Chapter 27

Bacteria and Archaea

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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Overview: Masters of Adaptation

- Prokaryotes thrive almost everywhere, including places too acidic, salty, cold, or hot for most other organisms
- Most prokaryotes are microscopic, but what they lack in size they make up for in numbers
- There are more in a handful of fertile soil than the number of people who have ever lived

- They have an astonishing genetic diversity
- Prokaryotes are divided into two domains: bacteria and archaea

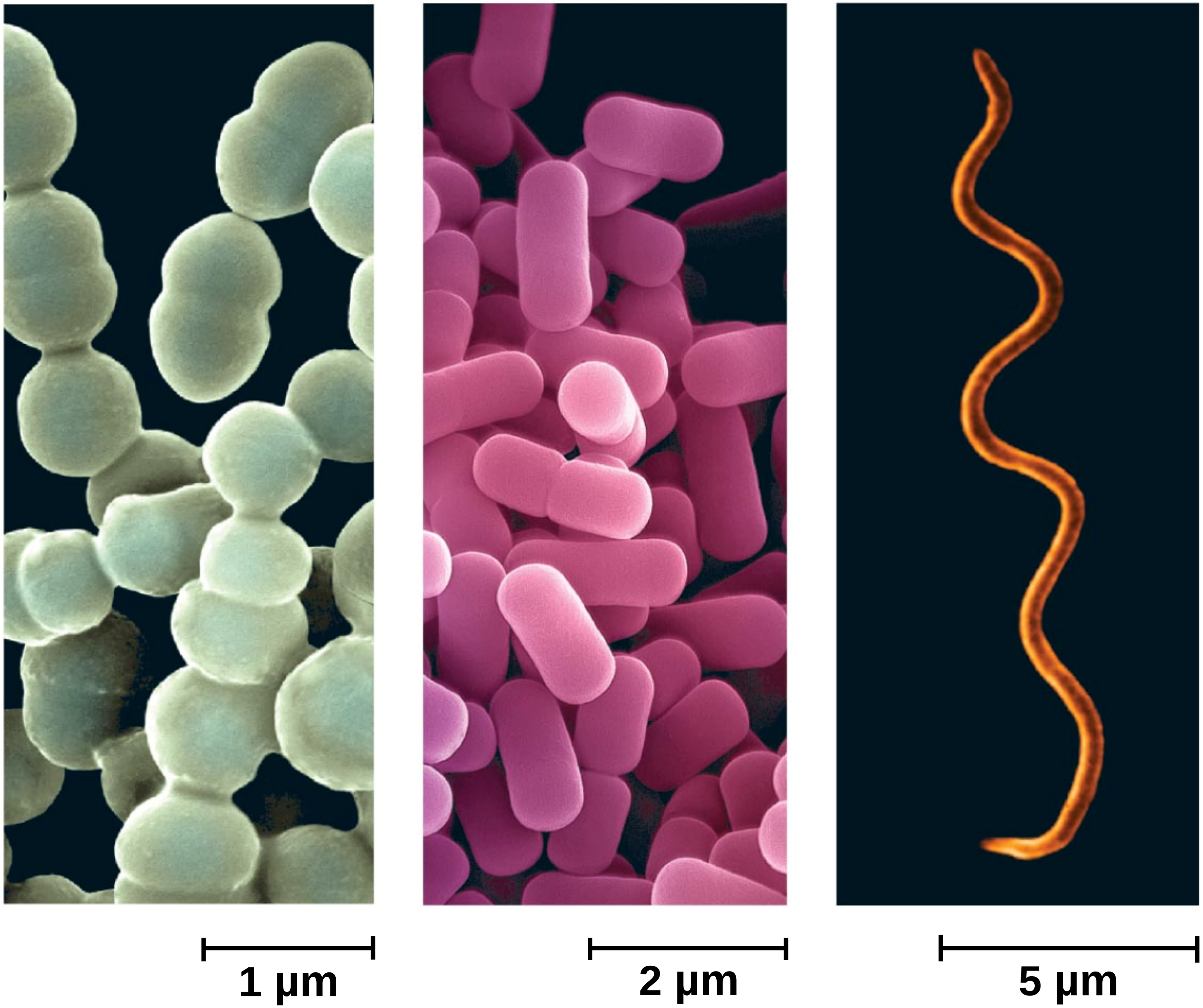
PLAY **Video: Tubeworms**

Fig. 27-1

Concept 27.1: Structural and functional adaptations contribute to prokaryotic success

- Most prokaryotes are unicellular, although some species form colonies
- Most prokaryotic cells are 0.5–5 µm, much smaller than the 10–100 µm of many eukaryotic cells
- Prokaryotic cells have a variety of shapes
- The three most common shapes are spheres (cocci), rods (bacilli), and spirals

Fig. 27-2



(a) Spherical (cocci)

(b) Rod-shaped (bacilli)

(c) Spiral

Cell-Surface Structures

- An important feature of nearly all prokaryotic cells is their cell wall, which maintains cell shape, provides physical protection, and prevents the cell from bursting in a hypotonic environment
- Eukaryote cell walls are made of cellulose or chitin
- Bacterial cell walls contain **peptidoglycan**, a network of sugar polymers cross-linked by polypeptides

Fig. 27-3c

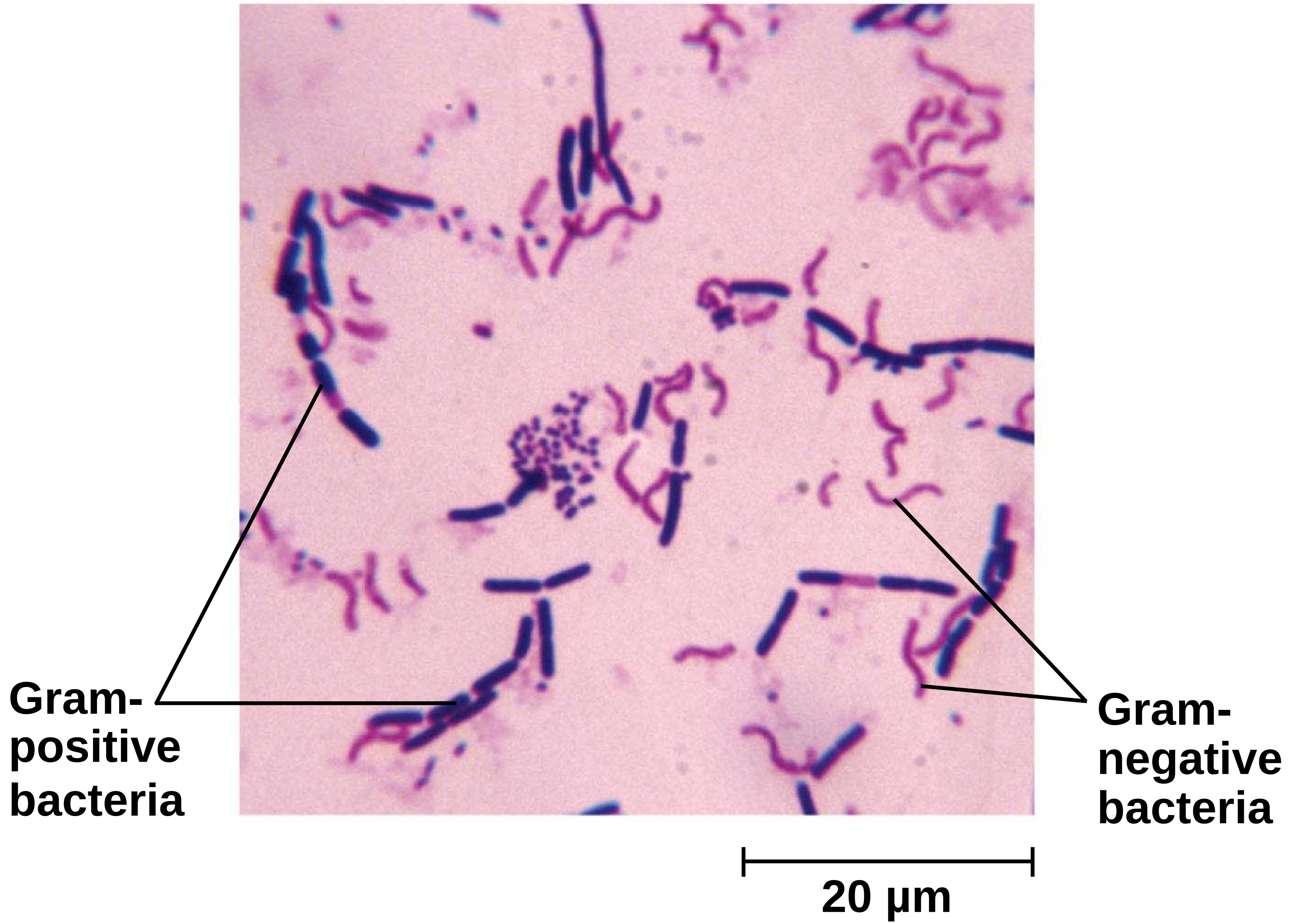
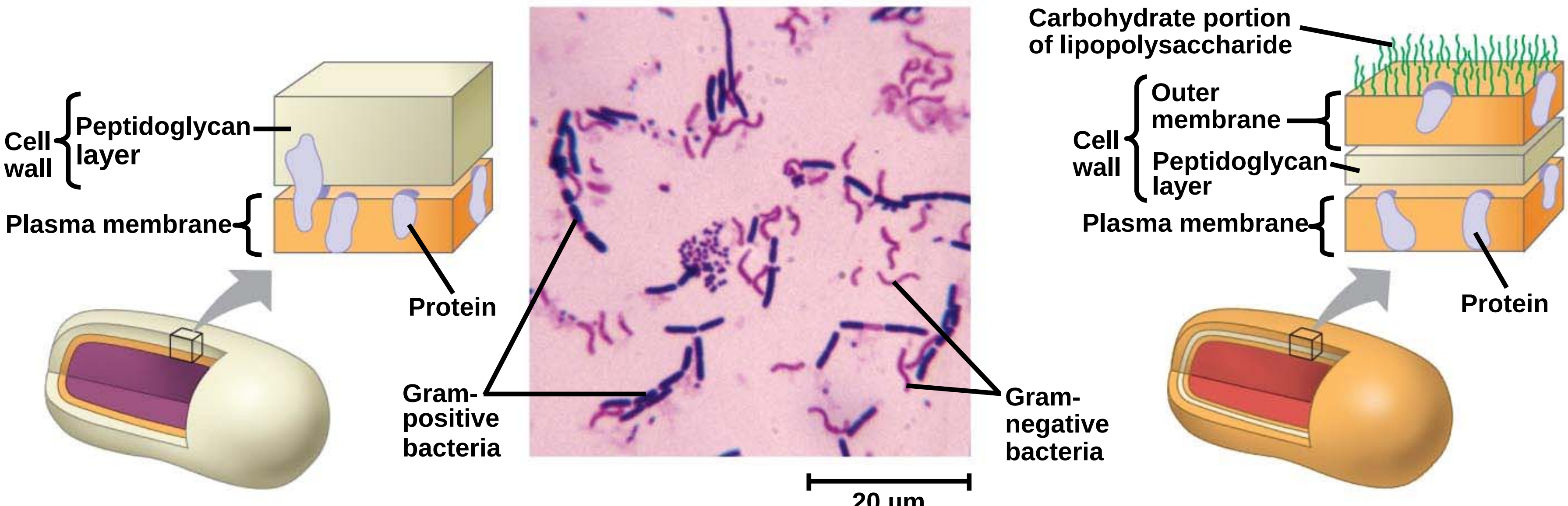


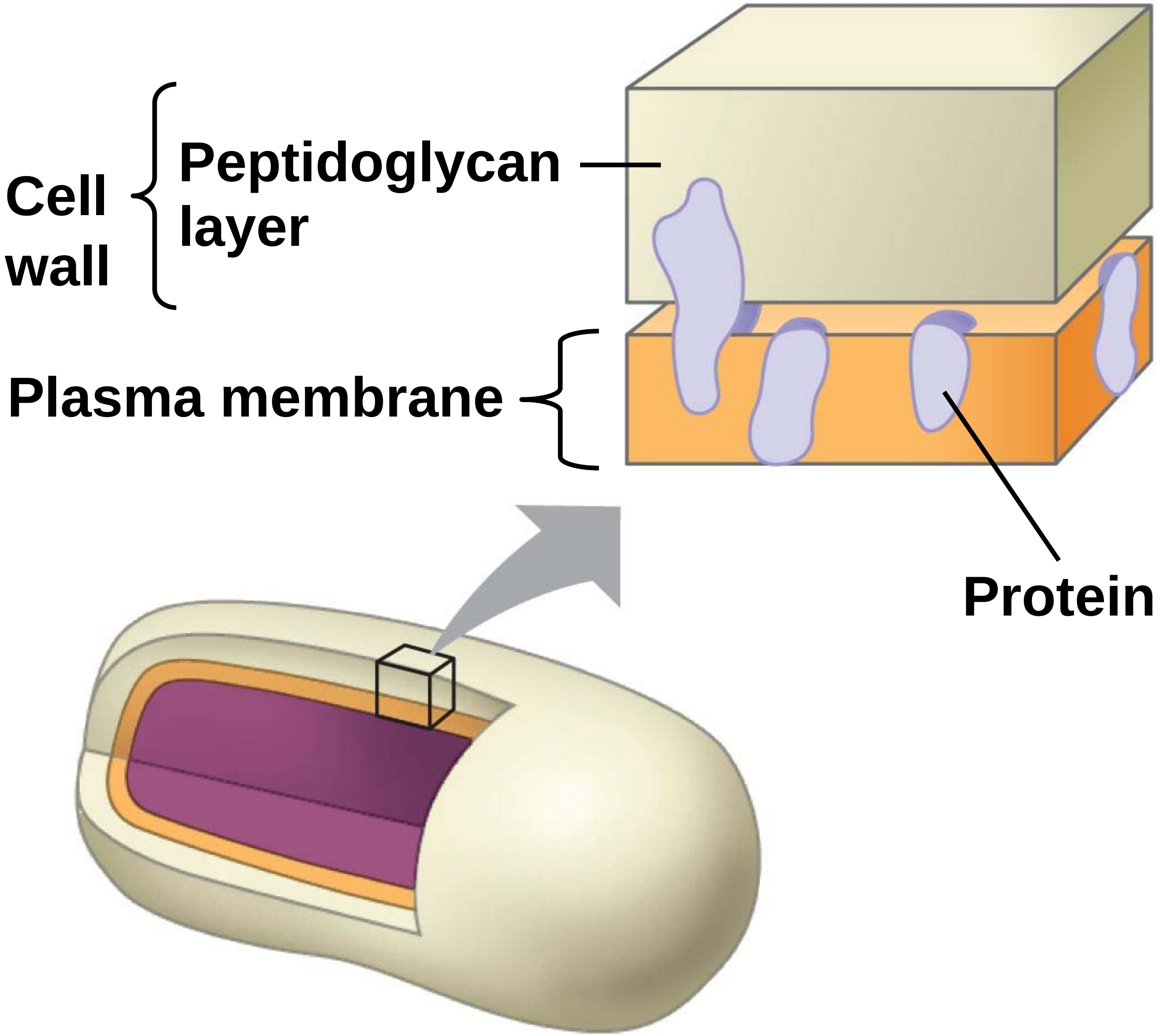
Fig. 27-3



(a) Gram-positive: peptidoglycan traps crystal violet.

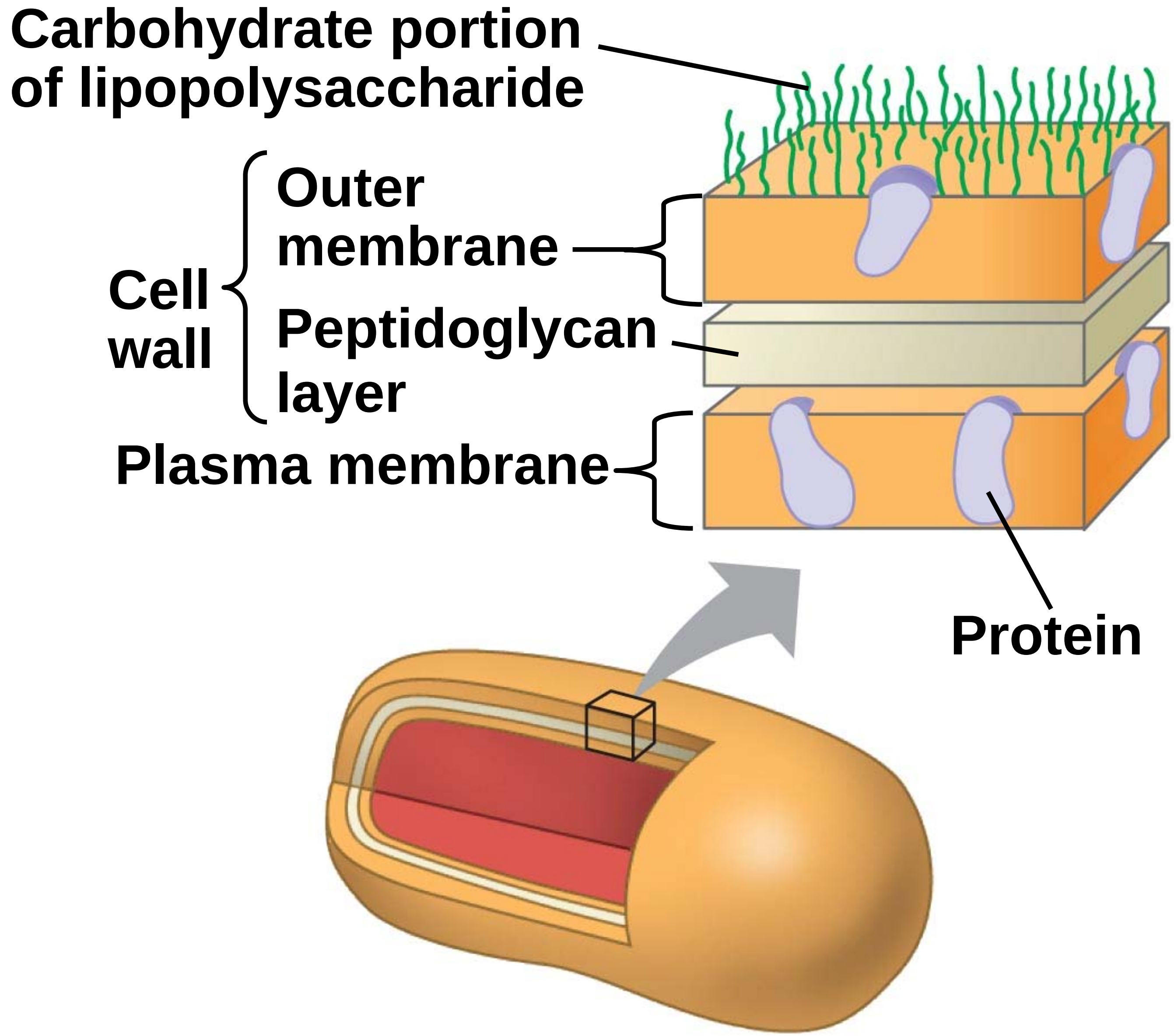
(b) Gram-negative: crystal violet is easily rinsed away, revealing red dye.

