Bacteria and Archaea

Chapter 27

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

2

An Introduction to Prokaryotes

- They're (Almost) Everywhere!
- Most prokaryotes are microscopic but what they lack in size they more than make up for in numbers
  - The number of prokaryotes in a single handful of fertile soil is greater than the number of people who have ever lived

3

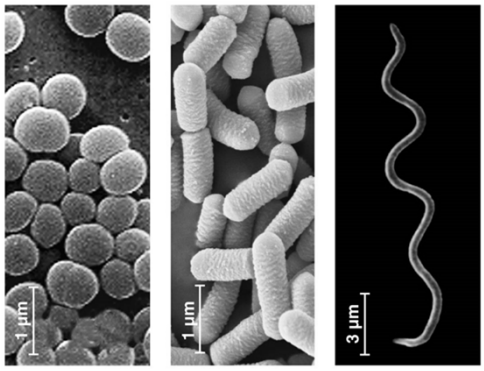
- Prokaryotes thrive almost everywhere including places too acidic, too salty, too cold, or too hot for most other organisms
- Biologists are discovering that these organisms have an astonishing genetic diversity

5

Structural, Functional, and Genetic Adaptations

- Structural, functional, and genetic adaptations contribute to prokaryotic success
- Most prokaryotes are unicellular although some species form colonies
- Prokaryotic cells have a variety of shapes
  - The three most common are spheres (cocci), rods (bacilli), and spirals

6



Cell-Surface Structures

- One of the most important features 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
  - Using a technique called the Gram stain scientists can classify many bacterial species into two groups based on cell wall composition, Gram-positive and Gram-negative

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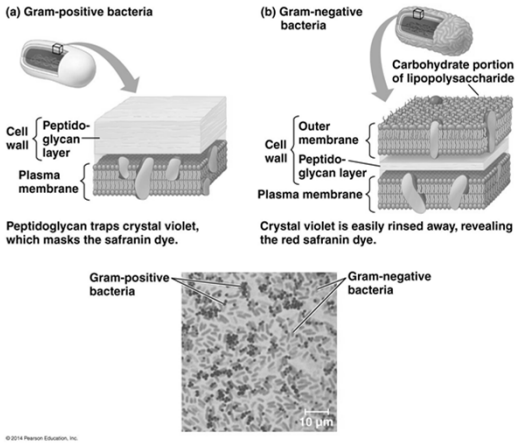

- The cell wall of many prokaryotes is covered by a capsule, a sticky layer of polysaccharide or protein
- Some prokaryotes have fimbriae and pili which allow them to stick to their substrate or other individuals in a colony

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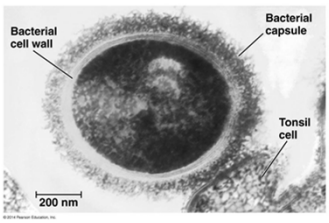
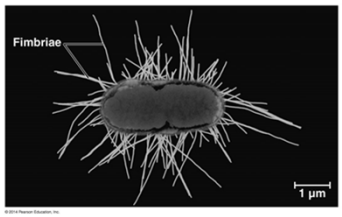
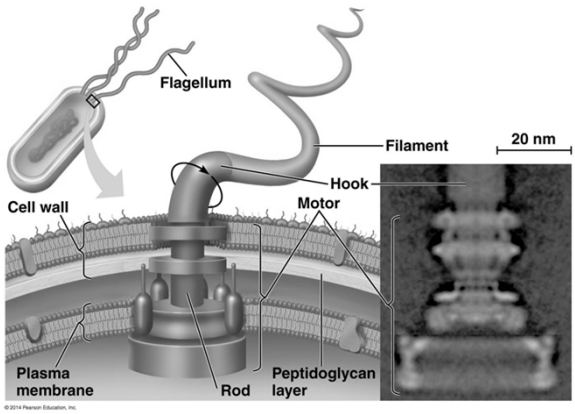




Motility

- Most motile bacteria propel themselves by flagella which 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

