Microbial Nutrition

Nutrition is a process by which chemical substances called **nutrients** are acquired from the environment and used in cellular activities such as metabolism and growth. With respect to nutrition, microbes are not really so different from humans. In general, all living things have an absolute need for the bioelements, traditionally listed as carbon, hydrogen, oxygen, phosphorus, potassium, nitrogen, sulfur, calcium, iron, sodium, chlorine, magnesium, and certain other elements.1 Beyond these basic requirements, microbes have signifi cant differences in the source, chemical form, and amount of the elements they use.

Any substance, whether an element or molecule, that must be provided to an organism is called an **essential nutrient.** Two categories of essential nutrients are **macronutrients** and **micronutrients.** Macronutrients are required in relatively large quantities and play principal roles in cell structure and metabolism. Examples of macronutrients are compounds containing carbon, hydrogen, and oxygen. Micronutrients, or **trace elements,** such as manganese, zinc, and nickel are present in much smaller amounts and are involved in enzyme function and maintenance of protein structure.

Another way to categorize nutrients is according to their carbon content. Most **organic** nutrients are molecules that contain a basic framework of carbon and hydrogen. Natural organic molecules are nearly always the products of living things. They range from the simplest organic molecule, methane (CH4), to large polymers (carbohydrates, lipids, proteins, and nucleic acids). In contrast, an **inorganic** nutrient is composed of an element or elements other than carbon and hydrogen. The natural reservoirs of many inorganic compounds are mineral deposits in the crust of the earth, bodies of water, and the atmosphere. Examples include metals and their salts (magnesium sulfate, ferric nitrate, sodium phosphate), gases (oxygen, carbon dioxide), and water.

The following list is a brief summary of some nutritional patterns in the intestinal bacterium *Escherichia coli*. Some nutrients are absorbed in a ready-to-use form, and others must be synthesized by the cell from simple compounds.

- Water content is the highest of all components (70%).
- About 97% of the dry cell weight is composed of organic compounds.
- Proteins are the most prevalent organic compound.
- About 96% of the cell is composed of six elements (represented by CHONPS).
- Chemical elements are needed in the overall scheme of cell growth, but most of them are available to the cell as compounds and not as pure elements.

- A cell as "simple" as *E. coli* contains on the order of 5,000 different compounds, yet it needs to absorb only a few types of nutrients to synthesize this great diversity. These include (NH4)2SO4, FeCl2, NaCl, trace elements, glucose, KH2PO4, MgSO4, CaHPO4, and water.

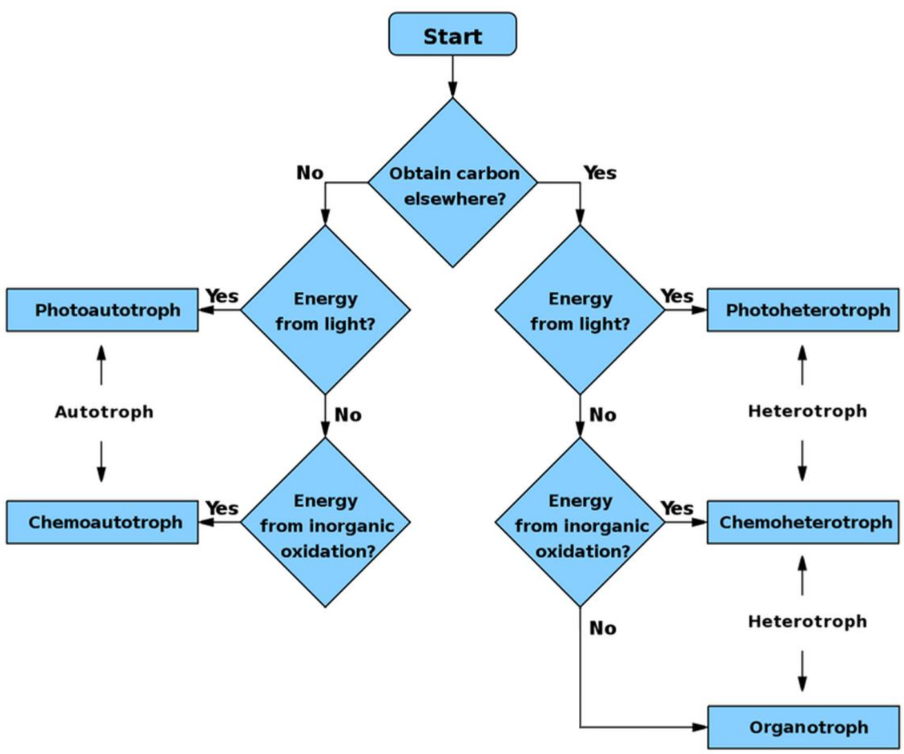
The source of nutrients is extremely varied: Microbes such as photosynthetic bacteria obtain their nutrients entirely in inorganic form from the environment. Others require a combination of organic and inorganic nutrients. For example, parasites that invade and live on the human body derive all essential nutrients from host tissues, tissue fluids, secretions, and wastes(Refer to **table 7.1**)

