Microbial Nutrition and Ecology

Carbon-based Nutritional Types

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

A heterotroph: organism obtain its **carbon in an organic** form heterotrophs are nutritionally dependent on other life forms. the common organic molecules that can satisfy this requirement are **proteins, carbohydrates, lipids, and nucleic acids**.

An autotroph: is an organism that uses inorganic CO 2 as its carbon source. Because autotrophs have the special capacity to convert CO 2 into organic compounds, they are not nutritionally dependent on other living things.

Growth Factors: Many fastidious bacteria lack the genetic and metabolic mechanisms to synthesize every organic compound they need for survival. An organic compound such as an amino acid, nitrogenous base, or vitamin that cannot be synthesized by an organism and must be provided as a nutrient is a growth factor .

all cells require 20 different amino acids for proteins synthesis, but many cells cannot synthesize all of them. ***Haemophilus influenzae,*** (meningitis& respiratory infections in humans) need for growth factors. It can grow only when hemin (factor X), NAD 1 (factor V), thiamine and pantothenic acid (vitamins), uracil, and cysteine are provided by another organism or a growth medium.

Classification of Nutritional Types

We saw earlier that microbes can be defined **according to their carbon sources** to **Autotrophs** or **Heterotroph**s. Another system classifies them **according to their energy source** to **Phototrophs** or **Chemotrophs.**

Microbes that photosynthesize are phototrophs, and those that gain energy from chemical compounds are chemotrophs.

I-Autotrophs and Their Energy Sources

Autotrophs derive energy from one of two possible nonliving sources: sunlight and chemical reactions involving simple chemicals.

a-Photoautotrophs and Photosynthesis Photoautotrophs are photosynthetic, they capture the energy of light rays and transform it into chemical energy that can be used in cell metabolism. In general, photosynthesis relies on special pigments to collect the light and uses the energy to convert CO_2 into simple organic compounds.

. 1-Oxygenic (oxygen-producing) photosynthesis: Sunlight absorbed by chlorophyll in which $(CH_2O)_n$ is shorthand for a carbohydrate(plants, algae, and cyanobacteria)

$$\mathbf{CO_2 + H_2O \longrightarrow (CH_2O)n + O_2}$$

The other form of photosynthesis is termed anoxygenic (no oxygen produced).

$$\mathbf{CO_2 + H_2S \longrightarrow (CH_2O)n + S^0 + H_2O}$$

Sunlight absorbed by bacteriochlorophyll. It uses a unique pigment, bacteriochlorophyll; its hydrogen source is hydrogen sulfide gas; and it gives off elemental sulfur as one product. The reactions all occur in the absence of oxygen as well. Common groups of photosynthetic bacteria are the purple and green sulfur bacteria that live in various aquatic habitats.

b-Chemoautotrophy. These prokaryotes survive totally on inorganic substances such as minerals, they remove electrons from inorganic substrates such as hydrogen gas, hydrogen sulfide, sulfur, or iron and combine them with carbon dioxide and hydrogen. Chemoautotrophic bacteria play an important part in recycling inorganic nutrients and elements.

II-Heterotrophs and Their Energy Sources

The majority of heterotrophic microorganisms are chemoheterotrophs that derive both carbon and energy from organic compounds. Processing these organic molecules by **respiration** or **fermentation** releases energy that is stored as ATP.

$$\mathbf{Glucose\ [(CH_2O)n] + O_2 \text{ -------------- } CO_2 + H_2O + Energy(ATP)}$$

. Chemoheterotrophic microorganisms belong to one of two main categories that differ in how they obtain their organic nutrients:

Saprobic Microorganisms Saprobes occupy a niche as decomposers of plant litter, animal matter, and dead microbes. bacteria and fungi, have a rigid cell wall and cannot engulf large particles of food. To compensate, they release enzymes to the extracellular environment and digest the food particles into smaller molecules that can be transported into the nonpathogenic saprobes can adapt to and invade a susceptible host. When a saprobe does infect a host, it is considered a **facultative parasite**. Such an infection usually occurs when the host is compromised, and the microbe is considered an **opportunistic pathogen**. For example, although its natural habitat is soil and water, *Pseudomonas aeruginosa* frequently causes infections in patients when it is carried into the hospital environment.

