

Chapter III: Bacterial nutrition

Microorganisms multiply using nutrients present in their environment. They share common requirements, including water, an energy source, a carbon source, a nitrogen source, and mineral elements. These basic needs are referred to as elementary needs. While many microorganisms can grow and multiply under these conditions, others cannot due to the absence of one or more essential components required for cellular life. These essential components, or growth factors, must be provided to ensure their development. Based on these needs, microorganisms are classified into trophic types.

I- Elementary needs

These are the basic requirements shared by all bacteria: water, energy source, carbon source, nitrogen source, and mineral elements.

1- Water

Water constitutes 80-90% of the cell's weight and plays a fundamental role in dissolving nutrients, facilitating their transport, and enabling hydrolysis reactions. The availability of free water is quantified by water activity (a_x), which ranges from 0 to 1.

- **Water activity (a_x):** This parameter measures the availability of free water, which is essential for microbial growth. In nutrients, some water is bound to components (e.g., salts, proteins) and is unavailable to microorganisms.
- Bacteria require a certain threshold of humidity for growth. Low a_x slows down bacterial growth.
- **Halophilic bacteria** thrive in high-salt environments (e.g., NaCl concentrations of 1-15%) with an a_x of around 0.75.

2- Energy source

The energy required for macromolecule synthesis is provided by adenosine triphosphate (ATP), synthesized by the bacteria. Based on their energy source, bacteria are classified into two main groups:

- **Phototrophs:** Derive energy from light, which is converted into ATP using pigments (e.g., chlorophyll, bacteriochlorophyll, carotenes).
 - **Photolithotrophs:** Use inorganic electron sources (e.g., H_2 , H_2S).
 - **Photoorganotrophs:** Use organic electron sources.
- **Chemotrophs:** Derive energy from chemical redox reactions.
 - **Chemolithotrophs:** Use inorganic electron donors (e.g., H_2S , NH_3 , Fe^{2+}).
 - **Chemoorganotrophs:** Use organic electron donors.

3- Carbon Source

Carbon is the most abundant element in bacteria and is essential for building organic molecules. Based on their carbon source, microorganisms are classified into:

- **Autotrophs:** Use carbon dioxide (CO_2) or bicarbonate ions (HCO_3^-) as their sole carbon source. Examples include phototrophic bacteria and most chemolithotrophs.
- **Heterotrophs:** Require organic molecules (e.g., sugars, organic acids, peptides, amino acids) for growth. Some heterotrophs can metabolize a wide range of organic substances, while others are limited to specific substrates.

4- Nitrogen Source

Nitrogen is essential for synthesizing proteins and nucleic acids, constituting 12% of the dry weight of bacteria. Nitrogen can be obtained from:

- **Inorganic sources:**
 - Nitrogen fixation: Some bacteria (e.g., *Rhizobium*, *Azotobacter*, *Clostridium*) can fix atmospheric nitrogen (N_2).
 - Nitrites (NO_2^-): Used by bacteria like *Nitrobacter*.
 - Nitrates (NO_3^-): Reduced to nitrites and then to ammonium (NH_4^+).
 - Ammonium (NH_4^+): Used by many bacteria.
- **Organic sources:** Amino groups (R-NH_2) from organic compounds, which are incorporated after deamination or transamination.

5- Sulfur and phosphorus sources

- **Sulfur:** Found in sulfur-containing amino acids (e.g., cysteine, methionine) and is essential for protein synthesis and coenzymes (e.g., biotin, coenzyme A). In culture media, sulfur is often provided as sulfate ions (SO_4^{2-}), which are reduced to sulfites (SO_3^{2-}) and then to sulfides (H_2S).
- **Phosphorus:** Required for ATP, nucleic acids, and coenzymes (e.g., NAD, NADP). It is absorbed as inorganic phosphate (PO_4^{3-}).

6- Other mineral elements

- **Potassium:** Acts as an enzymatic cofactor.
- **Magnesium:** Stabilizes cellular structures and acts as a cofactor.
- **Calcium:** Stabilizes bacterial cell walls and enhances heat resistance in endospores (e.g., *Bacillus*, *Clostridium*).
- **Sodium:** Essential for halophilic bacteria.
- **Iron:** A component of cytochromes in the electron transport chain. Bacteria produce siderophores to capture and transport insoluble iron into cells.

