

## Chapters 10-11

Identification, Classification and Diversity of Prokaryotes

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

## Taxonomic Ranks (fig 10.1)

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

Table 10.1 Taxonomic Ranks of the Bacterium *Escherichia coli*

Formal Rank	Example
Domain	Bacteria
Phylum	Proteobacteria
Class	Gamma proteobacteria
Order	Enterobacteriales
Family	Enterobacteriaceae
Genus	<i>Escherichia</i>
Species	<i>coli</i>

## 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

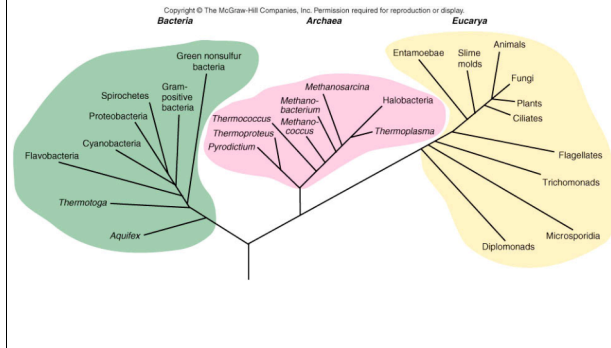
### ✓ What is a species?

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

### ✓ Problems with bacteria

- Organisms are diverse
- Knowledge of evolutionary history is incomplete
  - ⇒ Fossil record
- Some are obligate parasites

## Domain classification

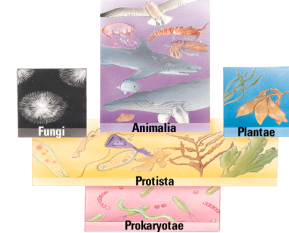


KINGDOM	CHARACTERISTICS
Monera	Prokaryotic; unicellular, but sometimes cells are grouped; nutrition by absorption, but in some forms by photosynthesis or chemosynthesis; reproduction asexual, usually by fission.
Protista	Eukaryotic; unicellular but sometimes cells are grouped; nutrition varies among 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

Five-kingdom scheme of classification

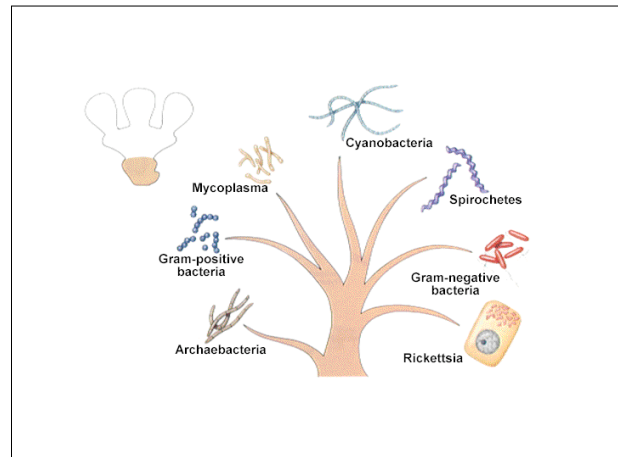
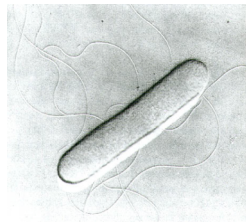


Harcourt Brace & Company items and derived items copyright. ©1998 by Harcourt Brace & Company

