There may be some changes to this lecture by the end of Tuesday

Microbiology: A Systems Approach, 2nd ed.

Chapter 4: "Prokaryotic" Profiles: the Bacteria and Archaea

Chapter 5: Eukaryotic Cells and Microorganisms

How are “Prokaryotes” Different from Eukaryotes?

- Organization of the genetic element (read the way their DNA is packaged)
  - No **nucleus**
  - Not wrapped around **histones**
- The makeup of their cell wall
  - Bacteria - have peptidoglycan
  - Archaea - pseudo-peptidoglycan, different from bacterial walls
- Their cytoplasmic organization
  - No double membrane-bound organelles

Cell structures and their function

- exoskeleton:
  - cell walls, glycocalyces
- plasma membrane:
  - fluid mosaic model
- genetic element:
  - nucleoid & plasmids; chromosomes
- intracellular communication:

  Structures that mediate the flow of
  energy, carbon and information
- extracellular communication:
  - transport (export and import)
  - movement and attachment (flagella & pili)

4.1 Prokaryotic Form and Function

- Prokaryotic cell
  - External
    - Appendages
      - Flagella
      - Pili
      - Fimbriae
    - Glycocalyx
      - Capsule, slime layer
  - Cell envelope
    - (Outer membrane)
    - Cell wall
    - Cell membrane
  - Internal
    - Cytoplasm
    - Ribosomes
    - Inclusions
    - Nucleoid/chromosome
    - Actin cytoskeleton
    - Endospore

Structures common to all bacterial cells

- Cell (cytoplasmic) membrane
- Ribosomes
- Genetic Element [one or more chromosomes

- Cells are “filled” with cytoplasm

Structures found in most bacterial cells

- Cell wall
- Surface coating known as
  “glycocalyx” (capsule or slime layer)

Structures found in some to many bacterial cells

External Protruding Structures

- Flagella (flagellum)
- Pili (Pilus)
- Fimbriae (fimbria)

Internal Structures

- Inclusion(s)
- Actin cytoskeleton
- Endospore(s)

