Chapter 9

Classification and Bacteria,

Taxonomy

- ✓Classification of organisms
  - ✒Establish criteria for identification
  - ✒Arrange related organisms into groups
  - ✒Provide information about evolution

Binomial nomenclature

- ✓"two-name" system
  - ✒*Genus*
  - ✒*species*
- ✓Strains are subgroups of species
  - ✒*Escherichia coli* 0157:H7

Microbe names

NAME OF MICROORGANISM	MEANING OF NAME
Entamoeba histolytica	Ent = intestinal, amoebae = shape and means of movement, histo = tissue, lytic = lysing, or digesting, tissue
Escherichia coli	Named after Theodor Escherich in 1888; found in the colon
Haemophilus ducreyi	Hemo = blood, phil = love; named after Augusto Ducrey in 1889
Neisseria gonorrhoeae	Named after Albert L. Neisser in 1879; causes the disease gonorrhea

Taxonomic Ranks (fig 9.2)

- ✓Kingdom (Animalia)
- ✓Phylum or Division (Chordata)
- ✓Class (Mammalia)
- ✓Order (Primates)
- ✓Family (Hominidae)
- ✓Genus (*Homo*)
- ✓Species (*sapiens*)

Bacterium vs human taxonomy

TAXONOMIC CATEGORY	HUMAN	BACTERIUM THAT CAUSES SYPHILIS
Kingdom	Animalia	Monera (Prokaryotae)
Division/Phylum	Chordata	Gracilicutes
Subphylum	Vertebrata	
Class	Mammalia	Scotobacteria
Order	Primate	Spirochaetales
Family	Hominidae	Spirochaetaceae
Genus	Homo	Treponema
Specific epithet	sapiens	pallidum

Problems in taxonomy

✓What is a species?

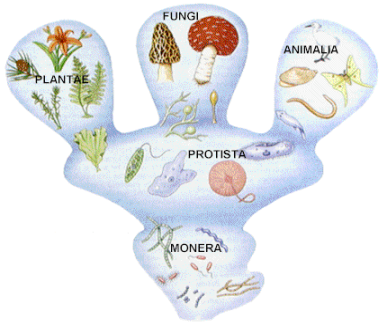
☞Cannot mate, non-fertile offspring, morphology, geographical distribution

✒Organisms are diverse

✓What is a kingdom?

✒Knowledge of evolutionary history is incomplete

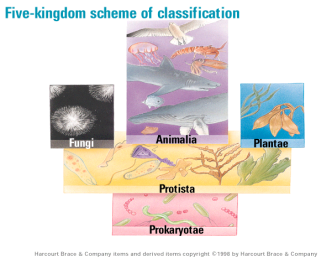
Five-Kingdom classification



KINGDOM	CHARACTERISTICS
Monera	Prokaryotic; unicellular, but sometimes cells are grouped; nutrition by absorption, but in some forms by photosynthesis or chemosynthesis; reproduction asexual, usually by fission.
Protista	Eukaryotic; unicellular but sometimes cells are grouped; nutrition varies among phyla and can be by ingestion, photosynthesis, or absorption; reproduction asexual and in some forms both sexual and asexual.
Fungi	Eukaryotic; unicellular or multicellular, nutrition by absorption, reproduction usually both sexual and asexual and often involves a complex life cycle.
Plantae	Eukaryotic; multicellular; nutrition by photosynthesis.
Animalia	Eukaryotic; multicellular; nutrition by ingestion but in some parasites by absorption; reproduction primarily sexual.

Five-Kingdom Classification

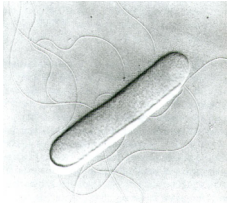
✓Monera
✓Protista
✓Fungi
✓Plantae
✓Animalia

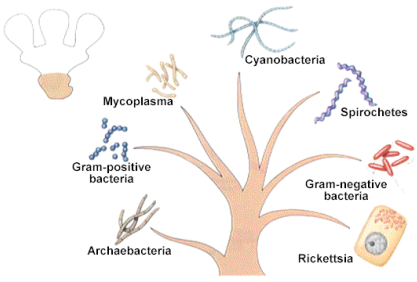


Monera

bacteria, cyanobacteria

✓Prokaryotic
✓Unicellular or grouped (not multicellular)
✓Nutrition by absorption, photosynthesis, or chemosynthesis
✓Asexual reproduction (binary fission)

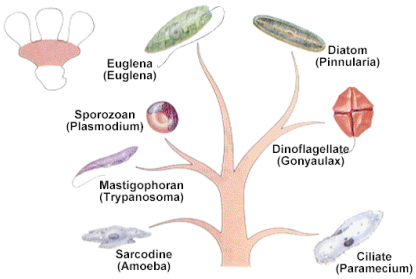




Protista

- ✓ Eukaryotic
- ✓ Unicellular or grouped
- ✓ Nutrition by ingestion, absorption or photosynthesis
- ✓ Asexual and sexual reproduction

Protista

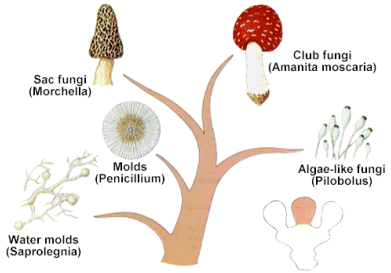


Fungi

yeasts, molds, mushrooms

- ✓ Eukaryotic
- ✓ Uni- or multicellular
- ✓ Nutrition by absorption
- ✓ Asexual and sexual reproduction; complex life cycle