Parasitic Microorganisms Parasites grow in or on the body of a host, which they harm to some degree. Because parasites can damage tissues (disease) or even cause death, they are also called **pathogens**. **Obligate parasites** (for example, the leprosy bacillus and the syphilis spirochete) are so dependent that they are unable to grow outside of a living host. Less strict parasites such as the gonococcus and pneumococcus can be cultured artificially if provided with the correct nutrients and environmental conditions.

Obligate intracellular. Microorganisms that spend all or part of their life cycle inside a host cell include viruses, a few bacteria (rickettsias, chlamydias) . Viruses are the most extreme, parasitizing the host's genetic and metabolic machinery. Rickettsias are primarily energy parasites, and the malaria protozoan is a hemoglobin parasite.

Environmental Factors That Influence Microbes

Temperature :The range of temperatures for microbial growth can be expressed as three cardinal temperatures. **The minimum temperature** is the lowest temperature that permits a microbe's continued growth and metabolism; below this temperature, its activities are inhibited.

The maximum temperature is the highest temperature at which growth and metabolism can proceed. If the temperature rises slightly above maximum, growth will stop. If it continues to rise beyond that point, the enzymes and nucleic acids will inactivated(denaturation)and the cell will die.

The optimum temperature covers a small range, intermediate between the minimum and maximum, which promotes the fastest rate of growth and metabolism. Some strict parasites will not grow if the temperature varies more than a few degrees below or above the host's body temperature. For instance, **rhinoviruses** (one cause of the common cold) multiply successfully only in tissues that are slightly below normal body temperature (33°C to 35°C). Other microbes are not so limited. Strains of ***Staphylococcus aureus*** grow within the range of 6°C to 46°C, and the intestinal bacterium ***Enterococcus faecalis*** grows within the range of 0°C to 44°C.

A psychrophile: optimum temperature below 15°C and is capable of growth at 0°C. It is obligate with respect to cold and generally cannot grow above 20°C. Rarely pathogenic.

Psychrotrophs or **facultative psychrophiles** that grow slowly in cold but have an optimum temperature above 20°C. Psychrotrophs such as *Staphylococcus aureus* and *Listeria monocytogenes* are a concern because they grow in refrigerated food and cause food-borne illness.

Mesophiles: organisms that grow at intermediate temperatures the optimum growth temperatures of most mesophiles fall into the range of 20°C to 40°C.. Most human pathogens have optima e between 30°C and 40°C (human body temperature is 37°C).

A thermophile: is a microbe that grows optimally at temperatures greater than 45°C. Thermophiles generally range in growth temperatures from 45°C to 80°C. Most eukaryotic forms cannot survive above 60°C, but a few bacteria, called hyperthermophiles, grow at between 80°C and 250°C . One of the most profitable discoveries so far was a strict thermophile *Thermus aquaticus*, which produces an enzyme that can make copies of DNA even at high temperatures. This enzyme—**Taq polymerase**—is now an essential component of the polymerase chain reaction or PCR, a process used in many areas of medicine, forensics, and biotechnology.

Gas Requirements

The atmospheric gases that most influence microbial growth are oxygen (O_2) and carbon dioxide (CO_2). It is an important respiratory gas, and it is also a powerful oxidizing agent that exists in many toxic forms, microbes fall into one of three categories: those that use **oxygen and can detoxify** it; those that can neither **use oxygen nor detoxify it**; and those **that do not use oxygen but can detoxify it.**

How Microbes Process Oxygen As oxygen gas enters into cellular reactions, it can be transformed into several toxic products. Singlet oxygen ($^1O_2$) is an extremely reactive molecule produced by both living and nonliving processes., it is one of the substances produced by phagocytes to kill invading bacteria. The buildup of singlet oxygen and the oxidation of membrane lipids and other molecules can damage and destroy a cell. The highly reactive superoxide ion (O^-_2), peroxide (H_2O_2), and hydroxyl radicals (OH) are other destructive metabolic by-products of oxygen. Most cells have developed enzymes that go about the business of scavenging and neutralizing these chemicals. The complete conversion of superoxide ion into harmless oxygen involves a two-step process and at least two enzymes:

Step 1- $2O_2^- + 2H^+$ ————H_2O_2 (hydrogen peroxide) + O_2 Superoxide dismutase

Step 2- $2H_2O_2$ ———n $2H_2O_2$ + O_2 Catalase

In this series of reactions essential for **aerobic organisms**, the superoxide ion is first converted to hydrogen peroxide and normal oxygen by the action of an enzyme called **superoxide dismutase**. Because hydrogen peroxide is also **toxic** to cells (it is used as a disinfectant and antiseptic), it must be degraded by an enzyme— either **catalase or**

peroxidase—into water and oxygen. If a microbe is not capable of dealing with toxic oxygen by these or similar mechanisms, it will be restricted to habitats free of oxygen.

