Nutrition and Metabolism of Prokaryotes

Prokaryotic metabolism refers to the ways prokaryotes obtain the energy and nutrients they need to live and reproduce. Prokaryotic species can be classified based on how they get the nutrients they need to survive. However, classifications based on metabolism often do not correspond with modern genetic classifications. The nutritional needs of a prokaryote are major factors in determining the prokaryote's ecological niche. These nutritional needs may determine the role of a prokaryotic organism in biogeochemical cycles. Special nutritional needs often allow for certain prokaryotes to also be used in industrial processes.

Classification of Prokaryotes Based on Metabolism

Two major nutritional needs can be used to group prokaryotes. These are (1) carbon metabolism - their source of carbon for building organic molecules within the cells and (2) energy metabolism - their source of energy used for growth.

In terms of carbon metabolism, prokaryotes are classified as either heterotrophic or autotrophic:

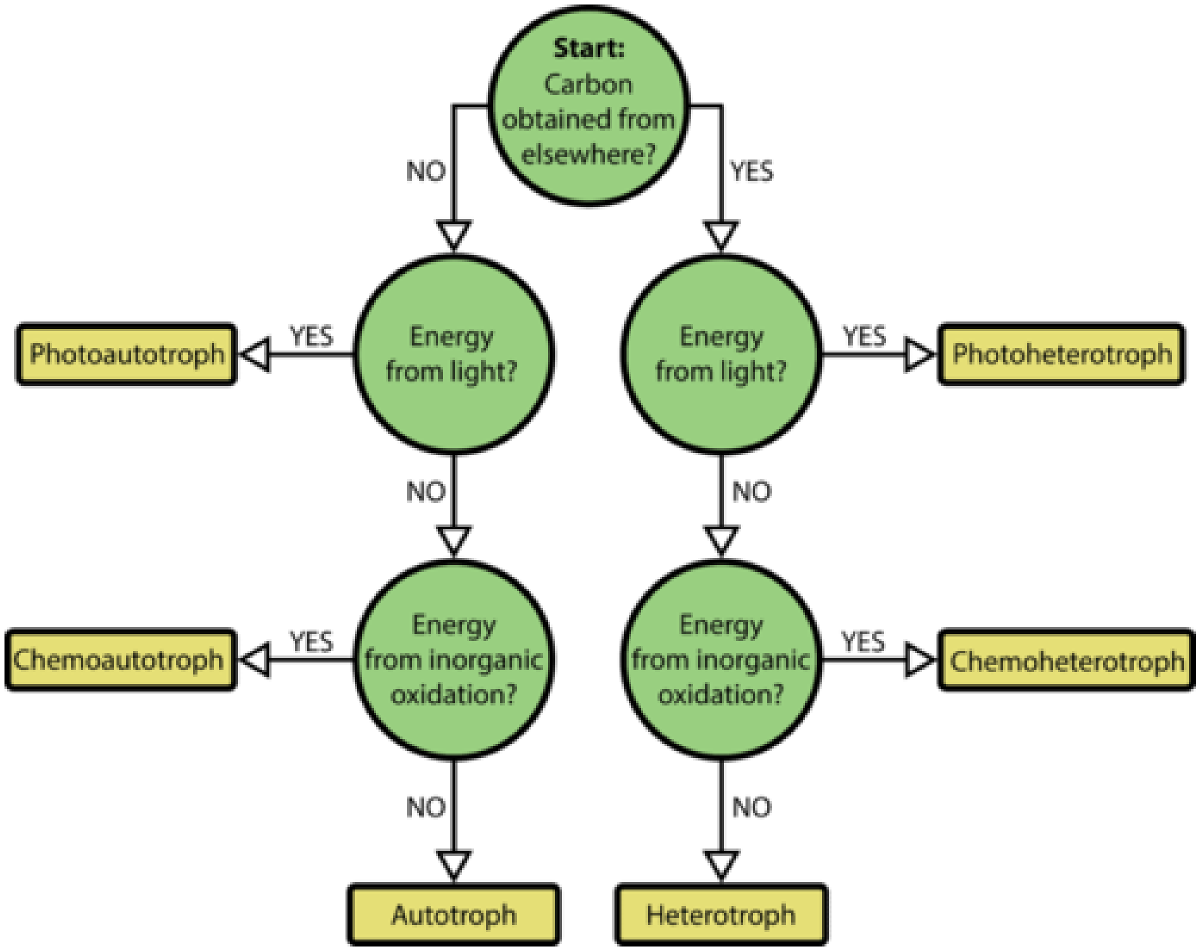
1. **Heterotrophic organisms** use organic compounds —usually from other organisms — as carbon sources.
2. **Autotrophic organisms** use carbon dioxide (CO_2) as their only or main source of carbon. Many autotrophic bacteria are photosynthetic and get their carbon from the carbon dioxide in the atmosphere.
3. **Amphitrophic organism- Euglena**