Fungi



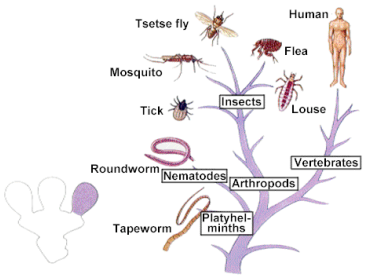
Plantae

- ✓ Eukaryotic
- ✓ Multicellular
- ✓ Nutrition by photosynthesis
- ✓ Asexual and sexual reproduction

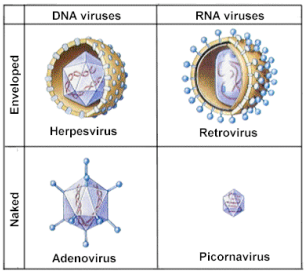
Animalia

- ✓ Eukaryotic
- ✓ Multicellular
- ✓ Nutrition by ingestion or by absorption
- ✓ Primarily sexual reproduction

Animalia

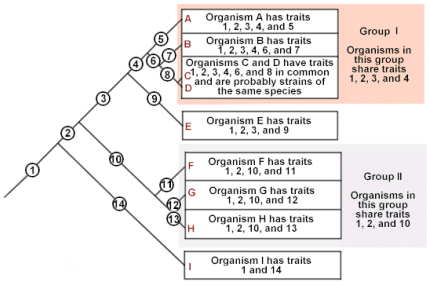


Viruses? Kingdom?



A dichotomous key

1a. Prokaryotic MONERA
1b. Eukaryotic see 2a
2a. Strictly unicellular PROTISTA
2b. Either uni-or multicellular see 3a
3a. Nutrition by photosynthesis PLANTAE
3b. Nutrition by absorption or ingestion see 4a
4a. Reproduce primarily sexually ANIMALIA
4b. Reproduce either sexually or asexually FUNGI



Bacterial Key

1a	Gram-positive	Go to 2
1b	Not gram-positive	Go to 3
2a	Cells spherical in shape	Gram-positive cocci
2b	Cells not spherical in shape	Go to 4
3a	Gram-negative	Go to 5
3b	Not gram-negative (lack cell wall)	Mycoplasma
4a	Cells rod-shaped	Gram-positive bacilli
4b	Cells not rod-shaped	Go to 6
5a	Cells spherical in shape	Gram-negative cocci
5b	Cells not spherical in shape	Go to 7
6a	Cells club-shaped	Corynebacteria
6b	Cells variable in shape	Propionibacteria
7a	Cells rod-shaped	Gram-negative bacilli
7b	Cells not rod-shaped	Go to 8
8a	Cells helical with several turns	Spirochetes
8b	Cells comma-shaped	Vibrioids

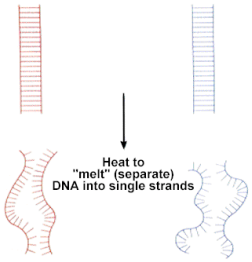
Classifying microorganisms

✓ Numerical taxonomy
- ✒Number of characteristics ~ >90% same species

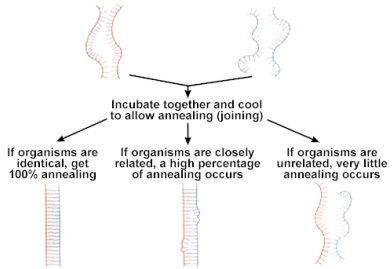
✓ Genetic Homology
- ✒Base composition (proportion of G and C)
- ✒DNA and RNA sequence
- ✒DNA hybridization
- ✒Protein profiles and amino acid sequences

✓ Ribosomes (sequence of RNA in ribosomes)
✓ Immunological reactions (monoclonal antibodies)
✓ Phage typing
- ✒determine similarities among bacteria

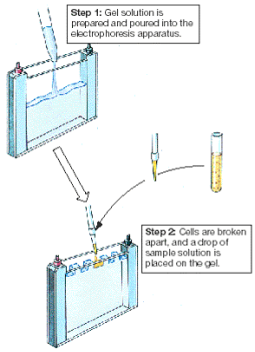
DNA hybridization



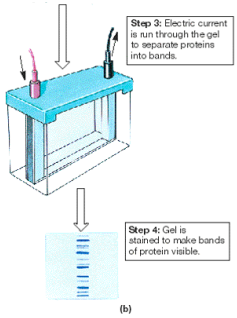
DNA Hybridization



Protein profiles



Protein profile (cont.)



Phage typing

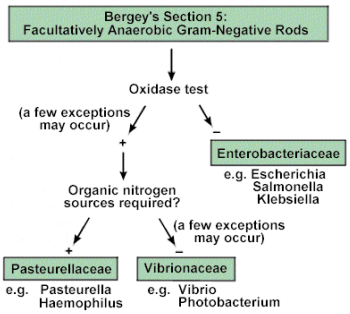
Classifying bacteria

- ✓ Morphology
- ✓ Staining
- ✓ Growth
- ✓ Nutrition
- ✓ Physiology
- ✓ Biochemistry
- ✓ Genetics
- ✓ Serology
- ✓ Phage typing
- ✓ rRNA
- ✓ Protein profiles

Bergey's Manual

- ✓ Is the organism prokaryotic or eukaryotic?
- ✓ To which major category of bacteria does the organism belong?
- ✓ To which group (within the category) does the organism belong?
- ✓ To which genus does the organism belong?
- ✓ To which species does the organism belong?