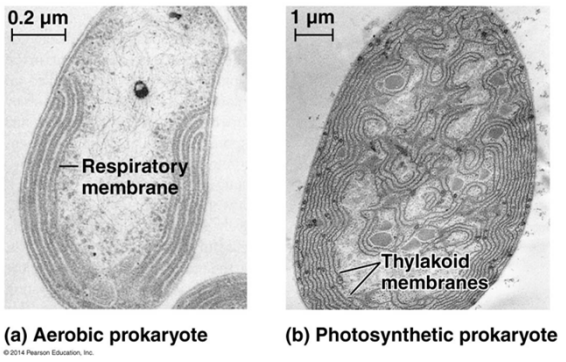
12



Internal and Genomic Organization

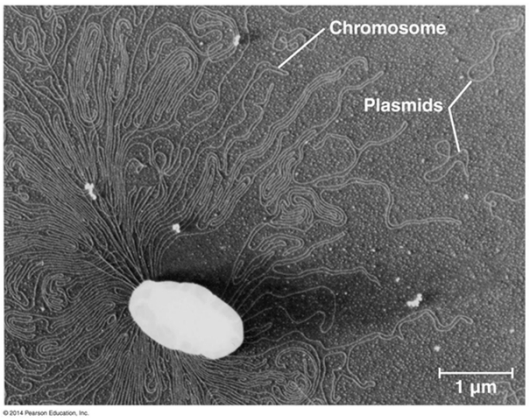
- Prokaryotic cells usually lack complex compartmentalization
  - Some prokaryotes do have specialized membranes that perform metabolic functions

14



- The typical prokaryotic genome is a ring of DNA that is not surrounded by a membrane and that is located in a nucleoid region
  - Some species of bacteria also have smaller rings of DNA called plasmids

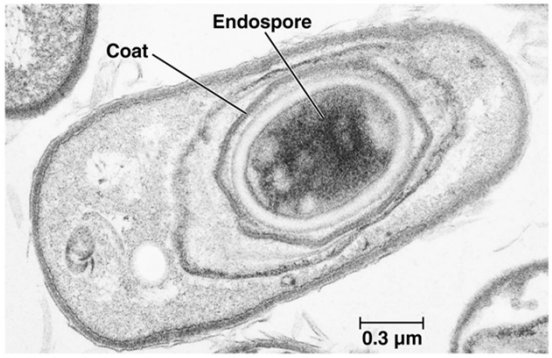
16



Reproduction and Adaptation

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

18



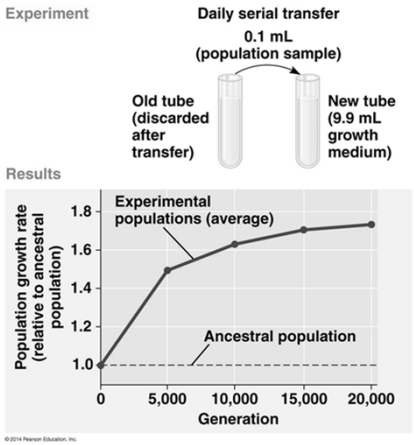
20

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
- Rapid reproduction and horizontal gene transfer facilitate the evolution of prokaryotes to changing environments

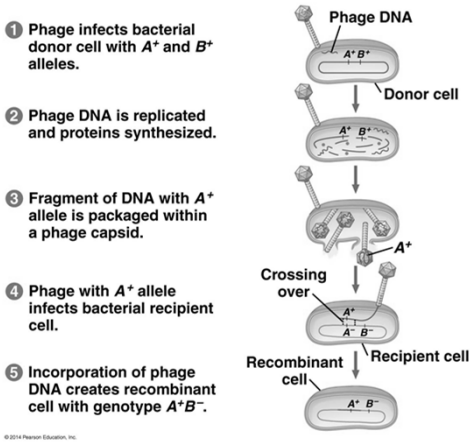


Genetic Recombination

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

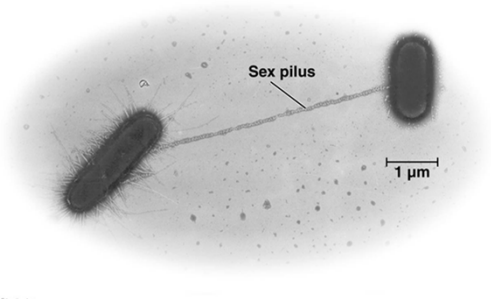
Transformation and Transduction

- 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)