## Monera

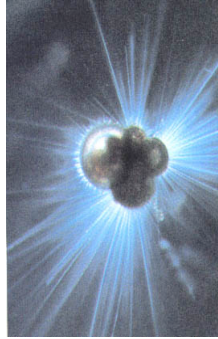
### bacteria, cyanobacteria

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

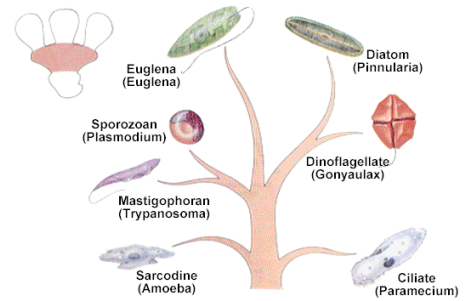


## Protista

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



## Protista



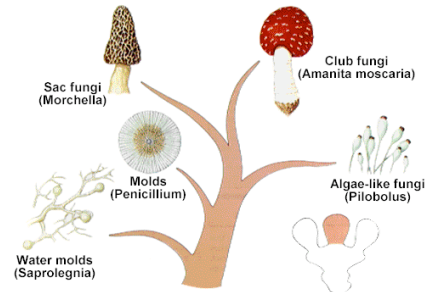
## Fungi

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

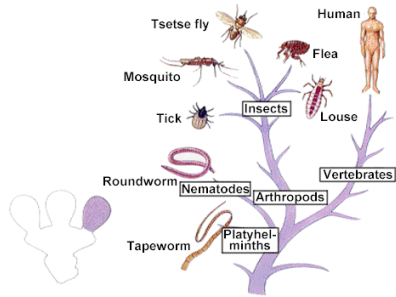


## Animalia

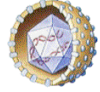
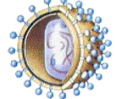
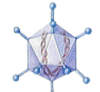

- ✓ Eukaryotic
- ✓ Multicellular
- ✓ Nutrition by ingestion or by absorption
- ✓ Primarily sexual reproduction



## Animalia

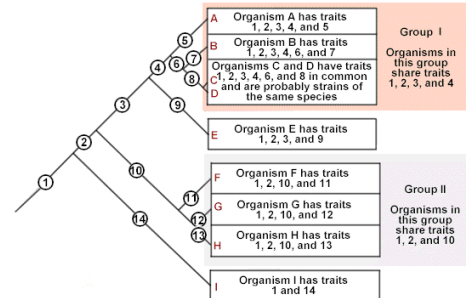


## Viruses? Kingdom?

	DNA viruses	RNA viruses
Enveloped	 Herpesvirus	 Retrovirus
Naked	 Adenovirus	 Picornavirus

## 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

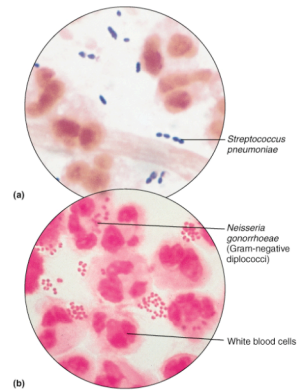
**Table 10.1** Taxonomic Ranks of the Bacterium *Escherichia coli*

Formal Rank	Example
Domain	Bacteria
Phylum	Proteobacteria
Class	Gammaproteobacteria
Order	Enterobacteriales
Family	Enterobacteriaceae
Genus	<i>Escherichia</i>
Species	<i>coli</i>

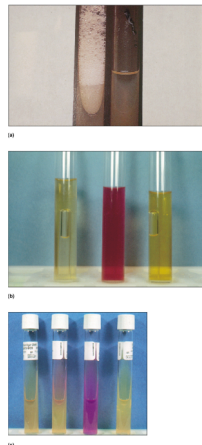
## Classifying microorganisms

- ✓ Numerical taxonomy
  - Number of characteristics ~ >90% same species
- ✓ Microscopic morphology
- ✓ Metabolic differences (Biochemistry)
- ✓ 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)
- ✓ Fatty acid analysis (FAME)
- ✓ Phage typing
  - determine similarities among bacteria