II- Growth factors

While many microorganisms (e.g., photolithotrophic autotrophs) can synthesize all cellular components from basic nutrients, others lack essential enzymes and require specific growth factors. These include:

- **Amino acids:** Required for protein synthesis.
- **Purines and pyrimidines:** Required for nucleic acid synthesis.
- **Vitamins:** Act as coenzymes or their precursors. Examples include:
 - **Biotin:** Involved in CO₂ fixation.
 - **Nicotinic acid:** Forms NAD and NADP, essential for dehydrogenation reactions.
 - **Pyridoxine (B₆):** Participates in amino acid metabolism.
 - **Riboflavin (B₂):** Forms FMN and FAD, involved in redox reactions.
 - **Vitamin K:** Essential for electron transport.

Syntrophy is a metabolic interaction where auxotrophic bacteria grow as satellite colonies around prototrophic bacteria that produce the required growth factors.

III- Trophic types (Nutritional classification)

Microorganisms are classified based on their carbon, energy, and electron sources:

Class of Need	Trophic Type	Nature of Need
Carbon Source	Autotrophs	CO ₂ as the sole or primary carbon source.
	Heterotrophs	Organic molecules as carbon source.
Energy Source	Phototrophs	Light as energy source.
	Chemotrophs	Oxidation of organic/inorganic compounds.
Electron Source	Lithotrophs	Inorganic electron donors.
	Organotrophs	Organic electron donors.
Growth Factors	Prototrophs	No growth factors required.
	Auxotrophs	Growth factors required.

Examples:

- **Photoautotrophs:** Perform photosynthesis (e.g., cyanobacteria, green and purple non-sulfur bacteria). Unlike plants, bacterial photosynthesis does not release oxygen.
- **Photoheterotrophs:** Use light for energy but require organic carbon sources.
- **Chemoautotrophs:** Derive energy from inorganic substances and fix CO₂ into organic matter (e.g., bacteria in hydrothermal vents).
- **Chemoheterotrophs:** Obtain energy and carbon from organic compounds (e.g., most pathogenic bacteria).

IV- Physicochemical parameters

Environmental factors such as temperature, pH, osmotic pressure, and oxygen availability influence microbial growth.

1- Temperature

Bacteria have minimum, maximum, and optimal growth temperatures. Based on these, they are classified as:

- **Psychrotrophs:** Grow at 0°C, optimal at 20-25°C.
- **Psychrophiles:** Optimal growth below 15°C.
- **Cryophiles:** Grow at subzero temperatures (optimal at -5°C).
- **Mesophiles:** Grow at 25-40°C, optimal at 37°C (includes most pathogens).
- **Thermophiles:** Optimal growth at 50-60°C.
- **Hyperthermophiles:** Optimal growth at 70-110°C.

2- pH

Bacteria grow within a specific pH range, with an optimal pH for growth. They are classified as:

- **Acidophiles:** Prefer acidic pH (e.g., *Lactobacillus*, optimal pH 6).
- **Neutrophiles:** Prefer neutral pH (6.5-7.5).
- **Alkaliphiles:** Prefer alkaline pH (e.g., *Vibrio cholerae*, optimal pH 9).

3- Osmotic Pressure

Bacteria are classified based on their tolerance to osmotic pressure:

- **Non-halophiles:** Require NaCl < 0.2 M.
- **Halophiles:** Require NaCl > 0.2 M (e.g., *Halobacterium salinarum*).

- **Halotolerant:** Tolerate high salt concentrations (e.g., *Staphylococcus*, *Lactobacillus*).
- **Osmophiles:** Thrive in high sugar concentrations.

4- Oxygen requirements

Based on oxygen needs, bacteria are classified as:

- **Strict aerobes:** Require oxygen for growth.
- **Microaerophiles:** Require low oxygen levels.
- **Facultative anaerobes:** Can grow with or without oxygen.
- **Aerotolerant anaerobes:** Do not use oxygen but can tolerate it.
- **Strict anaerobes:** Cannot grow in the presence of oxygen.