Bergey's manual



4 Categories of Bacteria (Bergey's manual)

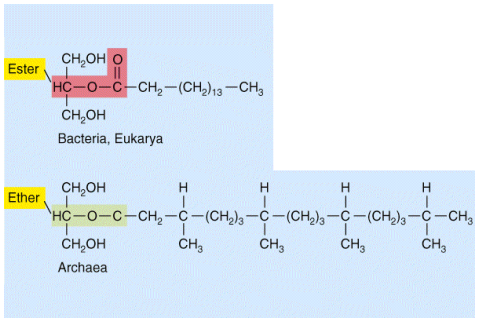
I. Gram-negative eubacteria that have cell walls.

II. Gram-positive eubacteria that have cell walls

III. Eubacteria lacking cell walls

IV. The Archaeobacteria

Eubacteria vs Archaeabacteria



Anaerobic chemotrophs

- ✓ Chemolithotrophs
- ✓ Chemooroganotrophs
- ✓ Chemoorganotrophs (fermentation)

Anaerobic chemolithotrophs

- ✓ Methanogens
- ✓ Generate energy by oxidizing hydrogen gas (H_2)
- ✓ Terminal electron acceptor is carbon dioxide (CO_2)

Methanogens

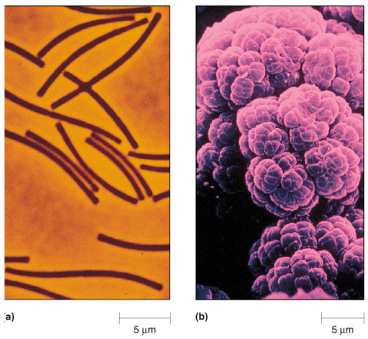


Figure 11.2

Anaerobic chemoorganotrophs

- ✓ Generate energy by oxidizing organic compounds (ex. Glucose)
- ✓ Terminal electron acceptor is something other than oxygen

Chemoorganotrophs (fermentation)

- ✓ Variety of end products (acids and gases)
- ✓ Ex. *Clostridium* species - form endospores
- ✓ Ex. Lactic acid bacteria (*Lactobacillus, Streptococcus, Enterococcus)*

Lactobacillus species

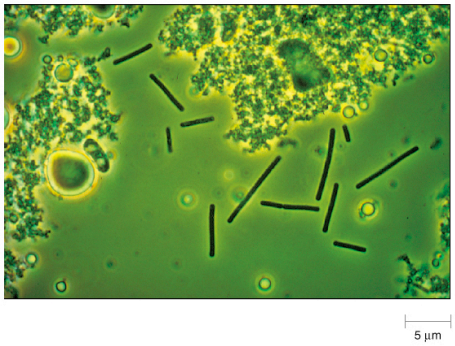


Figure 11.4

Anoxygenic phototrophs

- ✓ Purple bacteria
- ✓ Green bacteria

Purple bacteria

- ✓ Cytoplasmic membrane contains photosynthetic apparatus
- ✓ Reducing power (source of electrons) is sulfur
- ✓ Purple nonsulfur bacteria use organic molecules as source of electrons

Purple bacter

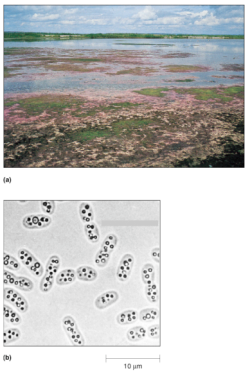


Figure 11.5

Green bacteria

- ✓ Accessory pigments are located in chlorosomes
- ✓ Source of electrons is hydrogen sulfide
- ✓ Green nonsulfur bacteria exhibit filamentous growth

Green bacteria

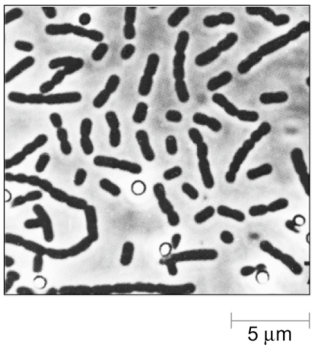


Figure 11.6

Oxygenic phototrophs

- ✓ Cyanobacteria
  - ✒ Nitrogen - fixing
  - ✒ Maintain structure and productivity of some soils
  - ✒ Some species are toxic to animals

Cyanobact

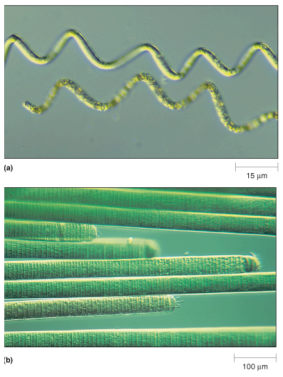


Figure 11.7

Heterocyst

Figure 11.9

Aerobic chemolithotrophs

- ✓ Sulfur - oxidizing bacteria
- ✓ Nitrifiers
- ✓ Hydrogen - oxidizing bacteria

Sulfur - oxidizing bacteria

- ✓ Live in sulfur springs
- ✓ Live in sewage - polluted waters
- ✓ Live on the surface of marine and freshwater sediments
- ✓ Ex. *Beggiatoa, Thiobacillus*