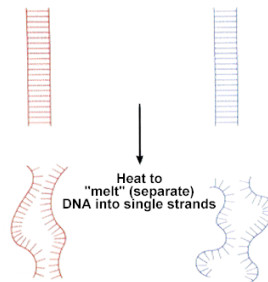
## Gram Stain



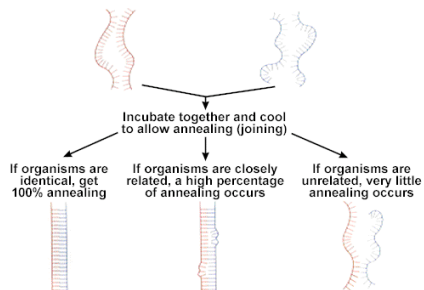
## Biochemical test



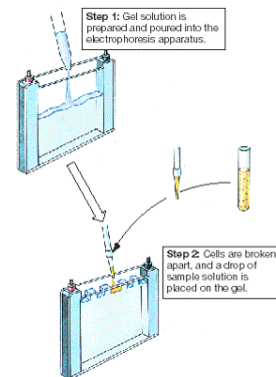
## DNA hybridization



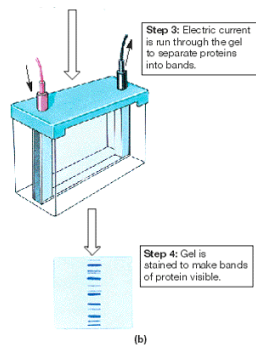
## DNA Hybridization



## Protein profiles



## Protein profile (cont.)



## Phage typing



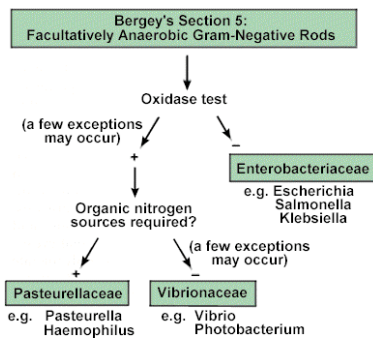
## Classifying bacteria

- ✓ 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?

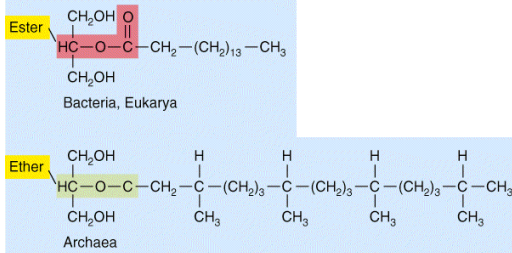
## Bergey's manual



## 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
- ✓ Chemoorganotrophs
- ✓ Chemoorganotrophs (fermentation)

## Anaerobic chemolithotrophs

- ✓ Methanogens
- ✓ Generate energy by oxidizing hydrogen gas (H<sub>2</sub>)
- ✓ Terminal electron acceptor is carbon dioxide (CO<sub>2</sub>)

## Methanogens

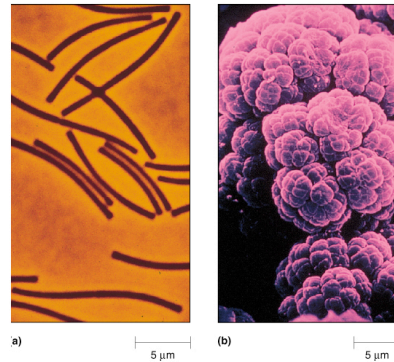


Figure 11.2

## 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

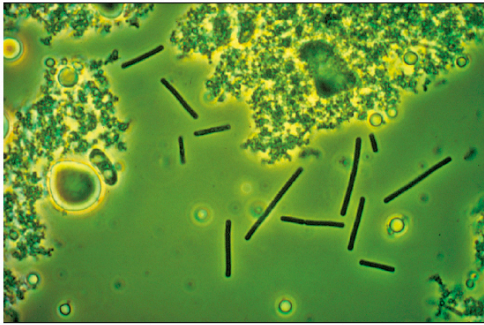


Figure 11.4

### Anoxygenic phototrophs

- ✓ Purple bacteria
- ✓ Green bacteria

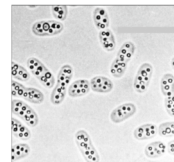
### Purple bacteria

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

### Purple bacteri



(a)



(b)