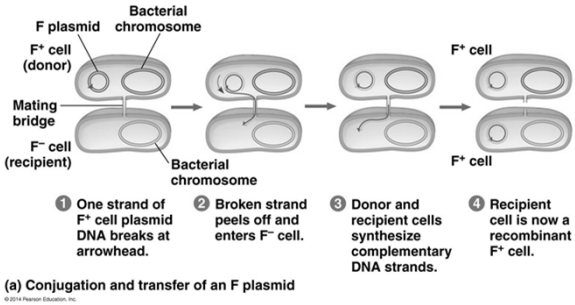
Conjugation and Plasmids

- 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

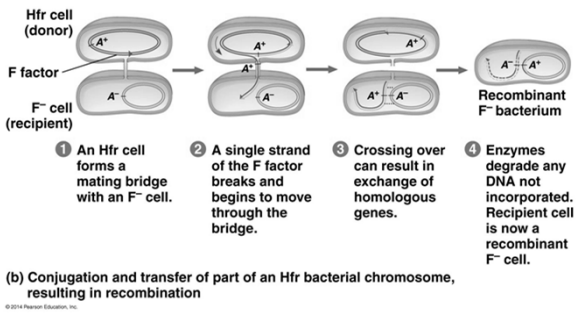
- Cells containing the F plasmid function as DNA donors during conjugation
  - Cells without the F factor function as DNA recipients during conjugation
    - The F factor is transferable during conjugation



(a) Conjugation and transfer of an F plasmid

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



(b) Conjugation and transfer of part of an Hfr bacterial chromosome, resulting in recombination

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

Nutritional and Metabolic Diversity

- A great diversity of nutritional and metabolic adaptations have evolved in prokaryotes
  - Examples of all four models of nutrition are found among prokaryotes
    - Photoautotrophy
    - Chemoautotrophy
    - Photoheterotrophy
    - Chemoheterotrophy

34

Table 27.1 Major Nutritional Modes

Mode	Energy Source	Carbon Source	Types of Organisms
AUTOTROPH			
Photoautotroph	Light	CO_2, HCO_3^-, or related compound	Photosynthetic prokaryotes (for example, cyanobacteria); plants; certain protists (for example, algae)
Chemoautotroph	Inorganic chemicals (such as H_2S, NH_3, or Fe^{2+})	CO_2, HCO_3^-, or related compound	Unique to certain prokaryotes (for example, *Sulfolobus*)
HETEROTROPH			
Photoheterotroph	Light	Organic compounds	Unique to certain aquatic and salt-loving prokaryotes (for example, *Rhodobacter*, *Chloroflexus*)
Chemoheterotroph	Organic compounds	Organic compounds	Many prokaryotes (for example, *Clostridium*) and protists; fungi; animals; some plants

Some electron donors and acceptors used by Bacteria and Archaea

Electron donor	Electron acceptor	Product	Category
H_2 or organic molecules	SO_4^{2-}	H_2S	Sulfate-reducers
H_2	CO_2	CH_4	Methanogens
CH_4	O_2	CO_2	Methanotrophs
S or H_2S	O_2	SO_4^{2-}	Sulfur bacteria
Organic molecules	Fe^{3+}	Fe^{2+}	Iron-reducers
NH_3	O_2	NO_2^-	Nitrifiers
Organic molecules	NO_3^-	N_2O, NO or N_2	Denitrifiers (nitrate reducers)
NO_2^-	O_2	NO_3^-	Nitrosifiers

Metabolic Relationships to Oxygen

- Prokaryotic metabolism also varies with respect to oxygen
  - Obligate aerobes require oxygen
  - Facultative anaerobes can survive with or without oxygen
  - Obligate anaerobes are poisoned by oxygen

37

Nitrogen Metabolism

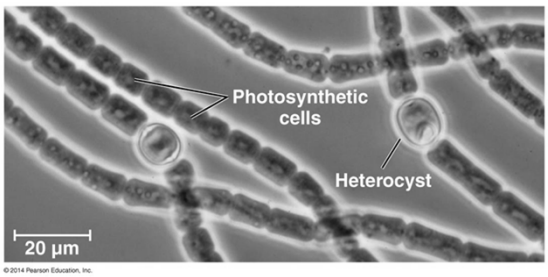
- Prokaryotes can metabolize nitrogen in a variety of ways
  - In a process called nitrogen fixation some prokaryotes convert atmospheric nitrogen to ammonia

38

Metabolic Cooperation

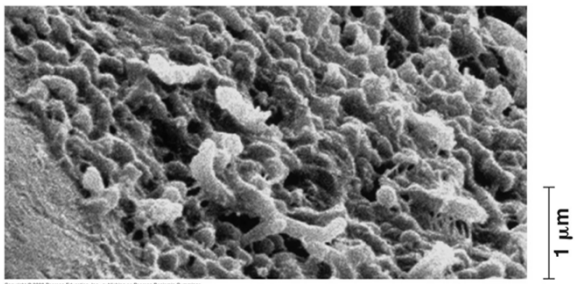
- Cooperation between prokaryotes allows them to use environmental resources they could not use as individual cells
  - In the cyanobacterium Anabaena photosynthetic cells and nitrogen-fixing cells exchange metabolic products