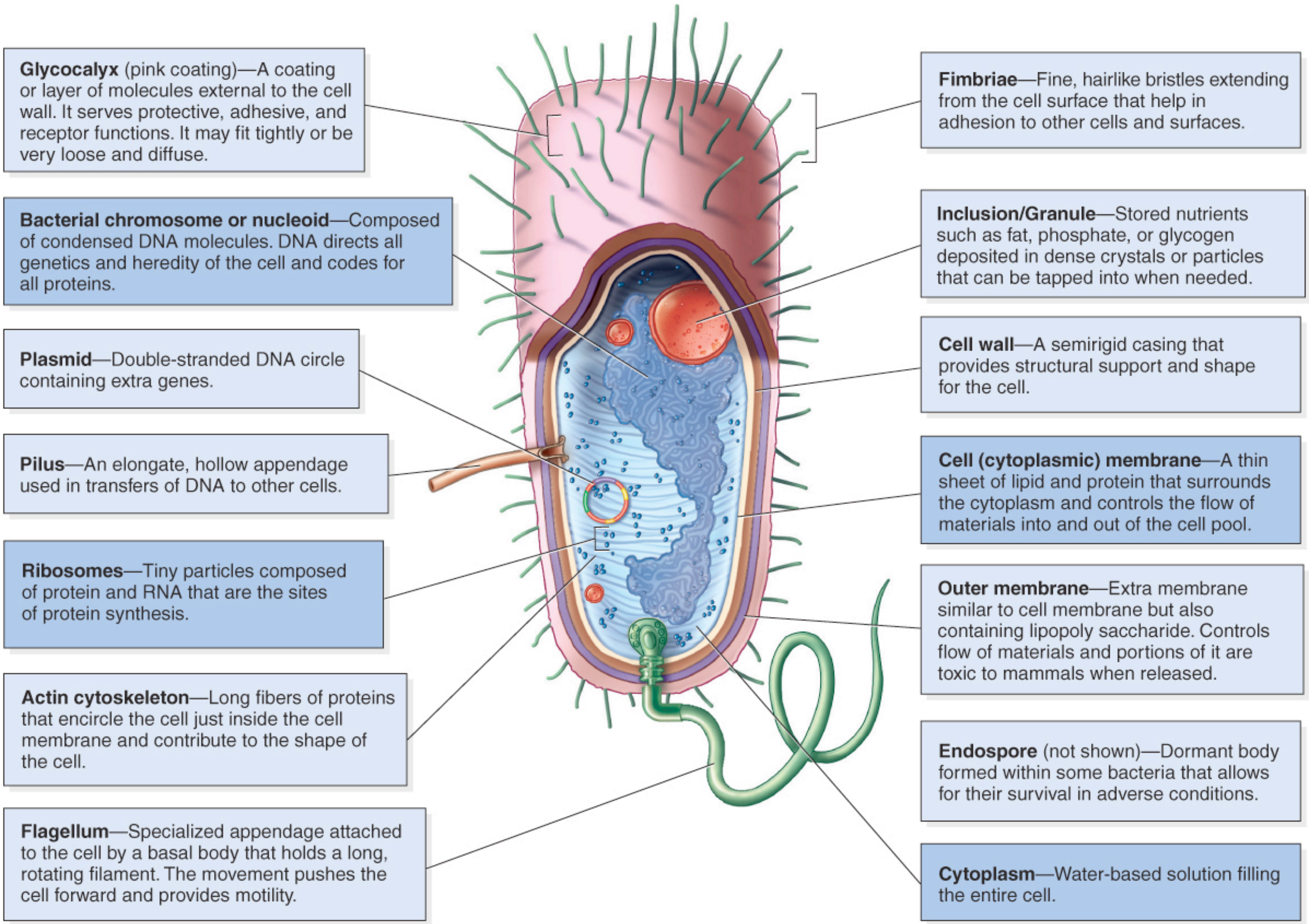

Glycocalyx (pink coating)—A coating or layer of molecules external to the cell wall. It serves protective, adhesive, and receptor functions. It may fit tightly or be very loose and diffuse.
Bacterial chromosome or nucleoid—Composed of condensed DNA molecules. DNA directs all genetics and heredity of the cell and codes for all proteins.
Plasmid—Double-stranded DNA circle containing extra genes.
Pilus—An elongate, hollow appendage used in transfers of DNA to other cells.
Ribosomes—Tiny particles composed of protein and RNA that are the sites of protein synthesis.
Actin cytoskeleton—Long fibers of proteins that encircle the cell just inside the cell membrane and contribute to the shape of the cell.
Flagellum—Specialized appendage attached to the cell by a basal body that holds a long, rotating filament. The movement pushes the cell forward and provides motility.
Fimbriae—Fine, hairlike bristles extending from the cell surface that help in adhesion to other cells and surfaces.
Inclusion/Granule—Stored nutrients such as fat, phosphate, or glycogen deposited in dense crystals or particles that can be tapped into when needed.
Cell wall—A semirigid casing that provides structural support and shape for the cell.
Cell (cytoplasmic) membrane—A thin sheet of lipid and protein that surrounds the cytoplasm and controls the flow of materials into and out of the cell pool.
Outer membrane—Extra membrane similar to cell membrane but also containing lipopoly saccharide. Controls flow of materials and portions of it are toxic to mammals when released.
Endospore (not shown)—Dormant body formed within some bacteria that allows for their survival in adverse conditions.
Cytoplasm—Water-based solution filling the entire cell.

Figure 4.1

4.2 External Structures

- **Appendages**: Cell extensions
  - Common but not present on all species
  - Can provide **motility** (**flagella** or axial filaments)
  - Can be used for attachment (**flagella, pili** and **fimbriae**) and mating (**pili**)

Flagellum (~a)

- Three parts: **Filament**, hook (sheath), and basal body
- Vary in both number and arrangement
  - Polar arrangement: flagella attached at one or both ends of the cell
    - **Monotrichous** - single flagellum (polar)
    - **Lophotrichous** - small bunches or tufts of flagella emerging from the same site (polar)
    - **Amphitrichous** - single flagellum, small bunches or tufts of flagella emerging from two sites
    - **Peritrichous** - dispersed randomly all over the cell

