Prokaryote metabolism

How prokaryotes get energy and nutrients. Chemotrophs and phototrophs. Heterotrophs and autotrophs.

Key points:

Some prokaryotes are phototrophs, getting energy from the sun. Others are chemotrophs, getting energy from chemical compounds.

Some prokaryotes are autotrophs, fixing carbon from CO. Others are heterotrophs, getting carbon from organic compounds of other organisms.

Prokaryotes may perform aerobic (oxygen requiring) or anaerobic (non-oxygen-based) metabolism, and some can switch between these modes.
Some prokaryotes have special enzymes and pathways that let them metabolize nitrogen- or sulphur-containing compounds.

Prokaryotes play key roles in the cycling of nutrients through ecosystems.

In the scheme of things, you and I have a fairly limited range of ways to feed ourselves. We may get to decide between veggies and ice cream (and hopefully, end up enjoying both in healthy quantities!). However, it's not too likely that we're going to photosynthesize. We're also unlikely to eat hydrogen sulphide, the compound responsible for "rotten egg smell," for breakfast.

Prokaryotes (bacteria and archaea) are way more diverse than humans in their nutritional strategies – that is, the ways they obtain fixed carbon (fuel molecules) and energy. Some species consume organic material like dead plants and animals. Others live off of inorganic compounds in rocks. One bacterium, Thiobacillus concretivorans, consumes metal-melting sulphuric acid!

In this article, we will take a closer look at the many ways that prokaryotes obtain and metabolize food, and how they can influence cycling of nutrients.

Nutritional modes

All of Earth's life forms need energy and fixed carbon (carbon incorporated into organic molecules) to build the macromolecules that make up their cells. This applies to humans, plants, fungi, and, of course, prokaryotes. Living organisms can be categorized by how they obtain energy and carbon.

First, we can categorize organisms by where they get fixed (usable) carbon:

Organisms that fix carbon from carbon dioxide (CO) or other inorganic compounds are called autotrophs.

Organisms that get fixed carbon from organic compounds made by other organisms (by eating the organisms or their by-products) are called heterotrophs.

In addition, we can categorize organisms by where they get energy:

Organisms that use the light (mainly the sun) as a source of energy are called phototrophs.

Organisms that use chemicals as a source of energy are called chemotrophs.

We can divide prokaryotes (and other organisms) into four different categories based on their energy and carbon sources:

We tend to be pretty familiar with photoautotrophs, such as plants, and chemoheterotrophs, such as humans and other animals. Prokaryote species fall into these two categories, as well as the two less familiar
Nutritional mode Energy
source
Carbon source
Photoautotroph Light Carbon dioxide
(or related
compounds)
Photo heterotroph Light Organic
compounds
Chemoautotroph Chemical
compounds
Carbon dioxide
(or related
compounds)
categories (photo heterotrophs and chemoautotrophs) to which plants and animals don't belong.

Aerobic and anaerobic respiration

Another metabolic area in which prokaryotes differ from humans (and are much more diverse than us!) is their need for oxygen. Some need it, some are poisoned by it, and some can take it or leave it depending on availability.

Prokaryotes that need O in order to metabolize are called obligate aerobes. Humans are also obligate aerobes (as you've found out if you've tried to hold your breath for too long).

Prokaryotes that can't tolerate O and only perform anaerobic metabolism are called obligate anaerobes. C. botulinum, the bacterium that causes botulism (a form of food poisoning) when it grows in canned food, is an obligate anaerobe – which is why it multiplies well inside of sealed cans.

Facultative anaerobes use aerobic metabolism when O_2 is present, but switch to anaerobic metabolism if it's absent. The bacteria that cause staph and strep infections are examples of facultative anaerobes.

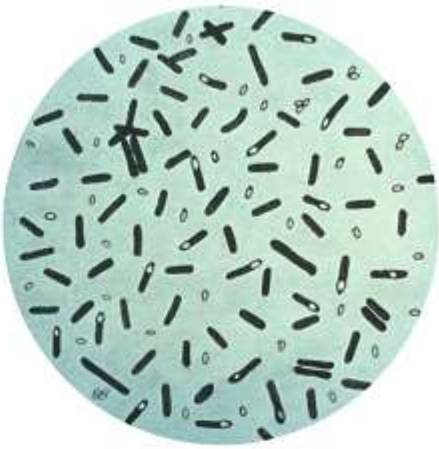


Image credit: "Clostridium botulinum," by the U. S. Centres for Disease Control and Prevention (Public Health Image Library), public domain.

Sulphur and nitrogen metabolism

Some bacteria and archaea have metabolic pathways that allow them to metabolize nitrogen and sulphur in ways that eukaryotes cannot. In some cases, they use nitrogen- or sulphur-containing molecules to obtain energy, but in other cases, they expend energy to convert these molecules from one form to another.