Fig. 27-3a



(a) Gram-positive: peptidoglycan traps crystal violet.

Fig. 27-3b



(b) Gram-negative: crystal violet is easily rinsed away, revealing red dye.

- Archaea contain polysaccharides and proteins but lack peptidoglycan
- Using the **Gram stain**, scientists classify many bacterial species into **Gram-positive** and **Gram-negative** groups based on cell wall composition
- Gram-negative bacteria have less peptidoglycan and an outer membrane that can be toxic, and they are more likely to be antibiotic resistant

- Many antibiotics target peptidoglycan and damage bacterial cell walls

- A polysaccharide or protein layer called a **capsule** covers many prokaryotes

Fig. 27-4

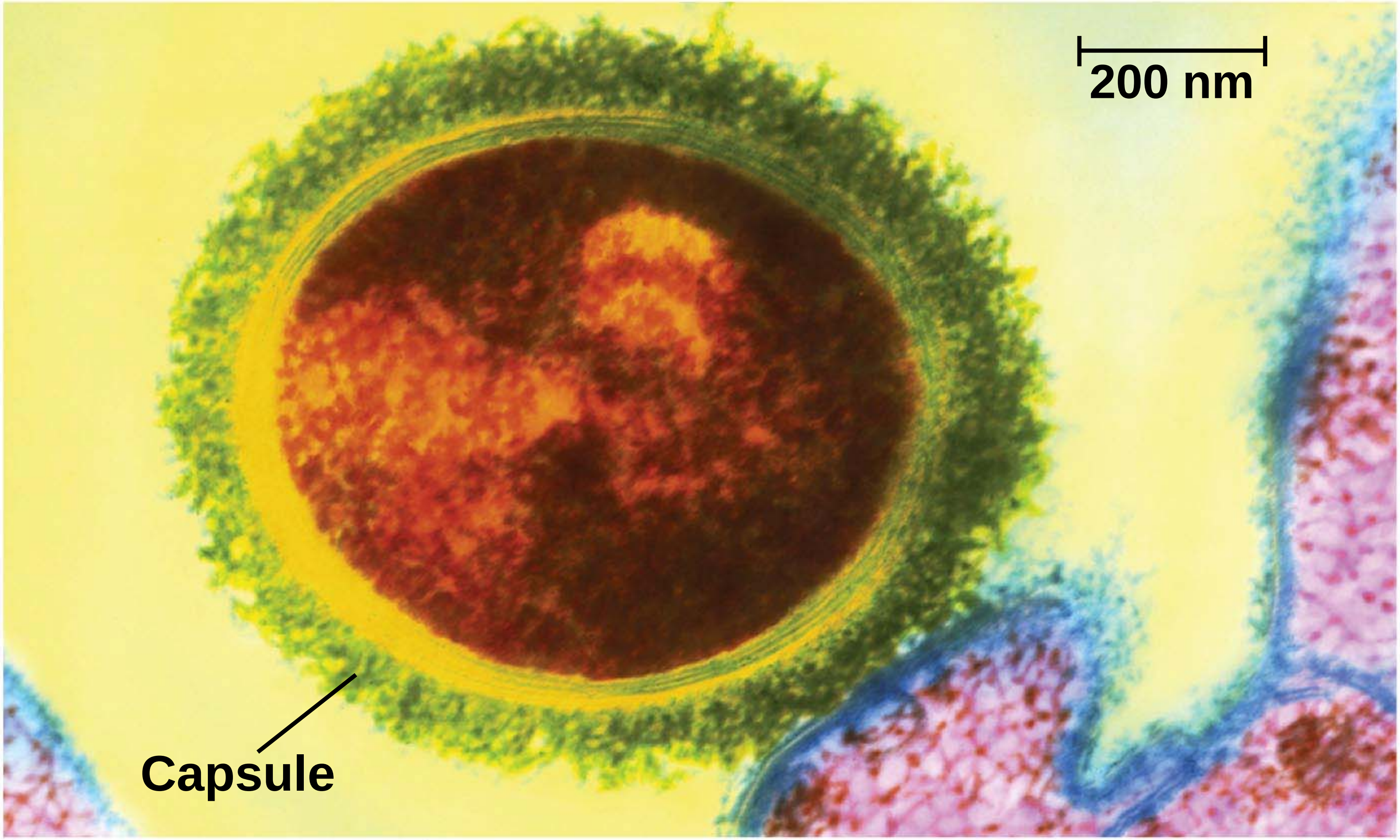
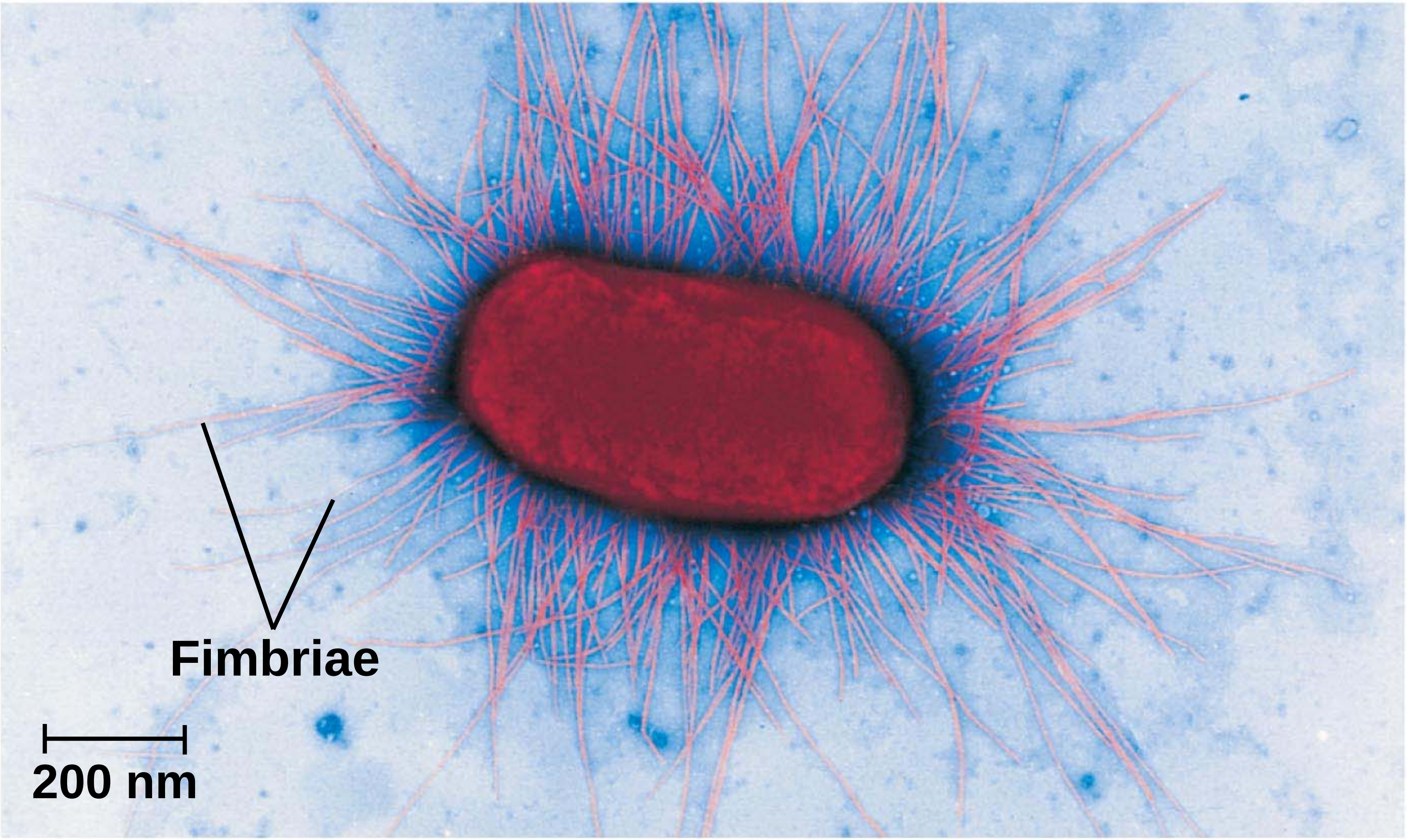


Fig. 27-5



- Some prokaryotes have **fimbriae** (also called *attachment pili*), which allow them to stick to their substrate or other individuals in a colony
- **Sex pili** are longer than fimbriae and allow prokaryotes to exchange DNA

Fig. 27-6

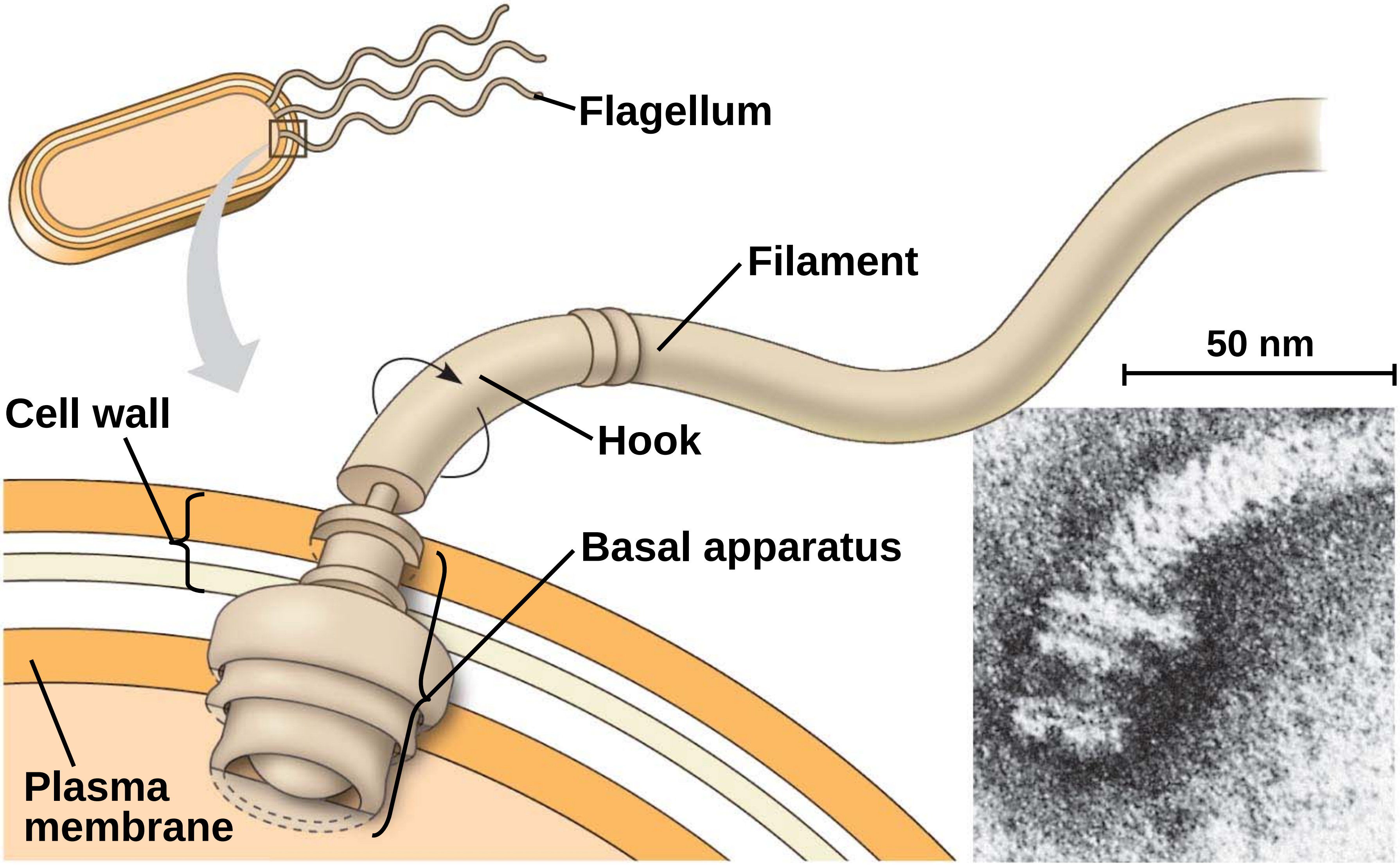

Flagellum
Filament
50 nm
Cell wall
Hook
Basal apparatus
Plasma
membrane

Fig. 27-6a

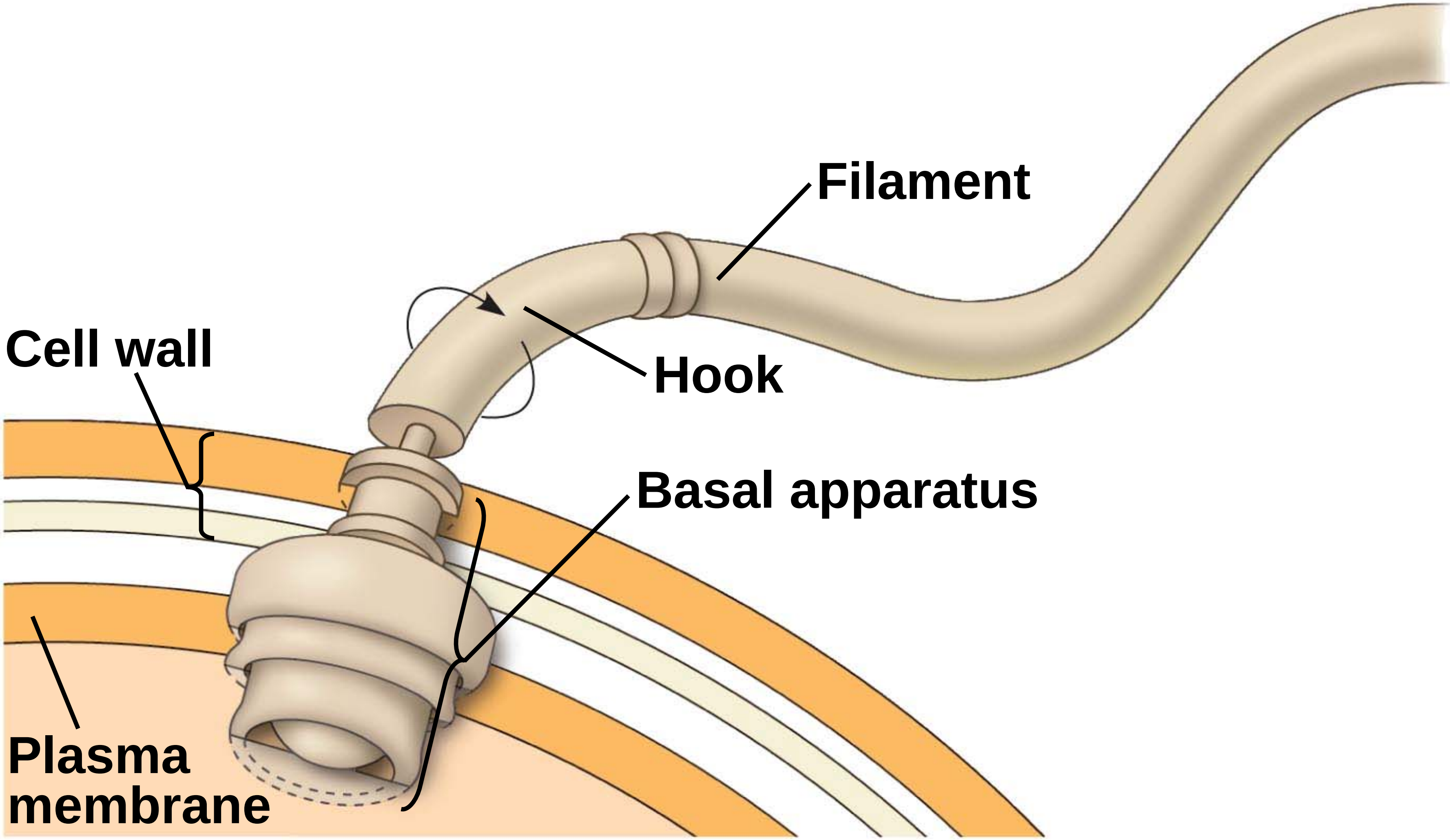
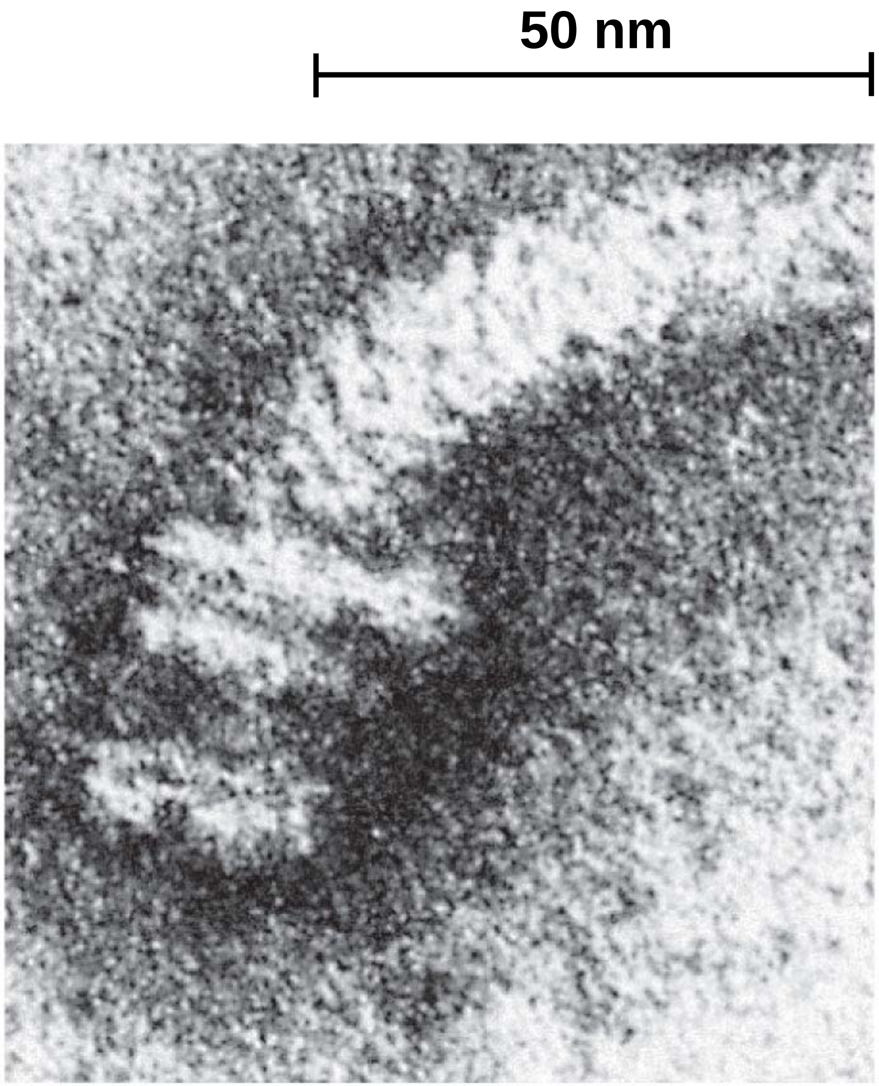