Carbon-based Nutritional Types

The element carbon is so key to the structure and metabolism of all life forms that the source of carbon defi nes two basic nutritional groups:

A **heterotroph** is an organism that must obtain its carbon in an organic form. Because organic carbon usually originates from organisms, heterotrophs are nutritionally dependent on other life forms. Among the common organic molecules that can satisfy this requirement are proteins, carbohydrates, lipids, and nucleic acids.

An **autotroph** is an organism that uses inorganic CO2 as its carbon source. Because autotrophs have the special capacity to convert CO2 into organic compounds, they are not nutritionally dependent on other living things.



Classification of Nutritional Types

The main determinants of a microbe's nutritional type are its sources of carbon and energy. Microbes that photosynthesize are phototrophs, and those that gain energy from chemical compounds are chemotrophs. Likewise, those microorganism use environmental CO2 as carbon source are called- Autotrophs and those use organic carbon as primary carbon source are called- Heterotrophs.

Photoautotrophs are autotrophs that produce complex organic compounds such as carbohydrates, fats, and proteins with the absorption of light. This process mediated by light is called photosynthesis. Photosynthesis is a process wherein plants absorb light from a light source (e.g. sunlight) and use carbon dioxide, inorganic salts, and water to produce an energy-rich carbohydrate like glucose ($C_6H_{12}O_6$) and to produce oxygen (O_2) as a by-product. Photoautotrophs are land plants and photosynthetic algae. These organisms have light-capturing pigments such as chlorophyll.

Chemoautotrophs are those that make their own food by chemosynthesis. Chemosynthesis is a process by which some organisms, such as certain bacteria, use chemical energy to produce carbohydrates. They are capable of utilizing inorganic compounds such as hydrogen sulfide, sulfur, ammonium, and ferrous iron as reducing agents, and synthesize organic compounds from carbon dioxide. Chemoautotrophs are found in hostile habitats such as deep sea vents and where light cannot easily penetrate through. They include the methanogens, halophiles, nitrifiers, thermoacidophiles, sulfur oxidizers, etc.

Photoheterotrophs are heterotrophic organisms that make use of light energy as their energy source. They also cannot use carbon dioxide as their sole carbon source. They use organic compounds from the environment. Heterotrophs are the consumers in the food chain, particularly the herbivores, carnivores and omnivores. All animals, some fungi and most bacteria are heterotrophs. They are not capable of producing their own food. Therefore, they obtain their energy requirements by feeding on organic matter or another organism. Photoheterotrophs, in particular, are microorganisms that derive their carbon requirements mainly from organic compounds in their environment. These organisms are purple non-sulfur bacteria, green non-sulfur bacteria, and heliobacteria. Photoheterotrophs may also be regarded as one of the two main sub-groups of phototrophs (the other, photoautotrophs). Phototrophs are organisms that use light energy for certain metabolic functions. They absorb photons from light to carry out cellular functions such as biosynthesis and respiration. Photoheterotrophs, in this regard, are organisms that depend solely on light energy as they generate ATP through photophosphorylation. These organisms do not rely on carbon dioxide as their sole carbon source. They may use organic compounds such as carbohydrates, fatty acids, and alcohols they obtain from the environment for their carbon requirements.

Chemoheterotrophs are chemotrophs that are heterotrophic organisms. They are not capable of fixing carbon to form their own organic compounds. They may be further classified as chemolithoheterotrophs or chemoorganoheterotrophs. Chemolithoheterotrophs are those that utilize inorganic energy sources whereas chemoorganoheterotrophs are those using organic energy sources. Chemoorganoheterotrophs may be further grouped based on the kind of organic substrate and compound they use. Decomposers obtain these substrates and compounds from dead organic matter. Herbivores and carnivores derive theirs from living organic matter. Most chemoheterotrophs obtain energy by ingesting organic molecules like glucose. In contrast, chemoautotrophs are autotrophs that use chemical energy to produce carbohydrates. They utilize inorganic compounds such as hydrogen sulfide, sulfur, ammonium, and ferrous iron as reducing agents, and synthesize organic compounds from carbon dioxide.