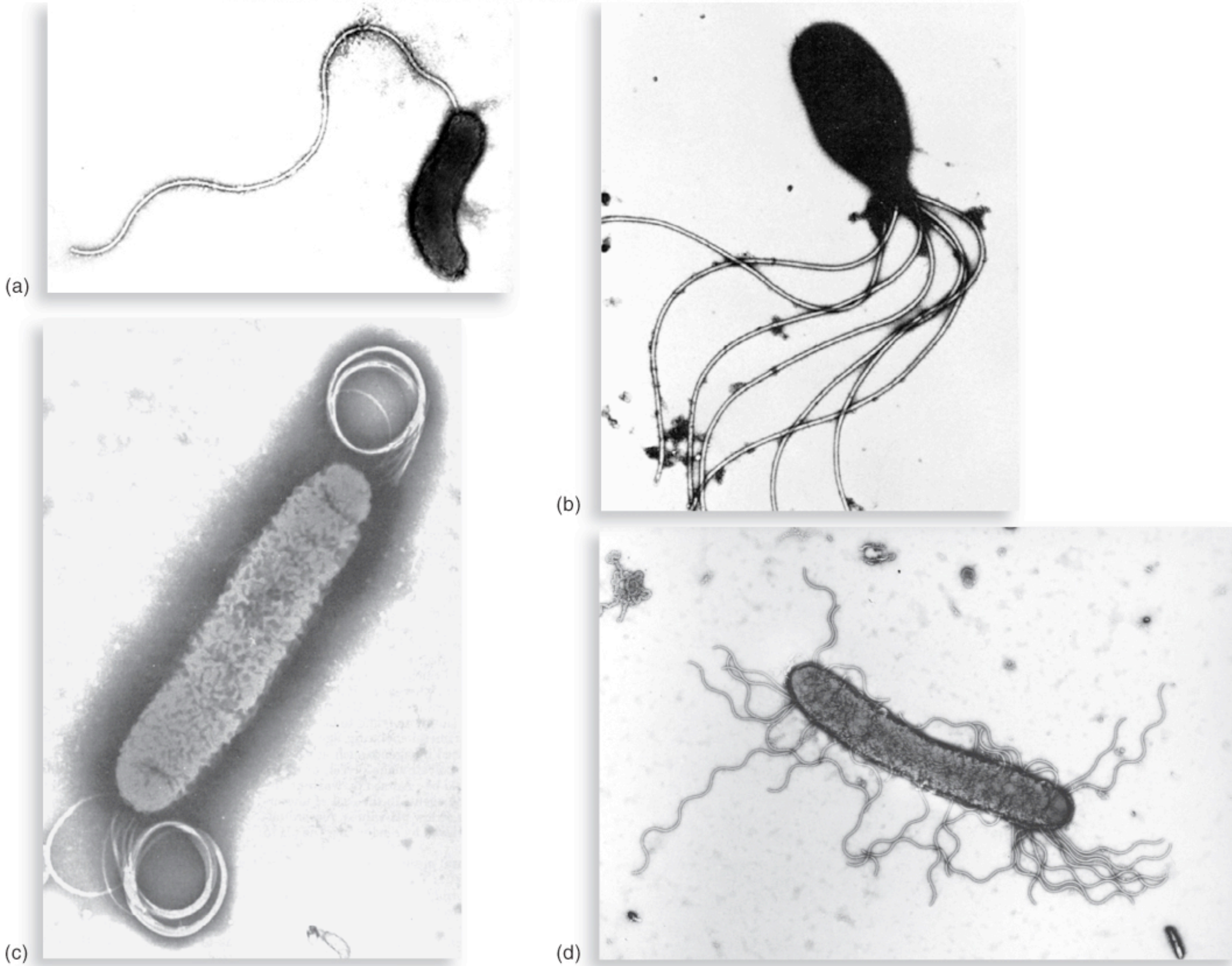


Figure 4.3

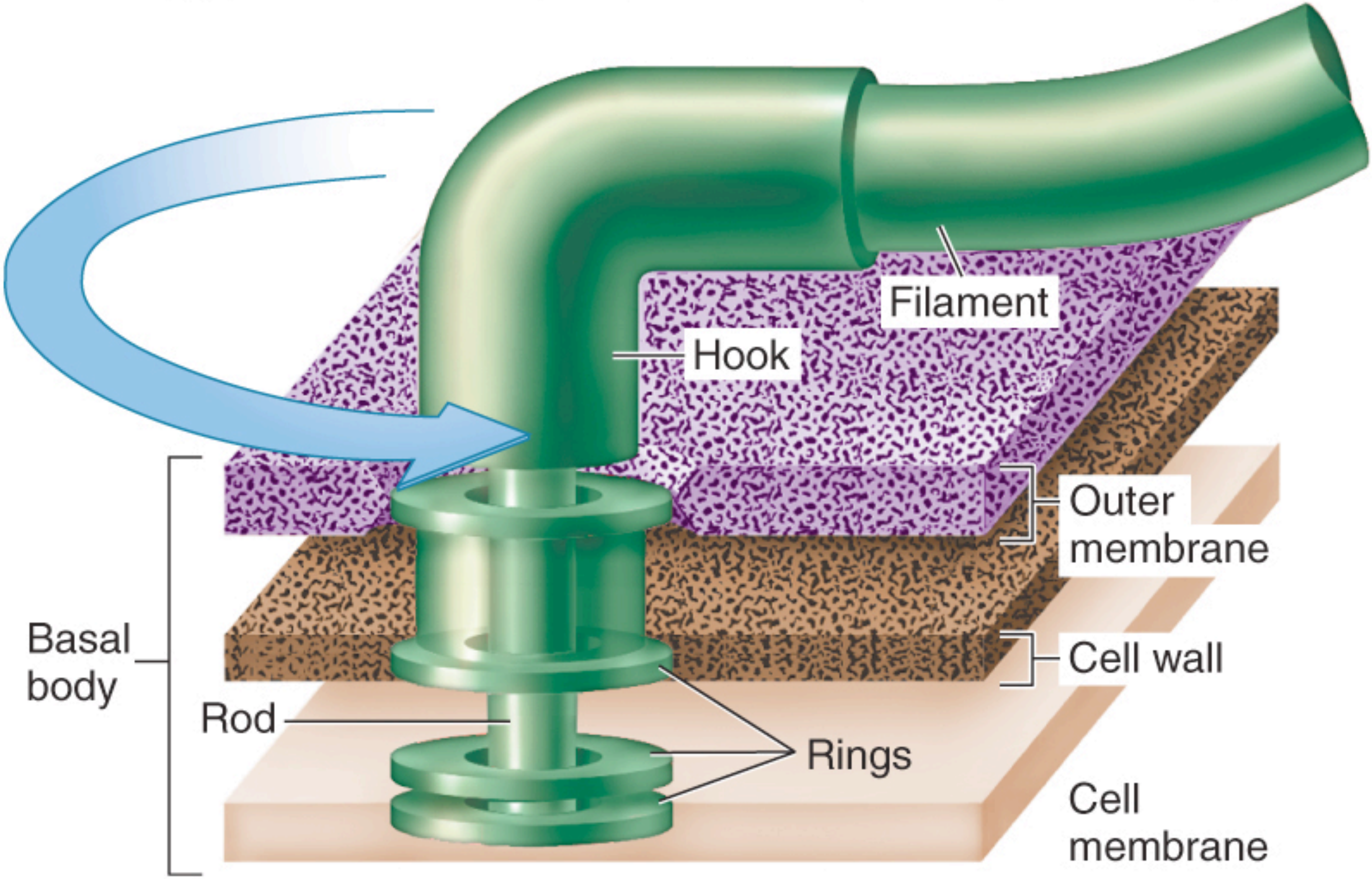

Filament
Hook
Outer membrane
Cell wall
Basal body
Rod
Rings
Cell membrane

Figure 4.2

Flagellar Function