39



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

41



Prokaryotic Phylogeny

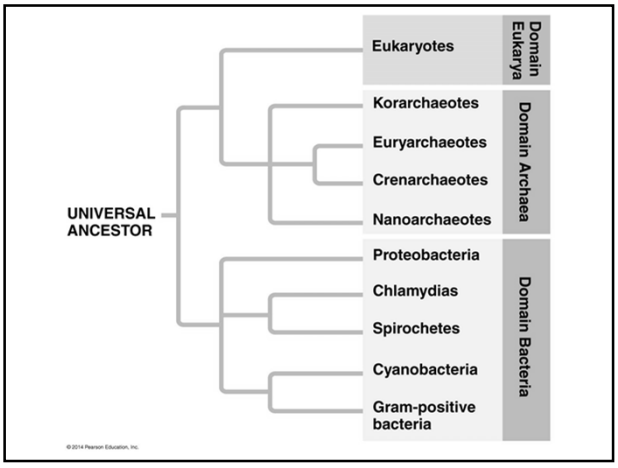
- Molecular systematics is illuminating prokaryotic phylogeny
  - Until the late 20th century systematists based prokaryotic taxonomy on phenotypic criteria
  - Applying molecular systematics to the investigation of prokaryotic phylogeny has produced dramatic results

43

Lessons from Molecular Systematics

- Molecular systematics is leading to a phylogenetic classification of prokaryotes
  - As a result systematists are identifying major new clades
- The next slide shows a tentative phylogeny of some of the major taxa of prokaryotes based on molecular systematics

44



Archaea

- Archaea share certain traits with bacteria and other traits with eukaryotes
- Some archaea live in extreme environments
  - Extreme thermophiles thrive in very hot environments
  - Extreme halophiles live in high saline environments
  - Methanogens live in swamps and marshes and produce methane as a waste product

46

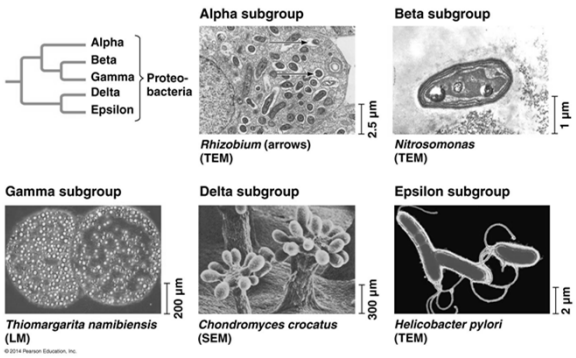
Table 27.2 A Comparison of the Three Domains of Life

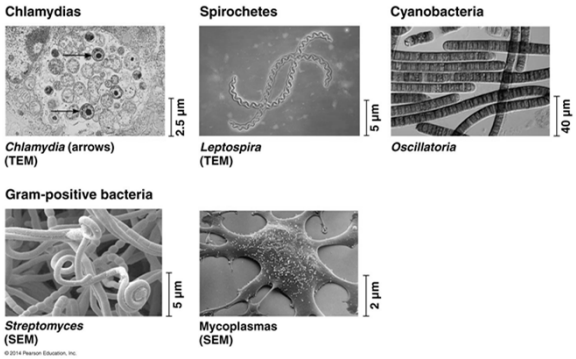
	DOMAIN		
CHARACTERISTIC	**Bacteria**	**Archaea**	**Eukarya**
Nuclear envelope	Absent	Absent	Present
Membrane-enclosed organelles	Absent	Absent	Present
Peptidoglycan in cell wall	Present	Absent	Absent
Membrane lipids	Unbranched hydrocarbons	Some branched hydrocarbons	Unbranched hydrocarbons
RNA polymerase	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 in many genes
Response to the antibiotics streptomycin and chloramphenicol	Growth usually inhibited	Growth not inhibited	Growth not inhibited
Histones associated with DNA	Absent	Present in some species	Present
Circular chromosome	Present	Present	Absent
Growth at temperatures > 100°C	No	Some species	No

Bacteria

- Diverse nutritional types are scattered among the major groups of bacteria
  - The two largest groups are the proteobacteria and the Gram-positive bacteria