Aerobe (aerobic organism) can use gaseous oxygen in its metabolism and possesses the enzymes needed to process toxic oxygen products. An organism that cannot grow without oxygen is an **obligate aerobe**.

A facultative anaerobe. is an aerobe that does not require oxygen for its metabolism and is capable of growth in the absence of it. it adopts an anaerobic mode of metabolism such as **fermentation**. Facultative anaerobes usually possess catalase and superoxide dismutase. This includes gram-negative intestinal bacteria and staphylococci.

A microaerophile requires a small amount of oxygen (1–15%) in metabolism. Growing strictly anaerobic bacteria usually requires special media, methods of incubation, and handling chambers that exclude oxygen.

Dental caries are partly due to the complex actions of aerobic and anaerobic bacteria in plaque. Most gingival infections consist of similar mixtures of oral bacteria that have invaded damaged gum tissues. Another common site for anaerobic infections is the large intestine. Anaerobic infections can occur following abdominal surgery and traumatic injuries (gas gangrene and tetanus).

Effects of pH Microbial growth and survival are also influenced by the pH of the habitat. The pH was defined as the degree of acidity or alkalinity of a solution The majority of organisms live or grow in habitats between pH 6 and pH 8

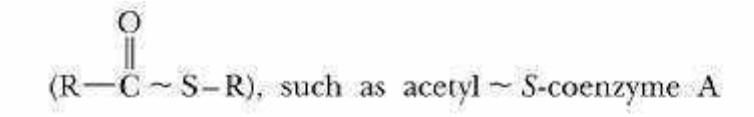
because strong acids and bases can be highly damaging to enzymes and other cellular substances. Although most microbes are **neutrophiles**, living around pH 7

Obligate **acidophiles** include *Euglena mutabilis*, an alga that grows in acid pools between 0 and 1.0 pH

Alkalinophiles live in hot pools and soils that contain high levels of basic minerals (up to pH 10.0). Bacteria that decompose urine create alkaline conditions, because ammonium (NH 4 1) can be produced when urea (a component of urine) is digested. Metabolism of urea is one way that Proteus spp. can neutralize the acidity of the urine to colonize and infect the urinary system.

Microbial Metabolism

Metabolism refers to all the biochemical reactions that occur in a cell or organism. The bacterial cell is a highly specialized energy transformer. Chemical energy generated by substrate oxidations is conserved by formation of high-energy compounds such as adenosine diphosphate (ADP) and adenosine triphosphate (ATP) or compounds containing the thioester bond



the energy is stored in these compounds as high-energy phosphate bonds. In the presence of proper enzyme systems, these compounds can be used as energy sources to synthesize the new complex organic compounds needed by the cell.

Metabolism: the sum of all chemical reactions occurring within a cell

.simultaneously. Involves degradation and biosynthesis of complex molecules

, **Catabolism**: the breakdown of larger, more complex molecules into smaller simpler ones, during which energy is released, trapped, and made available for work .

 Anabolism: the synthesis of complex molecules from simpler ones during which energy is added as input

Bacteria, like mammalian and plant cells, use ATP or the high-energy phosphate bond (~ P) as the primary chemical energy source. Bacteria also require the B-complex vitamins as functional coenzymes for many oxidation-reduction reactions needed for growth and energy transformation.

Enzymes:the chemical reactions of life would never proceed without a special class of proteins called enzymes. **Enzymes are a catalysts, chemicals that increase the rate of a chemical reaction without becoming part of the products or being consumed in the reaction**. Because of the free energy inherent in molecules, a reaction could occur spontaneously at some point even without an enzyme but at a very slow rate. A study of the enzyme urease shows that it increases the rate of the breakdown of urea by a factor of 100 trillion as compared to an uncatalyzed reaction.

