# *Chapter 11 The Diversity of Prokaryotic Microorganisms*

## *Summary Outline*

11.1 **Anaerobic Chemotrophs**

A. **Anaerobic organisms** use **terminal electron** acceptors other than $O_2$
B. **Anaerobic chemolithotrophs**
   1. Oxidize inorganic compound such as hydrogen to obtain energy
   2. $CO_2$ is the terminal electron acceptor
   3. Example: Methanogens (Domain Archae)
C. **Anaerobic chemoorganotrophs**—anaerobic respiration
   1. Oxidize organic compounds such as glucose to obtain energy
   2. The terminal electron acceptor is an organic compound other than $O_2$
   *3.* Example: *Desilfovibrio*
D. **Anaerobic chemoorganotrophs**—fermentation
   1. The **end products of fermentation** include a variety of **acids** and **gases** that
   2. are generally characteristic for a given species.
   3. ***Clostridium species*** are **Gram-positive rods**
   4. The **lactic acid bacteria** are a group of **Gram-positive organisms** that produce lactic acid as their primary fermentation end-products.

11.2 Anoxygenic phototrophs

A. **Phylogenetically diverse group** of bacteria that harvest the energy of sunlight, using **photosynthesis** to synthesize organic materials.
B. The purple bacteria
   1. The **purple bacteria are Gram-negative organisms** that appear red, orange or purple; the photosynthetic apparatus is contained within the cytoplasmic membrane.
   2. The **purple sulfur bacteria** preferentially use **sulfur** as a **source of reducing power**.
   3. The **purple nonsulfur bacteria** preferentially use **organic molecules** as a **source of reducing power**.
C. The **green bacteria**
   1. The **green bacteria are Gram-negative organisms** that are typically green or brownish in color. Their light harvesting pigments are located in structures called **chlorosomes**.
   2. The **green sulfur bacteria** use **hydrogen sulfide** as a **source of reducing power**.
   3. The **green nonsulfur bacteria** are characterized by their **filamentous growth**; metabolically, they resemble the purple nonsulfur bacteria.
   4. Other **anoxygenic phototrophs** include a Gram-positive rod that forms endospores.

11.3 **Oxygenic phototrophs**

A. The **cyanobacteria** are a diverse group of **Gram-negative bacteria** that are essential **primary producers**; unlike eukaryotic photosynthesizers, they can **fix nitrogen**.
B. Genetic evidence indicates that **chloroplasts** of plants and algae evolved from a species of cyanobacteria.
C. **Nitrogen-fixing cyanobacteria** provide an available source of both **carbon** and **nitrogen**.
D. **Filamentous cyanobacteria** may be involved in maintaining the structure and productivity of some soils.
E. **Some species** of cyanobacteria **produce toxins** that can be deadly to animals that ingest heavily contaminated water.

11.4 **Aerobic chemolithotrophs**

A. **Aerobic chemolithotrophs** generate energy by oxidizing reduced **inorganic compounds** using **$O_2$ as a terminal electron acceptor**.
B. **Sulfur-oxidizing bacteria** are **Gram-negative rods or spirals**, sometimes growing in filaments.
C. The **filamentous sulfur-oxidizers** *Beggiatoa* and *Thiothrix* live in sulfur springs, sewage-polluted waters, and on the surface of marine and freshwater sediments.
D. Nitrifiers—**Ammonia oxidizers** convert **ammonia to nitrite** and include *Nitrosomonas* and *Nitrosococcus*; **nitrite oxidizers** oxidize **nitrite to nitrate** and include *Nitrobacter* and *Nitrococcus*.
E. **Hydrogen-oxidizing bacteria** are **thermophilic bacteria** that are thought to be among the earliest bacterial forms.

11.5 **Aerobic chemoorganotrophs** oxidize **organic compounds** for energy using **$O_2$ as a terminal electron acceptor**.