Fig. 27-6b



Prokaryotic flagellum (TEM)

Motility

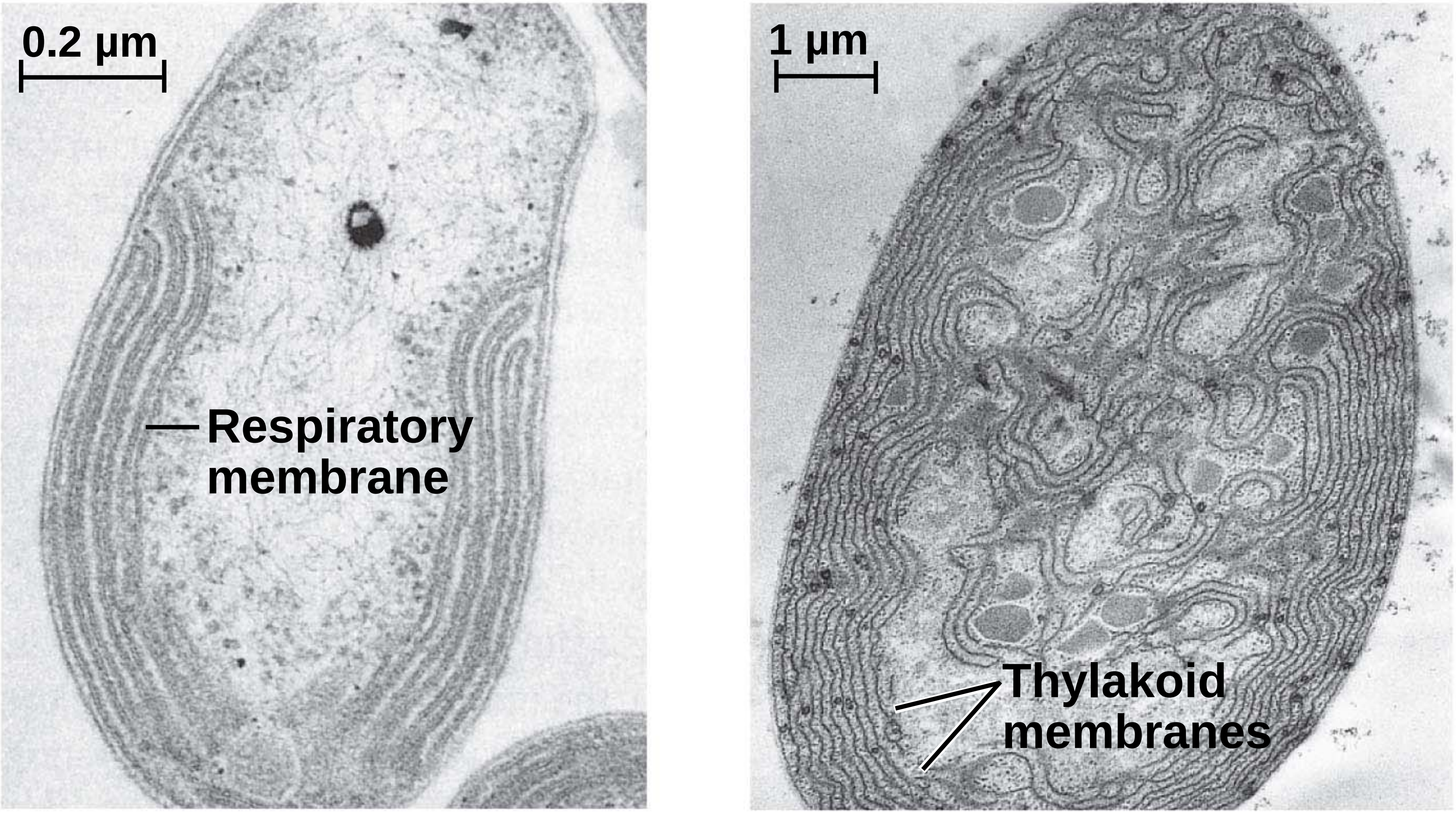
- Most motile bacteria propel themselves by flagella that are structurally and functionally different from eukaryotic flagella
- In a heterogeneous environment, many bacteria exhibit **taxis**, the ability to move toward or away from certain stimuli

PLAY **Video: Prokaryotic Flagella (*Salmonella typhimurium*)**

Internal and Genomic Organization

- Prokaryotic cells usually lack complex compartmentalization
- Some prokaryotes do have specialized membranes that perform metabolic functions

Fig. 27-7

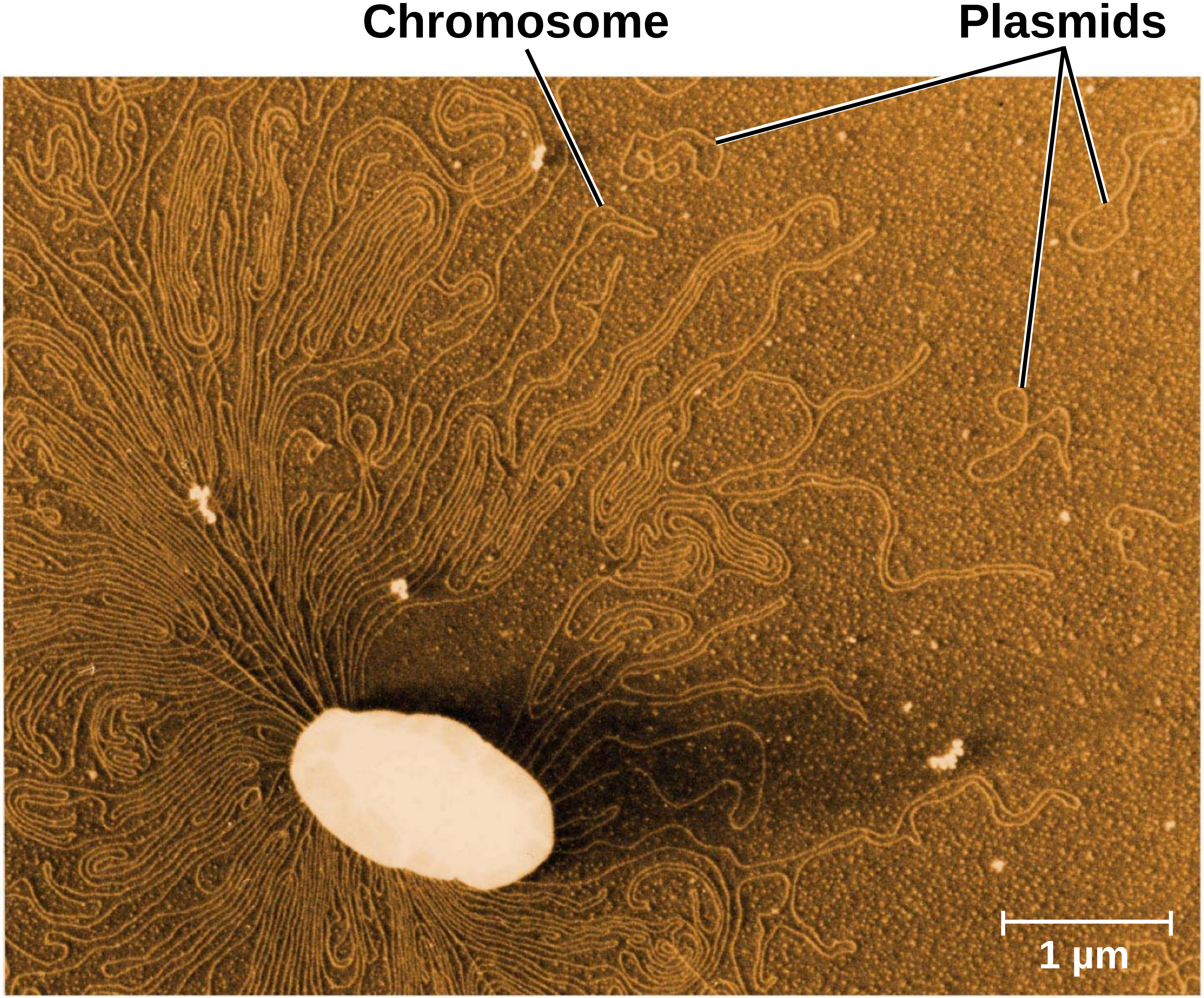


(a) Aerobic prokaryote

(b) Photosynthetic prokaryote

- The prokaryotic genome has less DNA than the eukaryotic genome
- Most of the genome consists of a circular chromosome
- Some species of bacteria also have smaller rings of DNA called **plasmids**

Fig. 27-8

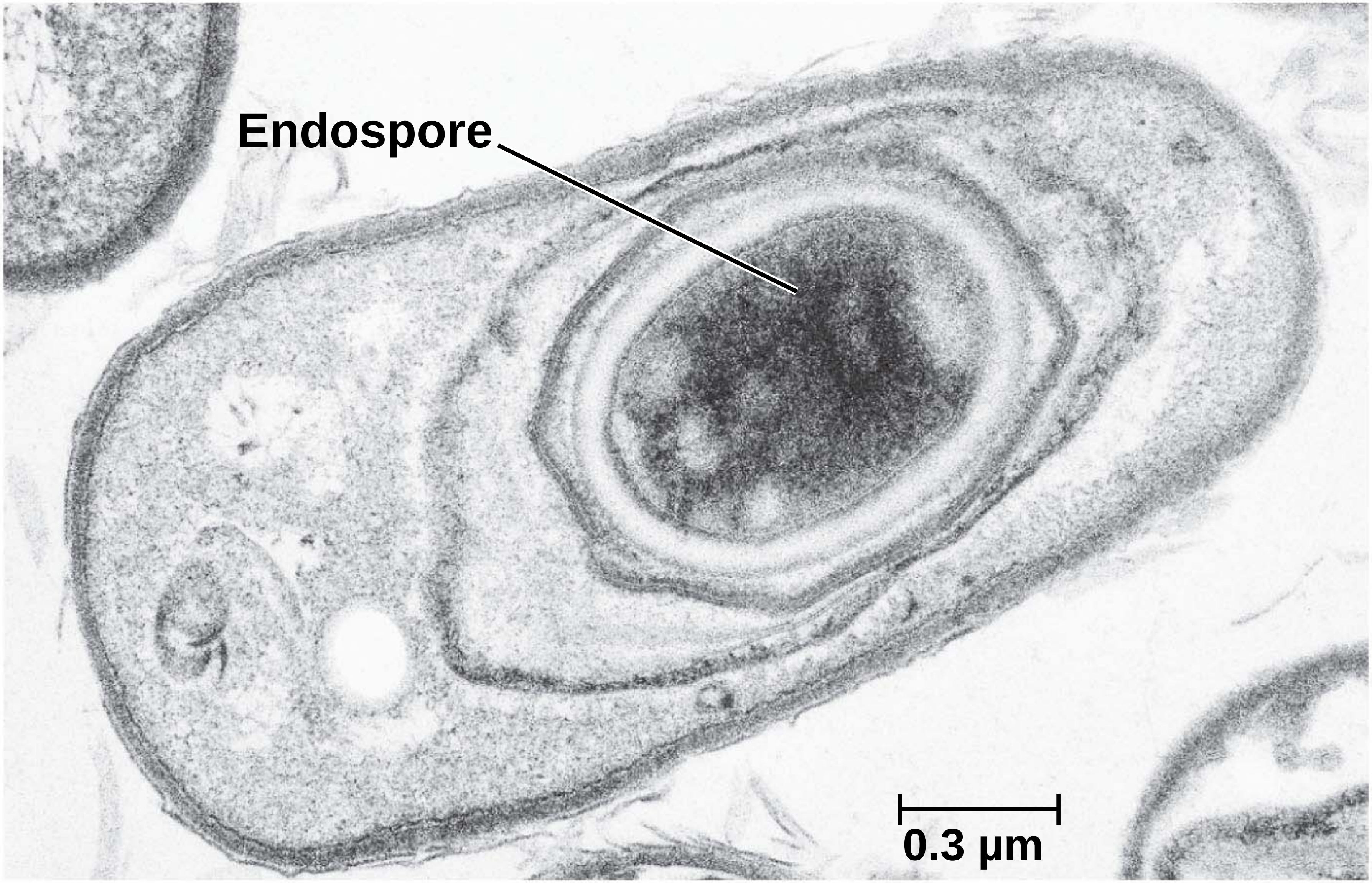


- The typical prokaryotic genome is a ring of DNA that is not surrounded by a membrane and that is located in a **nucleoid region**

Reproduction and Adaptation

- Prokaryotes reproduce quickly by binary fission and can divide every 1–3 hours
- Many prokaryotes form metabolically inactive **endospores**, which can remain viable in harsh conditions for centuries