- **Chemotaxis-** positive and negative
- **Phototaxis**
- Move by runs and tumbles

The rotation of the flagella enables bacteria to be motile.

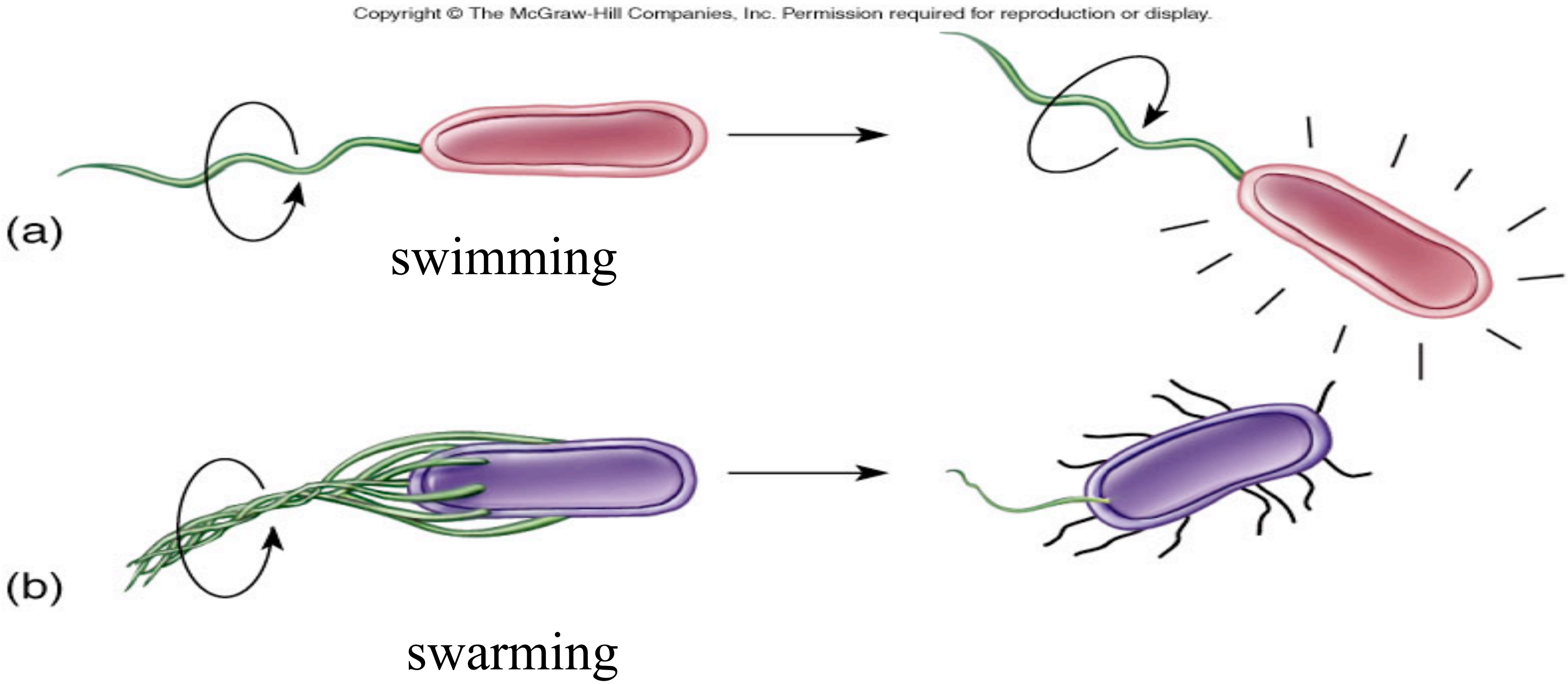
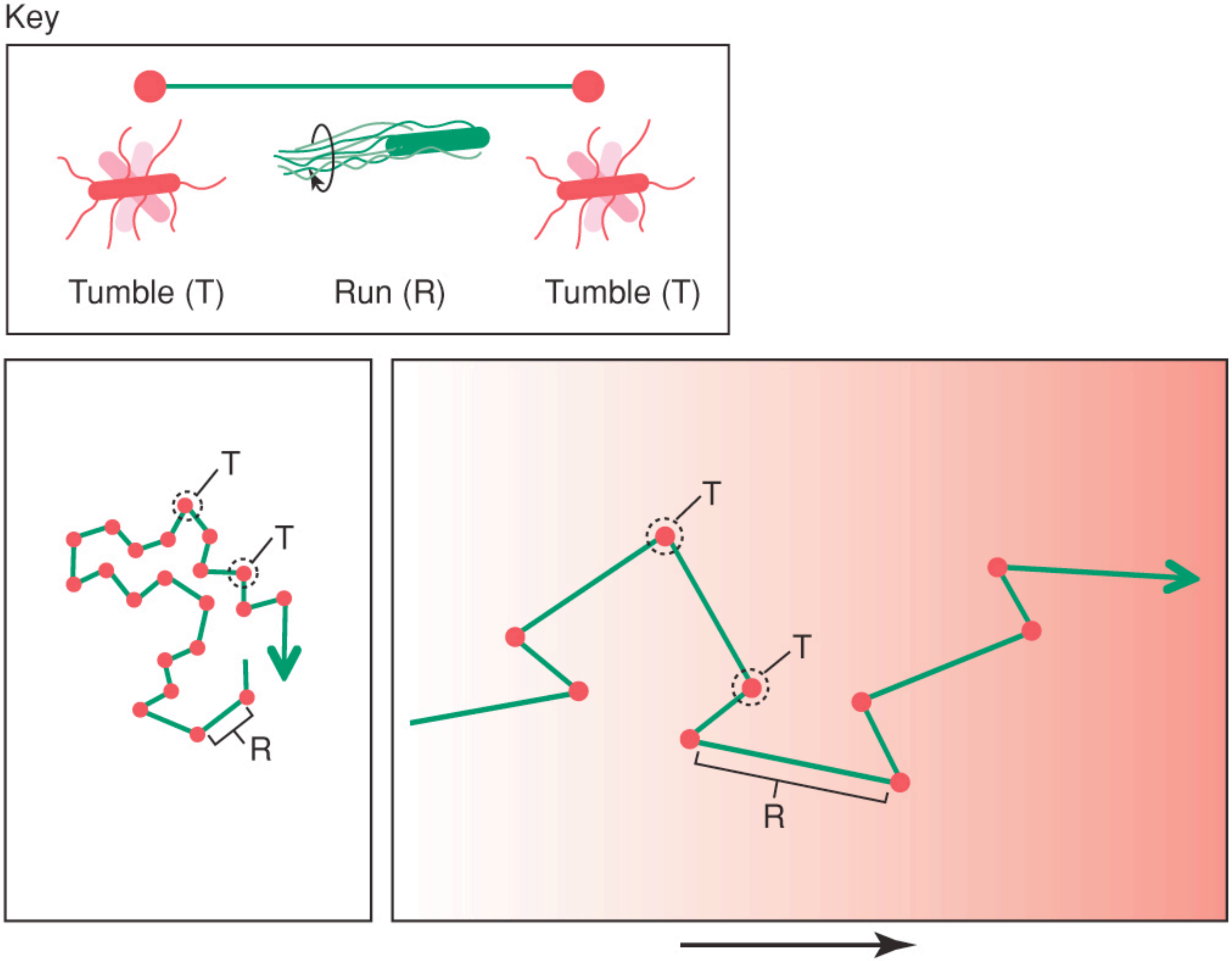


