- After glucose has been broken down to pyruvic acid, the pyruvic acid can be channeled into the next step of either fermentation or cellular respiration
- **Fermentation:** is metabolic process that releases energy from a sugar or other organic molecules (amino acids, organic acids, purines, and pyrimidines), does not require oxygen or an electron transport system, and uses an organic molecule as the final electron acceptor.

Types of fermentation

According to the state or nature of substrates, there are two types of fermentation

1. **Submerged fermentation:** the microorganisms grow in liquid nutrient media or dissolved substrates like producing of yogurt.
2. **Solid-state fermentation:** is the cultivation of microorganisms on solid substrates like bread making.

Types of fermentation

According to types of microorganisms, there are three types of fermentation:

1. Bacterial fermentation
2. Yeast fermentation
3. Mold fermentation

Fermentation pathways

Some fermentation pathways used by the microbes that inhabit the human body are as follows:

- **a.** Lactic acid fermentation
- **b.** Alcohol fermentation
- **c.** Propionic acid fermentation
- **d.** Mixed acid fermentation
- **e.** Butanediol fermentation

Lactic acid fermentation

- During glycolysis, a molecule of glucose is oxidized to two molecules of **pyruvic acid**.
- In the next step, the two molecules of pyruvic acid are reduced by two molecules of NADH to form two molecules of **lactic acid**.
- Because lactic acid is the end-product of the reaction, it does not undergo further oxidation, and most of the energy produced by the reaction remains

stored in the lactic acid. Thus, this fermentation yields only a small amount of energy.

- This process can produce yogurt and cheese from milk and pickles from cucumbers.

Types of Lactic acid fermentation

- **Homolactic fermentation**

– In homolactic fermentation, one molecule of glucose is converted to two molecules of lactic acid.
– $C_6H_{12}O_6 \rightarrow 2\ C_3H_6O_3$
– Homolactic bacteria: *Streptococcus*, *Lactobacillus*, and *Bacillus*

- **Heterolactic fermentation**

– In heterolactic fermentation one molecule of glucose is converted to one molecule of lactic acid, one molecule of ethanol, and one molecule of carbon dioxide (CO_2).
– $C_6H_{12}O_6 \rightarrow C_3H_6O_3 + C_2H_5OH + CO_2$
– Heterolactic bacteria: *Escherichia coli* and *Salmonella*

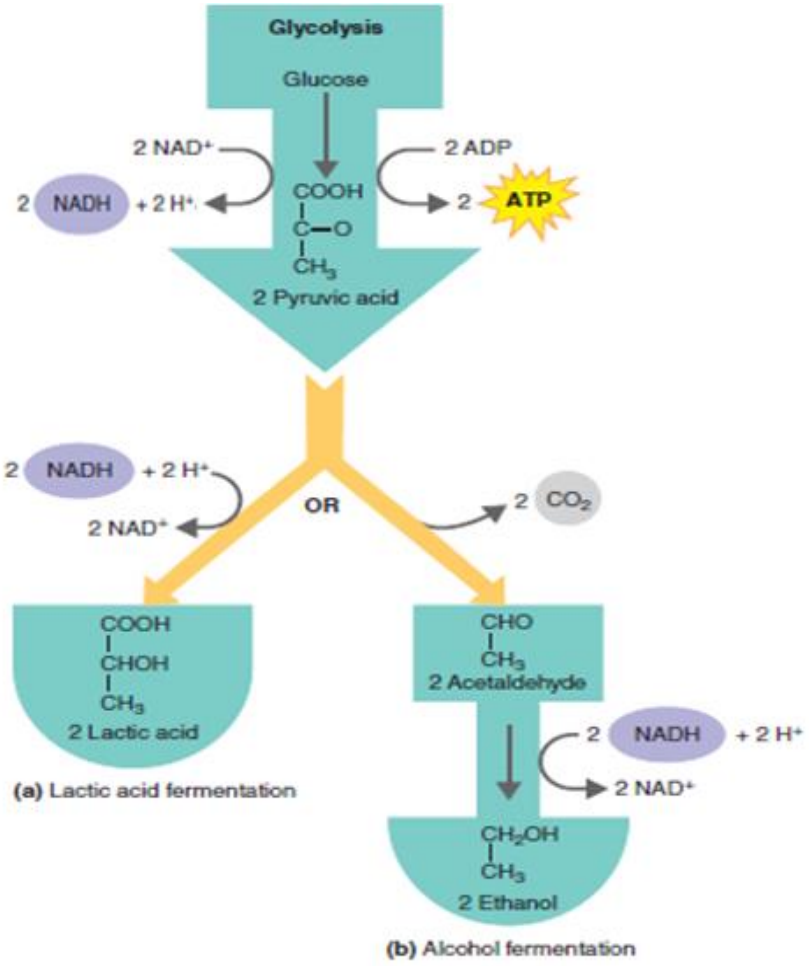
Alcohol fermentation

- In an alcohol fermentation (**ethanol fermentation**), the two molecules of pyruvic acid are converted to two molecules of **acetaldehyde** and two molecules of CO_2.
- The two molecules of acetaldehyde are reduced by two molecules of NADH to form two molecules of **ethanol**.
- Again, alcohol fermentation is a low energy- yield process because most of the energy remains in the ethanol, the end-product.
- Alcohol fermentation is carried out by a number of bacteria and yeasts. The ethanol and CO_2 produced by the yeast *Saccharomyces*.
- Ethanol fermentation uses for the production of alcoholic beverages and ethanol fuel. It is important in bread-making, brewing, and wine-making.

Fermentation versus cellular respiration

- Fermentation differs from cellular respiration in a way that it uses organic molecules such as carbohydrates as (**endogenous**) electron acceptors instead of molecular oxygen (which is an **exogenous** electron acceptor) in cellular respiration.
- However, compared with oxidative phosphorylation of cellular respiration (38 ATP), fermentation produces less ATP molecules (2 ATP).

Fermentation pathways



Ethanol fermentation

Materials

- Grape juice (no preservative)
- Culture of wine yeast (*Saccharomyces cerevisiae*)
- Flasks
- Balloon
- pH meter

Procedure

1. Add about 100 ml of grape juice to the flask.
2. Determine the pH of the juice with a pH meter and record the pH.
3. Sterilize grape juice medium by autoclave.
4. Agitate the container of yeast culture to suspend it, remove 5 ml with a pipette, and add it to the flask.
5. Cover the flask opening with balloon, then incubates at 15 - 17° C for 2 - 5 days.
6. After incubation time, remove the balloon and note the aroma of the flask contents.
7. Determine the pH and record it.