Checklist of Enzyme Characteristics

- Most composed of protein; may require cofactors
- Act as organic catalysts to speed up the rate of cellular reactions
- Lower the activation energy required for a chemical reaction to proceed
- Enable metabolic reactions to proceed at a speed compatible with life

• Have unique characteristics such as shape, specificity, and function

• Provide an active site for target molecules called substrates

• Are much larger in size than their substrates

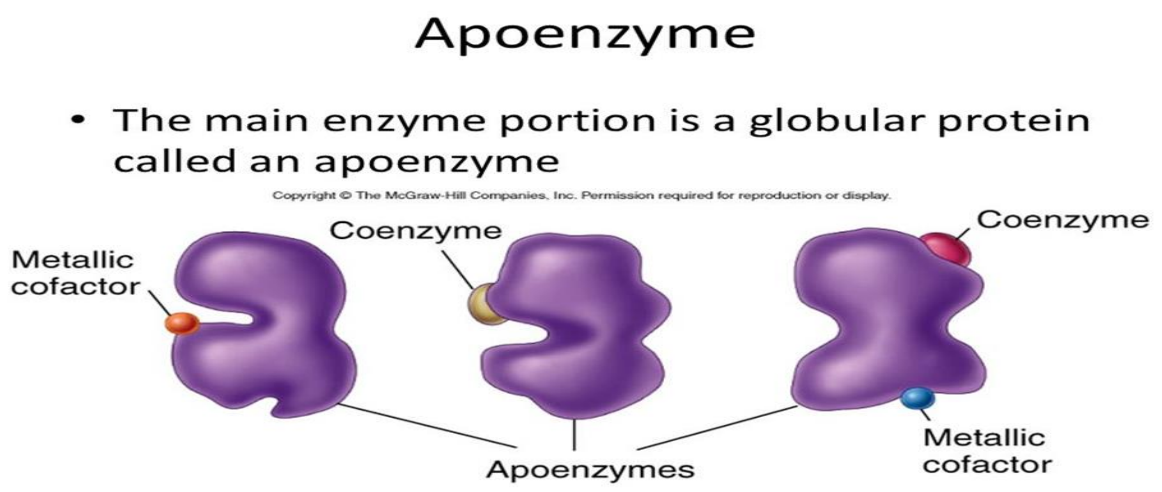
• Associate closely with substrates but do not become integrated into the reaction products
• Are not used up or permanently changed by the reaction

• Can be recycled, thus function in extremely low concentrations

• Are greatly affected by temperature and pH

• Can be regulated by feedback and genetic mechanisms

E + S -----> ES ------> E + P



The primary structure of all enzymes is protein enzymes can be classified

1-Simple enzyme :- consist of protein alone

2- conjugated enzymes (holoenzyme) :- contain protein and non protein molecules , is a combination of a protein, (apoenzyme) and one or more cofactors. **Cofactors** are either **organic molecules** , called **coenzymes(vitamin)** Organic molecules that work in conjunction with apoenzyme to perform a necessary alteration of a substrate, the general function of coenzyme is to remove functional group from one substrate molecule and add it to another substrate .**inorganic elements** including iron, copper, magnesium, manganese, zinc, cobalt, selenium and many other, in general metals activate enzymes ,help bring the active site and substrate close together) that these enzymes need to become functional.

Table 3 : Enzymes, Catalytic Actions, and Cofactors

NO	Enzyme	Action	Metallic Cofactor Required
-1	Catalase	Breaks down hydrogen peroxide	Iron (Fe)
-2	Oxidase	Adds electrons to oxygen	Iron, copper (Cu)
-3	Hexokinase	Transfers phosphate to glucose	Magnesium (Mg)
-4	Urease	Splits urea into an ammonium ion	Nickel (Ni)
-5	Nitrate reductase	Reduces nitrate to nitrite	Molybdenum (Mo)
-6	DNA polymerase complex	Synthesis of DNA	Zinc (Zn) and Mg

Enzymes are classified and named according to characteristics such as **site of action**, **type of action**, and **substrate** . In general, an enzyme name is composed of two parts: a prefix or stem word derived from a certain characteristic —usually the substrate acted upon or the type of reaction catalyzed , or both—followed by the ending ase. The system classifies the enzyme in one of these six classes, on the basis of its general biochemical action:

1-Oxidoreductases transfer electrons from one substrate to another, and .

.dehydrogenases transfer a hydrogen from one compound to another

.2-Transferases transfer functional groups from one substrate to another .

.3-Hydrolases cleave bonds on molecules with the addition of water .

