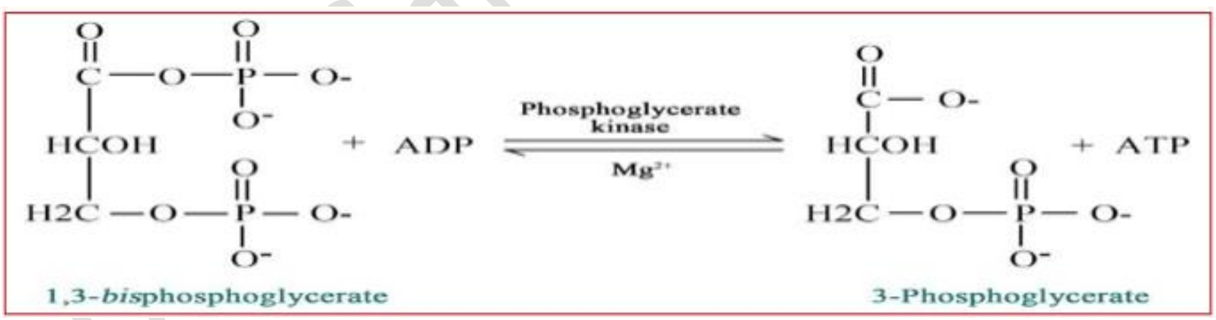
The enzyme glyceraldehyde 3-phosphate dehydrogenase transfers 1 hydrogen molecule from glyceraldehyde phosphate to nicotinamide adenine dinucleotide to form NADH + H+.

Glyceraldehyde 3-phosphate dehydrogenase adds a phosphate to the oxidized glyceraldehyde phosphate to form 1,3-bisphosphoglycerate.



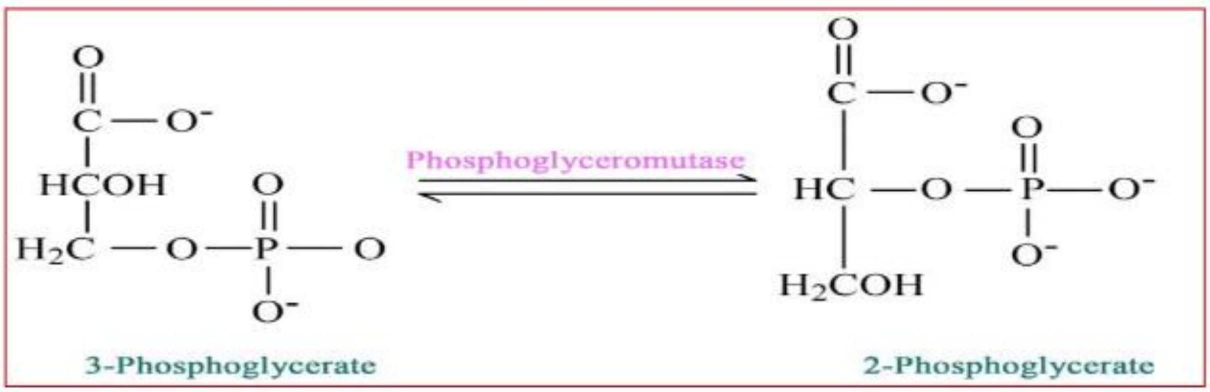
Step 7

Phosphate is transferred from 1,3-bisphosphoglycerate to ADP to form ATP with the help of phosphoglycerokinase. Thus two molecules of phosphoglycerate and ATP are obtained at the end of this reaction.