Fig. 4.4 The operation of flagella and the mode of locomotion in bacteria with polar and peritrichous flagella.



(a) No attractant or repellent **(b)** Gradient of attractant concentration

Figure 4.5

Chemotaxis is the movement of bacteria in response to chemical signals.

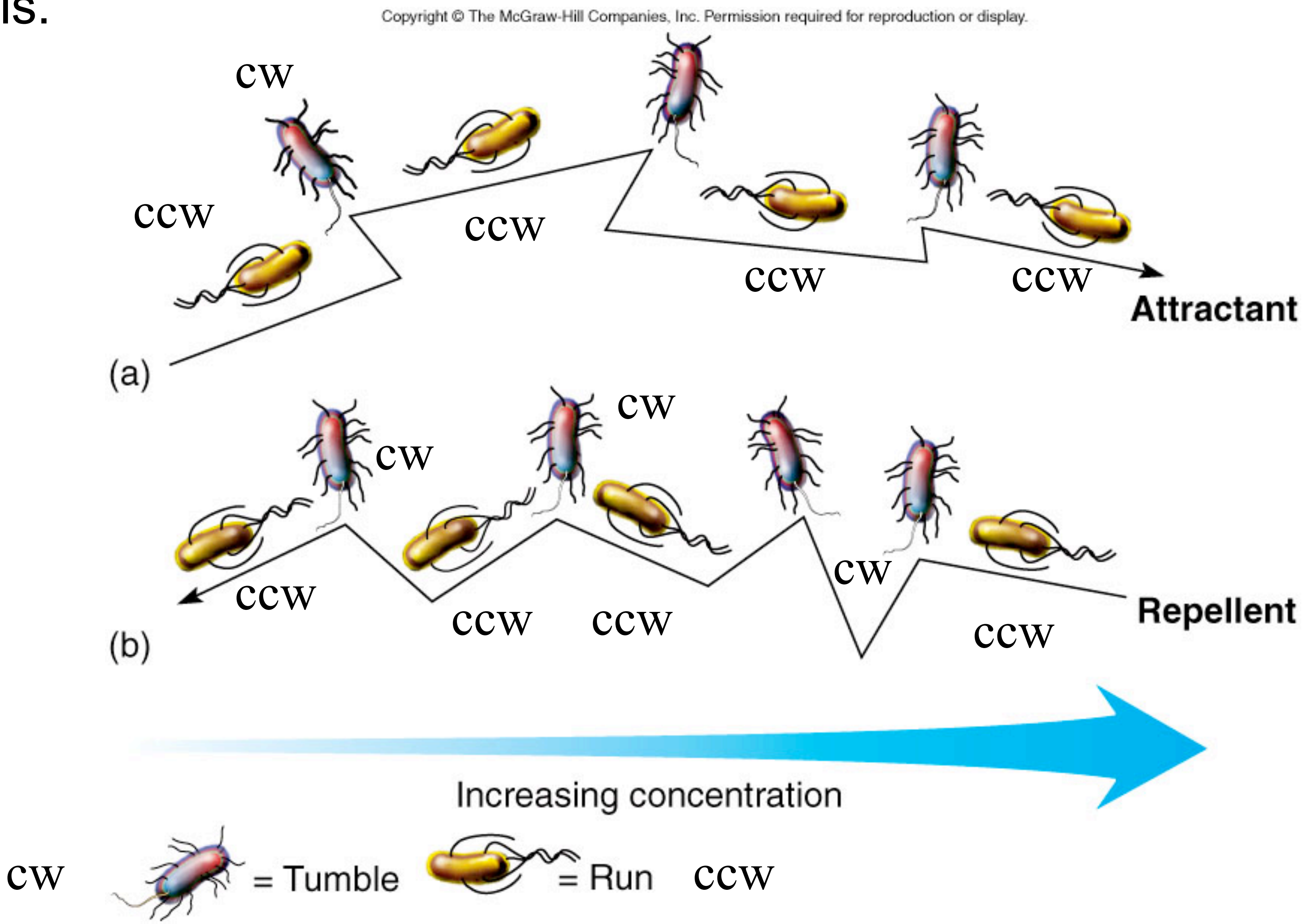


Fig. 4.5 Chemotaxis in bacteria

Axial Filaments

- AKA periplasmic flagella
- In spirochetes
- A type of internal flagellum that is enclosed in the space between the cell wall and the cell membrane