Energy metabolism in prokaryotes is classified as one of the following:

1. **Phototrophic organisms** capture light energy from the sun and convert it into chemical energy inside their cells.
2. **Chemotrophic organisms** break down either organic or inorganic molecules to supply energy for the cell. Some chemotrophic organisms can also use their organic energy-supplying molecules as a carbon supply, which would make them chemoheterotrophs.
3. **Photoheterotrophs** are organisms that capture light energy to convert to chemical energy in the cells, but they get carbon from organic sources (other organisms). Examples are purple non-sulfur bacteria, green non-sulfur bacteria, and heliobacteria.
4. **Chemoheterotrophs** are organisms that get their energy source and carbon source from organic sources. Chemoheterotrophs must consume organic building blocks that they are unable to make themselves. Most get their energy from organic molecules such as sugars. This mode of obtaining nutrition is very common among eukaryotes, including humans.

5. **Photoautotrophs** are organisms that capture light energy and use carbon dioxide as their carbon source. There are many photoautotrophic prokaryotes, including cyanobacteria. Photoautotrophic prokaryotes use similar compounds to those of plants to trap light energy.
6. **Chemoautotrophs** are organisms that break down inorganic molecules to supply energy for the cell and use carbon dioxide as a carbon source. Chemoautotrophs include prokaryotes that break down hydrogen sulfide (H_2S the "rotten egg" smelling gas) and ammonia (NH_4). *Nitrosomonas,* a species of soil bacterium, oxidize NH_4^+ to nitrite (NO_2^-). This reaction releases energy that the bacteria use. Many chemoautotrophs also live in extreme environments, such as deep sea vents.

Figure below illustrates how to group a given prokaryote based on its metabolic type.



Chemoheterotrophs

Most microbes are **chemoheterotrophic;** they use organic compounds as both carbon and energy sources. Heterotrophic microbes live off of nutrients that they take from living hosts or find in dead organic matter. Microbial metabolism is the main reason for the decomposition of dead organisms. Without prokaryotic decomposition, many biogeochemical cycles, such as the carbon cycle and the nitrogen cycle, could not occur. The remains of dead organisms would litter the planet, and the nutrients within them would be unavailable for other organisms to use. Pathogenic (disease-causing) prokaryotes are heterotrophic, as they are predators or parasites of other organisms. Bacteria of the species *Bdellovibrio* are predators and intracellular parasites of other bacteria. *Bdellovibrio* bacteria are chemoheterotrophs.

Autotrophs

Most photosynthetic microbes are autotrophs; they use inorganic cabon (carbon dioxide) as a carbon source. Some photosynthetic bacteria are photoheterotrophs, meaning that they use organic carbon compounds as a carbon source for growth. Some photosynthetic organisms also fix nitrogen. To learn more about photosynthesis, see the *Photosynthesis* concepts.