Filamentous sulfur bacteria

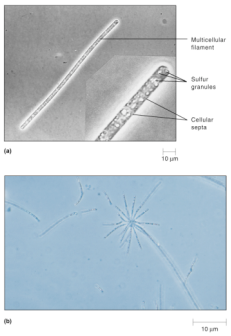


Figure 11.10

Nitrifiers

- ✓ Ammonia oxidizers convert ammonia to nitrite (ex. *Nitrosomonas*)
- ✓ Nitrite oxidizers convert nitrite to nitrate (ex. *Nitrobacter*)

Hydrogen - oxidizing bacteria

- ✓ Thermophilic bacteria
- ✓ Ex. *Aquifex* and *Hydrogenobacter*

Aerobic chemoorganotrophs

- ✓ Obligate aerobes
- ✓ Facultative anaerobes

Obligate aerobes

- ✓ Large variety of bacteria
- ✓ Ex. *Micrococcus* species
- ✓ Ex. *Mycobacterium* species
- ✓ Ex. *Pseudomonas* species
- ✓ Ex. *Thermus aquaticus*
- ✓ Ex. *Deinococcus radiodurans*

Micrococcus luteus

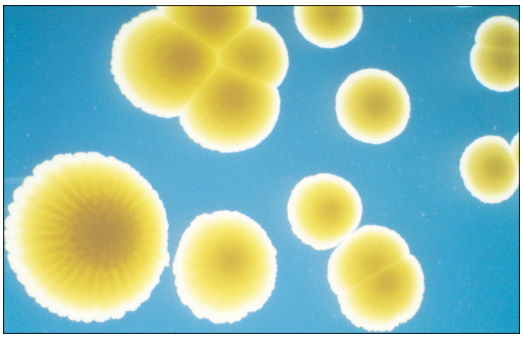


Figure 11.12

Pseudomonas species

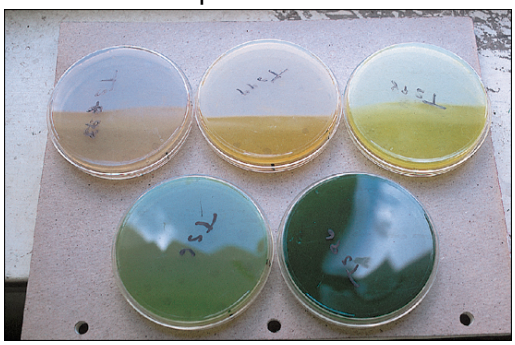


Figure 11.13

Facultative anaerobes

- ✓ Ex. *Corynebacterium* species
- ✓ Ex. *Enterobacteriaceae* family

Corynebacterium

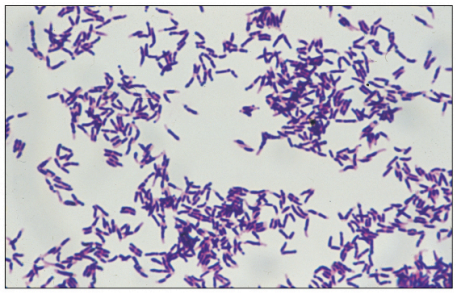


Figure 11.14

Enterobacteriaceae

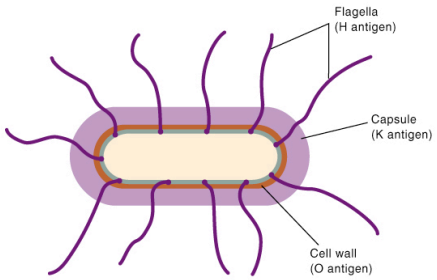


Figure 11.15

Thriving in terrestrial environments

- ✓ Resting state
- ✓ Association with plants

Resting bacteria

- ✓ Form endospores
- ✓ Form cyst
- ✓ Form fruiting bodies
- ✓ Form conidia at the end of hyphae

Endospore - formers

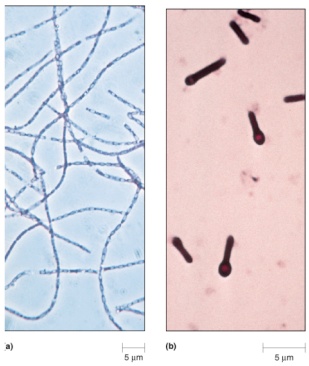


Figure 11.16

A vegetative cell and a cyst

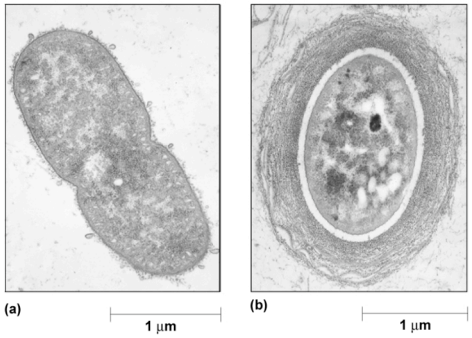


Figure 11.17

Fruiting bodie

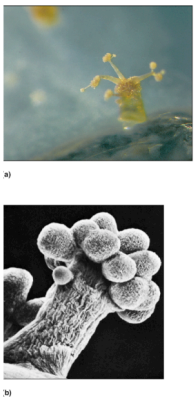


Figure 11.18

Conidia

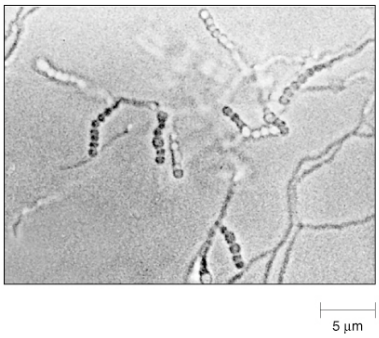


Figure 11.19

Association with plants

- ✓ Plant pathogens (*Agrobacterium* species)
- ✓ Symbiotic relationship (*Rhizobium* species)