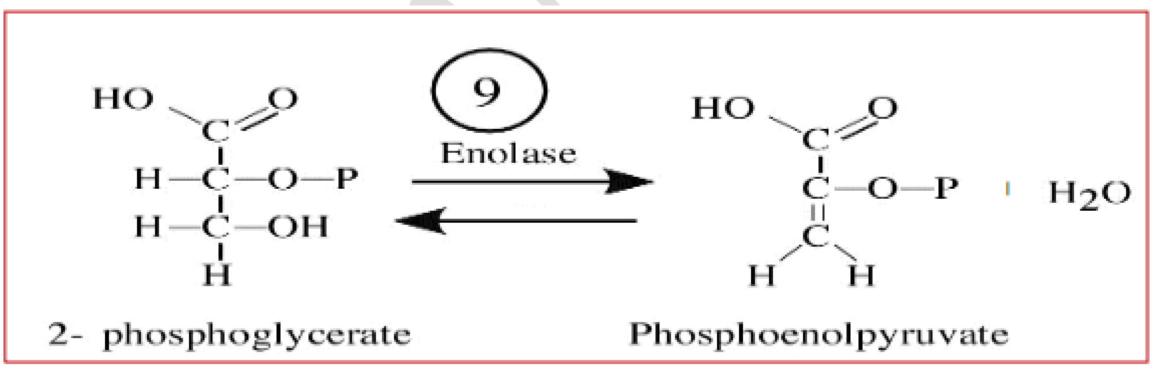
Step 8

The phosphate of both the phosphoglycerate molecules is relocated from the third to the second carbon to yield two molecules of 2-phosphoglycerate by the enzyme phosphoglyceromutase.



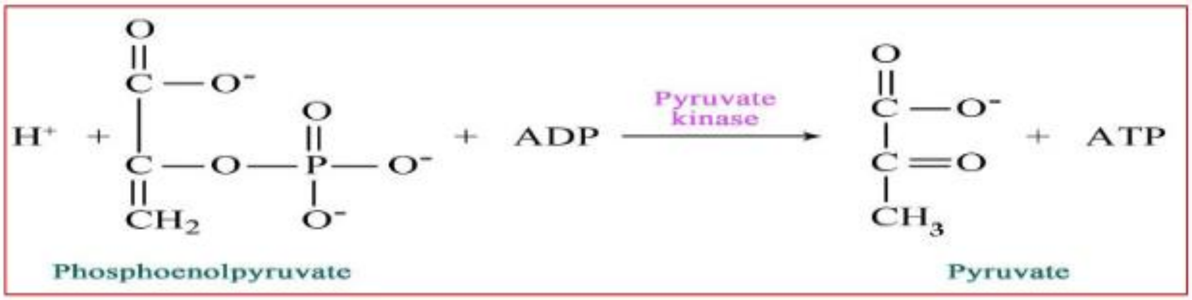
Step 9

The enzyme enolase removes a water molecule from 2-phosphoglycerate to form phosphoenolpyruvate.