Prokaryotes such as cyanobacteria that harvest energy from the sun for photosynthesis are photoautotrophs. Chemoautotrophs oxidize inorganic molecules to get energy. For example, a species of nitrifiying soil bacteria called *Nitrosomonas* oxidize NH_4^+ to nitrite (NO_2^-). This reaction releases energy that the bacteria can use. *Nitrosomonas* bacteria and other nitrifying prokaryotes are very important to the nitrogen cycle. Nitrogen fixation by bacteria also benefits other organisms. Nitrogen is an element needed for growth by all organisms. While extremely common (about 80 percent by volume) in the atmosphere, nitrogen gas (N_2) cannot be used by most organisms. The role of prokaryotes in the nitrogen cycle is shown in **Figure** below.

Aerobic Bacteria vs Anaerobic Bacteria

Following are the important difference between aerobic and anaerobic bacteria:

Difference between Aerobic and Anaerobic	
AEROBIC	**ANAEROBIC**
Need oxygen to survive	Do not require oxygen to survive
Produce more energy	Produce less energy
Molecular oxygen is the final electron acceptor	Carbon dioxide, sulfur, fumarate or ferric is the final electron acceptor
Bacteria are seen on the surface of liquid	Bacteria are settled at the bottom of the liquid
Example: Mycobacterium tuberculosis	Example: Clostridium

Aerobic bacteria

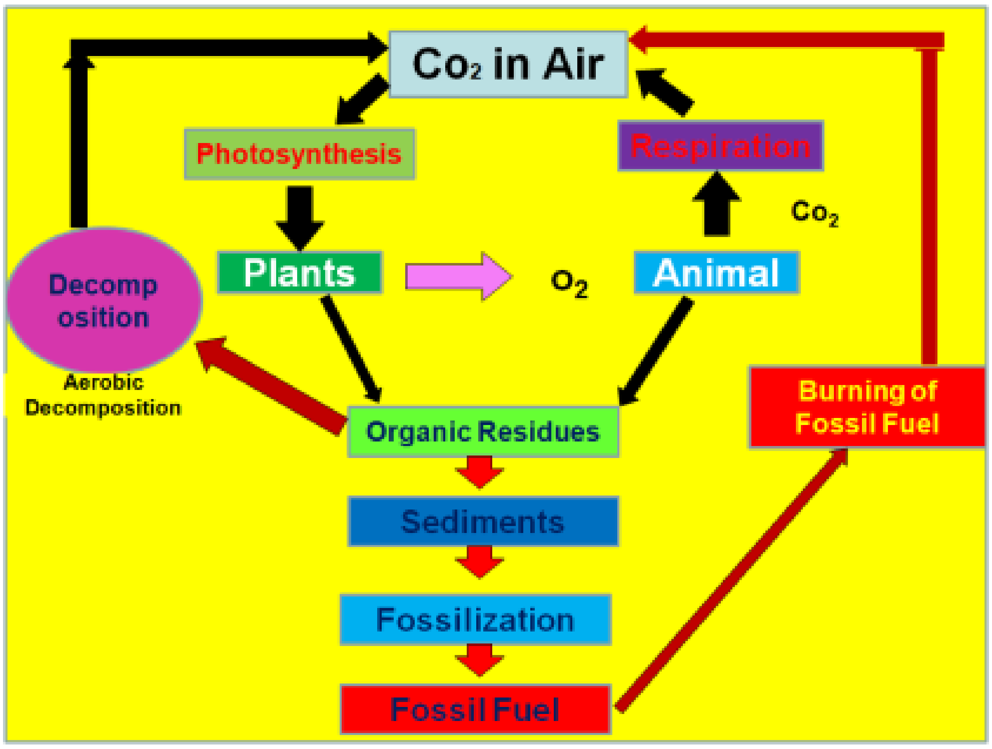
The bacteria that grow in the presence of oxygen are called aerobic bacteria. They have the ability to detoxify oxygen with the help of enzymes. The final electron acceptor is molecular oxygen. Water is produced from the final electron acceptor. When in liquid medium they are seen on the surface of the medium. Example: *Nocardia, Bacillus*.