.4-Lyases add groups to or remove groups from double-bonded substrates .

5-Isomerases change a substrate into its . a compound that has the same molecular isomeric form. An isomer is formula as another compound but differs in arrangement of the atoms

6-Ligases catalyze the formation of bonds with the input of ATP and the removal of . : water substrate, Example

Sucrose = Sucrase \ Lipids = Lipase \ DNA = DNase \ Proteins = Protease

removes a Hydrogen = Dehydrogenase \ removes a phosphate = phosphatase

The Role of Microbial Enzymes in Disease:-Many pathogens secrete unique exoenzymes that help them avoid host defenses or promote their multiplication in tissues. Because these enzymes contribute to pathogenicity, they are referred to as **virulence factors** or **toxins** in some cases, **Streptococcus pyogenes (**a cause of throat and skin infections) produces a **streptokinase** that digests blood clots and apparently assists in invasion of wounds. Another exoenzyme from this bacterium is called **streptolysin** In mammalian hosts, streptolysin damages blood cells and tissues .It is also responsible for lysing red blood cells used in blood agar dishes, and this trait is used for identifying the bacteria growing in culture.

Pseudomonas aeruginosa, a respiratory and skin pathogen, produces elastase and collagenase which digest elastin and collagen ,two proteins found in connective tissue . These increase the severity of certain lung diseases and burn infections.

Clostridium perfringens, an agent of gas gangrene, synthesizes lecithinase C a lipase that profoundly, damages cell membranes and accounts for the tissue death associated with this disease. Not all enzymes digest tissues; some, such as penicillinase, inactivate penicillin and thereby protect a microbe from this drug

Biological Oxidation and Reduction The compound that loses the electrons is oxidized, and the compound that receives the electrons is reduced. Such oxidation reduction or **redox reactions** are common in the cell and indispensable to energy transactions.

Electron donor + Electron acceptor—----Electron donor + Electron acceptor

Reduced + oxidized oxidized + reduced

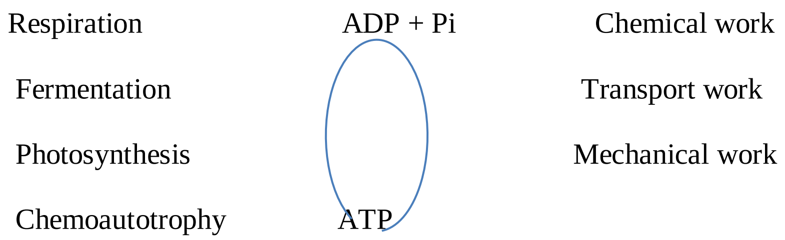
One example of a typical redox reaction is seen in this overall equation associated with aerobic respiration

Oxidation

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + H_2O + \text{Energy}$$

Glucose **Reduction**

ATP has been described as metabolic currency because it can be earned, banked, saved, spent, and exchanged. ATP is a three-part molecule consisting of a nitrogen base (adenine) linked to a 5-carbon sugar (ribose), with a chain of three phosphate groups bonded to the ribose . ATP is an important energy molecule of the cell. It donates free energy to anabolic reactions and is continuously regenerated by three phosphorylation processes: substrate-level phosphorylation, oxidative phosphorylation, and photophosphorylation in certain organisms.



Bioenergetics is a study of the mechanisms of cellular energy release, including catabolic and anabolic routes.

Catabolism: An Overview of Nutrient Breakdown and Energy Release The primary catabolism of fuels (such as glucose) that results in energy release in many organisms proceeds through a series of three coupled pathways:

1. Glycolysis, also called the Embden-Meyerhof-Parnas (EMP) pathway.
2. Krebs cycle, also known as the citric acid or tricarboxylic acid cycle.
3. Respiratory chain (electron transport and oxidative phosphorylation)

Energy Strategies in Microorganisms

1- Aerobic respiration is a series of reactions (glycolysis, Krebs cycle, and the respiratory chain) that converts glucose to CO_2, produces H_2O, and generates energy .It relies on free oxygen as the final acceptor for electrons and hydrogens, and generates a relatively large amount of ATP. Aerobic respiration is characteristic of many bacteria, fungi, protozoa, and animals. is a type of heterotrophic metabolism that uses oxygen and in which 38 moles of ATP are derived from the oxidation of 1 mole of glucose, yielding 380,000 cal. (An additional 308,000 cal is lost as heat.)