A. **Obligate aerobes** generate energy exclusively by respiration.
   1. ***Micrococcus* species** are **Gram-positive cocci** found in soil and on dust particles, inanimate objects, and skin.
   2. ***Mycobacterium* species** are **acid-fast**.
   3. ***Pseudomonas* species** are **Gram-negative rod-shaped bacteria** that are widespread in nature and have extremely diverse metabolic capabilities.
   4. ***Thermus aquaticus*** is the source of ***Taq* polymerase**, which is an essential component in the **polymerase chain reaction**.
   5. ***Deinococcus radiodurans*** can survive high doses of gamma radiation.
B. **Facultative anaerobes**
   1. ***Corynebacteium* species** are **Gram-positive pleiomorphic rod-shaped organisms** that commonly inhabit the soil, water and the surface of plants.
   2. Members of the family **Enterobacteriaceae** are **Gram-negative rods** that typically inhabit the intestinal tract of animals, although some reside in rich soil. **Enterics** that **ferment lactose** are included in the group called **coliforms** and are used as indicators of fecal pollution.

11.6 **Ecophysiology**: **Thriving in terrestrial environments**

A. **Bacteria** that **form a resting stage**
   1. **Endospores** are most resistant to environmental extremes.
   2. **Endospore-forming** genera include ***Bacillus*** and ***Clostridium***.
   3. ***Azotobacter* species** are **Gram-negative pleiomorphic rods** that form a resting cell called a **cyst** and are notable for their ability to **fix nitrogen** under aerobic conditions.
   4. The **myxobacteria** aggregate to form a **fruiting body** when nutrients are exhausted; within the fruiting body cells differentiate to form a **dormant microcyst**.
   5. ***Streptomyces* species** are **Gram-positive bacteria** that resemble fungi in their pattern of growth; they form chains of conidia at the end of hyphae. Many species **naturally produce antibiotics**.
B. **Bacteria that associate with plants**
   1. ***Agrobacterium* species** cause the plant disease crown gall.
   2. ***Rhizobium* species** reside as **endosymbionts** that fix nitrogen and reside within cells in nodules formed on the roots of legumes.

11.7 **Ecophysiology**: **Thriving in aquatic environments**

A. **Sheathed bacteria** form chains of cells encased in a tube; the sheath **enables cells to attach to solid objects** in favorable habitats while sheltering them from attack by predators.
B. **Prosthecate bacteria**
   1. Examples include ***Caulobacter* species** and ***Hyphomicrobium* species**.
C. **Bacteria that derive nutrients from other organisms**

1. ***Bdellovibrio* species** are highly **motile Gram-negative rods** that prey on other bacteria.
2. Certain species of **bioluminescent bacteria** of the Gram-negative genera ***Photobacterium*** and ***Vibrio*** establish a symbiotic relationship with specific types of squid and fish.
3. ***Legionella* species** often reside within protozoa and can **cause respiratory disease** when inhaled in aerosolized droplets.

D. **Bacteria that move by unusual mechanisms**
1. **Spirochetes** are a group of **Gram-negative spiral-shaped bacteria** that move by means of an **axial filament**.
   a. ***Spirochaeta*** thrive in mud and anaerobic waters.
   b. ***Leptospira interrogans*** causes **leptospirosis**.
   c. ***Treponema pallidum*** causes **syphilis**.
2. **Magnetotatic bacteria** such as *Magnetospirillum magnetotacticum* contain a string of **magnetic crystals** that enable them to move up or down in water or sediments to the microaerophilic niches they require.

E. **Bacteria that form storage granules**
1. ***Spirillum volutans*** stores **polyphosphate granules**.
2. ***Thiomargarita namibiensis* stores granules of sulfur** and has a nitrate-containing vacuole.