Plant tumor

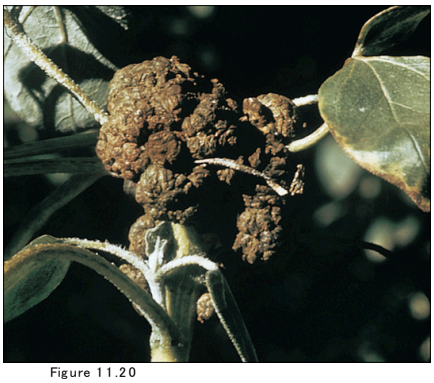


Figure 11.20

Symbiotic relationshi

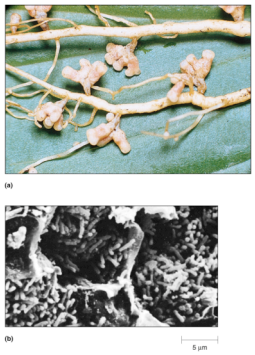


Figure 11.21

Aquatic bacteria

- ✓ Sheathed bacteria
- ✓ Prosthecate bacteria
- ✓ Bacteria that derive nutrients from other bacteria
- ✓ Bioluminescent bacteria
- ✓ Bacteria that move by unusual mechanisms

Aquatic bacteria

- ✓ Sheathed bacteria
- ✓ Prosthecate bacteria
- ✓ Bacteria that derive nutrients from other bacteria
- ✓ Bioluminescent bacteria
- ✓ Bacteria that move by unusual mechanisms
- ✓ Bacteria that form storage granules

Sheathed bacteria

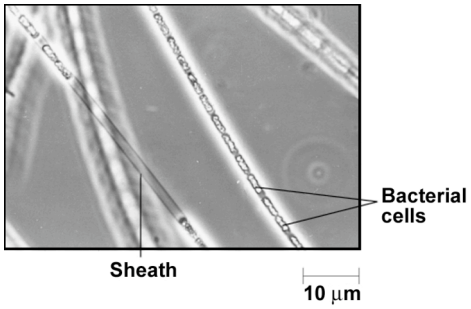


Figure 11.22

Prosthecate bacteria - *Hyphomicrobium*

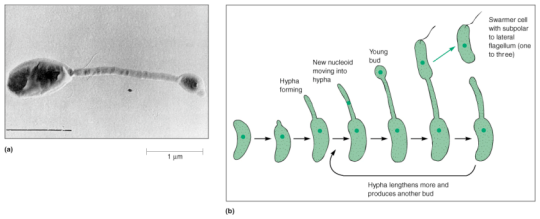


Figure 11.24

Bdellovibrio

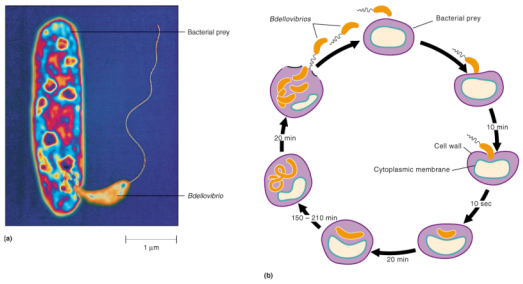


Figure 11.25

Bioluminescent bacteria

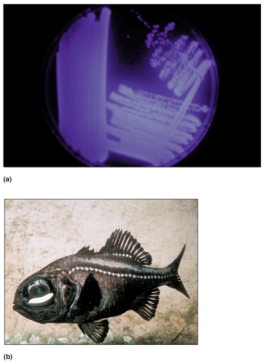


Figure 11.26

Spirochete

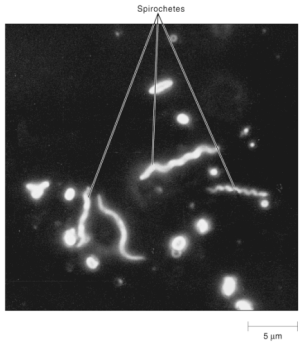


Figure 11.27

Animals as habitats

- ✓ Skin
- ✓ Mucous membrane
- ✓ Obligate intracellular parasites

Skin

- ✓ Ex. *Staphylococcus aureus*
- ✓ Ex. *Staphylococcus epidermidis* (normal flora)

Mucous membrane

- ✓ *Streptococcus*
- ✓ *Corynebacterium*
- ✓ *Lactobacillus*
- ✓ Enterobacteriaceae
- ✓ *Bacteroides*
- ✓ *Bifidobacterium*
- ✓ *Campylobacter* and *Helicobacter*
- ✓ *Haemophilus*
- ✓ *Neisseria*
- ✓ *Mycoplasma*
- ✓ *Treponema* and *Borrelia*

