Bacterial Metabolism

Metabolism describes the collective biochemical reactions or chemical changes that take place within a bacterial cell, and any compound produced in metabolism is a metabolite. These changes make energy and materials for cells and organisms to reproduce and stay healthy. Metabolism also helps get rid of toxic substances.

Basic chemical reactions:

1. Anabolism & Catabolism (biosynthetic and degradative reactions)
2. Oxidation & Reduction reactions (Redox reactions)
3. ATP production & Energy storage

Microbial life can exist only where molecules and cells remain organized, and energy is needed by all microorganisms to maintain organization and cellular steady state.In order to survive, microorganisms must multiply, that is, they must produce copies of themselves. Multiplication requires that the cells synthesize all of their cell components. The reactions involved in the synthesis of cell components are termed anabolic reactions (anabolism or endergonic).

Anabolic reactions require energy. To gain this energy, cells must carry out other biochemical reactions termed catabolic reactions (catabolism or exergonic) which are degradative reactions yielding energy.

Oxidation and reduction always occur together. One substance gets reduced (electron acceptor) and other substances gets oxidized (electron donor). Both processes are coupled to one another, that is they occur simultaneously.

Activation energy (sparkle) is the minimum amount of energy that is required to start reaction or activate atoms or molecules to a condition in which they can undergo chemical transformation. Even energy-releasing (exergonic) reactions require some amount of activation energy, before they can proceed with their energy-releasing steps.

In order for the reaction to take place, some or all of the chemical bonds in the reactants must be broken so that new bonds, those of the products, can form.

These metabolic reactions are catalyzed by enzymes, the key proteins in the cell. They responsible for the cells ability to carry out its functions necessary for cell multiplication. Enzymes catalyze (speed up) the large number of chemical reactions in the cell, but remain unchanged during these reactions**.** However, an enzyme can covert substrate into a product in a short time. Enzymes work by lowering energy of activation for the chemical reaction. The sequence of enzymatically –catalyzed steps from a starting raw material to final end products is called enzymatic pathways or metabolic pathways.

Many enzymes cannot function unless they have another molecule, coenzyme, bound to them. Coenzymes are small, nonprotein molecules such as nicotinamide adenine dinucleotide NAD and flavin adenine dinucleotide FAD. They participate in the formation of ATP by the process of oxidative phosphorylation (transfer of electrons through a series of proteins and coenzymes from a high to low energy state) and store reducing power in the form of H atoms. Reducing power is produced and stored in coenzyme following the removal of H atoms from certain compounds in glycolysis.

NAD (oxidized form) and NADH (reduced form)

FAD (oxidized form) and FADH (reduced form)

ATP (Adenosine triphosphate): A currency and storage form of energy for many cellular reactions.

The breakdown of an ATP molecule is accomplished by an enzyme called adenosine triphosphatase. The products of ATP breakdown are adenosine diphosphate (ADP) and **phosphate ion.** Adenosine diphosphate and the phosphate ion can be reconstituted to form ATP. To accomplish ATP formation, energy necessary for the synthesis can be made available in the microorganism by three important processes:

1. Aerobic respiration

Aerobic respiration is the oxidation of organic compounds, such as glucose, lipids and proteins to yield ATP, simpler organic or inorganic compounds (precursor molecules) and water. Oxygen as the terminal acceptor of electrons and in which 38 moles of ATP is derived from the complete oxidation of 1 mole of glucose.

The oxidation of glucose may involve four fundamental biochemical pathways.

A. Glycolysis (Embden-Meyerhoff-Parnas Pathway)

Is a multistep catabolic pathway that occurs in the cytoplasm of microbial cells. Glucose molecule is broken down to 2 molecules of pyruvic acid. Two molecules of ATP (net) (energy gained 4 ATP molecules, energy expended 2 ATP molecules) and 2 reduced NADH are synthesized using the energy given off during the chemical reactions. Two molecules of ATP are used to energize the molecules.

Pyruvate oxidation

In the presence of oxygen, pyruvate is transformed to acetyl CoA (decarboxylation) can enter to the citric acid cycle for further catabolism. During the conversion of pyruvate into the acetyl group, 2 molecules of NADH and 2 CO2 are produced.

B. Krebs cycle (citric acid or tricarboxylic acid cycle TCA).

The Krebs cycle (named for the scientist who discovered it) uses the two molecules of pyruvic acid formed in glycolysis and yields 2 ATP, 6 NADH and 2 FADH (high-energy molecules) and 4 CO2. The NADH and FADH will be used in the electron transport system.