Anaerobic bacteria

The bacteria that grow in the absence of oxygen are called anaerobic bacteria. It does not have the ability to detoxify oxygen. The final electron acceptor is carbon dioxide, sulfur, fumarate or ferric. Acetate like substances, methane, nitrate and sulfide are produced by these bacteria. When in liquid medium they are seen at the bottom of the medium. Example: *Bacteroids, E.Coli.*

Carbon Sources

Carbon cannot only be found in living organisms, the earth or our atmosphere; if you look into our everyday life you will find out that our lives are almost all based on carbon. From the materials we use like wood, paper, textiles, cement and plastics to the burning of fossil fuels for transportation and energy production. The usage of fossil fuels together with industrial revolution have increased our ability to support life on our planet exponentially (so called carrying capacity). Carbon is the fundamental building block for all organic chemistry. It is the essential ingredient to produce the coatings and treatments our customers depend on to create safe, high-performing, long-lasting materials and products.



Carbon is one of the essential elements of life and one of the foundational elements of all life on Earth. Consequently, one of the most important resource cycles is the carbon cycle which transfers carbon between various carbon reservoirs. In order for the carbon cycle to function, there are numerous sources and sinks of carbon which absorb and release carbon at different rates and help regulate carbon concentrations around the globe. Reservoirs that emit more carbon than they absorb are net carbon sources and reservoirs that absorb more than they emit are net carbon sinks. However, due to the increase in carbon that has been emitted due to human activity, as well as human-caused land use change, this cycle has become unbalanced, and as such, artificial methods to assist the carbon cycle have become more common.

Renewable Carbon Source

Renewable carbon can come from the atmosphere (via carbon capture and utilization, CCU), biosphere (through the use of biomass) or technosphere (through recycling or CCU) – but not from the geosphere. 'These are the only three sources of renewable carbon: recycling, biobased and CO2-based. **Basically carbon from biological materials**.

Non-Renewable Carbon Resources

Most non-renewable energy sources are fossil fuels: coal, petroleum, and natural gas. Carbon is the main element in fossil fuels. For this reason, the time period that fossil fuels formed (about 360-300 million years ago) is called the Carboniferous Period. All fossil fuels formed in a similar way.

Aerobic carbon utilization of renewable and non-renewable substrate

Describe following processes:

1. Alcohol fermentation using sugars

   Alcohol fermentation is done by yeast and some kinds of bacteria. These microorganisms convert sugars in ethyl alcohol and carbon dioxide. Alcoholic fermentation begins after glucose enters the cell. The glucose is broken down into pyruvic acid. This pyruvic acid is then converted to CO2, ethanol, and energy for the cell. Humans have long taken advantage of this process in making bread, beer, and wine. In these three products the same microorganism is used: the common yeast or Saccharomyces Cerevisae. Hence we used different classification of sugars in this experiment to verify its feasibility and distinction in their reaction. Moreover as this experiment aimed to degrade sugars into its glucose units, the resultant precipitate will be forming rapidly when we used the glucose as sugar. Alcoholic fermentation begins after glucose enters the cell. The glucose is broken down into pyruvic acid. This pyruvic acid is then converted to CO_2, ethanol, and energy for the cell. In the process, these microorganisms convert sugars in ethyl alcohol and carbon dioxide.

   Baker's yeast- commonly used as a leavening in baking bread and bakery products. -a single-celled microorganism found on and around the human body.