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

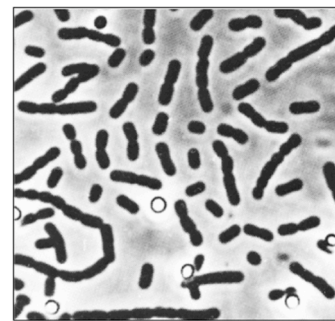


Figure 11.6

## Oxygenic phototrophs

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

## Cyanobact

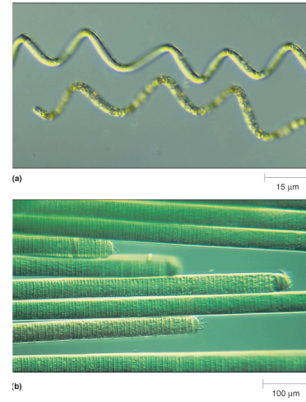


Figure 11.7

## 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

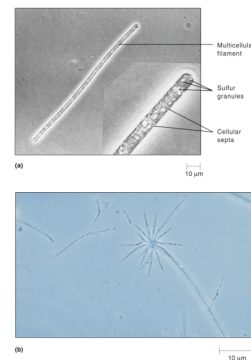


Figure 11.10

## 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*

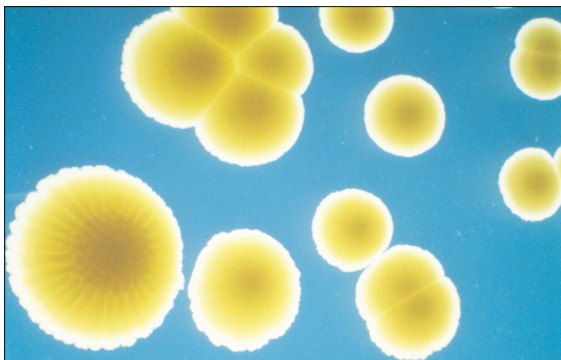


Figure 11.12

### *Pseudomonas* species

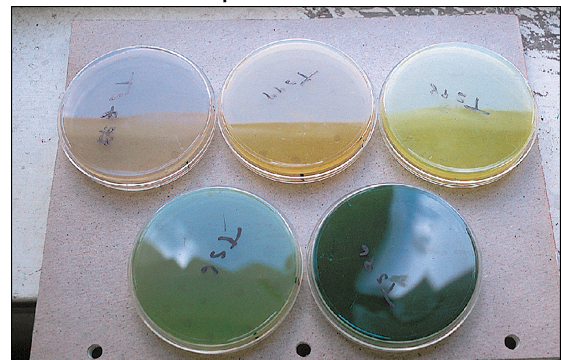


Figure 11.13

## Facultative anaerobes

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

## *Corynebacterium*

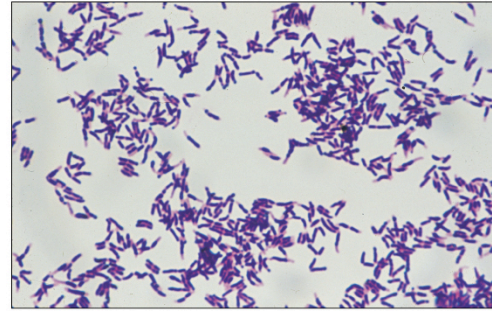


Figure 11.14

## *Enterobacteriaceae*

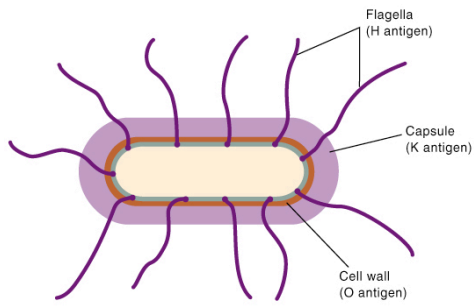


Figure 11.15

## 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

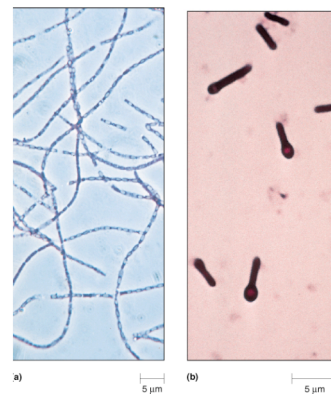


Figure 11.16

### A vegetative cell and a cyst

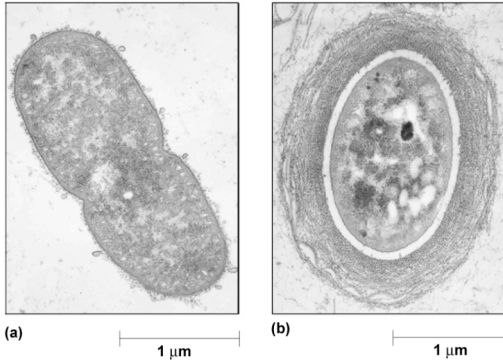


Figure 11.17

### Fruiting bodie

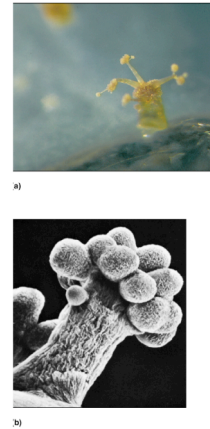


Figure 11.18

### Conidia

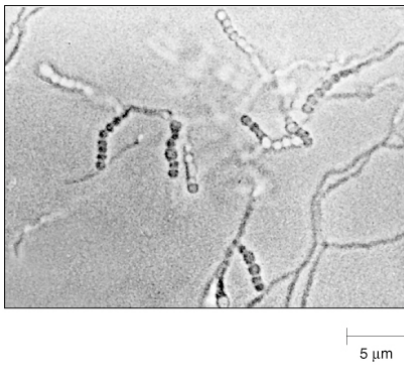


Figure 11.19

### Association with plants

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