Sulphur metabolism

Some fascinating examples of sulphur-metabolizing prokaryotes are found in deep-sea ecosystems. For instance, certain prokaryotic species can oxidize hydrogen sulphide (H_2S) from piping hot hydrothermal vents. They use energy released in this process to fix inorganic carbon from the water into sugars and other organic molecules in a process called chemosynthesis.

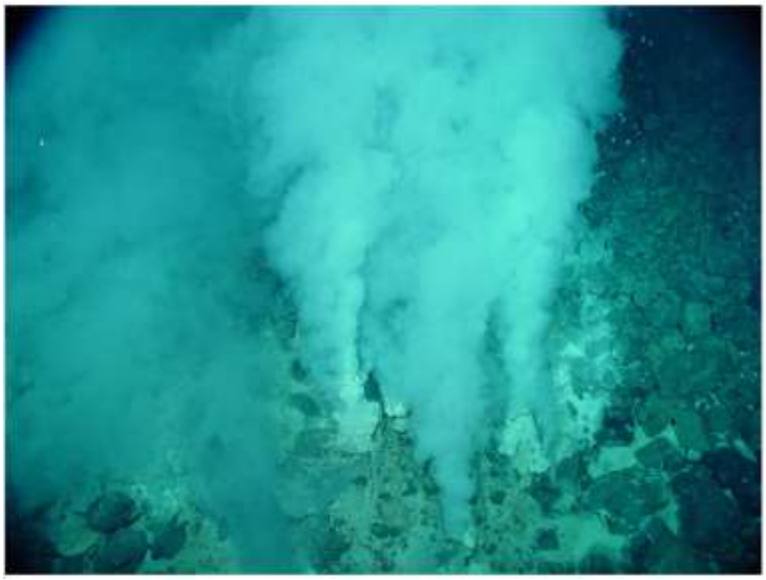


Image: "Champagne vent white smokers.jpg," by NOAA (public domain).

Sulphur-metabolizing prokaryotes form the basis of food chains in their deep-sea habitats (where not the tiniest ray of light can reach to support photosynthesis). The sulphur metabolizers support entire communities of organisms, including worms, crabs, and shrimp, thousands of meters below the ocean surface.

Nitrogen metabolism

Nitrogen-metabolizing prokaryotes include nitrogen fixers, nitrifiers, and denitrifiers. They play key roles in the nitrogen cycle by converting nitrogen compounds from one chemical form to another.

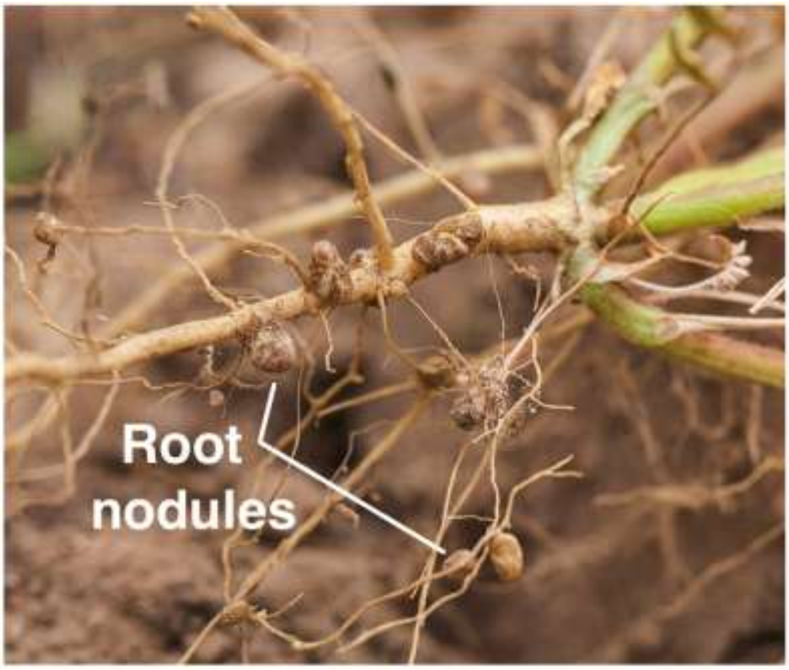


Image modified from "Nitrogen-fixing nodules in the roots of legumes..JPG," by Terraprima (CC BY-SA 3.0).

Nitrogen-fixing prokaryotes convert (“fix”) atmospheric nitrogen (N) into ammonia (NH), which plants and other organisms can incorporate into organic molecules. Some plant species in the legume family, such as peas, form mutually beneficial relationships (mutualisms) with nitrogen-fixing bacteria. The plants house and feed the bacteria in structures called root nodules, and the bacteria provide fixed nitrogen to the roots.

Other prokaryotes in the soil, called nitrifying bacteria, convert the ammonia into other types of compounds (nitrates and nitrites), which may also be absorbed by plants. Denitrifying prokaryotes do more or less the reverse, turning nitrates into N gas.