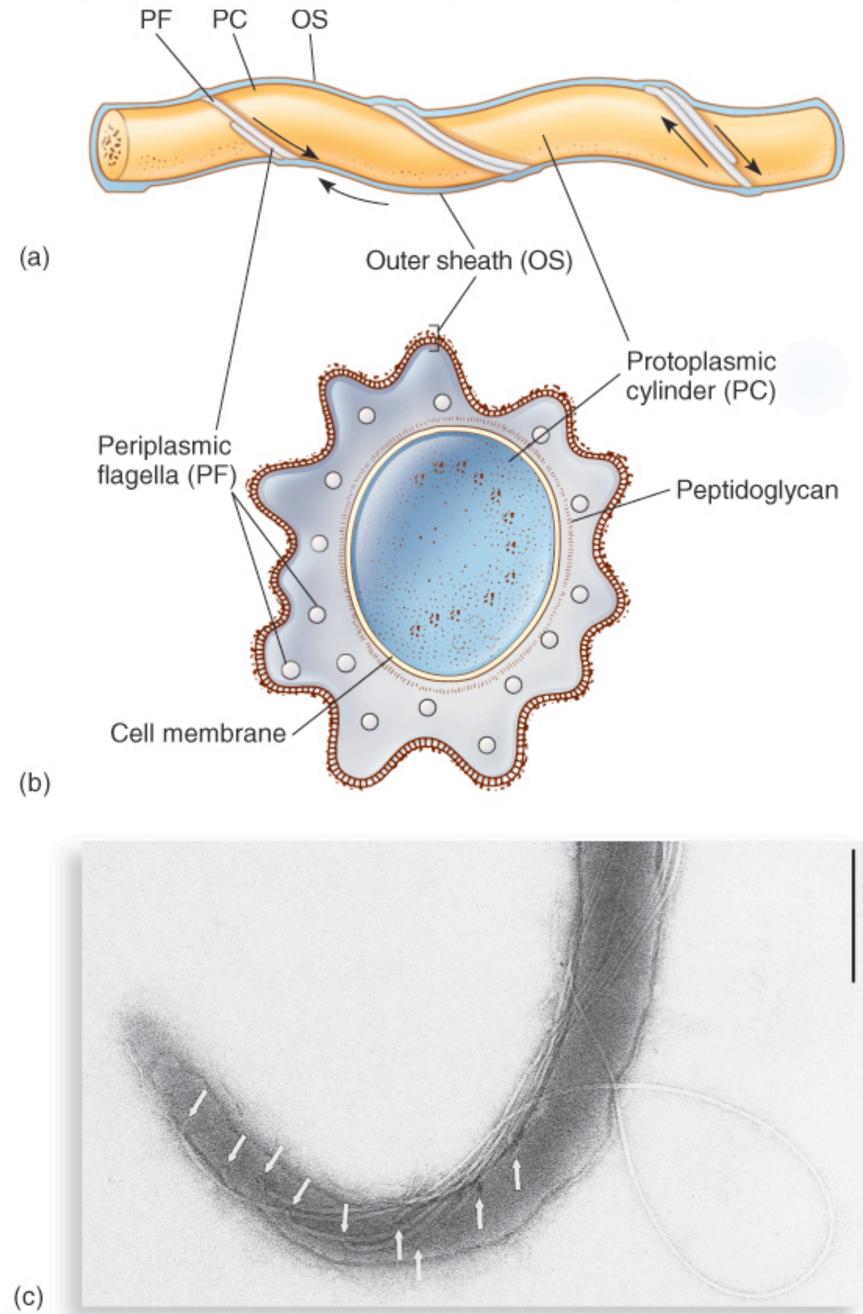

PF
PC
OS
(a)
Outer sheath (OS)
Protoplasmic cylinder (PC)
Periplasmic flagella (PF)
Peptidoglycan
Cell membrane
(b)
(c)

Figure 4.6

Pili

- Elongate, rigid tubular structures
- Made of the protein pilin