Fig. 27-9



- Prokaryotes can evolve rapidly because of their short generation times

Fig. 27-10a

EXPERIMENT

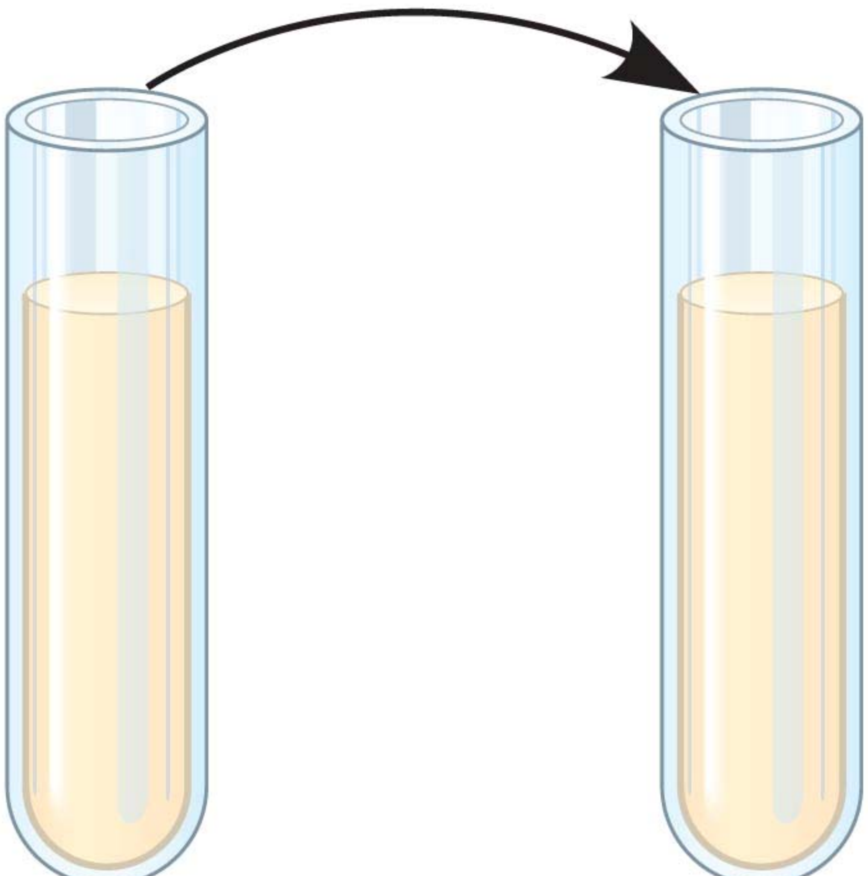
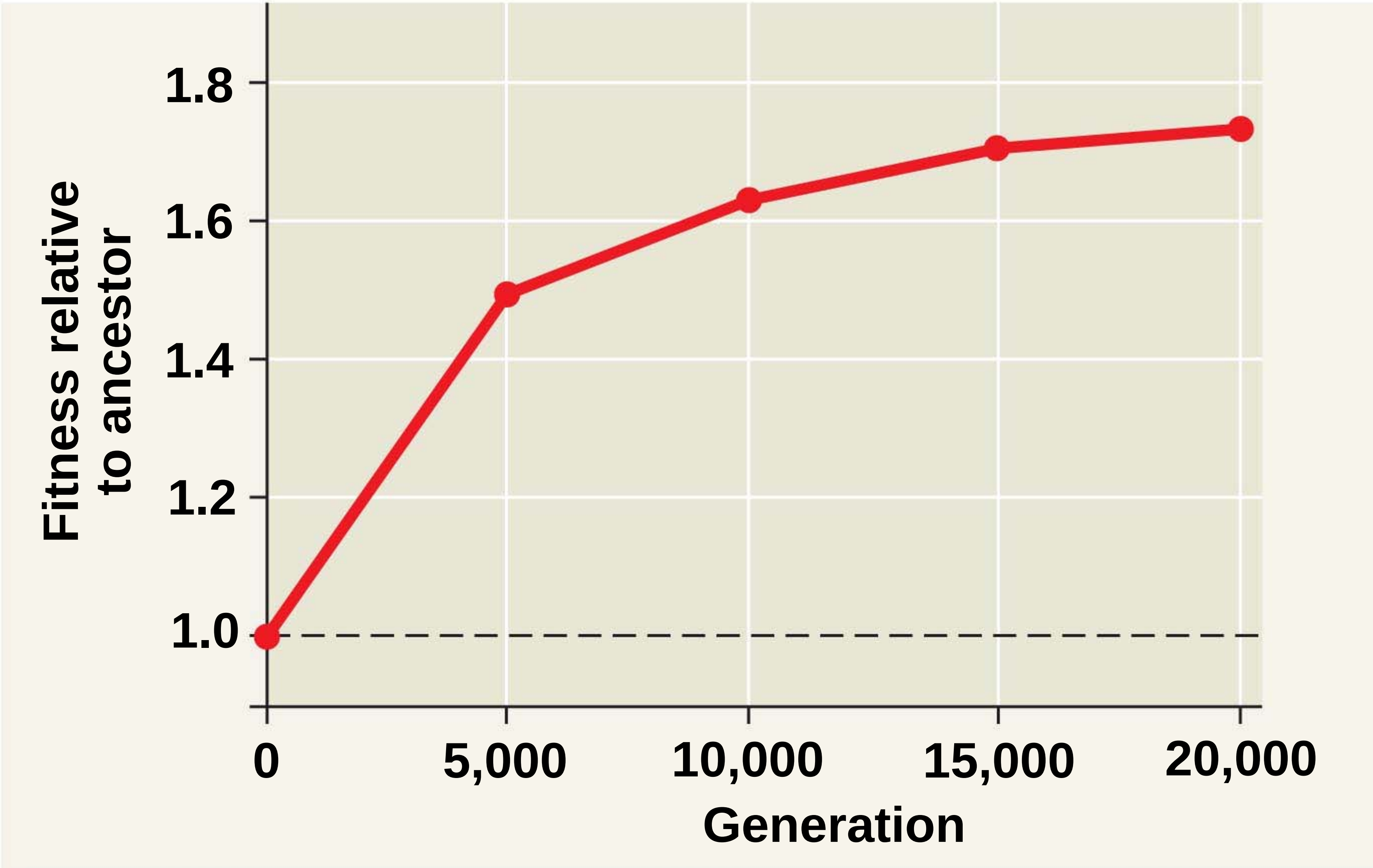


Fig. 27-10b

RESULTS



Concept 27.2: Rapid reproduction, mutation, and genetic recombination promote genetic diversity in prokaryotes

- Prokaryotes have considerable genetic variation
- Three factors contribute to this genetic diversity:
  - Rapid reproduction
  - Mutation
  - Genetic recombination

Rapid Reproduction and Mutation

- Prokaryotes reproduce by binary fission, and offspring cells are generally identical
- Mutation rates during binary fission are low, but because of rapid reproduction, mutations can accumulate rapidly in a population
- High diversity from mutations allows for rapid evolution

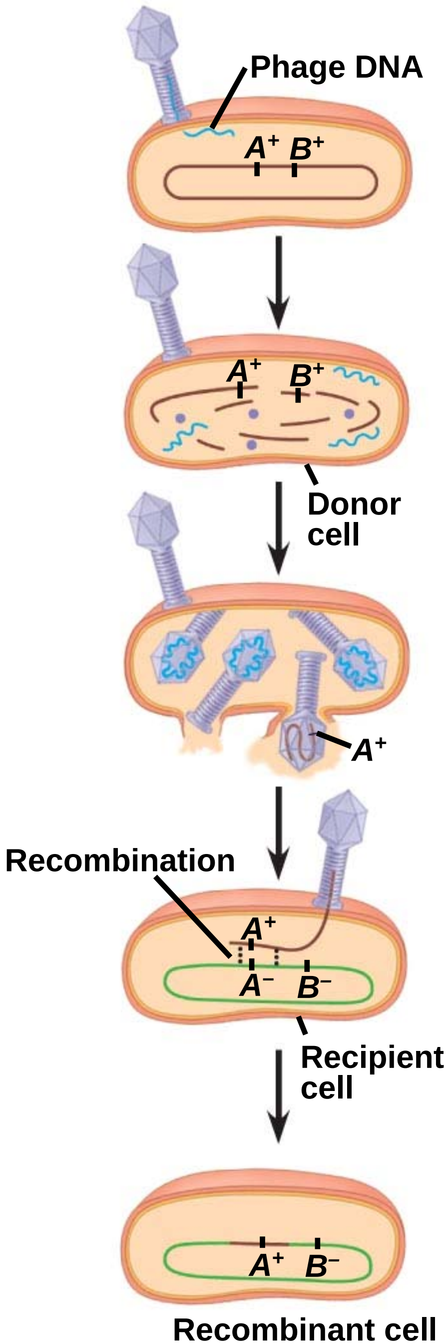
Genetic Recombination

- Additional diversity arises from genetic recombination
- Prokaryotic DNA from different individuals can be brought together by transformation, transduction, and conjugation

Transformation and Transduction

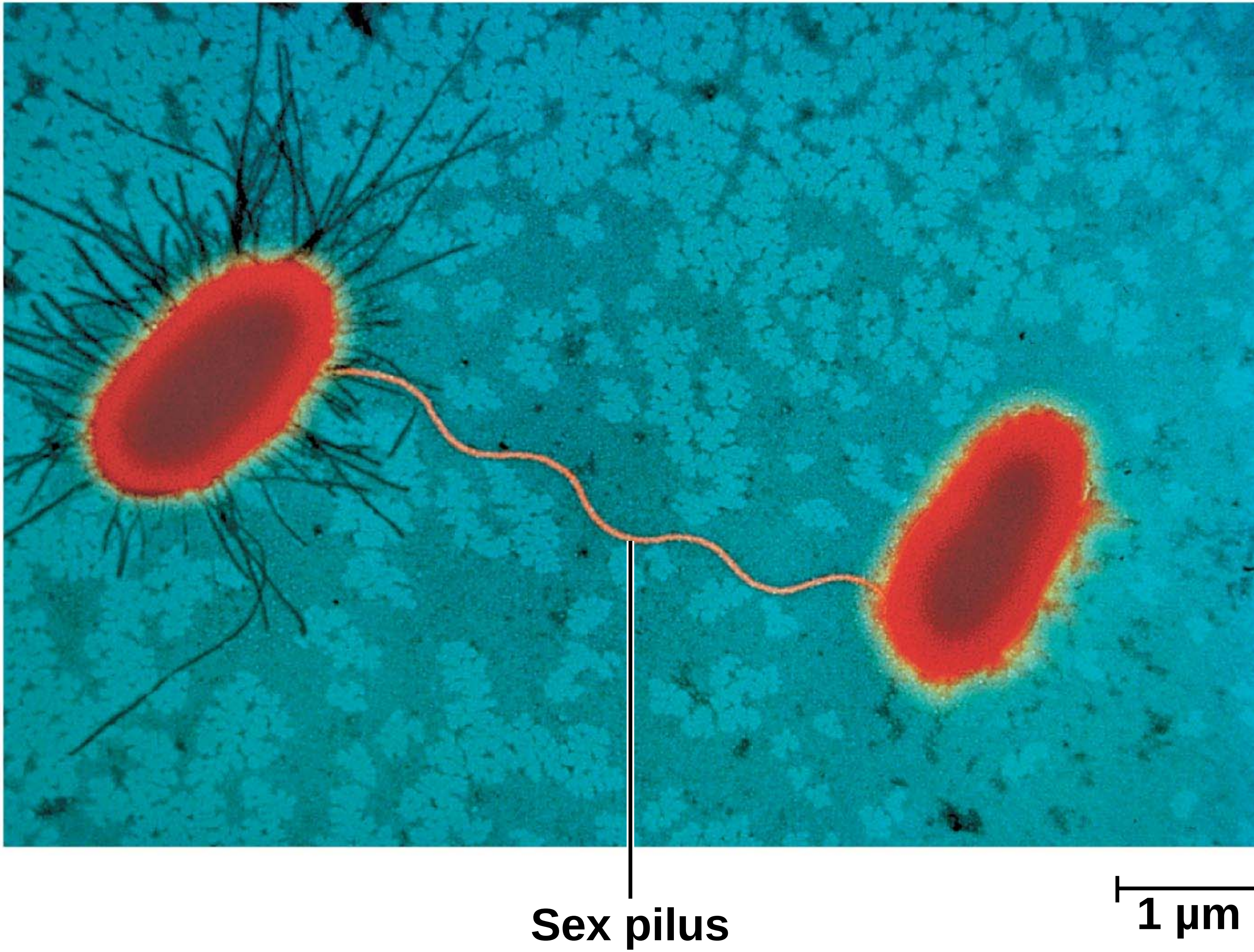
- A prokaryotic cell can take up and incorporate foreign DNA from the surrounding environment in a process called **transformation**
- **Transduction** is the movement of genes between bacteria by bacteriophages (viruses that infect bacteria)

Fig. 27-11-4



Phage DNA
A^+ B^+
A^+ B^+
Donor cell
A^+
Recombination
A^+
A^- B^-
Recipient cell
A^+ B^-
Recombinant cell

Fig. 27-12



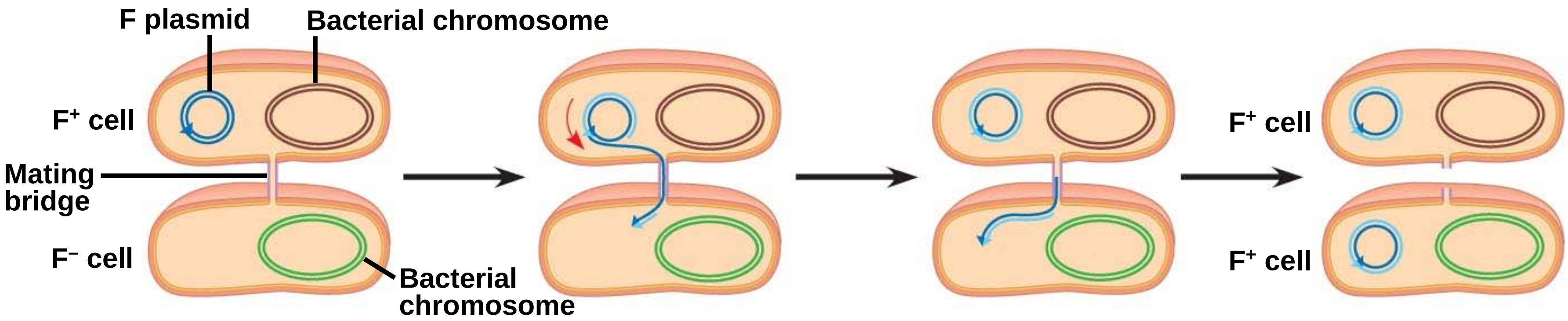
Conjugation and Plasmids

- **Conjugation** is the process where genetic material is transferred between bacterial cells
- Sex pili allow cells to connect and pull together for DNA transfer
- A piece of DNA called the **F factor** is required for the production of sex pili
- The F factor can exist as a separate plasmid or as DNA within the bacterial chromosome

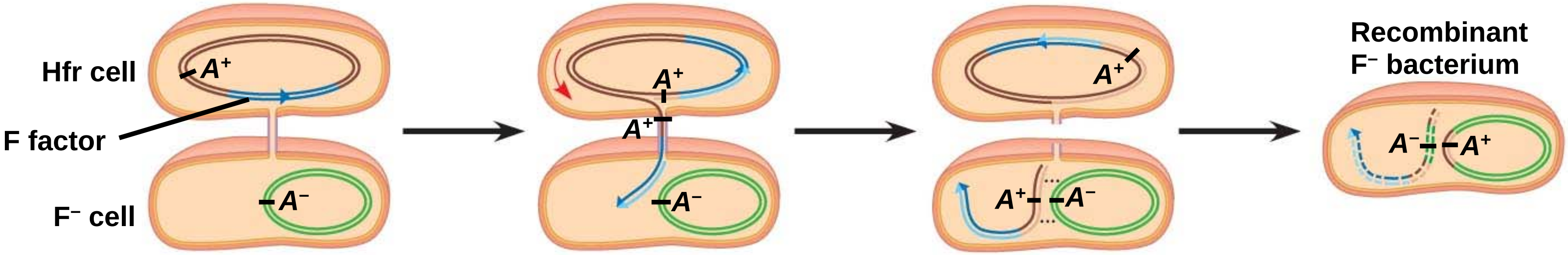
The F Factor as a Plasmid

- Cells containing the **F plasmid** function as DNA donors during conjugation
- Cells without the F factor function as DNA recipients during conjugation
- The F factor is transferable during conjugation

Fig. 27-13



(a) Conjugation and transfer of an F plasmid



(b) Conjugation and transfer of part of an Hfr bacterial chromosome

The F Factor in the Chromosome

- A cell with the F factor built into its chromosomes functions as a donor during conjugation
- The recipient becomes a recombinant bacterium, with DNA from two different cells
- It is assumed that horizontal gene transfer is also important in archaea

R Plasmids and Antibiotic Resistance

- **R plasmids** carry genes for antibiotic resistance
- Antibiotics select for bacteria with genes that are resistant to the antibiotics
- Antibiotic resistant strains of bacteria are becoming more common

Concept 27.3: Diverse nutritional and metabolic adaptations have evolved in prokaryotes

- *Phototrophs* obtain energy from light
- *Chemotrophs* obtain energy from chemicals
- *Autotrophs* require CO_2 as a carbon source
- *Heterotrophs* require an organic nutrient to make organic compounds
- These factors can be combined to give the four major modes of nutrition: photoautotrophy, chemoautotrophy, photoheterotrophy, and chemoheterotrophy

Table 27-1

Table 27.1 Major Nutritional Modes

Mode of Nutrition	Energy Source	Carbon Source	Types of Organisms
Autotroph			
Photoautotroph	Light	CO_2	Photosynthetic prokaryotes (for example, cyanobacteria); plants; certain protists (for example, algae)
Chemoautotroph	Inorganic chemicals	CO_2	Certain prokaryotes (for example, *Sulfolobus*)
Heterotroph			
Photoheterotroph	Light	Organic compounds	Certain prokaryotes (for example, *Rhodobacter, Chloroflexus*)
Chemoheterotroph	Organic compounds	Organic compounds	Many prokaryotes (for example, *Clostridium*) and protists; fungi; animals; some plants

The Role of Oxygen in Metabolism

- Prokaryotic metabolism varies with respect to O_2:
  - **Obligate aerobes** require O_2 for cellular respiration
  - **Obligate anaerobes** are poisoned by O_2 and use fermentation or **anaerobic respiration**
  - **Facultative anaerobes** can survive with or without O_2