### Plant tumor



Figure 11.20

### Symbiotic relationship

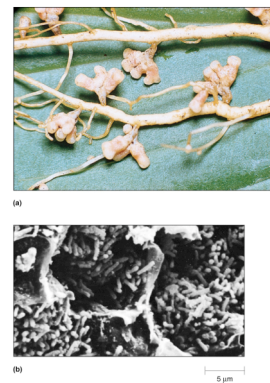


Figure 11.21

## Aquatic bacteria

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

## Aquatic bacteria

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

### Sheathed bacteria

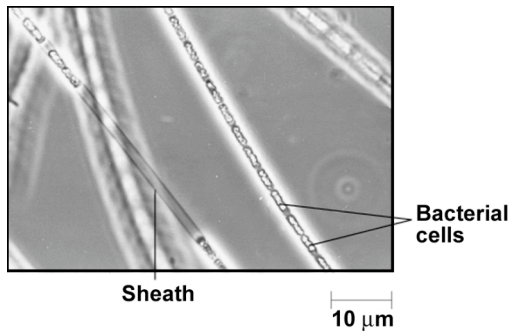


Figure 11.22

### Prosthecae bacteria - *Hyphomicrobium*

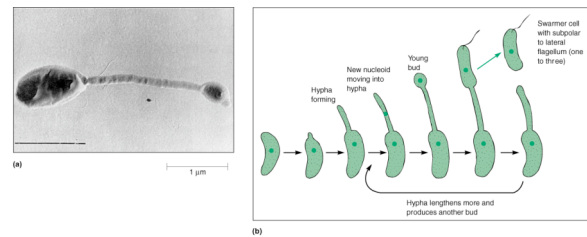


Figure 11.24

### *Bdellovibrio*

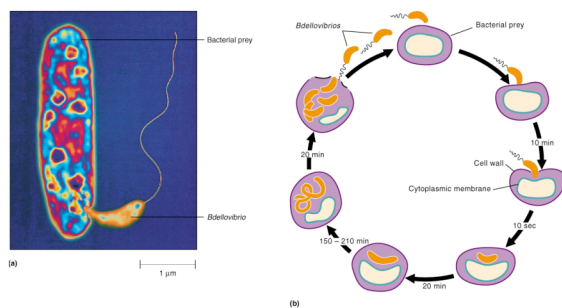


Figure 11.25

### Bioluminescent bacteria



Figure 11.26

## Spirochete

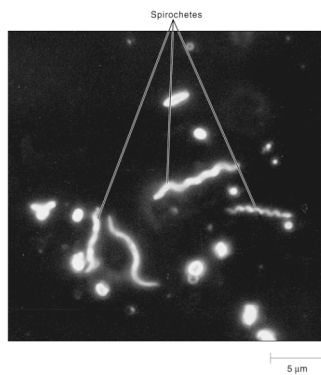


Figure 11.27

## 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*

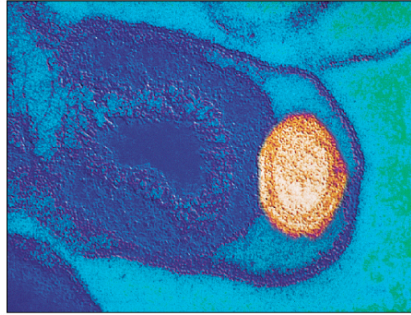


Figure 11.28

## Obligate intracellular parasites

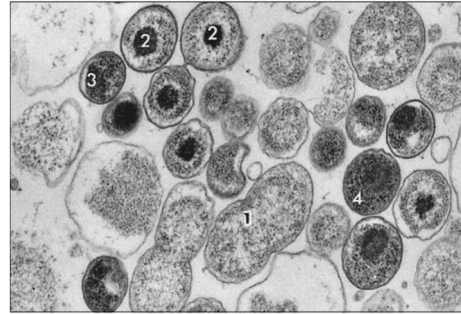
- ✓ Cannot reproduce outside a host cell
- ✓ Transferred by blood - sucking arthropods
- ✓ *Rickettsia rickettsii* - Rocky mountain spotted fever
- ✓ *Rickettsia prowazekii* - Epidemic typhus
- ✓ *Coxsakiella* - Can form a sporelike structure - Q-fever
- ✓ *Chlamydia* - Person to person transmission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