C. Electron transport chain (ETC)

Occurs at the bacterial cytoplasmic membrane. ATP is generated by a series of oxidation and reduction reactions that involve the transfer of protons and electrons (H atoms) through the electron transport chain.

Here, a series of coenzymes NADH, FADH, quinone and a set of small proteins called cytochromes acts as carriers and transfers the electrons from one molecule to another in the system (oxidative phosphorylation) by chemiosmosis. Hydrogen atoms are removed from a substrate by a dehydrogenase associated with the NAD. The hydrogen atoms are then transferred to FAD, quinone and to cytochromes.

However, these proteins can accept only electrons, so at this stage the protons separate from the electrons and transferred to the outside of the cytoplasmic membrane. The higher concentration of protons on the outside creates a positive charge and generate proton motive force. The protons tend to equalize their concentration on each side of the cytoplasmic membrane. Protons can pass to the inside of the cell by ATPase enzyme that convert the energy of the proton gradient into ATP by catalyzing the following reversible reaction:

$$\text{ADP} + \text{P} \rightleftharpoons \text{ATP}$$

2. Anaerobic respiration

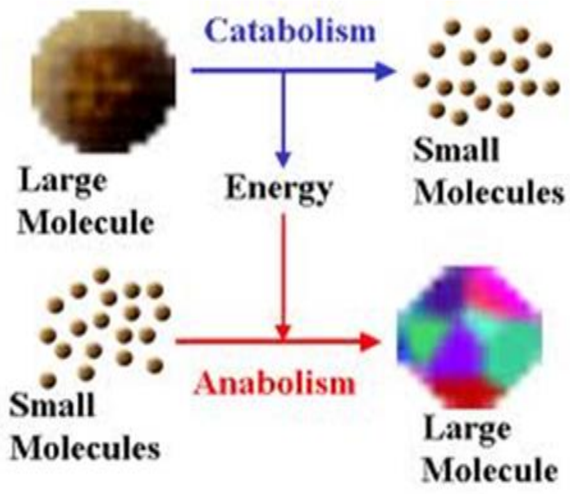
In facultative anaerobes and obligate anaerobes bacteria. Final electron acceptor other than oxygen (nitrate, sulfate and CO2). However, not all of the carriers of the ETC participate in anaerobic respiration. Consequently, ATP is generated less than in aerobic respiration (variable, fewer than 38 but more than 2).