ALCOHOL FERMENTATION- is done by

1. Bacteria: Zymomonas mobilis
2. Closteridium acetobutylicum
3. Klebsiella pneumonia
4. Yeast
    I. Saccharomyces cerevisiae
    II. Saccharomyces carlsbergenesiae
    III. Saccharomyces saki
    IV. Saccharomyces oviformis
    V. Candida utilis
    VI. Mucur sp
        1. Ethanol (ethyl alcohol, EtOH) is a clear, colourless liquid with a characteristic, pleasant odour. Ethyl alcohol is the intoxicating component in beer, wine and other alcoholic beverages.
        2. In dilute aqueous solution, it has a somewhat sweet flavor, but in more concentrated solutions it has a burning taste.
        3. It is also being used as a biofuel in several countries across the world.
        4. Large industrial plants are the primary sources of ethanol production, though some people have chosen to produce their own ethanol.
        5. Ethanol production from agricultural products has been in practice for more than 100 years. Ethanol can be produced from many kinds of raw materials that contain starch, sugar or cellulose etc.

In general there are three groups of raw materials from which ethanol can be produced: 1) beet, sugar cane, sweet sorghum and fruits 2) starchy material such as corn, milo, wheat, rice, potatoes, cassava, sweet potatoes etc. 3) cellulose materials like wood, used paper, crop residues etc.

The third group of materials mostly include biomass. Recently, biomass is being considered as an important biological resource for the production of ethanol

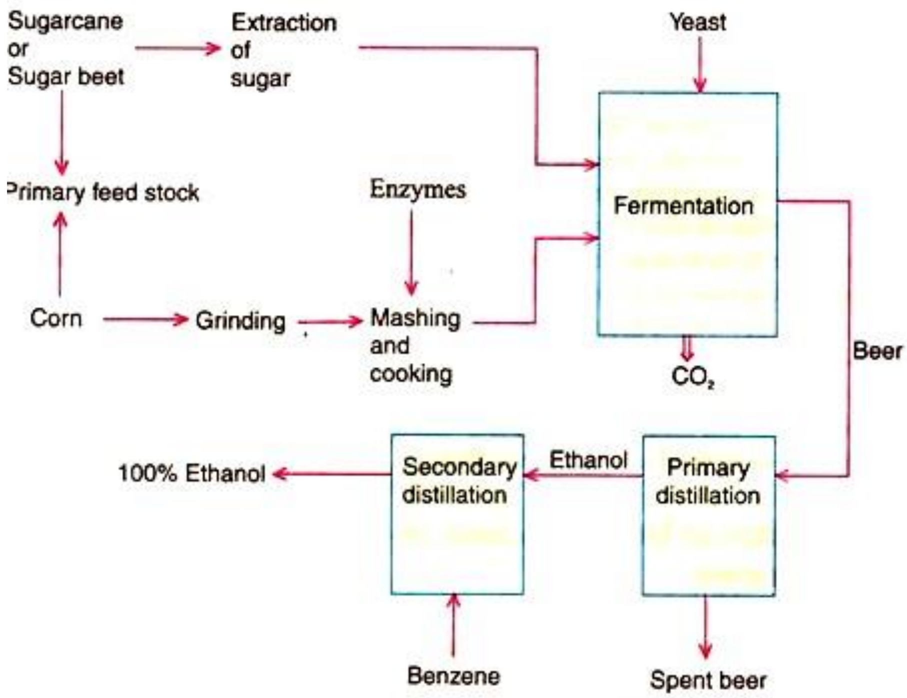


Fig. 20.6: Ethanol production from molasses.

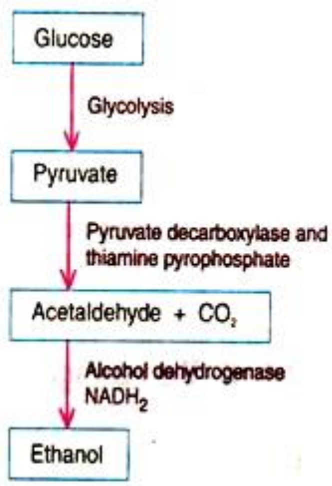


Fig. 20.7 : Biosynthesis of ethanol.