Mycoplasma pneumoniae

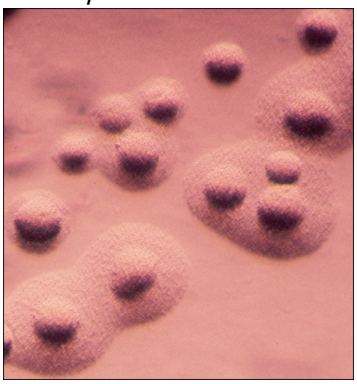
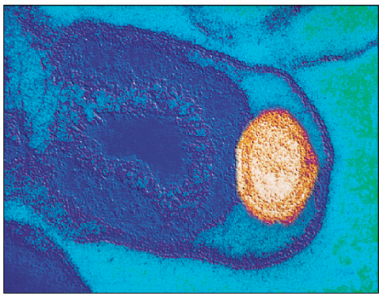


Figure 11.28

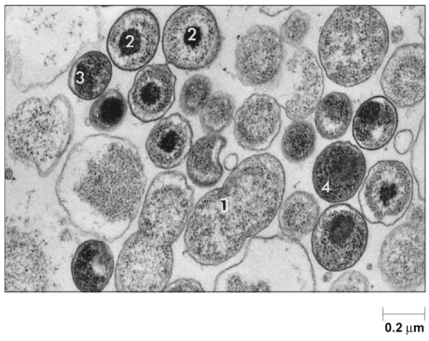
Obligate intracellular parasites

- ✓ Cannot reproduce outside a host cell
- ✓ Transferred by blood - sucking arthropods
- ✓ *Rickettsia rickettsii* - Rocky mountain spotted fever
- ✓ *Rickettsia prowazekii* - Epidemic typhus
- ✓ *Coxsiella* - Can form a sporelike structure - Q-fever
- ✓ *Chlamydia* - Person to person transmission - STDs, eye infections, pneumonia,

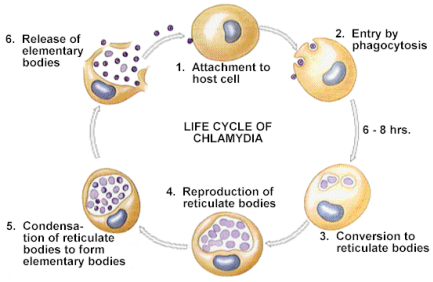
Coxiella



Chlamydia



Rickettsiae and Clamydiae present special problems



Archaea

- ✓ Methanogens
  - ✒ Oxidize H_2 and use CO_2 as an electron acceptor to produce methane
- ✓ Halophiles
  - ✒ Minimum of 9% NaCl. Many photosynthesis using bacteriorhodopsin.
- ✓ Thermophiles
  - ✒ Volcanic vents, hot and sulfuric conditions

Extreme halophiles

- ✓ Located in salt lakes, soda lakes
- ✓ Ex. *Halobacterium*

Extreme halophiles

Figure 11.31

Extreme thermophiles

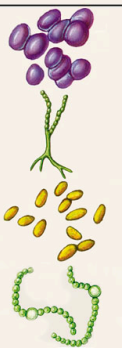
- ✓ Ex. *Methanothermus* species
- ✓ Sulfate - reducing obligate anaerobes (Ex. *Thermococcus*)
- ✓ Sulfur - oxidizing (Ex. *Sulfolobus*)

Sulfolobus

Thermophilic extreme acidophiles

- ✓ Ex. *Thermoplasma* species
  - ✒ Coal refuse piles
- ✓ Ex. *Picrophilus* species
  - ✒ Lives below a pH of 1

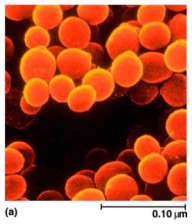
Major Group	Typical Examples
Archaebacteria	Methanogens, thermophiles, halophiles
Actinomycetes	*Streptomyces, Actinomyces*
Chemoautotrophs	Sulfur bacteria, *Nitrobacter, Nitrosomonas*
Cyanobacteria	*Anabaena, Nostoc*



Bacteria (1)

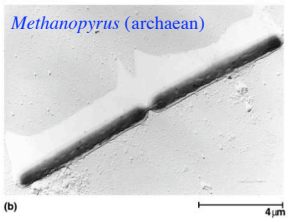
Bacteria (2)

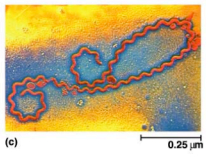
Major Group	Typical Examples
Enterobacteria	*Escherichia coli, Salmonella, Vibrio*
Gliding and budding bacteria	Myxobacteria, *Chondromyces*
Pseudomonads	*Pseudomonas*
Rickettsias and chlamydias	*Rickettsia, Chlamydia*
Spirochaetes	*Treponema*



Micrococcus

Methanopyrus (archaean)



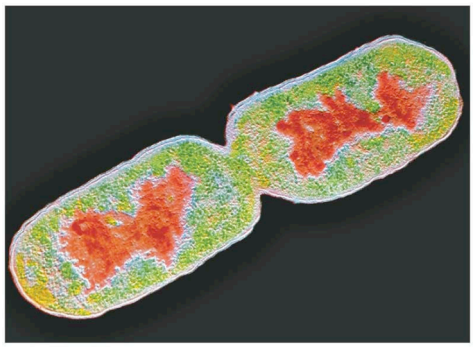


Leptospirosis interrogans (c)