## Coxiella



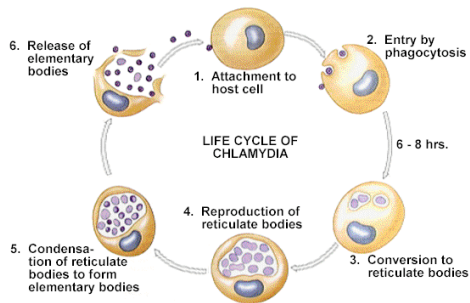
0.1 μm

## Chlamydia



0.2 μm

## Rickettsiae and Chlamydiae 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

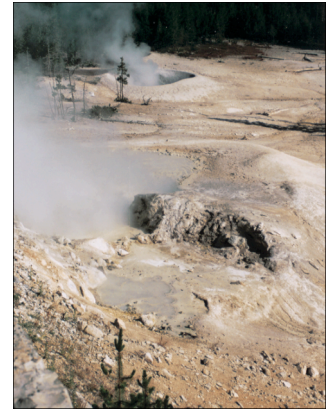


Figure 11.31

## 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

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.

Major Group	Typical Examples
Archaeobacteria	Methanogens, thermophiles, halophiles
Actinomycetes	<i>Streptomyces</i> , <i>Actinomyces</i>
Chemoautotrophs	Sulfur bacteria, <i>Nitrobacter</i> , <i>Nitrosomonas</i>
Cyanobacteria	<i>Anabaena</i> , <i>Nostoc</i>

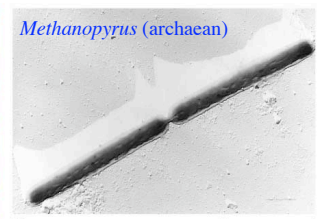
**Bacteria (1)**

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.

<b>Bacteria (2)</b>	
Major Group	Typical Examples
Enterobacteria	<i>Escherichia coli</i> , <i>Salmonella</i> , <i>Vibrio</i>
Gliding and budding bacteria	Myxobacteria, <i>Chondromyces</i>
Pseudomonads	<i>Pseudomonas</i>
Rickettsias and chlamydias	<i>Rickettsia</i> , <i>Chlamydia</i>
Spirochaetes	<i>Treponema</i>

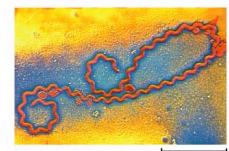


(a) 0.10 μm



(b) 4 μm

*Micrococcus*



*Leptospira interrogans* (c) 0.25 μm

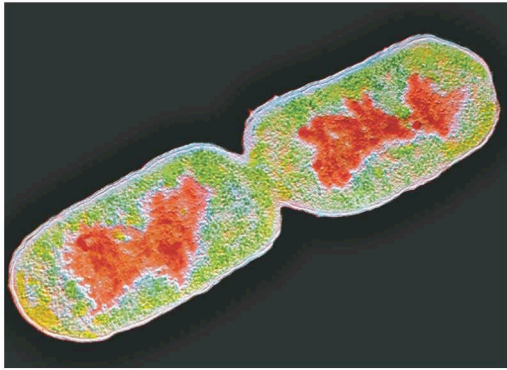
*Clostridium* endospores



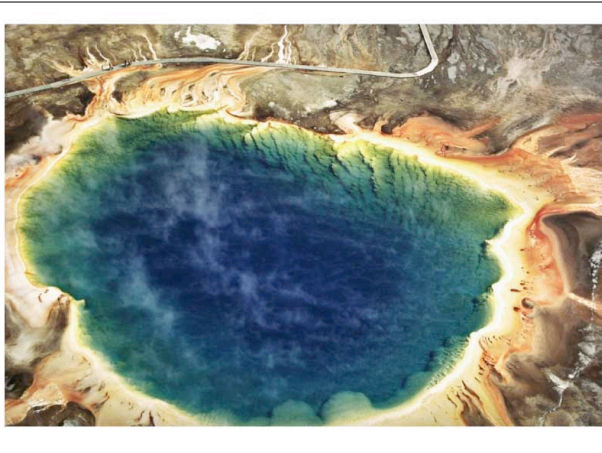
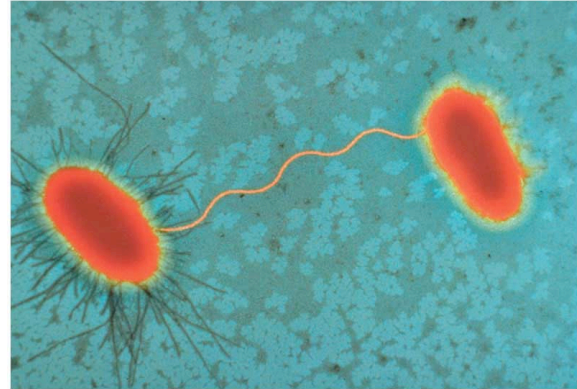
*Aquifex* (archaeon)