Glucose ($C_6H_{12}O_6$) +6 O_2 + 38 ADP + 38 P i ---------- 6 CO_2 + 6 H_2O + 38 ATP

2- **Facultative** and **aerotolerant anaerobes** may use only the glycolysis scheme to incompletely oxidize or **ferment** glucose.(, oxygen is not required, organic compounds are the final electron acceptors, and a relatively small amount of ATP is synthesized)

3- Some strictly anaerobic microorganisms metabolize by means of **anaerobic res piration**. This system may involve the same three pathways as aerobic respiration, but it does not use molecular oxygen as the final electron acceptor. Instead, it uses oxidized ions NO_3^-, SO_4^{+2}, or CO_3^{3-}.

glycolysis :-The process called glycolysis (EMP) is an anaerobic pathway that converts glucose through several steps into pyruvic acid and synthesize a small amount of ATP in the absence of oxygen. Heterotrophic bacteria

The Krebs Cycle :- The Krebs cycle is the oxidative process in respiration by which pyruvate (via acetyl coenzyme A) is completely decarboxylated to CO_2. The pathway yields 15 moles of ATP (150,000 calories). It occurs in the cytoplasm of prokaryotes and the mitochondrial matrix of eukaryotes.

Fermentation

Type of heterotrophic metabolism, an organic compound rather than oxygen is the terminal electron (or hydrogen) acceptor. Less energy is generated from this incomplete form of glucose oxidation, but the process supports anaerobic growth. organic end products are secreted into the medium as waste metabolites (usually alcohol or acid).

-lactic acid fermentation, in *Streptococcus lactis* and many *Lactobacillus casei*, *L. pentosus* is a single organic acid. Organisms that produce only lactic acid from glucose fermentation are **homofermenters**

- Organisms that ferment glucose to multiple end products, such as acetic acid, ethanol, formic acid, and CO_2, are referred to as **heterofermenters**. ex.*Lactobacillus*, *Leuconostoc*, and *Microbacterium* species and the family Enterobacteriaceae (e.g., *Escherichia coli*, *Salmonella*, *Shigella*, and *Proteus* species). produce CO_2 and H_2 with different combinations of acid end products (formate, acetate, lactate, and succinate).

-Other bacteria such as, *Aeromonas*, *Serratia*, , and *Bacillus* species also form CO_2 and H_2 as well as other neutral end products (ethanol, [acetoin],).

Many obligately anaerobic (*Clostridium* Spp.) ferment glucose with the production of butyrate, acetate, CO_2, and H_2, whereas other *Clostridum* species. form these fermentation end products plus others (butanol, aceton, and ethanol). Similarly, the anaerobic propionic acid bacteria (*Propionibacterium* species) and the related *Veillonella* species ferment glucose to form CO_2, propionate, acetate, and succinate.

Glyoxylate Cycle

Occurs in some bacteria, is a modification of the Krebs cycle. Acetyl coenzyme A is generated directly from oxidation of fatty acids or other lipid compounds

Electron Transport and Oxidative Phosphorylation

In the final stage of respiration, ATP is formed through a series of electron transfer reactions within the cytoplasmic membrane that drive the oxidative phosphorylation of ADP to ATP. Bacteria use various flavins, cytochrome, and non-heme iron components as well as multiple cytochrome oxidases for this process.

Cytochrome oxidases in many pathogenic bacteria are studied by the bacterial oxidase reaction, which subdivides Gram-negative organisms into two major groups, oxidase positive and oxidase negative

Both bacterial and mammalian electron transfer systems can carry out electron transfer (oxidation) reactions with NADH + H^+, NADPH + H^+, and succinate.

Bacterial Photosynthesis

Bacterial photosynthesis is a light-dependent, anaerobic mode of metabolism. Carbon dioxide is reduced to glucose, which is used for both biosynthesis and assimilation

, *Heliobacterium chlorum,* staining Gram positive contain a new type of chlorophyll, i.e., bacteriochlorophyll ,

The Nitrogen Cycle

The nitrogen cycle consists of a recycling process by which organic and inorganic nitrogen compounds are used metabolically and recycled among bacteria, plants, and animals. Important processes, including ammonification, mineralization, nitrification, denitrification, and nitrogen fixation, are carried out primarily by bacteria

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