Milk and dairy fermentation products-Among all fermented dairy products we can mention:

6. **Yogurt** and **<u>Greekyogurt</u>** (milk fermented exclusively by *Lactobacillus bulgaricus* and *Streptococcus thermophilus*). **Milk** is converted into **curd** or **yogurt** by the process of fermentation. **Milk** consists of globular proteins called casein. Here **curd** forms because of the **chemical** reaction between the lactic acid bacteria and casein. During fermentation, the bacteria use enzymes to produce energy (ATP) from lactose.
7. **Sour cream** (once milk is collected from farms, it is divided into two products through centrifugation; cream and skim milk. Cream is the low density fraction. After fermentation, the cream becomes sour cream) sour cream was made by letting cream that was skimmed off the top of milk ferment at a moderate temperature. It can also be prepared by the souring of

pasteurized cream with acid-producing bacterial culture. The bacteria that developed during fermentation thickened the cream and made it more acidic, a natural way of preserving it.

8. **Cheese** (the milk is coagulated by specific enzymes, then fermented. Depending on the time of maturation and on different potential stages of cooking and pressing, different types of cheese are obtained: soft or hard cheese). Most cheeses are acidified to a lesser degree by bacteria, which turn milk sugars into lactic acid, by fermentation of the fungus *Mucor miehei*, but others have been extracted from various species of the *Cynara* thistle family. Cheesemakers near a dairy region may benefit from fresher, lower-priced milk, and lower shipping costs.
9. **Kefir** (drink made from fermented milk, fermentation includes specific bacteria such as *Torula kefir* and yeasts such as *Saccharomyces kefir*). During fermentation, changes in the composition of ingredients occur. Lactose, the sugar present in milk, is broken down mostly to lactic acid (25%) by the lactic acid bacteria, which results in acidification of the product.[28] Propionibacteria further break down some of the lactic acid into propionic acid (these bacteria also carry out the same fermentation in Swiss cheese). Other substances that contribute to the flavor of kefir are pyruvic acid, acetic acid, diacetyl and acetoin (both of which contribute a "buttery" flavor), citric acid, acetaldehyde, and amino acids resulting from protein breakdown

Skyr (fermented fresh acid-curd soft cheese made from skim milk). A small portion of a previous batch of skyr is then added to the warm milk to introduce the essential culture (the active bacterial culture), and with the addition of rennet the milk starts to curdle. It is left to ferment for 5 hours before being cooled down to 18 °C (64 °F). After pasteurization the product is strained through fabric to remove the liquid whey. Bacteria such as *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* play an important role in the fermentation of skyr. They also play a major role in the production of yogurt, but the yeast which is active in the low temperature step ensures that the dairy becomes a skyr and not a yogur

10. **Rayeb, laban, labneh or Ayran**, which are fermented milks originated in the Middle East more than 10,000 years ago and have remained essential in the diet of most Arab countries. Leben as a drink is traditionally prepared by letting milk ferment for around 24 hours, then churning and removing the butter. The remaining buttermilk can keep for several days at room temperature. In modern times, it is produced industrially.

2. Biogas formation –

   A *biogas plant* is the name often given to an anaerobic digester that treats farm wastes or energy crops. It can be produced using anaerobic digesters (air-tight tanks with different configurations). These plants can be fed with energy crops such as maize silage or biodegradable wastes including sewage sludge and food waste. During the process, the micro-organisms transform biomass waste into biogas (mainly methane and carbon dioxide) and digestate. Higher quantities of biogas can be produced when the wastewater is co-digested with other residuals from the dairy industry, sugar industry, or brewery industry. For example, while mixing 90% of wastewater from beer factory with 10% cow whey, the production of biogas was increased by 2.5 times compared to the biogas produced by wastewater from the brewery only.

1. Polymers $\xrightarrow{\text{Anaerobic bacteria}}$ Monomers

2. Monomers $\xrightarrow{\text{Acidogenic bacteria}}$ Organic acids

3. Organic acids $\xrightarrow{\text{Methanogenic bacteria}}$ Methane + CO_2 + other gases