Nitrogen Metabolism

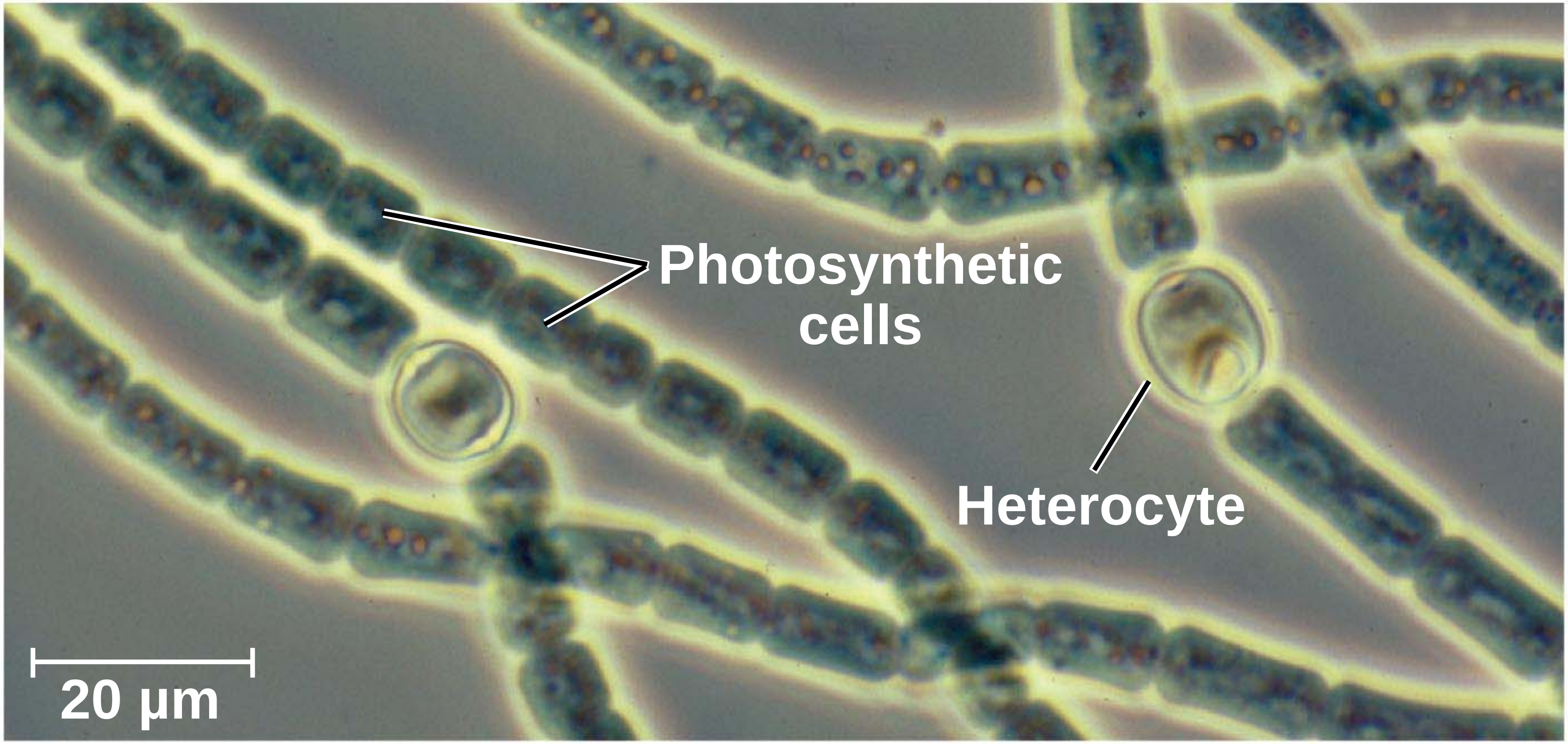
- Prokaryotes can metabolize nitrogen in a variety of ways
- In **nitrogen fixation**, some prokaryotes convert atmospheric nitrogen (N_2) to ammonia (NH_3)

Metabolic Cooperation

- Cooperation between prokaryotes allows them to use environmental resources they could not use as individual cells
- In the cyanobacterium *Anabaena*, photosynthetic cells and nitrogen-fixing cells called **heterocytes** exchange metabolic products

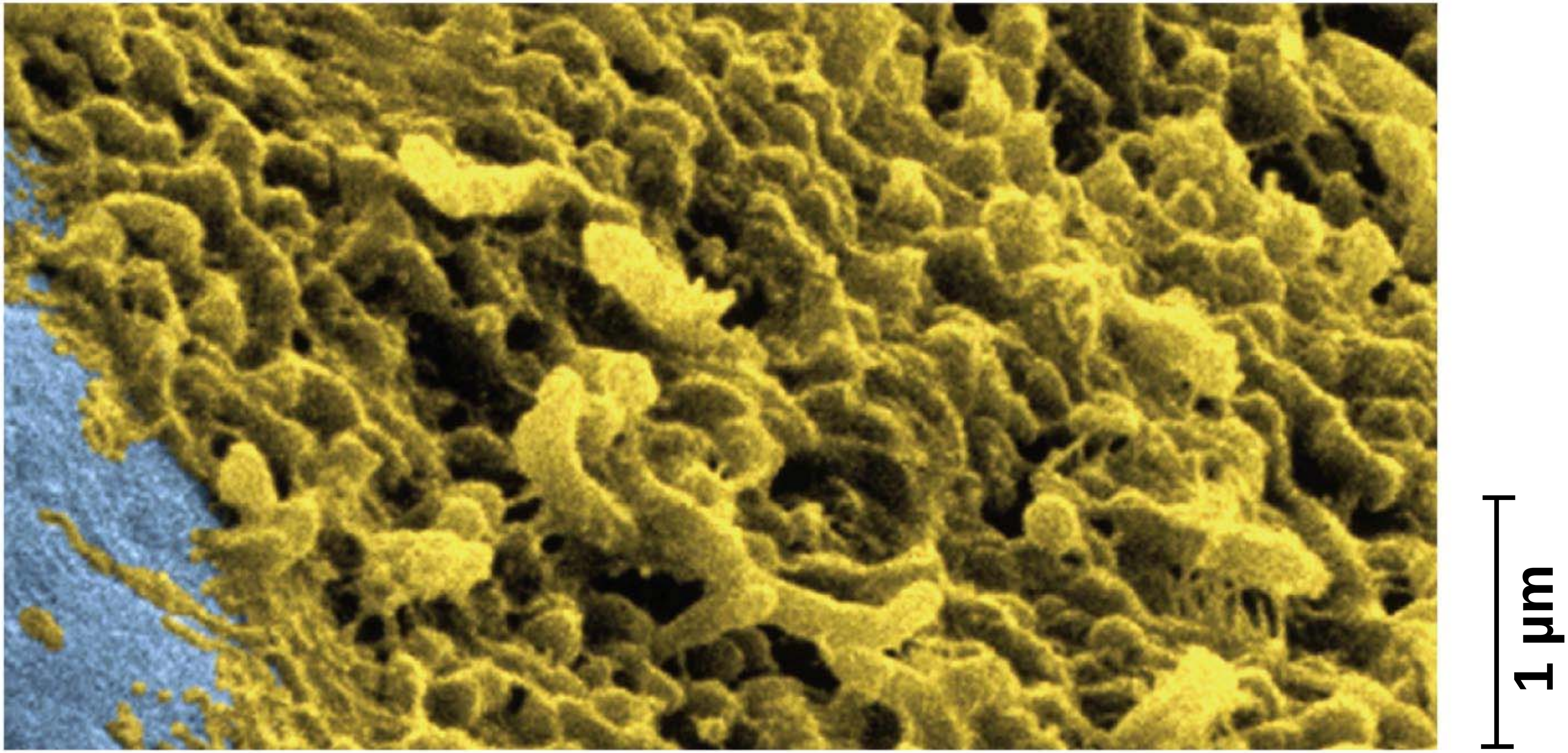
PLAY **Video: Cyanobacteria (*Oscillatoria*)**

Fig. 27-14



- In some prokaryotic species, metabolic cooperation occurs in surface-coating colonies called **biofilms**

Fig. 27-15



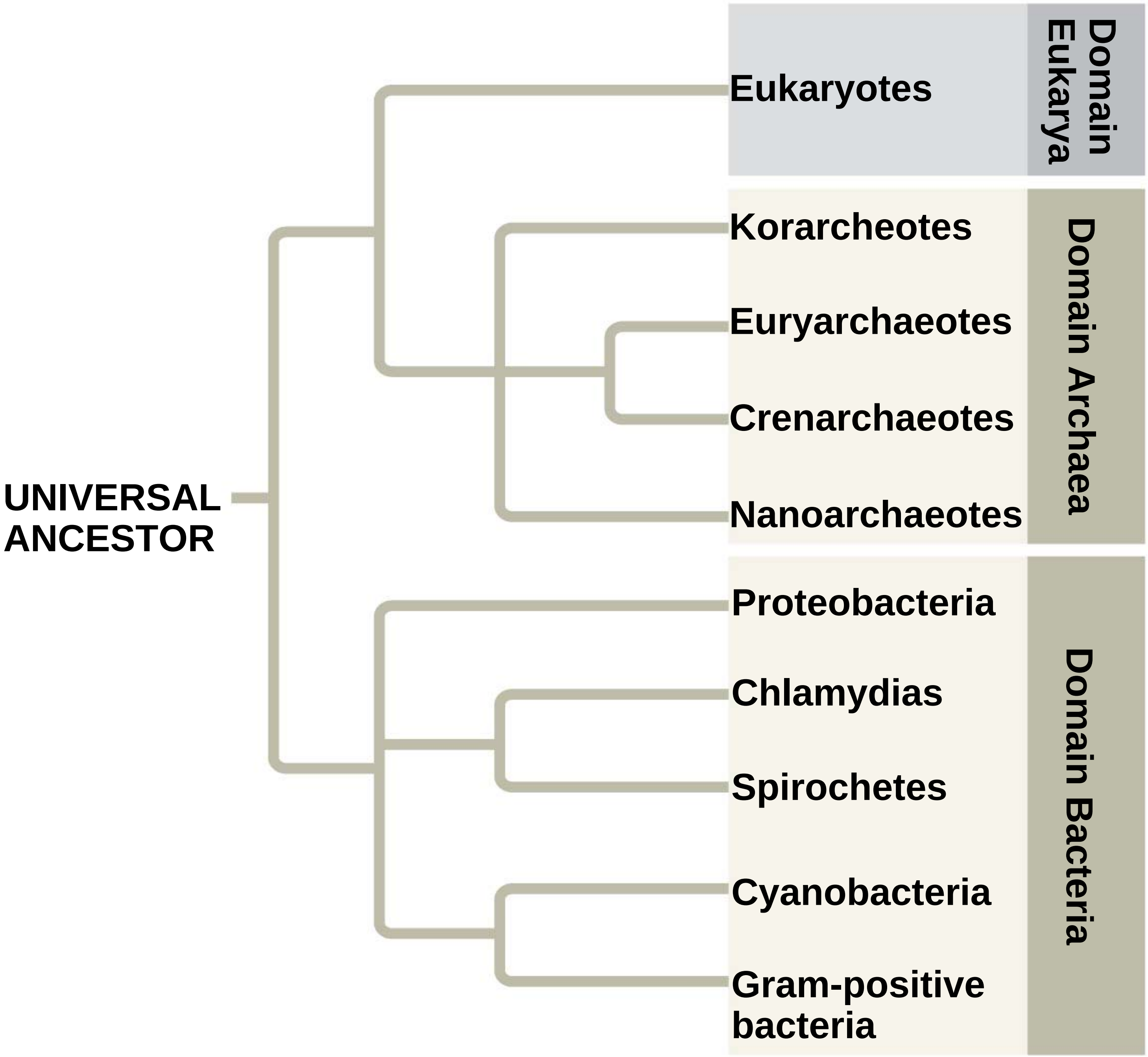
Concept 27.4: Molecular systematics is illuminating prokaryotic phylogeny

- Until the late 20th century, systematists based prokaryotic taxonomy on phenotypic criteria
- Applying molecular systematics to the investigation of prokaryotic phylogeny has produced dramatic results

Lessons from Molecular Systematics

- Molecular systematics is leading to a phylogenetic classification of prokaryotes
- It allows systematists to identify major new clades

Fig. 27-16


Eukaryotes
Domain Eukarya
Korarcheotes
Euryarchaeotes
Crenarchaeotes
Nanoarchaeotes
Domain Archaea
UNIVERSAL ANCESTOR
Proteobacteria
Chlamydias
Spirochetes
Cyanobacteria
Gram-positive bacteria
Domain Bacteria

- The use of polymerase chain reaction (PCR) has allowed for more rapid sequencing of prokaryote genomes
- A handful of soil many contain 10,000 prokaryotic species
- Horizontal gene transfer between prokaryotes obscures the root of the tree of life

Archaea

- Archaea share certain traits with bacteria and other traits with eukaryotes

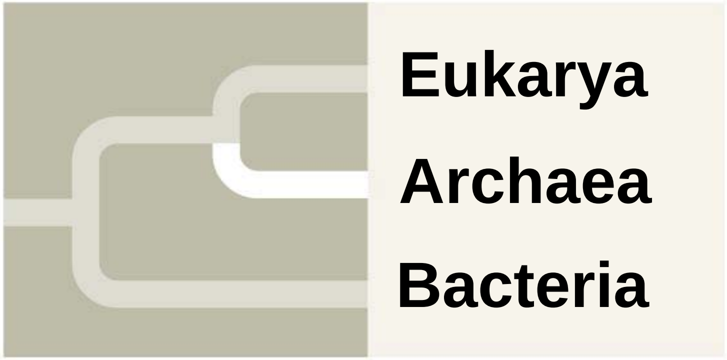

Eukarya
Archaea
Bacteria

Table 27.2 A Comparison of the Three Domains of Life

CHARACTER	DOMAIN		
	Bacteria	Archaea	Eukarya
Nuclear envelope	Absent	Absent	Present
Membrane-enclosed organelles	Absent	Absent	Present
Peptidoglycan in cell wall	Present	Absent	Absent
Membrane lipids	Unbranched hydrocarbons	Some branched hydrocarbons	Unbranched hydrocarbons
RNA polymerase	One kind	Several kinds	Several kinds
Initiator amino acid for protein synthesis	Formyl-methionine	Methionine	Methionine
Introns in genes	Very rare	Present in some genes	Present
Response to the antibiotics streptomycin and chloramphenicol	Growth inhibited	Growth not inhibited	Growth not inhibited
Histones associated with DNA	Absent	Present in some species	Present
Circular chromosome	Present	Present	Absent
Growth at temp-eratures > 100°C	No	Some species	No

- Some archaea live in extreme environments and are called **extremophiles**
- **Extreme halophiles** live in highly saline environments
- **Extreme thermophiles** thrive in very hot environments

Fig. 27-17

- **Methanogens** live in swamps and marshes and produce methane as a waste product
- Methanogens are strict anaerobes and are poisoned by O_2
- In recent years, genetic prospecting has revealed many new groups of archaea
- Some of these may offer clues to the early evolution of life on Earth

海底的生命之泉

科學家近來在海底發現一種新的熱泉生態系統，分析結果顯示，
地球上的生命可能由一些前所未知的方式演化而來。

撰文／布萊德雷（Alexander S. Bradley）　翻譯／王心瑩

新發現

這裡是生命的搖籃嗎？

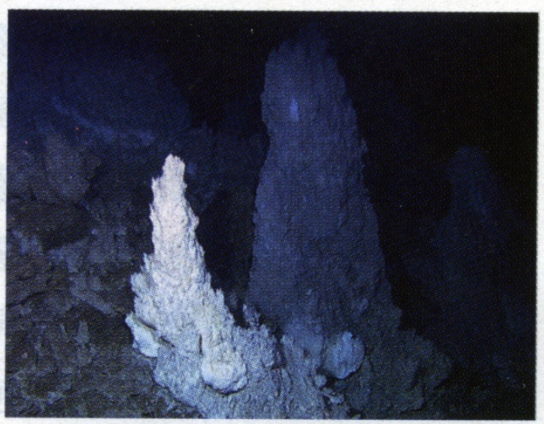
「失落的城市」熱泉坐落在水面下的山頂處，該處稱為亞特蘭提斯地塊，位於大西洋中洋脊板塊交界處以西15公里。經過研究，我們知道熱泉的煙囪構造如何形成，也發現那裡的化學反應非常特殊，地球上最初生命的誕生之地可能就類似這樣的地方。

這個地塊主要是由橄欖岩構成，滲入地塊裂縫的海水會與橄欖岩產生反應，將橄欖岩轉變為蛇紋岩。這種蛇紋石化作用會引發好幾個過程，都對「失落的城市」週遭的化學環境至關重要。首先，它使滲入岩石的熱水呈現鹼性，而且含有鈣；這些水從熱泉出口噴出、與海水混合後，會形成碳酸鈣，沉積在出口周圍，形成白色煙囪構造。其次，它使熱泉充滿了富含能量的氣體，因此生活在煙囪壁上和內部的甲烷菌之類微生物不需要太陽能便可繁衍。最後，蛇紋石化作用所產生的化學條件可以讓無機化合物合成出有機化合物，而這正是演化出生命的必要條件。

失落的城市……

「失落的城市」和「黑煙囪」都是海底熱泉，此外兩者大不相同。以下是「失落的城市」的幾個特點：

- 位於大西洋中洋脊火山群西方15公里處
- 水溫為90℃
- pH值偏鹼性
- 白煙囪是由碳酸鈣構成
- 該處有些生命形式可以獨立生存，不須仰賴太陽能



黑煙囪……

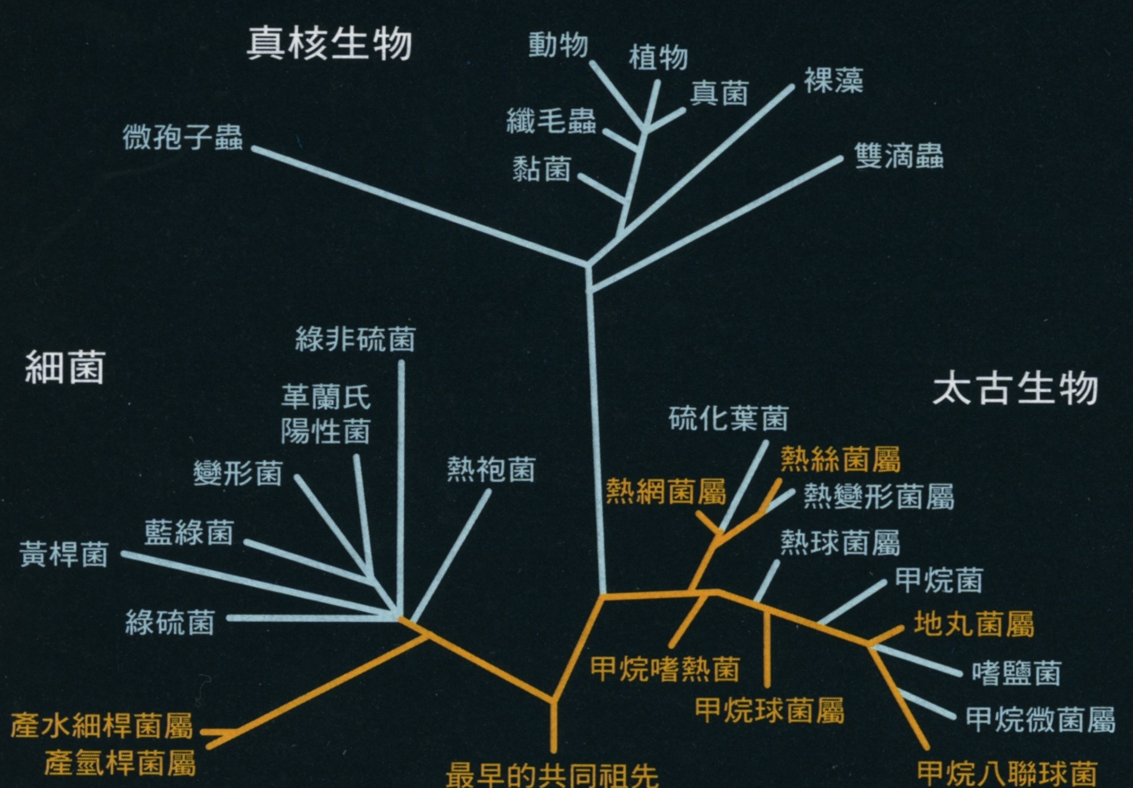
黑煙囪接近上升的岩漿，因此有許多特點與「失落的城市」完全不一樣：

- 位於大西洋中洋脊火山群中
- 水溫高達400℃
- pH值偏酸性
- 硫化物製造出黑煙，並累積構成煙囪
- 該處的生命形式必須間接仰賴太陽能

支持的證據

有些生物熱愛溫泉

根據現存生物遺傳物質的分析結果，「生命可能起源於熱泉生態系統」的假說或可成立，而當時的熱泉也許很類似「失落的城市」。科學家根據RNA序列畫出系譜樹，呈現出地球上所有生命的親緣關係。如同「失落的城市」的甲烷菌（屬於甲烷團聚形太古生物目），位於系譜樹根部的許多微生物住在高溫的熱泉環境，有些位於陸地上，有些在海底，而且那些微生物（橘色）都可利用氫，顯示地球上所有生物最早的共同祖先便住在此種環境。