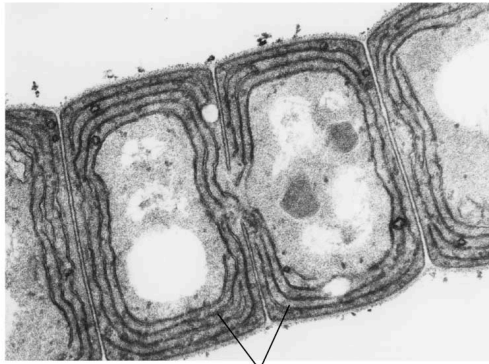
Binary fission



Conjugation

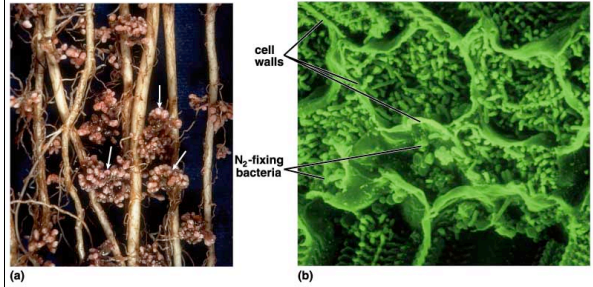


## Oscillatoria (chlorophyll in membranes)

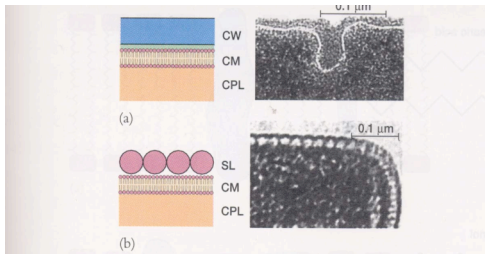


membranes bearing chlorophyll

## Nitrogen fixing bacteria

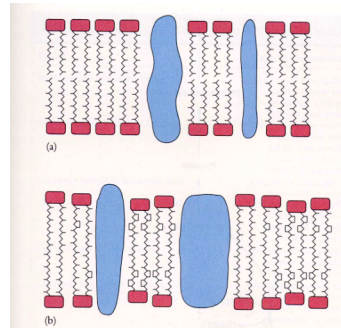


## Envelops of archaeobacteria

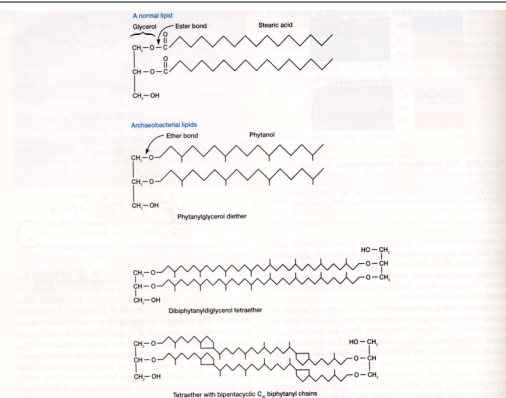


**Figure 20.1** Cell Envelopes of Archaeobacteria. Schematic representations and electron micrographs of (a) *Methanobacterium formicicum*, a typical gram-positive organism, and (b) *Thermoproteus tenax*, a gram-negative archaeobacterium. CW, cell wall; SL, surface layer; CM, cell membrane or plasma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

## Membranes of archaeobacteria

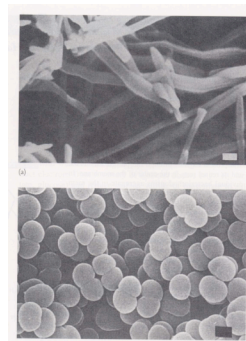


**Figure 20.5** Examples of Archaeobacterial Membranes. (a) A membrane composed of integral proteins and a bilayer of  $C_{30}$  diethers. (b) A rigid monolayer composed of integral proteins and  $C_{40}$  tetraethers.