TABLE 7.1 Sources and Biological Functions of Essential Elements and Nutrients

Element/Nutrient Forms Found in Nature		Sources/Reservoirs of Compounds	Significance to Cells
Carbon	CO_2 (carbon dioxide) gas CO_3^{2-} (carbonate) Organic compounds	Air (0.036%*) Sediments Living things	CO_2 is produced by respiration and used in photosynthesis; CO_3^{2-} is found in cell walls and skeletons; organic compounds are essential to the structure and function of all organisms and viruses.
Nitrogen	N_2 gas NO_3^- (nitrate) NO_2^- (nitrate) NH_3 (ammonium) Organic nitrogen (proteins, nucleic acids)	Air (79%*) Soil and water Soil and water Soil and water Organisms	Nitrogen gas is available only to certain microbes that fix it into other inorganic nitrogen compounds—nitrates, nitrites, and ammonium—the primary sources of nitrogen for algae, plants, and the majority of bacteria; animals and protozoa require organic nitrogen; all organisms use NH_3 to synthesize amino acids and nucleic acids.
Oxygen	O_2 gas Oxides H_2O	Air (20%*), a major product of photosynthesis	Oxygen gas is necessary for the metabolism of nutrients by aerobes. Oxygen is a significant element in organic compounds and inorganic compounds (see water, sulfates, phosphates, nitrates, carbon dioxide).
Hydrogen	H_2 gas H_2O H_2S (hydrogen sulfide) CH_4 (methane) Organic compounds	Waters, swamps, volcanoes, vents Organisms	Water is the most abundant compound in cells and a solvent for metabolic reactions; H_2, H_2S, and CH_4 gases are produced and used by bacteria and archaea; H^+ ions are the basis for transfers of cellular energy and help maintain the pH of cells.
Phosphorus	PO_4^{3-} (phosphate)	Rocks, Mineral deposits	Phosphate, a key component of DNA and RNA, is critical to the genetic makeup of cells and viruses; also found in ATP and NAD, where it takes part in numerous metabolic reactions; its presence in phospholipids provides stability to cell membranes.
Sulfur	S PO_4^{2-} (sulfate) SH (sulfhydryl)	Mineral deposits, volcanic sediments	Elemental sulfur is oxidized by some bacteria as an energy source; sulfur is found in vitamin B1; sulfhydryl groups are part of certain amino acids, where they form disulfide bonds that shape and stabilize proteins.
Potassium	K^+	Mineral deposits, ocean water	Plays a role in protein synthesis and membrane transport
Sodium	Na^+	Same as potassium	Major participant in membrane actions; maintains osmotic pressure in cells
Calcium	Ca^+	Oceanic sediments, rocks, and minerals	A component of protozoan shells (as $CaCO_3$); stabilizes cell walls; adds resistance to bacterial endospores
Magnesium	Mg^{2+}	Geologic sediments, rocks	A central atom in the chlorophyll molecule; required for function of membranes, ribosomes, and some enzymes
Chloride	Cl^-	Ocean water, salt lakes	May function in membrane transport; required by obligate halophiles to regulate osmotic pressure
Zinc	Zn^{2+}	Rocks, minerals	An enzyme cofactor; regulates eukaryotic genetics
Iron	Fe^{2+}	Rocks, minerals	Essential element for the structure of respiratory proteins (cytochromes)
Micronutrients: copper, cobalt, nickel, molybdenum manganese, iodine		Geologic sediments	Required in tiny amounts to serve as cofactors in specialized enzyme systems of some microbes but not all

*As a portion of the earth's atmosphere.

TABLE 7.2 Nutritional Categories of Microbes by Energy and Carbon Source

Category/ Carbon Source	Energy Source	Example
Autotroph/CO_2	**Nonliving Environment**	
Photoautotroph	Sunlight	Photosynthetic organisms, such as algae, plants, cyanobacteria
Chemoautotroph	Simple inorganic chemicals	Only certain bacteria, such as methanogens, deep-sea vent bacteria
Heterotroph/ Organic	**Other Organisms or Sunlight**	
Chemoheterotroph	Metabolic conversion of the nutrients from other organisms	Protozoa, fungi, many bacteria, animals
1. Saprobe	Metabolizing the organic matter of dead organisms	Fungi, bacteria (decomposers)
2. Parasite	Utilizing the tissues, fluids of a live host	Various parasites and pathogens; can be bacteria, fungi, protozoa, animals
Photoheterotroph	Sunlight or organic matter	Purple and green photosynthetic bacteria