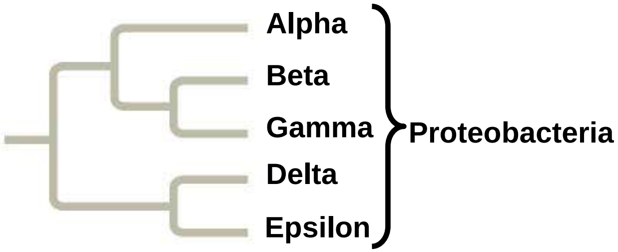
Bacteria

- Bacteria include the vast majority of prokaryotes of which most people are aware
- Diverse nutritional types are scattered among the major groups of bacteria

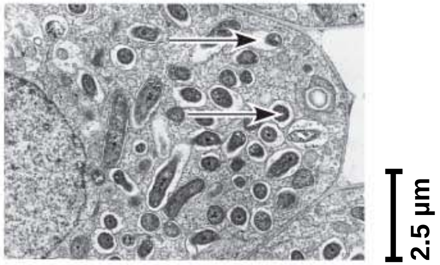
Proteobacteria

- These gram-negative bacteria include photoautotrophs, chemoautotrophs, and heterotrophs
- Some are anaerobic, and others aerobic

Fig. 27-18a

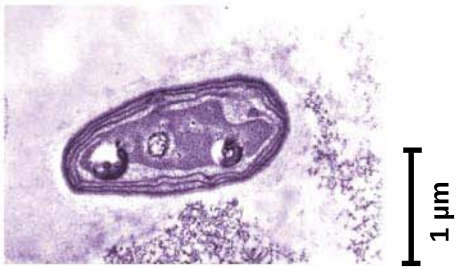


Subgroup: Alpha Proteobacteria



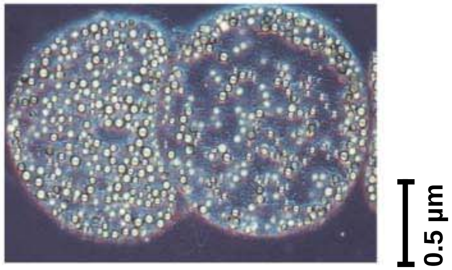
Rhizobium **(arrows) inside a root cell of a legume (TEM)**

Subgroup: Beta Proteobacteria



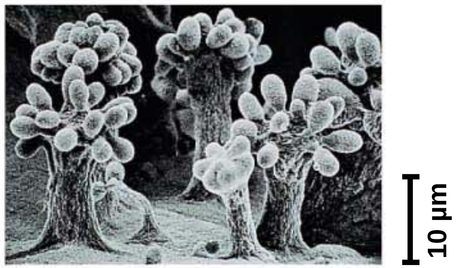
Nitrosomonas **(colorized TEM)**

Subgroup: Gamma Proteobacteria

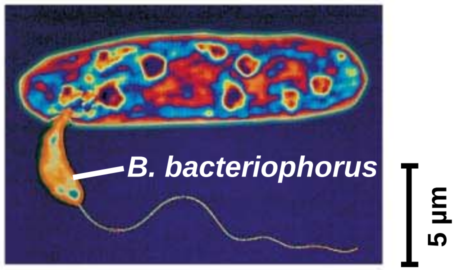


Thiomargarita namibiensis **containing sulfur wastes (LM)**

Subgroup: Delta Proteobacteria

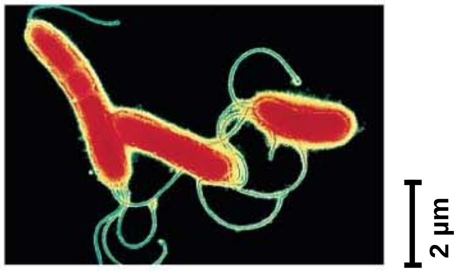


Fruiting bodies of *Chondromyces crocatus*, a myxobacterium (SEM)



Bdellovibrio bacteriophorus **attacking a larger bacterium (colorized TEM)**

Subgroup: Epsilon Proteobacteria



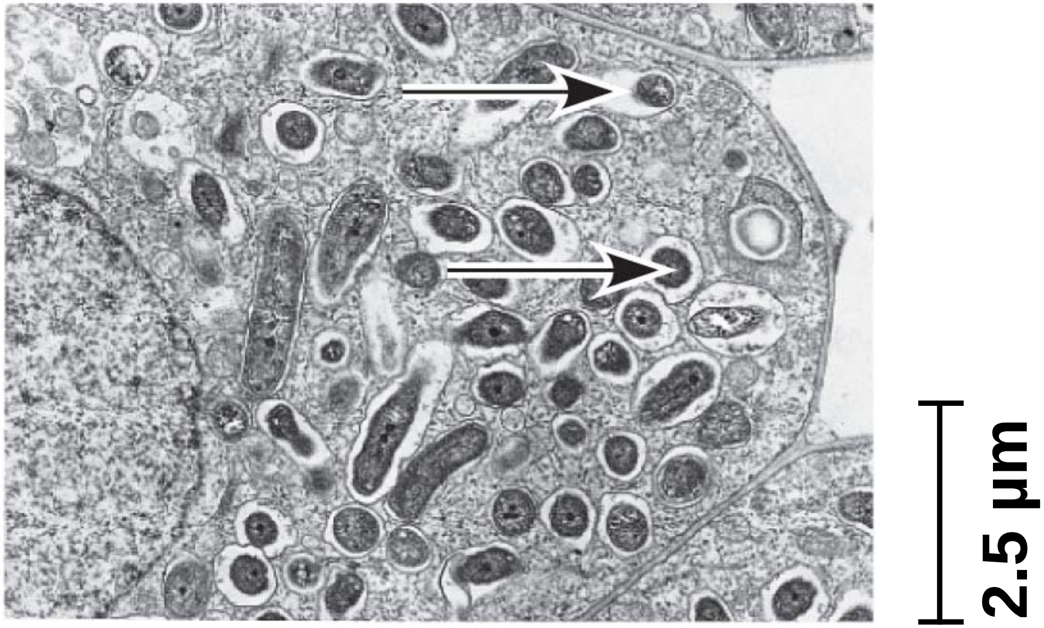
Helicobacter pylori **(colorized TEM)**

Subgroup: Alpha Proteobacteria

- Many species are closely associated with eukaryotic hosts
- Scientists hypothesize that mitochondria evolved from aerobic alpha proteobacteria through endosymbiosis

- Example: *Rhizobium*, which forms root nodules in legumes and fixes atmospheric N_2
- Example: *Agrobacterium*, which produces tumors in plants and is used in genetic engineering

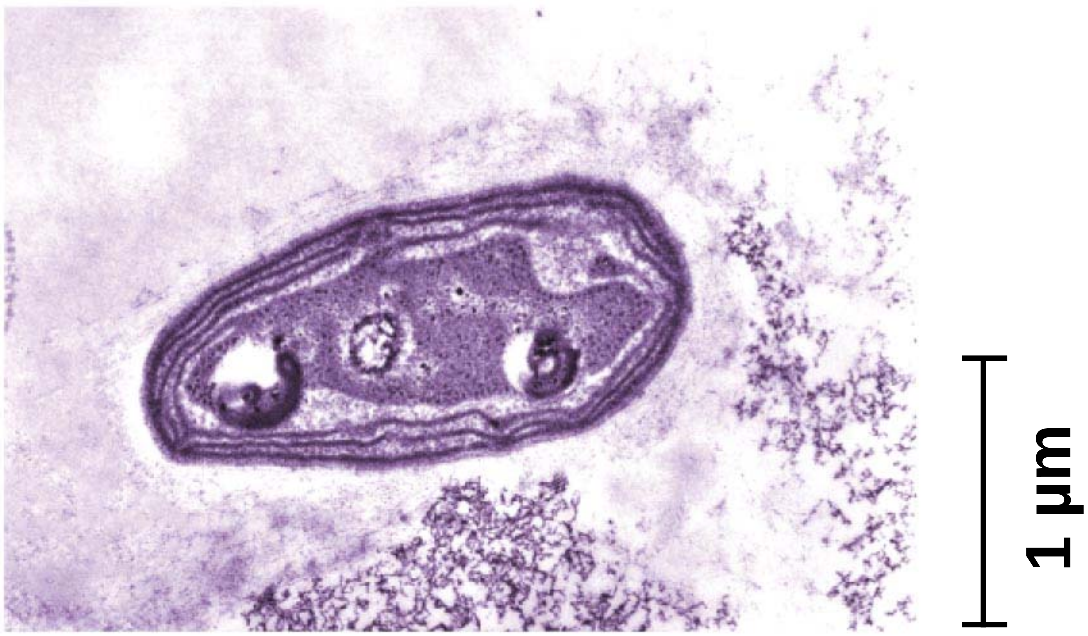
Fig. 27-18c



***Rhizobium* (arrows) inside a root cell of a legume (TEM)**

Subgroup: Beta Proteobacteria

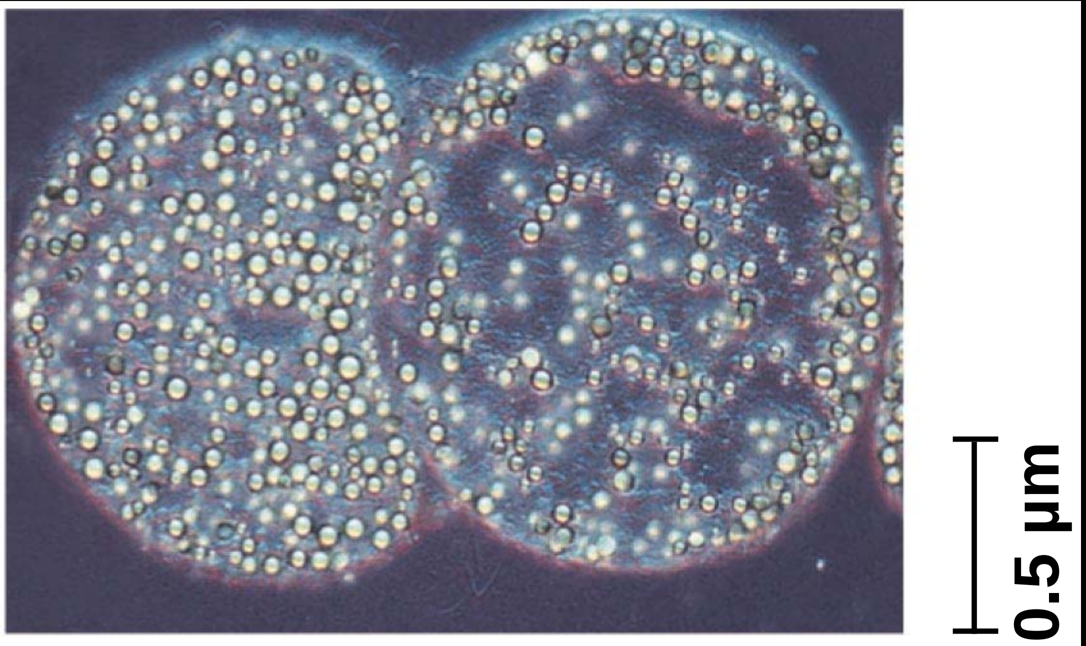
- Example: the soil bacterium *Nitrosomonas*, which converts NH_4^+ to NO_2^-



Nitrosomonas **(colorized TEM)**

Subgroup: Gamma Proteobacteria

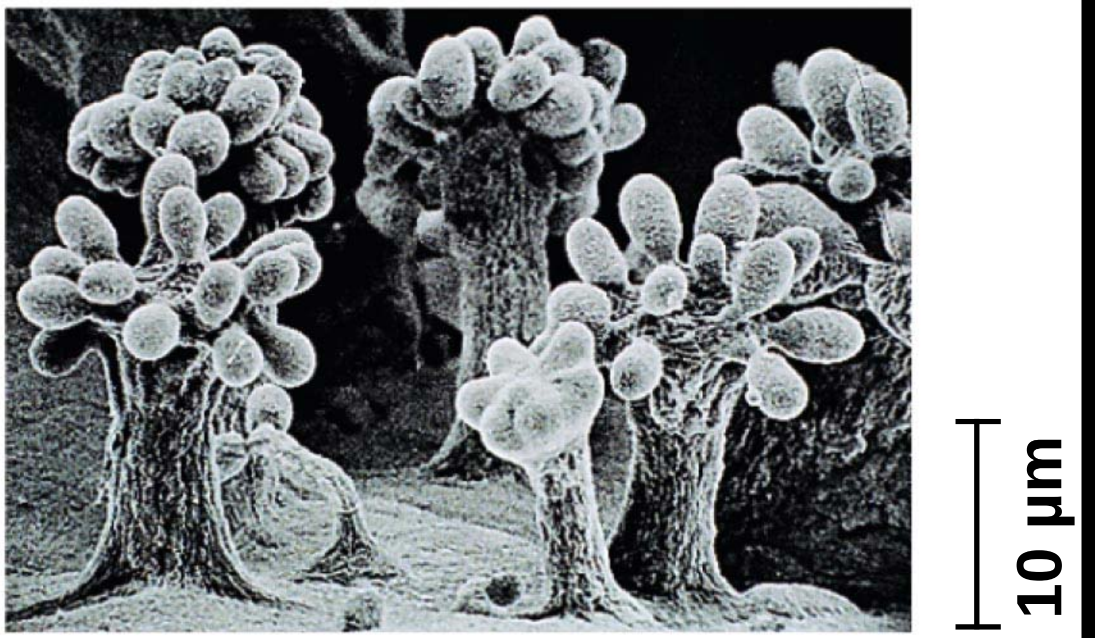
- Examples include sulfur bacteria such as *Chromatium* and pathogens such as *Legionella*, *Salmonella*, and *Vibrio cholerae*
- *Escherichia coli* resides in the intestines of many mammals and is not normally pathogenic



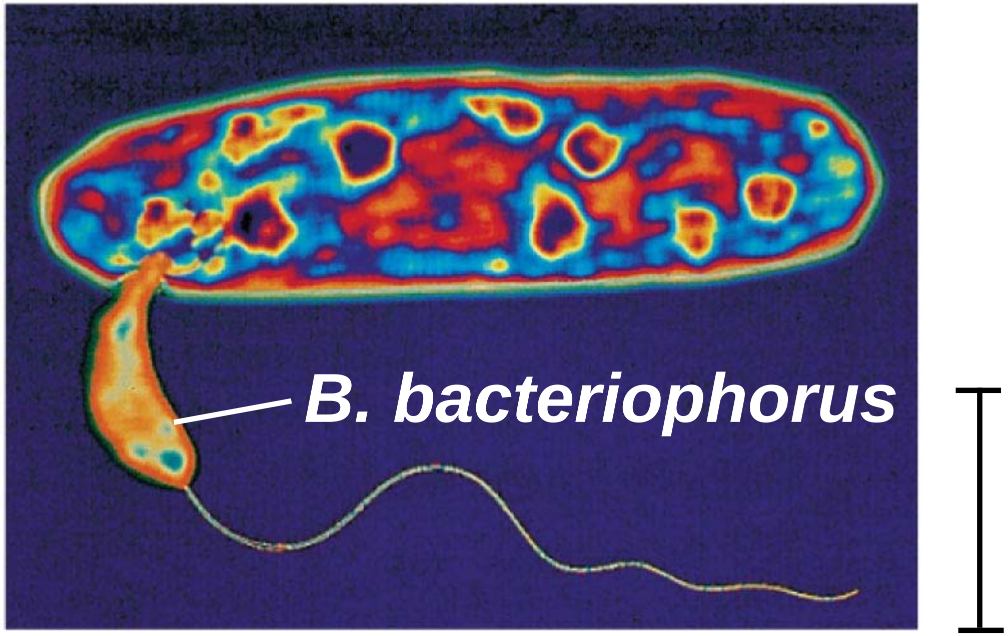
Thiomargarita namibiensis **containing sulfur wastes (LM)**