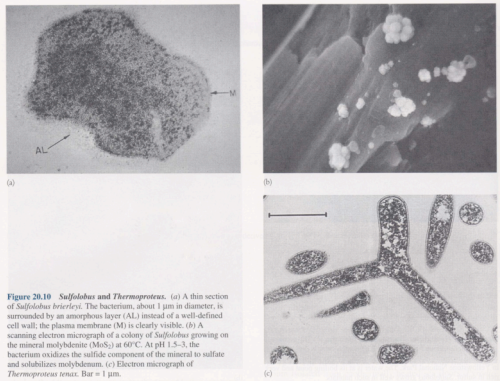
**Figure 20.3** Archaeobacterial Membrane Lipids. An illustration of the difference between archaeobacterial lipids and those of other bacteria. Archaeobacterial lipids are derivatives of isoprenyl glycerol ethers rather than the usual glycerol fatty acid esters. Three examples of common archaeobacterial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

## Halobacteria

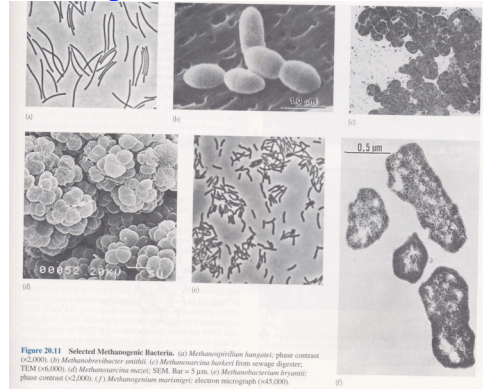


**Figure 20.14** Examples of Halobacteria. (a) *Halobacterium salinarum*. A young culture that has formed long rods. SEM. Bar = 1  $\mu$ m. (b) *Halococcus morrhuae*. SEM. Bar = 1  $\mu$ m.

## Thermophilic



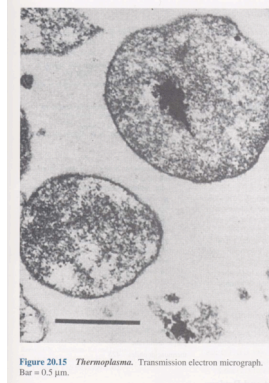
## Methanogenic



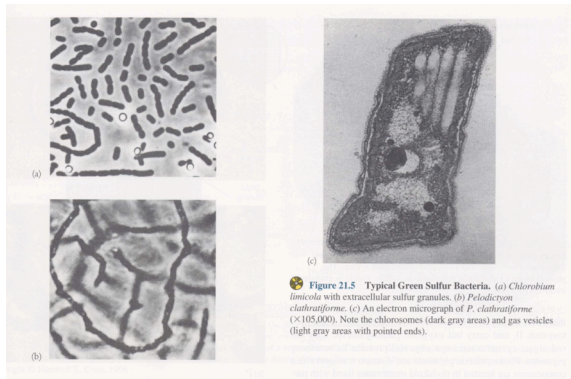
## Archaeobacteria in a black smoker



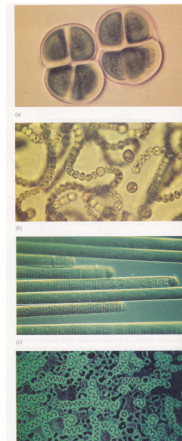
## Thermoplasma



## Green sulfur bacteria



## Cyanobacteria



## Thylacoids

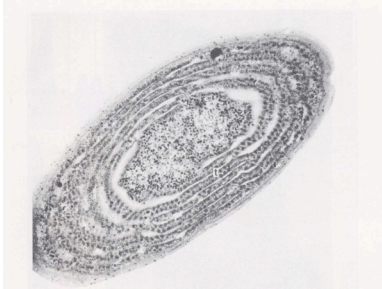


Figure 21.6 Cyanobacterial Thylakoids and Phycobilisomes. *Synechococcus lividus* with an extensive thylakoid system. The phycobilisomes lining these thylakoids are clearly visible as granules at location 1 ( $\times 60,000$ ).

## 26.1 The Three Domains of Life on Earth

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

<sup>a</sup>70S ribosomes are smaller than 80S ribosomes.

© 2001 Sinauer Associates, Inc.