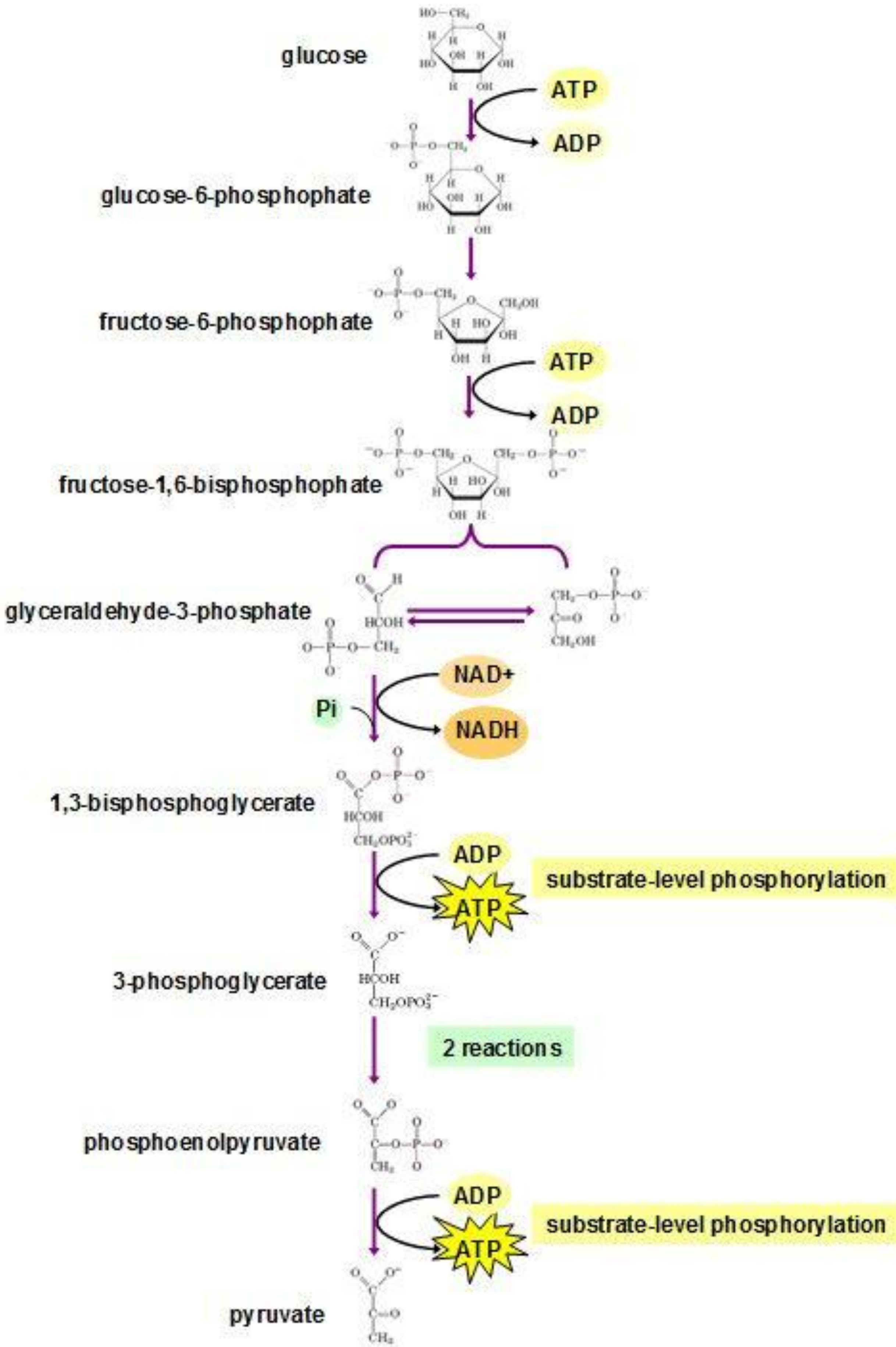
Step 10

A phosphate from phosphoenolpyruvate is transferred to ADP to form pyruvate and ATP by the action of pyruvate kinase. Two molecules of pyruvate and ATP are obtained as the end products.



Key Points of Glycolysis

- It is the process in which a glucose molecule is broken down into two molecules of pyruvate.
- The process takes place in the cytoplasm of plant and animal cells.
- Six enzymes are involved in the process.
- The end products of the reaction include 2 pyruvate, 2 ATP, and 2 NADH molecules.


glucose
ATP
ADP
glucose-6-phosphophate
fructose-6-phosphophate
ATP
ADP
fructose-1,6-bisphosphophate
glyceraldehyde-3-phosphate
NAD+
Pi
NADH
1,3-bisphosphoglycerate
ADP
ATP
substrate-level phosphorylation
3-phosphoglycerate
2 reactions
phosphoenolpyruvate
ADP
ATP
substrate-level phosphorylation
pyruvate

Six enzymes regulate glycolysis.

Step 1: Hexokinase/Glucokinase

Glucokinase is found in hepatocytes (liver cells) and pancreatic cells. It is activated by insulin. Hexokinase, on the other hand, is found in most tissues. Both enzymes serve the same function: to use ATP to catalyze the irreversible phosphorylation of glucose.

The product of this reaction, glucose 6-phosphate, is now unable to spontaneously diffuse out of the cell. Glucose 6-phosphate also has an inhibitory effect on the hexokinase enzyme.

Step 3: Phosphofructokinase 1 (PFK-1)

Phosphofructokinase 1, also known as PFK-1, uses ATP to catalyze the irreversible conversion of fructose 6-phosphate into fructose 1,6-bisphosphate. This step is highly regulated. Citrate (a metabolic product of aerobic respiration) and ATP have a negative feedback effect on PFK-1.