Subgroup: Delta Proteobacteria

- Example: the slime-secreting myxobacteria



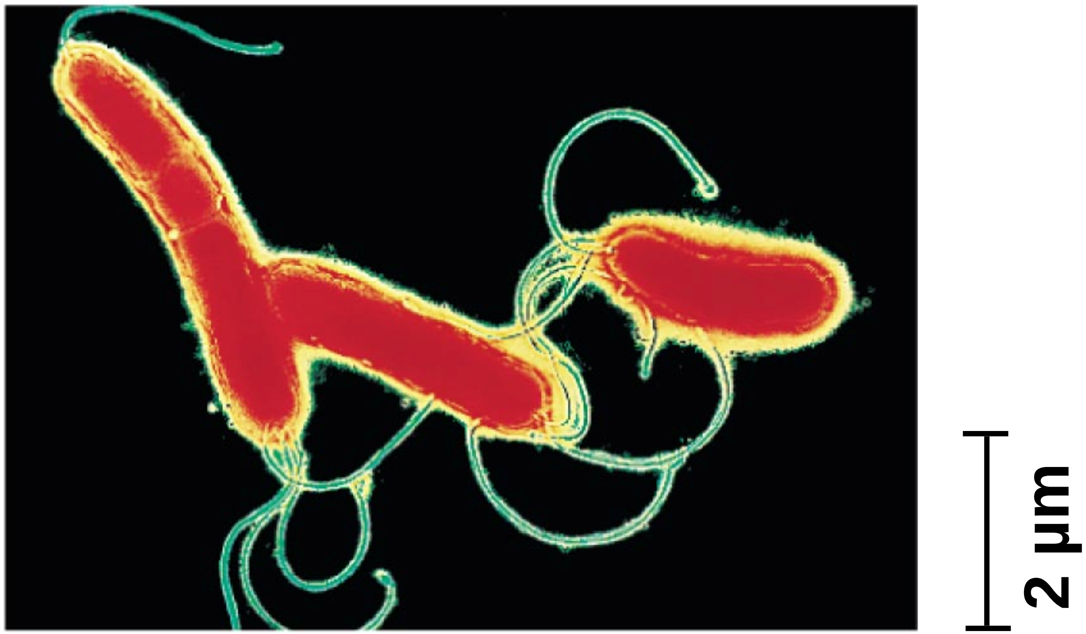
Fruiting bodies of *Chondromyces crocatus*, a myxobacterium (SEM)



Bdellovibrio bacteriophorus **attacking a larger bacterium (colorized TEM)**

Subgroup: Epsilon Proteobacteria

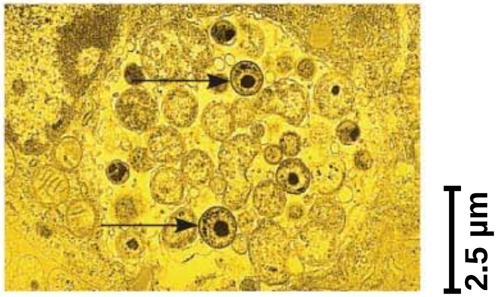
- This group contains many pathogens including *Campylobacter*, which causes blood poisoning, and *Helicobacter pylori*, which causes stomach ulcers



Helicobacter pylori **(colorized TEM)**

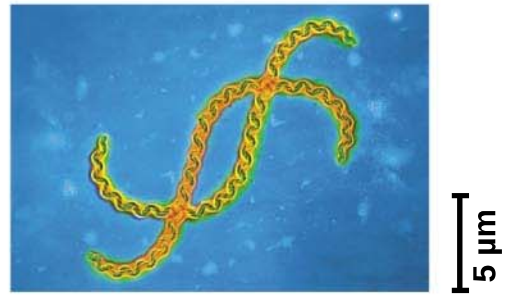
Fig. 27-18i

CHLAMYDIAS



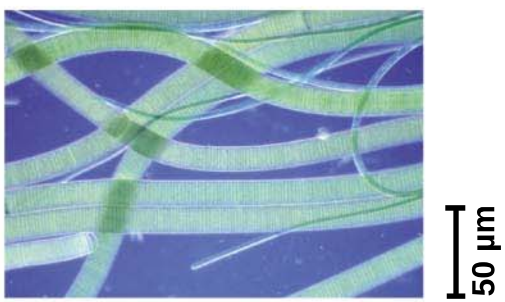
Chlamydia **(arrows) inside an animal cell (colorized TEM)**

SPIROCHETES



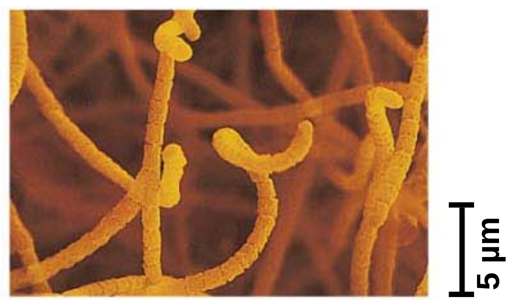
Leptospira, a **spirochete (colorized TEM)**

CYANOBACTERIA

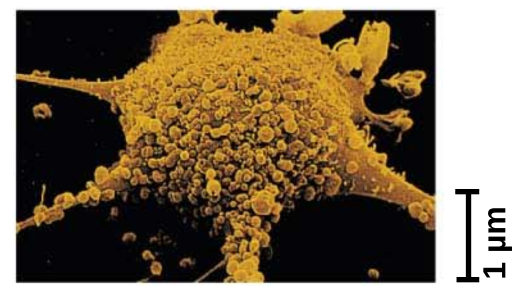


Two species of *Oscillatoria,* filamentous cyanobacteria (LM*)*

GRAM-POSITIVE BACTERIA



Streptomyces, **the source of many antibiotics (colorized SEM)**

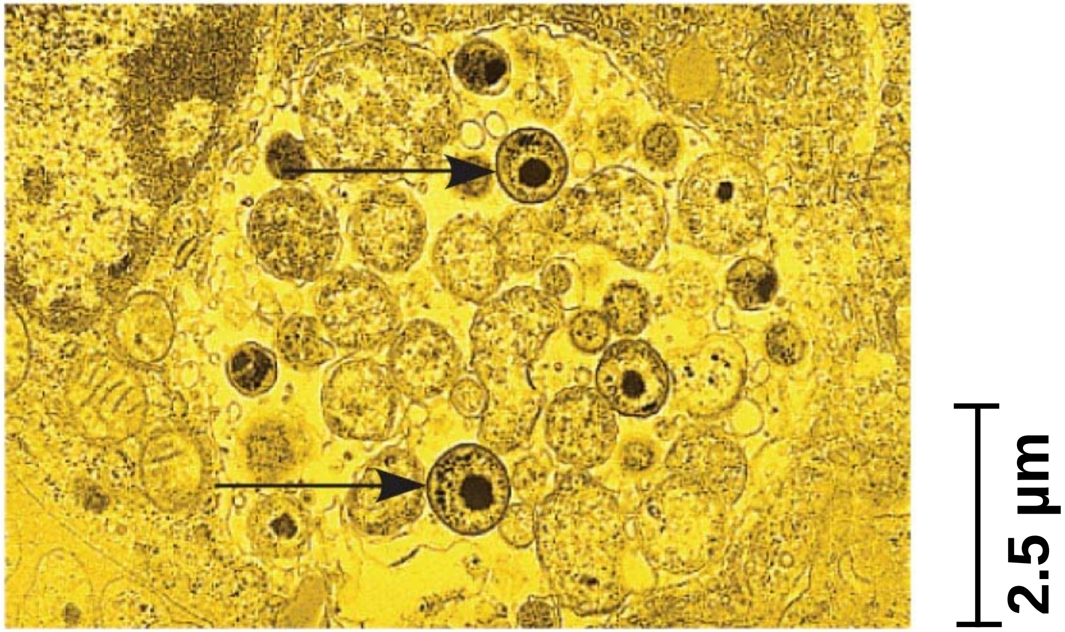


Hundreds of mycoplasmas covering a human fibroblast cell (colorized SEM)

Chlamydias

- These bacteria are parasites that live within animal cells
- *Chlamydia trachomatis* causes blindness and nongonococcal urethritis by sexual transmission

Fig. 27-18j

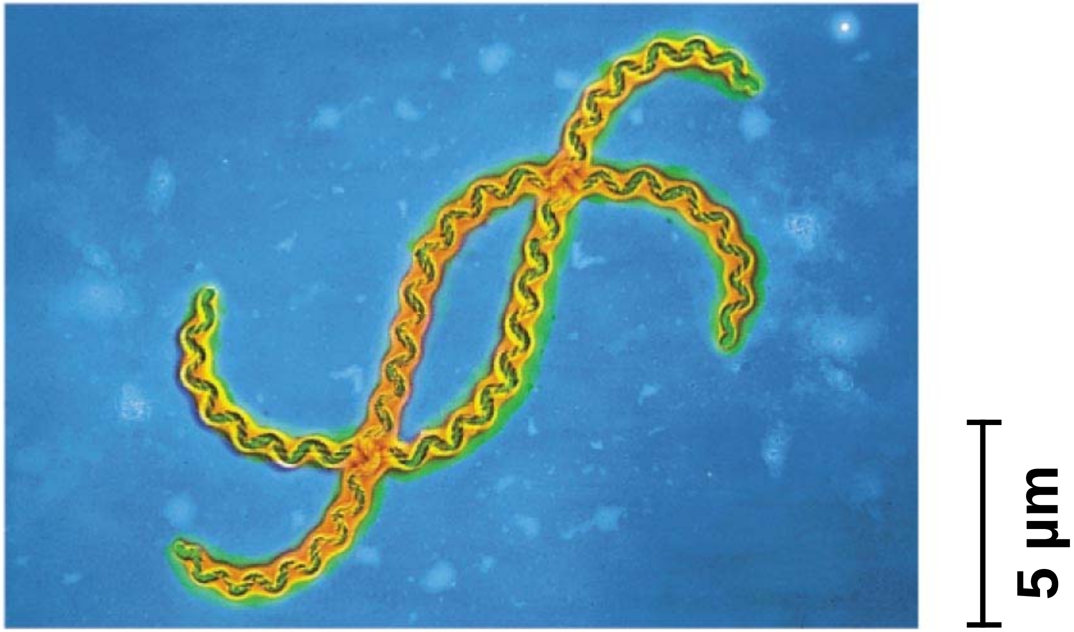


***Chlamydia* (arrows) inside an animal cell (colorized TEM)**

Spirochetes

- These bacteria are helical heterotrophs
- Some, such as *Treponema pallidum*, which causes syphilis, and *Borrelia burgdorferi*, which causes Lyme disease, are parasites

Fig. 27-18k

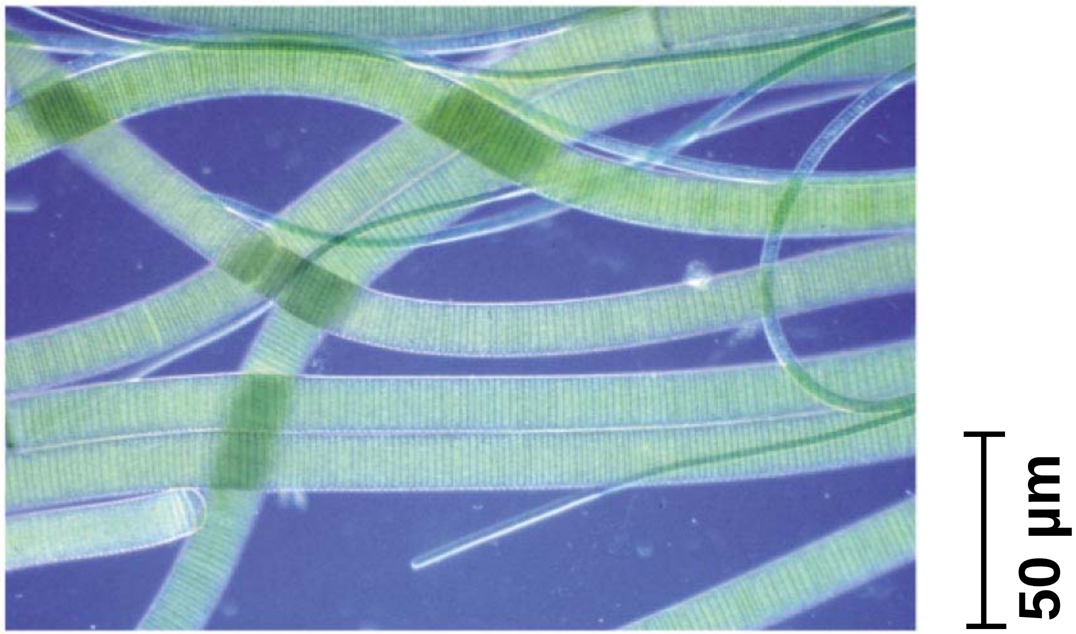


***Leptospira*, *a* spirochete**
(colorized TEM)

Cyanobacteria

- These are photoautotrophs that generate O_2
- Plant chloroplasts likely evolved from cyanobacteria by the process of endosymbiosis

Fig. 27-18l

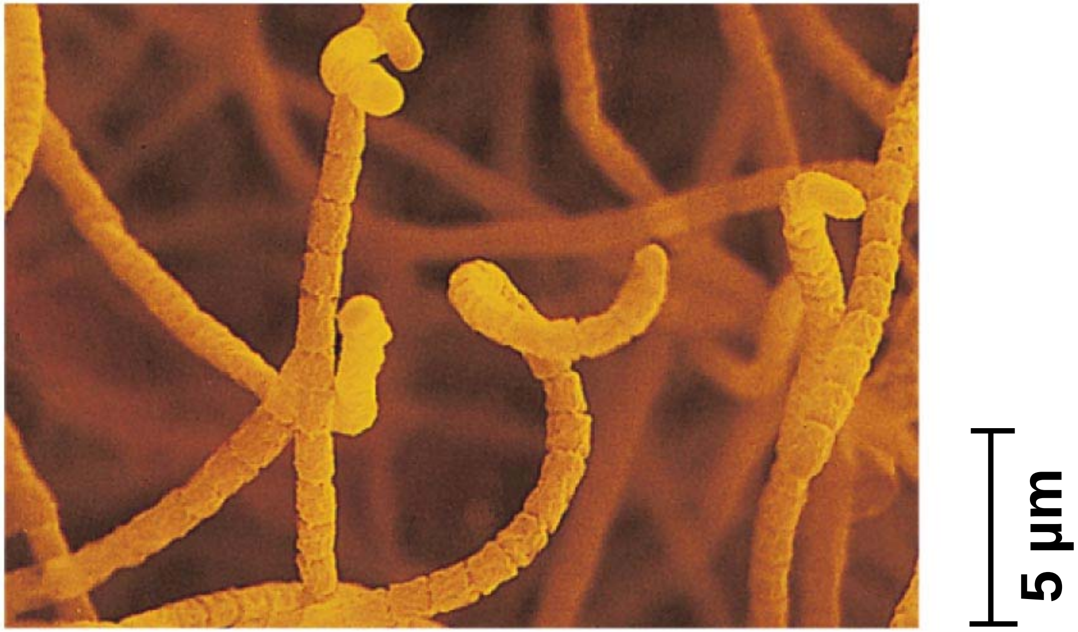


Two species of *Oscillatoria,* filamentous cyanobacteria (LM*)*

Gram-Positive Bacteria

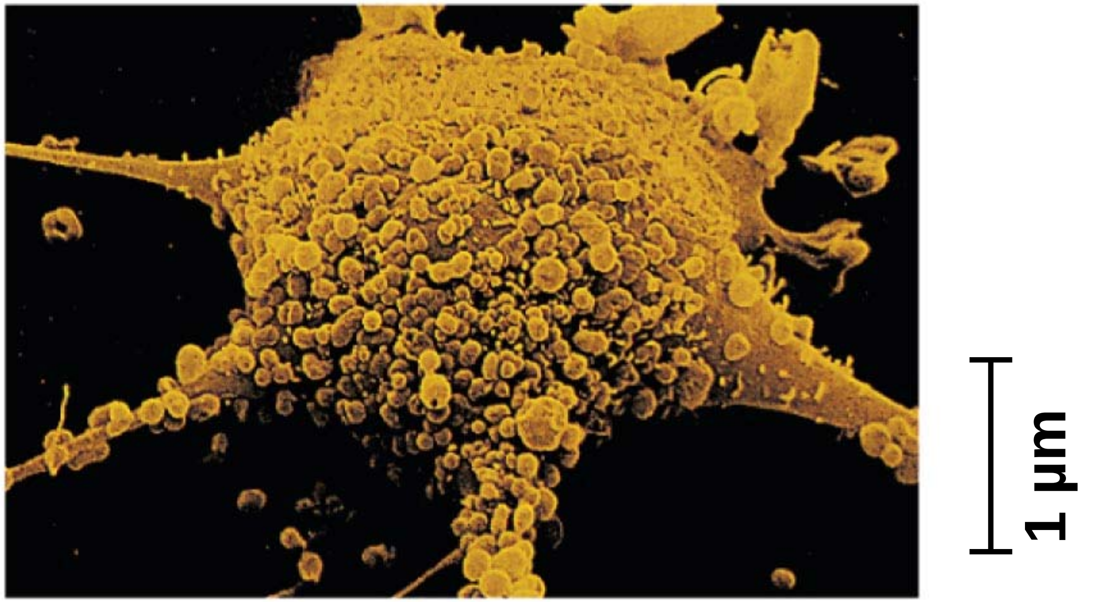
- Gram-positive bacteria include
  - Actinomycetes, which decompose soil
  - *Bacillus anthracis*, the cause of anthrax
  - *Clostridium botulinum*, the cause of botulism
  - Some *Staphylococcus* and *Streptococcus*, which can be pathogenic
  - Mycoplasms, the smallest known cells

Fig. 27-18m



***Streptomyces*, the source of many antibiotics (colorized SEM)**

Fig. 27-18n



Hundreds of mycoplasmas covering a human fibroblast cell (colorized SEM)