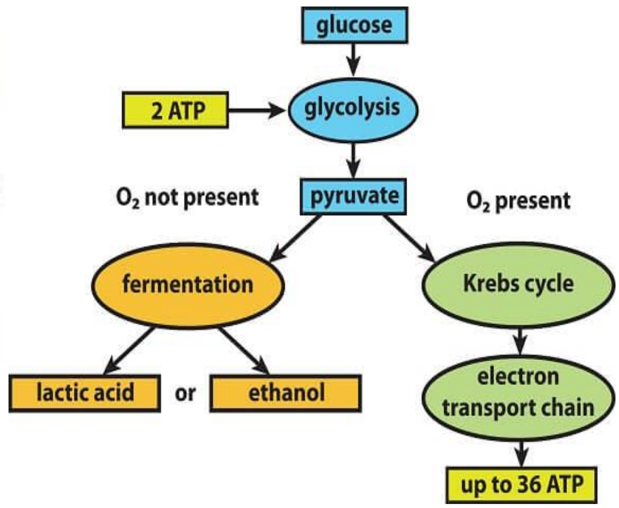
3. Fermentation

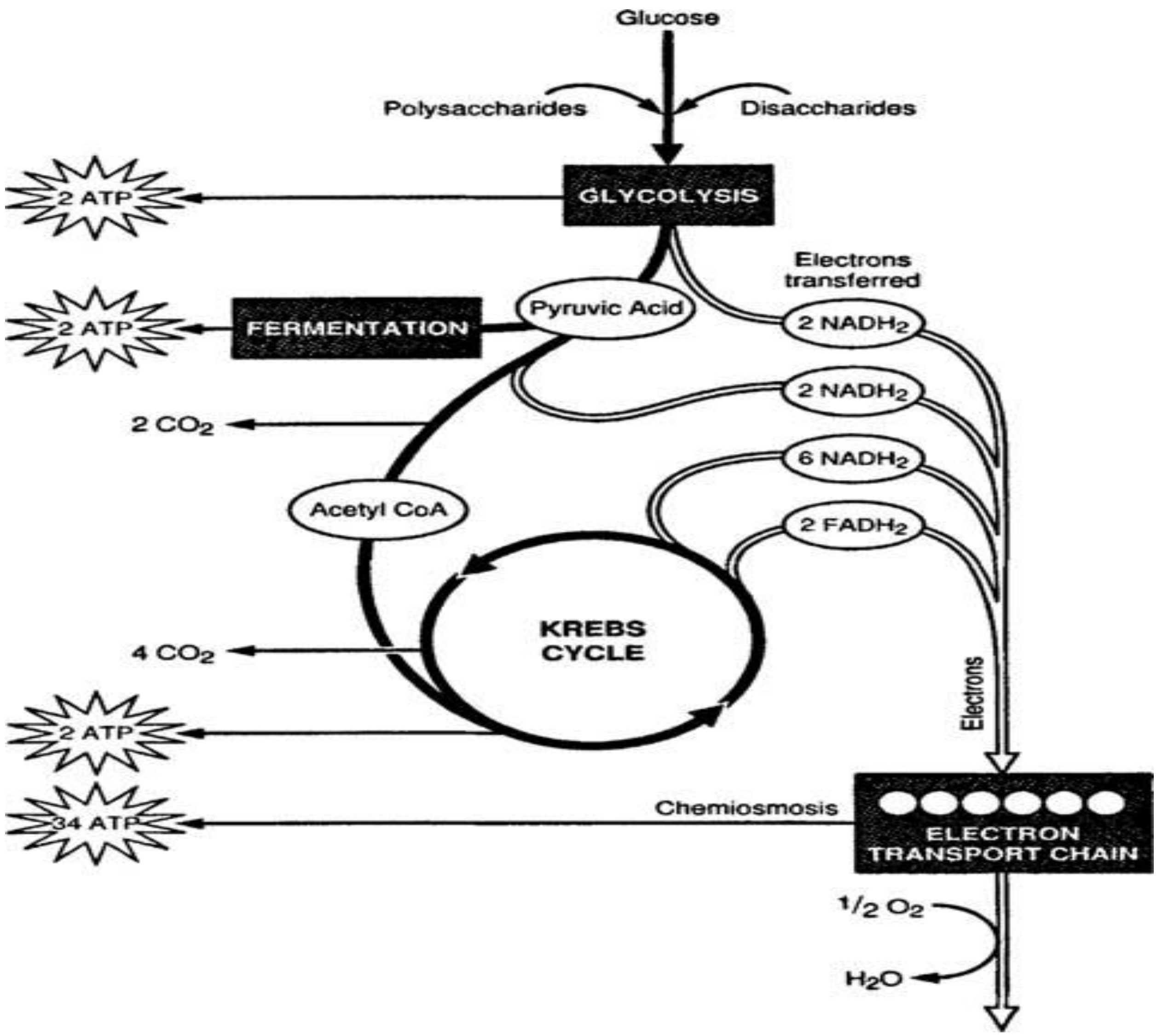
Pyruvic acid can be metabolized further in the absence of oxygen, with the result of lactic acid, ethanol, acetic acid, propionic acid formic acid and CO2, depending on the microorganism. The final electron receptor is organic compound, and 2 ATP generated from it. Fermentation pathways are useful as tools in biochemical identification and food production such as beer, cheese, yogurt, vinegar etc. NADH is oxidized to NAD+ by reduced pyruvic acid to lactic acid.

Photosynthesis

Another group of bacteria can absorb light energy, convert into ATP and multiply. These bacteria are highly visible in their natural habitats because they possess green pigments. These organisms use organic or inorganic compounds as a source of carbon. Is a process used by plants and other organisms to convert light energy to chemical energy (carbohydrates) from carbon dioxide and water. Oxygen is also released as a waste product.


Catabolism
Large Molecule
Energy
Small Molecules
Small Molecules
Anabolism
Large Molecule


glucose
2 ATP
glycolysis
O_2 not present
pyruvate
O_2 present
fermentation
Krebs cycle
lactic acid
or
ethanol
electron transport chain
up to 36 ATP


Glucose
Polysaccharides
Disaccharides
2 ATP
GLYCOLYSIS
Electrons transferred
2 ATP
FERMENTATION
Pyruvic Acid
2 NADH$_2$
2 NADH$_2$
2 CO$_2$
6 NADH$_2$
Acetyl CoA
2 FADH$_2$
KREBS CYCLE
4 CO$_2$
Electrons
2 ATP
34 ATP
Chemiosmosis
ELECTRON TRANSPORT CHAIN
1/2 O$_2$
H$_2$O