Why would this be? The presence of citrate and/or ATP indicates that the cell's energy needs are being met, and thus signals that the glycolysis pathway is not immediately needed. Since this step is an irreversible conversion—and thus requires energy to be performed—shutting down PFK-1 when it is not needed allows the cell to conserve valuable energy.

On the other hand, the presence of AMP (adenosine monophosphate) indicates low energy in the cell and activates PFK-1.

Step 6: G3P dehydrogenase

G3P dehydrogenase catalyzes the reversible conversion of glyceraldehyde 3-phosphate into 1,3-bisphosphoglycerate, which generates one molecule of NADH. However, one molecule of glucose (a 6-carbon structure) generates 2 molecules of glyceraldehyde 3-phosphate—so this step yields two molecules of NADH per glucose molecule.

Step 7: Phosphoglycerate kinase

Phosphoglycerate kinase catalyzes the reversible conversion of 1,3-bisphosphoglycerate into 3-phosphoglycerate, or the removal of a phosphate group from 1,3-bisphosphoglycerate. This generates one ATP per molecule of phosphoglycerate (or 2 ATP per glucose molecule).

Step 10: Pyruvate kinase

The final enzyme of glycolysis, pyruvate kinase, catalyzes the irreversible conversion of phosphoenolpyruvate into pyruvate, or the removal of a phosphate group from phosphoenolpyruvate. This generates one ATP per molecule of phosphoenolpyruvate (or 2 ATP per glucose molecule).

All intermediates in glycolysis have a phosphate group attached to them except glucose and pyruvate. Why does the phosphorylation of glucose take place during glycolysis?

The pathway of the breakdown of glucose into pyruvic acid is termed as glycolysis. This pathway is a step-wise process in which all molecules except glucose and pyruvate bear the phosphate group. The steps are:

There are several reasons behind the addition of phosphate group to the reaction intermediates:

1- The plasma membrane bears different transport proteins for carrying different molecules. However, the plasma membrane lacks any transporter for phosphorylated compounds. Hence, no intermediate will escape the cell even if there is a concentration difference inside and outside the cell.

2- In the energy-yielding steps of the glycolysis, the release of energy from the phospho compounds during the breakdown of the phosphate bond is stored as ATP. This occurs by the donation of the phosphate group to adenosine diphosphate to form adenosine triphosphate.

3- Enzymes are required to carry out metabolic reactions such as glycolysis reactions. The binding of a phosphate group helps the enzyme to carry out the reactions.