- Found on Gram-negative bacteria
- One special kind is used in **conjugation**

Pili enable conjugation to occur, which is the transfer of DNA from one bacterial cell to another.

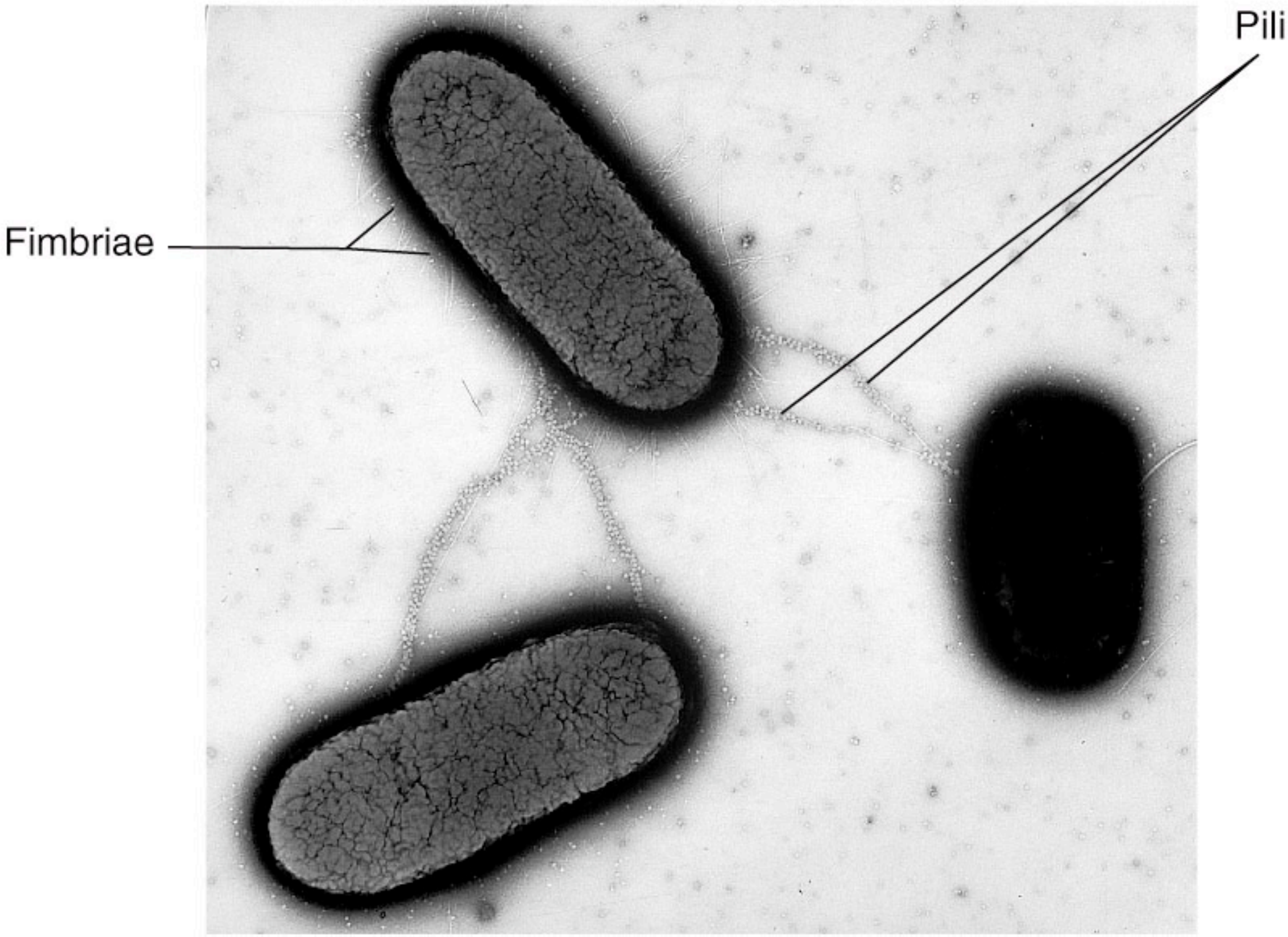
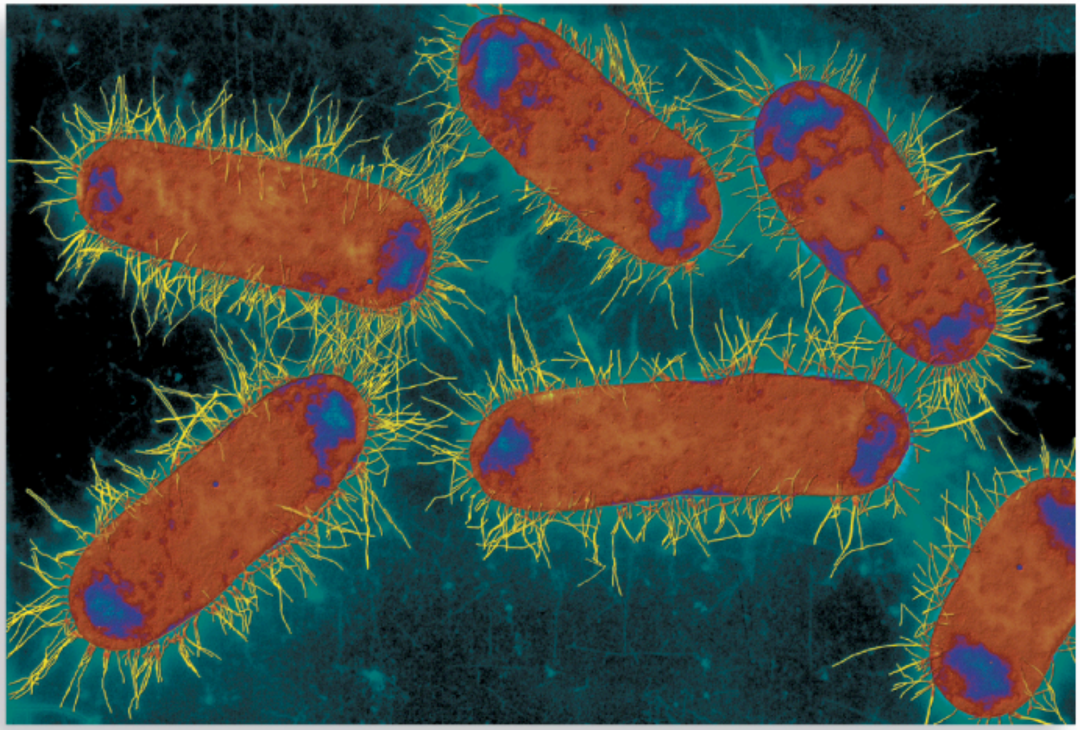