11.8 **Ecophysiology**: **Animals as habitats**

A. **Bacteria that inhabit the skin**
1. ***Staphylococcus* species** are **Gram-positive cocci** that are facultative anaerobes.
2. ***S. epidermidis*** is part of the normal flora of the skin.
3. ***S. aureus*** causes a variety of diseases including **skin and wound infections**, as well as **food poisoning**.

B. **Bacteria that inhabit mucous membranes**
1. ***Bacteroides* species** are strictly **anaerobic Gram-negative** rods that **inhabit the mouth, intestinal tract,** and **genital tract** of humans and other animals.
2. ***Bifidobacterium* species** are **irregular Gram-positive rods** that reside primarily in the **intestinal tract** of animals.
3. ***Campylobacter*** and ***Helicobacter* species** are **microaerophilic, curved Gram-negative rods**.
   a. ***C. jejuuni*** causes **diarrheal disease** in humans.
   b. ***H. pylori*** causes **stomach ulcers**.
4. ***Haemophilus* species** are **Gram-negative coccobacilli** that require compounds found in blood for growth.
   a. ***H. influenzae*** causes a variety of diseases, primarily in children
   b. ***H. ducreyi*** causes **chancroid**.
5. ***Neisseria* species** are **Gram-negative diplococci** that are nutritionally **fastidious**, **obligate aerobes** that grow in the **oral cavity** and **genital tract**.
   a. ***N. meningitidis*** causes **meningitis**.
   b. ***N. gonorrhoeae*** causes **gonorrhea**.
6. ***Mycoplasma* species lack a cell wall**; they often have sterols in their membrane that provides strength and rigidity. ***M. pneumoniae*** causes a form of **pneumonia**.
7. ***Treponema*** and ***Borrelia* species** are **spirochetes** that typically inhabit mucous membranes and body fluids of humans and other animals.
   a. ***T. pallidum*** causes **syphilis**.
   b. ***B. recurrentis*** and ***B. hermsii*** cause **relapsing fever**.
   c. ***B. burgdorferi*** causes **Lyme disease**.

C. **Obligate intracellular parasites** are unable to reproduce outside a host cell; most have lost the ability to synthesize substances needed for extracellular growth.

1. Species of ***Rickettsia,*** Orientia and ***Ehrlichia*** are tiny **Gram-negative rods** that are spread when a blood-sucking **arthropod** transfers bacteria during a blood meal.
   a. ***R. rickettsi*** causes **Rocky Mountain spotted fever**.
   b. ***R. prowazekii*** causes **epidemic typhus**.
   c. ***O. tsutsugamushi*** causes **scrub typhus**.
   d. ***E. chaffeenis*** causes human **ehrlichiosis**.
2. ***Coxiella burnetti*** is a **Gram-negative rod** that survives well outside the host due to the production of **spore-like structures**.
3. ***Chlamydia*** **species** are transmitted directly from person to person.

11.9 **Ecophysiology**: The **Archaea thrive in extreme environments**

*A*. **Extreme halophiles** are found in salt lakes, soda lakes, and brines used for curing fish; they can grow well in saturated salt solutions. They include ***Halobacterium, Halorubrum, Natronobacterium*** and ***Natronococcus***.

B. **Extreme thermophiles**
   1. ***Methanothermus*** and ***Methanopyrus*** are **hyperthermophiles** that **generate methane**.
   2. **Sulfur- and sulfate-reducing hyperthermophiles** are **obligate anaerobes** that use **sulfur** or sulfate as a **terminal electron acceptor**. They include ***Thermococcus, Archaeoglobus, Thermoproteus, Pyrodictium*** and ***Pyrolobus***.
   3. **Sulfur-oxidizing hyperthermophiles** oxidize sulfur compounds, using **$O_2$ as a terminal electron acceptor**, to **generate sulfuric acid**. They are exemplified by the genus ***Sulfolobus***, which is an obligate aerobe.

C. **Thermophilic extreme acidophiles** include ***Thermoplasma*** and ***Picrophilus*** **species**.