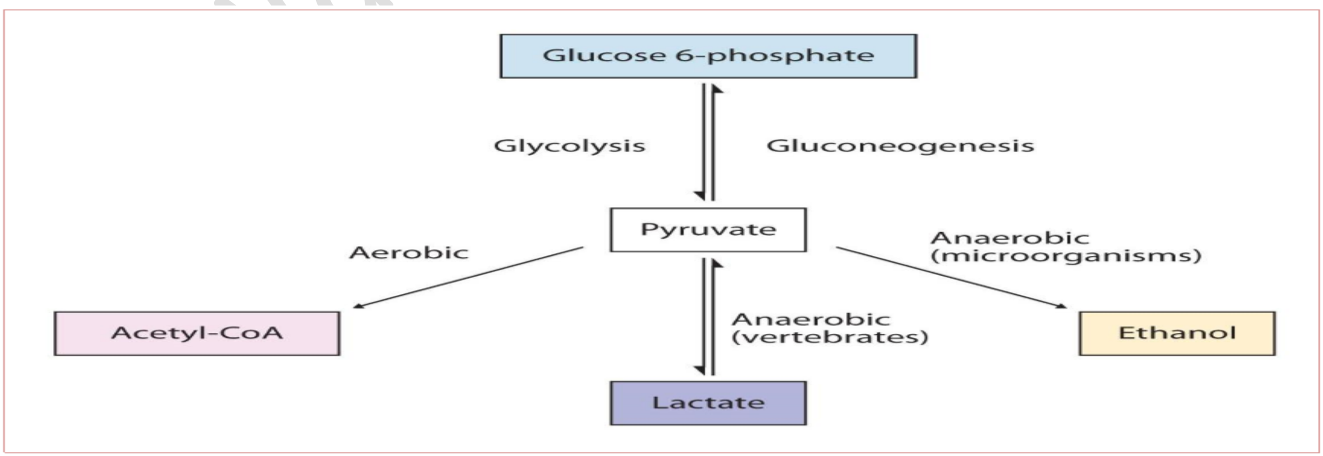
Fate of pyruvate

The fate of pyruvate depends on the availability of oxygen. If oxygen is available, then pyruvate is shuttled into the mitochondria and continues through several more biochemical reactions called the "Citric Acid Cycle." This is called aerobic metabolism.

Pyruvate is the connecting link between many metabolic processes such as cellular respiration, fermentation, fatty acid biosynthesis, and gluconeogenesis. Pyruvate is the end product of glycolysis. Two molecules of pyruvate are produced by the partial oxidation of glucose. The three main ways by which pyruvate is utilized by cells are aerobic respiration, lactic acid fermentation, and alcoholic fermentation (anaerobic respiration). In aerobic respiration, pyruvate is transported to mitochondria, where it undergoes oxidative decarboxylation to produce acetyl CoA, which enters the Krebs cycle. During fermentation, as the name suggests, lactic acid and alcohol are produced.

The Three Fates of Pyruvate. The most common future of pyruvate are as follows:

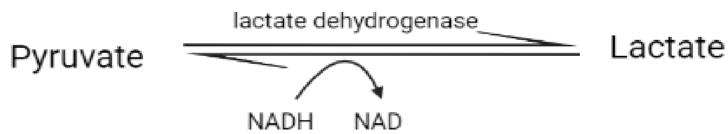
- Lactate formation
- Ethanol formation
- Acetyl CoA formation