48





The Roles of Prokaryotes

- 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

51

Chemical Recycling

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

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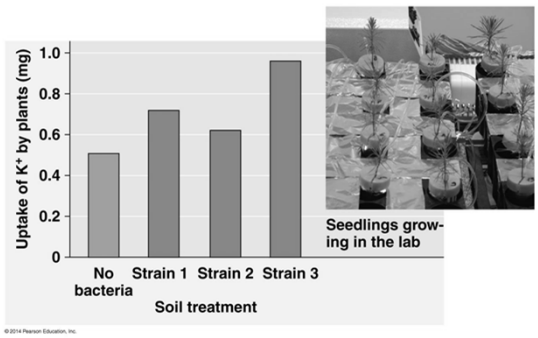
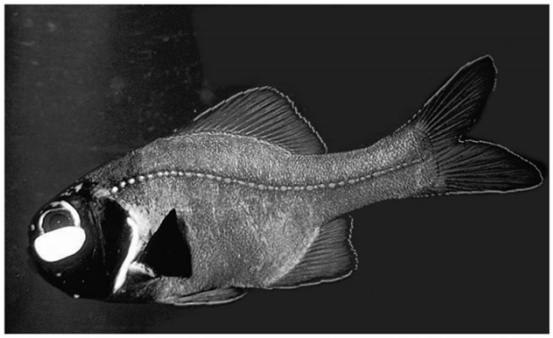


Symbiotic Relationships

- Many prokaryotes live with other organisms in symbiotic relationships
  - 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
- Other types of prokaryotes live inside hosts as parasites

54



Impacts on Humans

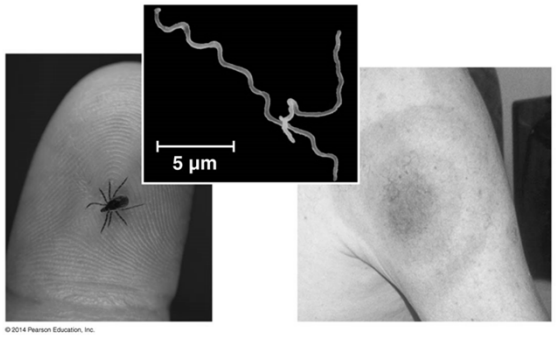
- Prokaryotes have both harmful and beneficial impacts on humans
  - Parasites that cause disease are called pathogens
- Some prokaryotes are human pathogens but many others have positive interactions with humans

56

Pathogenic Prokaryotes

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

57



- Koch's postulates used to identify specific pathogen as cause of a disease
  - find the same pathogen in all diseased individuals
  - isolate pathogen from diseased individual and grow in pure culture
  - use cultured pathogen to cause disease in healthy experimental host
  - isolate pathogen from diseased experimental host

59

Some Diseases Caused by Bacteria

Bacterium	Lineage	Tissues affected	Disease
Chlamydia trachomatis	Planctomyces	Urogenital tract	Genital tract infection
Clostridium botulinum	Gram positives	Gastrointestinal tract, nervous system	Food poisoning (botulism)
Clostridium tetani	Gram positives	Wounds, nervous system	Tetanus
Haemophilus influenzae	Gram negatives	Ear canal, nervous system	Ear infections, meningitis
Mycobacterium tuberculosis	Gram positives	Respiratory tract	Tuberculosis
Neisseria gonorrhoeae	Proteobacteria (β group)	Urogenital tract	gonorrhea
Propionibacterium acnes	Actinomycetes	Skin	Acne
Pseudomonas aeruginosa	Proteobacteria (β group)	Urogenital canal, eyes, ear canal	Urinary tract infection, eye and ear infection
Salmonella enteritidis	Proteobacteria (γ group)	Gastrointestinal tract	Food poisoning
Streptococcus pneumoniae	Gram positives	Respiratory tract	Pneumonia
Streptococcus pyogenes	Gram positives	Respiratory tract	Strep throat, scarlet fever
Treponema pallidum	Spirochetes	Urogenital tract	Syphilis
Vibrio parahaemolyticus	Proteobacteria (γ group)	Gastrointestinal tract	Food poisoning
Yersinia pestis	Gram negatives	Lymph and blood	Plague

- Pathogenic prokaryotes typically cause disease by releasing exotoxins or endotoxins
  - exotoxins-proteins secreted by the cells; can cause disease without the pathogen being present
  - endotoxins-toxic component of the outer membranes of some gram-negative bacteria
- Many pathogenic bacteria are potential weapons of bioterrorism

61

Prokaryotes in Research and Technology

- Experiments using prokaryotes have led to important advances in DNA technology
- Prokaryotes are the principal agents in bioremediation
  - These organisms can be used to remove pollutants from the environment

62

- Prokaryotes are also major tools in:
  - Mining
  - The synthesis of vitamins
  - Production of antibiotics, hormones, and other products

64