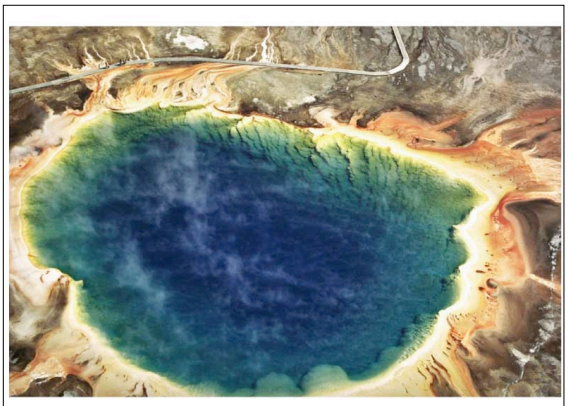
Clostridium endospores

Aqiofex (archaean)

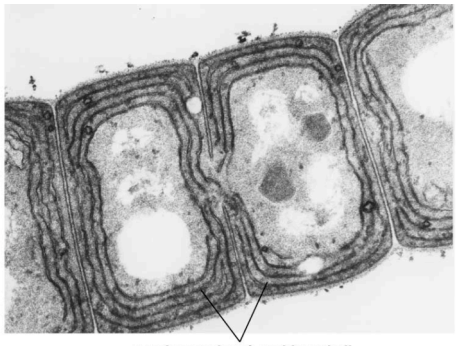
Binary fission



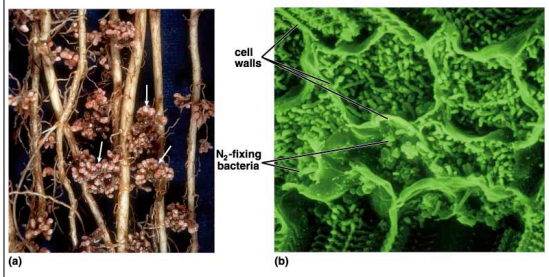
Conjugation



Oscillatoria (chlorophyll in membranes)



Nitrogen fixing bacteria



Envelops of archaeobacteria

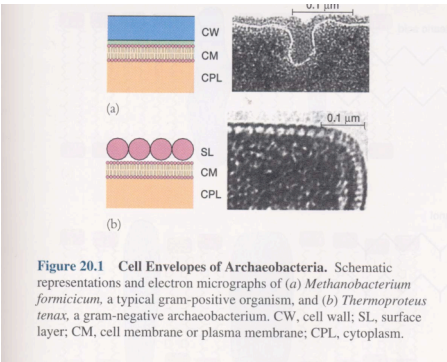


Figure 20.1 Cell Envelopes of Archaeobacteria. Schematic representations and electron micrographs of (*a*) *Methanobacterium formicicum*, a typical gram-positive organism, and (*b*) *Thermoproteus tenax*, a gram-negative archaeobacterium. CW, cell wall; SL, surface layer; CM, cell membrane or plasma membrane; CPL, cytoplasm.

Membranes of archaeobacteria

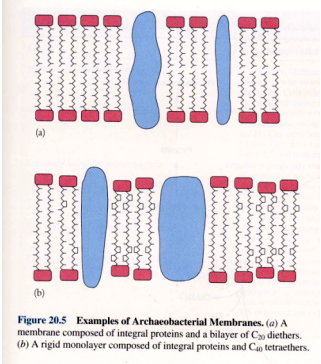


Figure 20.5 **Examples of Archaeobacterial Membranes.** (*a*) A membrane composed of integral proteins and a bilayer of C_{20} diethers. (*b*) A rigid monolayer composed of integral proteins and C_{40} tetraethers.

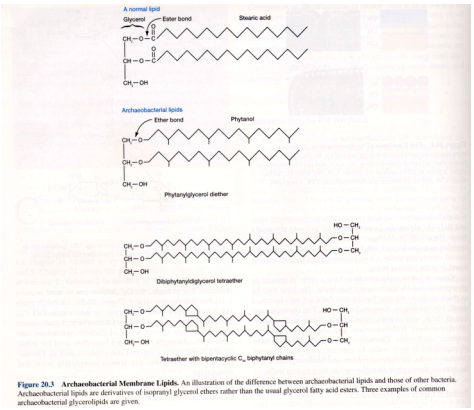


Figure 20.3 **Archaeobacterial Membrane Lipids.** An illustration of the difference between archaeobacterial lipids and those of other bacteria. Archaeobacterial lipids are derivatives of isoprenyl glycerol ethers rather than the usual glycerol fatty acid esters. Three examples of common archaeobacterial glycerolipids are given.

Halobacteria

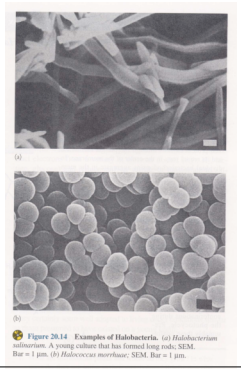


Figure 20.14 **Examples of Halobacteria.** (*a*) *Halobacterium salinarium*. A young culture that has formed long rods; SEM. Bar = 1 μm. (*b*) *Halococcus morrhuae*; SEM. Bar = 1 μm.