Concept 27.5: Prokaryotes play crucial roles in the biosphere

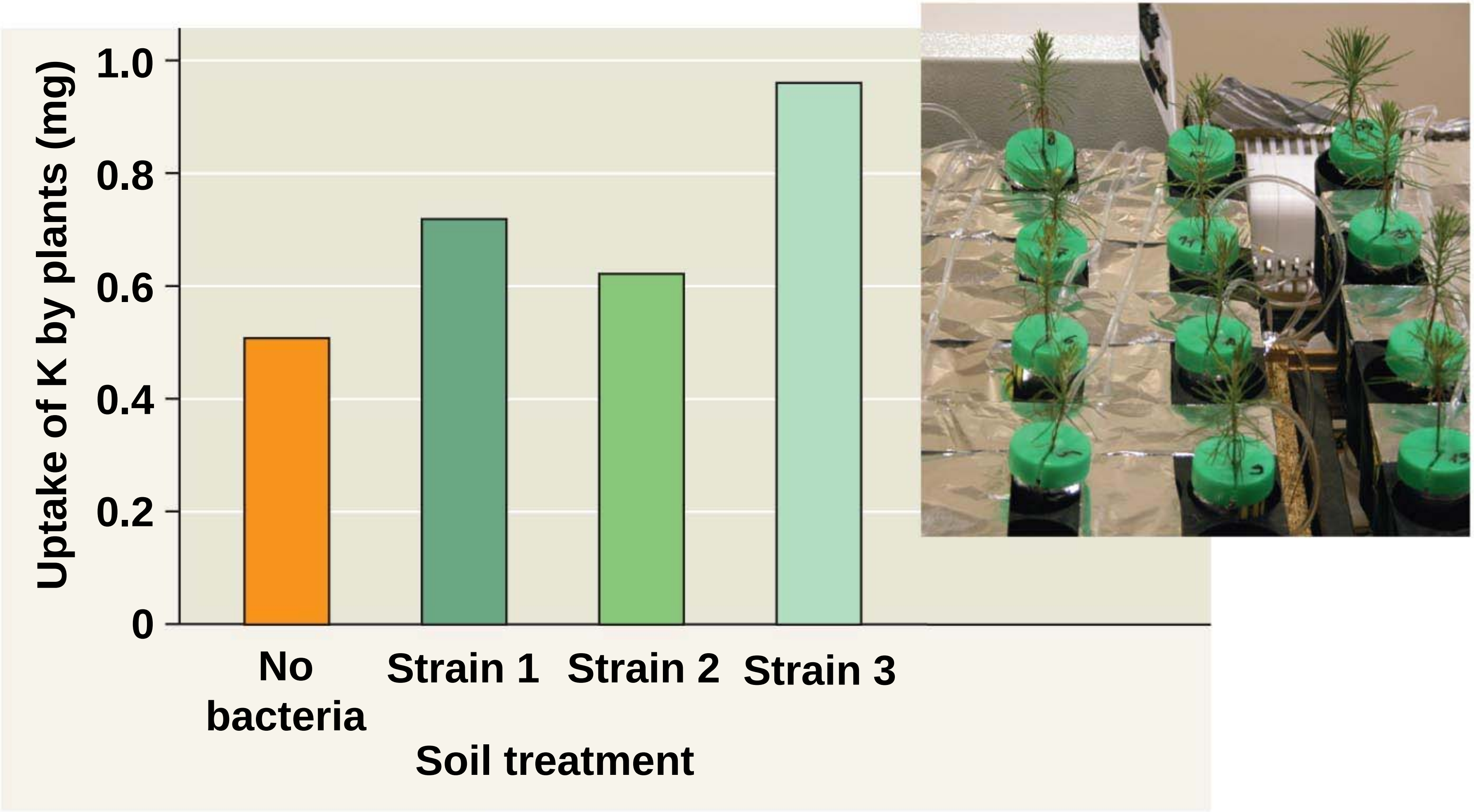
- Prokaryotes are so important to the biosphere that if they were to disappear the prospects for any other life surviving would be dim

Chemical Cycling

- Prokaryotes play a major role in the recycling of chemical elements between the living and nonliving components of ecosystems
- Chemoheterotrophic prokaryotes function as **decomposers**, breaking down corpses, dead vegetation, and waste products
- Nitrogen-fixing prokaryotes add usable nitrogen to the environment

- Prokaryotes can sometimes increase the availability of nitrogen, phosphorus, and potassium for plant growth
- Prokaryotes can also “immobilize” or decrease the availability of nutrients

Fig. 27-19



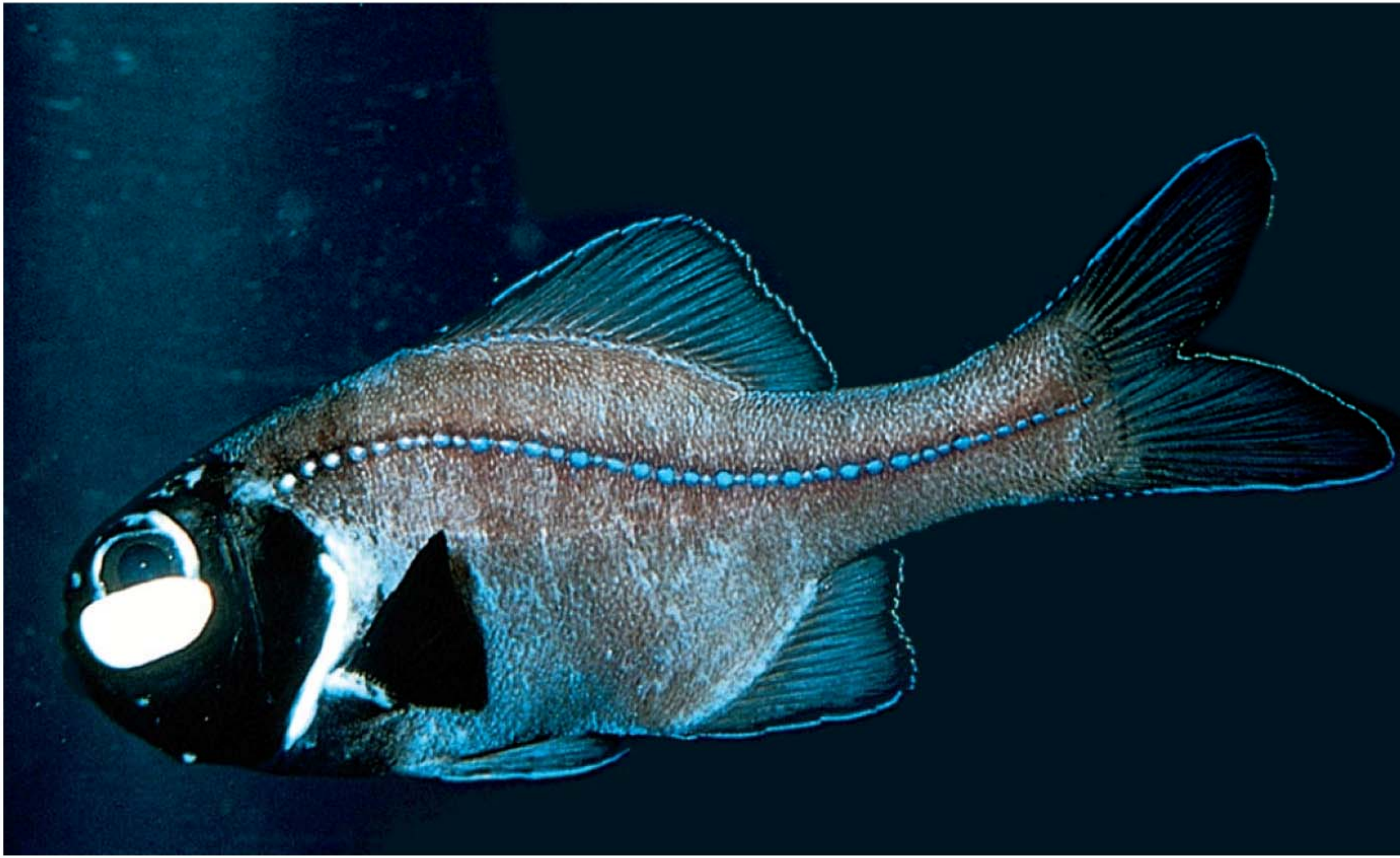
Uptake of K by plants (mg)
1.0
0.8
0.6
0.4
0.2
0
No bacteria
Strain 1
Strain 2
Strain 3
Soil treatment

Ecological Interactions

- **Symbiosis** is an ecological relationship in which two species live in close contact: a larger **host** and smaller **symbiont**
- Prokaryotes often form symbiotic relationships with larger organisms

- In **mutualism**, both symbiotic organisms benefit
- In **commensalism**, one organism benefits while neither harming nor helping the other in any significant way
- In **parasitism**, an organism called a **parasite** harms but does not kill its host
- Parasites that cause disease are called **pathogens**

Fig. 27-20



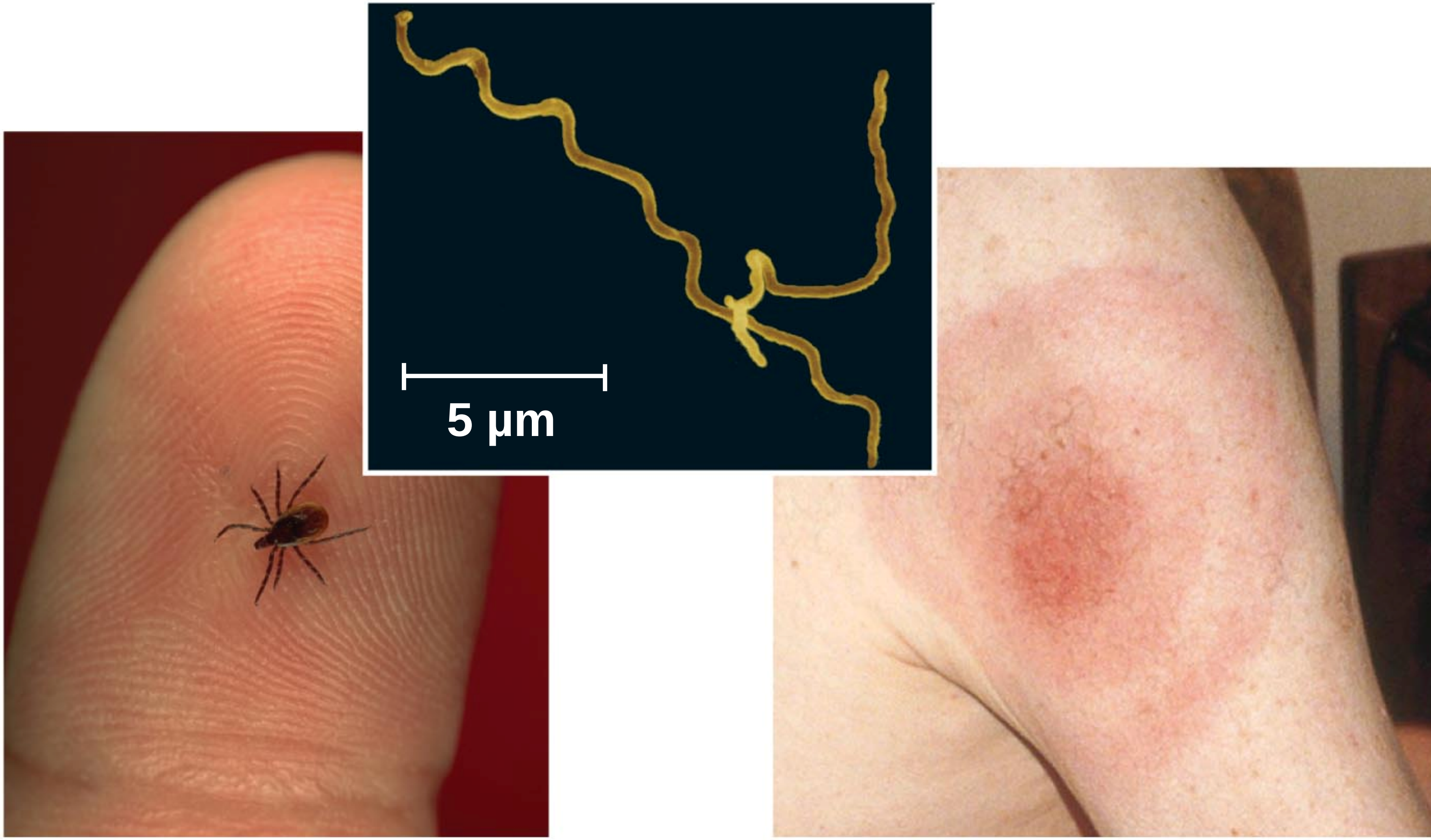
Concept 27.6: Prokaryotes have both harmful and beneficial impacts on humans

- Some prokaryotes are human pathogens, but others have positive interactions with humans

Pathogenic Prokaryotes

- Prokaryotes cause about half of all human diseases
- Lyme disease is an example

Fig. 27-21



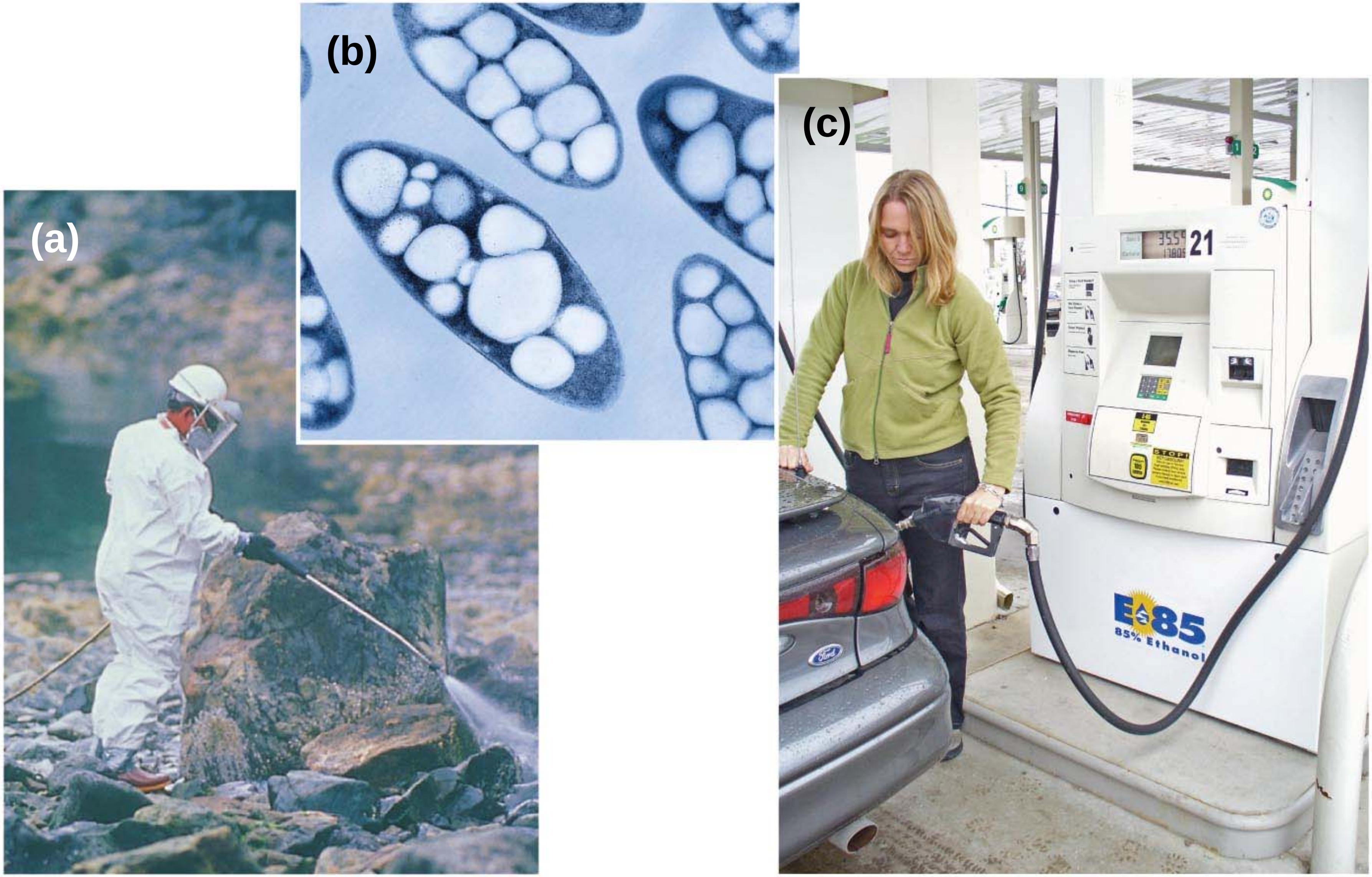
- Pathogenic prokaryotes typically cause disease by releasing exotoxins or endotoxins
- **Exotoxins** cause disease even if the prokaryotes that produce them are not present
- **Endotoxins** are released only when bacteria die and their cell walls break down
- Many pathogenic bacteria are potential weapons of bioterrorism

Prokaryotes in Research and Technology

- Experiments using prokaryotes have led to important advances in DNA technology
- Prokaryotes are the principal agents in **bioremediation**, the use of organisms to remove pollutants from the environment

- Some other uses of prokaryotes:
  - Recovery of metals from ores
  - Synthesis of vitamins
  - Production of antibiotics, hormones, and other products

Fig. 27-22



You should now be able to:

1. Distinguish between the cell walls of gram-positive and gram-negative bacteria
2. State the function of the following features: capsule, fimbriae, sex pilus, nucleoid, plasmid, and endospore
3. Explain how R plasmids confer antibiotic resistance on bacteria

4. Distinguish among the following sets of terms: photoautotrophs, chemoautotrophs, photoheterotrophs, and chemoheterotrophs; obligate aerobe, facultative anaerobe, and obligate anaerobe; mutualism, commensalism, and parasitism; exotoxins and endotoxins