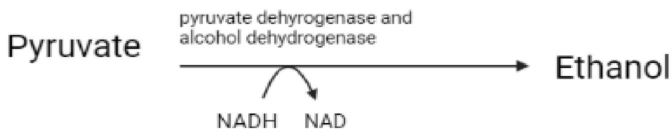
FATE OF PYRUVATE

Anaerobic condition

Lactic Acid Fermentation

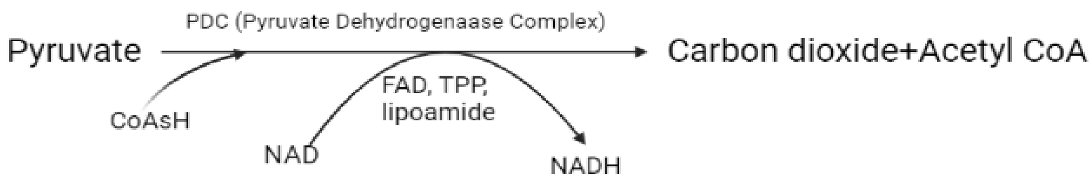


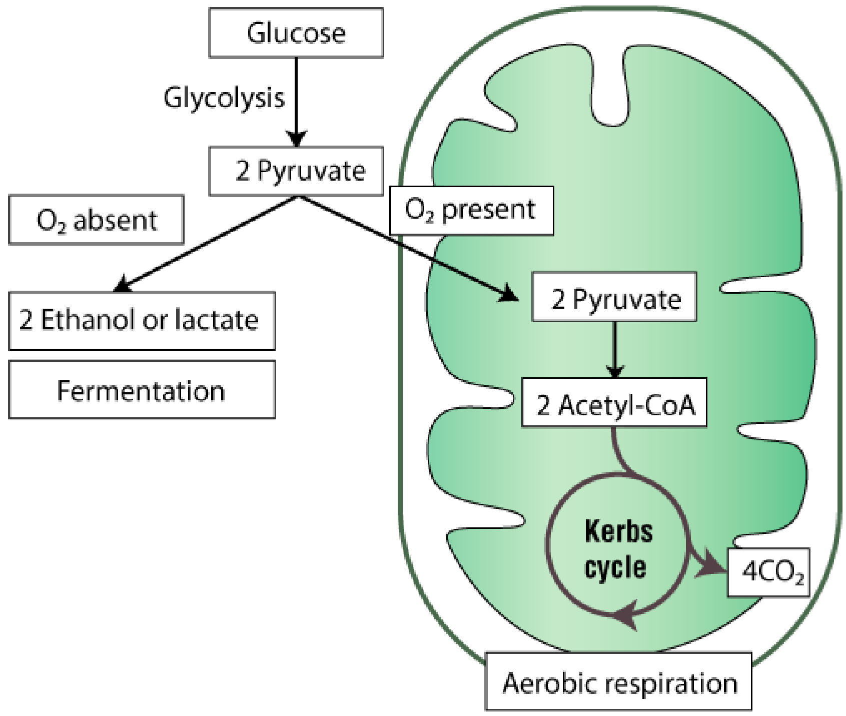
Ethanol Fermentation



Aerobic condition

Acetyl CoA formation





Pyruvate can enter in lactic acid fermentation and alcoholic fermentation in anaerobic conditions, in aerobic condition pyruvate loses hydrogen and carbon dioxide and converts into acetyl CoA enters into the TCA cycle, and also enters into the biosynthetic pathway. In the case of low glucose levels, pyruvate enters into gluconeogenesis.

The fate of pyruvate in anaerobic conditions

In anaerobic conditions, pyruvate is partitioned into lactic acid fermentation and alcoholic fermentation.

Pyruvate works as a terminal electron acceptor in lactic acid fermentation.

When tissue can't be supplied by oxygen, or during exercise when less oxygen reaches muscle than it needs, then pyruvate acts as a terminal electron acceptor from NADH (formed during glycolysis) and is converted into lactate, a process called lactic acid fermentation. RBC, retina cells, and muscles during exercise and hypoxic conditions respire by lactic acid fermentation. During lactic acid fermentation, pyruvate accepts an electron from NADH and reduced into lactate to restore the NAD+ for further cycling of the reaction.

Pyruvate + NADH → lactate + NAD

lactate dehydrogenase

Lactate formed in the active muscles transported to the liver where it can be broken down or restored into glucose, the restored glucose from lactate is transported to muscles this cycle is called a **Cori cycle.**

The fate of Pyruvate in alcoholic fermentation

Yeast and other microorganisms ferment glucose into ethanol, and glycolytic end product pyruvate enters into alcoholic fermentation, this step takes place via a two-step reaction.

The first step is the decarboxylation of pyruvate, where pyruvate changes into acetaldehyde by losing carbon by the action of pyruvate decarboxylase enzyme in presence of TPP and Mg++.

Pyruvate → Acetaldehyde + CO_2

pyruvate decarboxylase

In the second step, acetaldehyde accepts an electron from NADH (formed during glycolysis) to restore it into NAD+ for the further cycle, and converted into ethanol, by the action of alcohol dehydrogenase enzyme.

Acetaldehyde + NADH → Ethanol + NAD+

alcohol dehydrogenase

The fate of pyruvate in the case of aerobic respiration

During aerobic respiration, pyruvate changes into Acetyl CoA, and now enters into the TCA cycle (Krebs cycle), via oxidative decarboxylation, this reaction is catalyzed by pyruvate dehydrogenase complex

Pyruvate + E1 + E2 + E3+TPP+ lipoate +CoA-SH+ FAD+ NAD^+ → Acetyl CoA+ E1+E2+E3+ TPP+ lipoate +FAD +NADH $+H^+$

The fate of pyruvate in the biosynthetic pathway

Pyruvate can also enter into the biosynthetic pathways such as fatty acids biosynthesis and gluconeogenesis. Pyruvate changed into acetyl CoA by the action of pyruvate dehydrogenase complex this acetyl CoA also enters into the biosynthetic pathway beside TCA. Pyruvate can also enter gluconeogenesis by the action of pyruvate carboxykinase converting it into oxaloacetate which with a several-step reaction changes into glucose.