Thermophilic

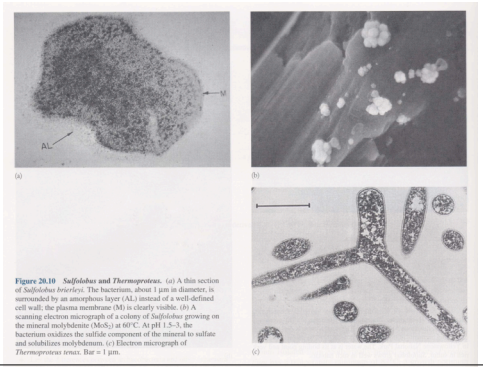


Figure 20.10 ***Sulfolobus* and *Thermoproteus*.** (*a*) A thin section of *Sulfolobus brierleyi*. The bacterium, about 1 μm in diameter, is surrounded by an amorphous layer (AL) instead of a well-defined cell wall; the plasma membrane (M) is clearly visible. (*b*) A scanning electron micrograph of a colony of *Sulfolobus* growing on the mineral molybdenite (MoS_2) at 60°C. At pH 1.5–3, the bacterium oxidizes the sulfide component of the mineral to sulfate and solubilizes molybdenum. (*c*) Electron micrograph of *Thermoproteus tenax*. Bar = 1 μm.

Methanogenic

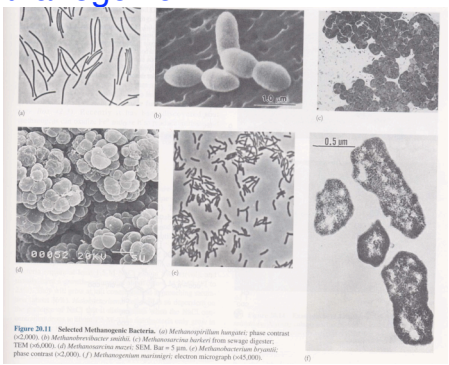


Figure 20.11 **Selected Methanogenic Bacteria.** (*a*) *Methanospirillum hungatei*; phase contrast (×2,000). (*b*) *Methanobrevibacter smithii*. (*c*) *Methanosarcina barkeri* from sewage digester; TEM (×6,000). (*d*) *Methanosarcina mazei*; SEM. Bar = 5 μm. (*e*) *Methanobacterium bryantii*; phase contrast (×2,000). (*f*) *Methanogenium marisnigri*; electron micrograph (×45,000).

Archaeobacteria in a black smoker

Thermoplasma

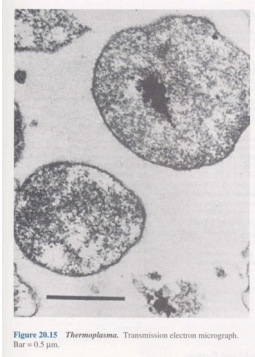


Figure 20.15 *Thermoplasma.* Transmission electron micrograph. Bar = 0.5 μm.

Green sulfur bacteria

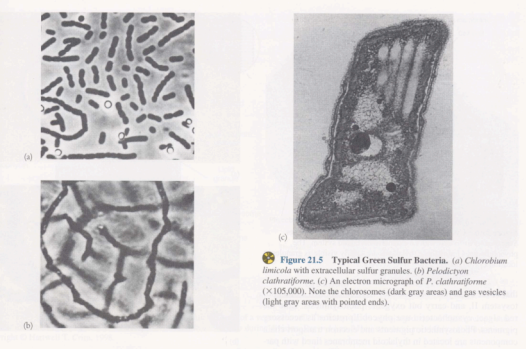
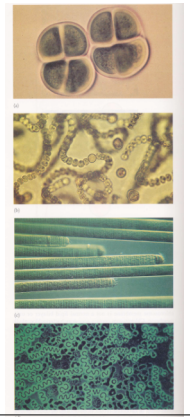


Figure 21.5 Typical Green Sulfur Bacteria. (*a*) *Chlorobium limicola* with extracellular sulfur granules. (*b*) *Pelodictyon clathratiforme*. (*c*) An electron micrograph of *P. clathratiforme* (×105,000). Note the chlorosomes (dark gray areas) and gas vesicles (light gray areas with pointed ends).

Cyanobacteria



Thylacoids

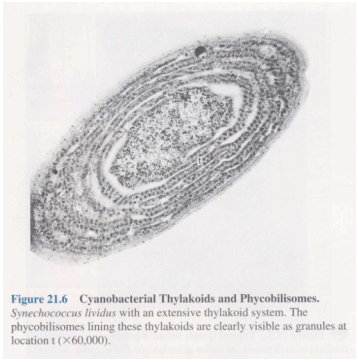


Figure 21.6 Cyanobacterial Thylakoids and Phycobilisomes. *Synechococcus lividus* with an extensive thylakoid system. The phycobilisomes lining these thylakoids are clearly visible as granules at location t (×60,000).

26.1 The Three Domains of Life on Earth

CHARACTERISTIC	BACTERIA	DOMAIN ARCHAEA	EUKARYA
Membrane-enclosed nucleus	Absent	Absent	*Present*
Membrane-enclosed organelles	Absent	Absent	*Present*
Peptidoglycan in cell wall	*Present*	Absent	Absent
Membrane lipids	Ester-linked Unbranched	*Ether-linked Branched*	Ester-linked Unbranched
Ribosomes[a]	70S	70S	*80S*
Initiator tRNA	*Formylmethionine*	Methionine	Methionine
Operons	Yes	Yes	*No*
Plasmids	Yes	Yes	*Rare*
RNA polymerases	One	Several	Three
Sensitive to chloramphenicol and streptomycin	*Yes*	No	No
Ribosomes sensitive to diphtheria toxin	*No*	Yes	Yes
Some are methanogens	No	*Yes*	No
Some fix nitrogen	Yes	Yes	*No*
Some conduct chlorophyll-based photosynthesis	Yes	*No*	Yes

[a]70S ribosomes are smaller than 80S ribosomes.