Biogeochemical cycles

The constant recycling of chemical elements is vital to the functioning of ecosystems. In Earth's biogeochemical cycles, chemical elements are converted among various different forms in a repeating cycle.

By virtue of their diverse metabolisms, prokaryotes play important roles in many global cycles. Here, we'll take a closer look at their function in two of these: the nitrogen and carbon cycles.

Nitrogen cycle

As we saw in the last section, nitrogen-fixing prokaryotes convert (“fix”) atmospheric nitrogen (N) into ammonia (NH). Plants and other organisms can then use the ammonia to build molecules such as amino acids and nucleotides.

Other prokaryotes in the soil, the nitrifying bacteria, convert ammonia into other types of compounds (nitrates and nitrites), which may also be absorbed by plants. The denitrifying prokaryotes, which convert nitrates into N, move nitrogen atoms from the soil back to the atmosphere.

The image below shows a simplified version of the nitrogen cycle, emphasizing the roles of prokaryotes.

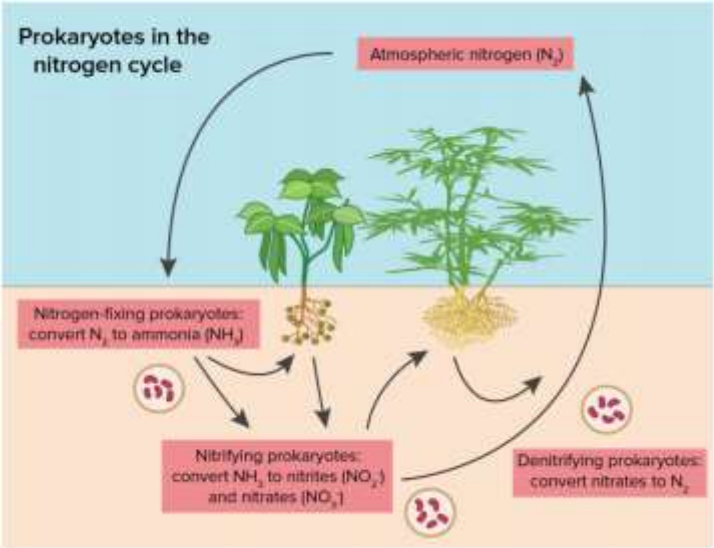
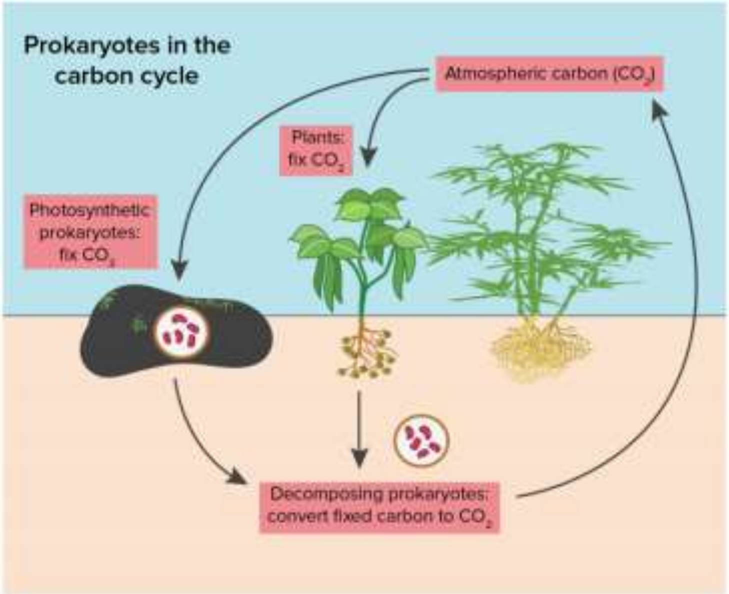


Image modified from "Nitrogen cycle" by Johann Dréo (CC BY-SA 3.0). The modified image is licensed under a CC BY-SA 3.0 license.

Carbon cycle

Prokaryotes are also important in the carbon cycle. Photosynthetic prokaryotes, such as cyanobacteria, use light energy to remove CO from the atmosphere and fix it into organic molecules. This is the same basic process carried out by photosynthetic plants. Prokaryotic decomposers, on the other hand, move carbon in the opposite direction. When they break down dead organic material (from previously living plants and animals), they return CO to the atmosphere via cellular respiration. Decomposition also releases a variety of other elements and inorganic molecules for reuse.

The image below shows a simplified version of the carbon cycle, emphasizing the roles of prokaryotes.


Prokaryotes in the carbon cycle
Atmospheric carbon (CO_2)
Plants: fix CO_2
Photosynthetic prokaryotes: fix CO_2
Decomposing prokaryotes: convert fixed carbon to CO_2