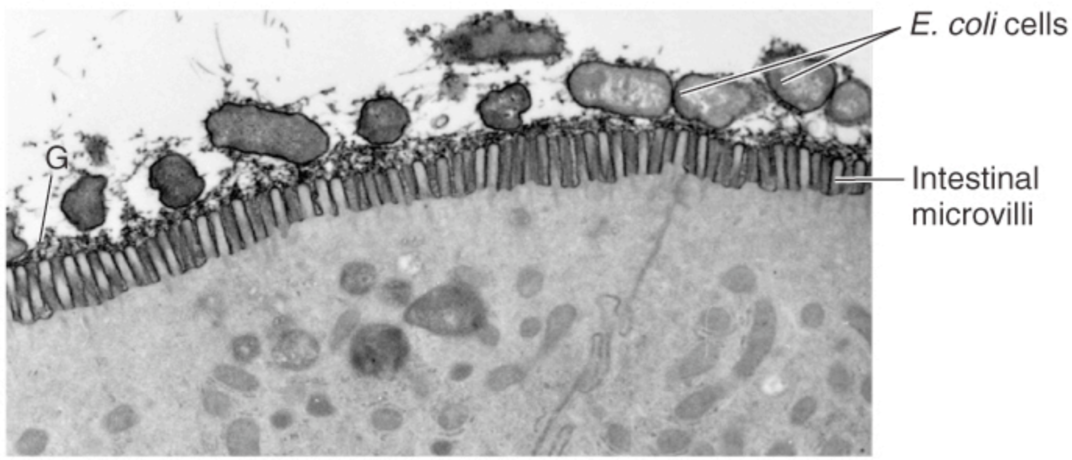
Fig. 4.8 Three bacteria in the process of conjugating ("threesome")

Fimbriae

- Small, bristlelike fibers
- Most contain protein
- Tend to stick to each other and to surfaces



(a)



(b)

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Figure 4.7

“Cell envelope” (*in sensu lato*) sloppy term that distracts from principles of cell architecture

- Glycocalyx

- Cell wall
  - Gram-positive
  - Gram-negative
- Non cell wall

- Cytoplasmic (Cell, Plasma) membrane

The **Glycocalyx**

- Develops as a coating of repeating polysaccharide units, protein, or both
- Protection (drought, pressure, immune stress)
- Sometimes helps the cell adhere to the biotic and abiotic environment (**attachment** & **aggregation**)
- Differs among bacteria in thickness, organization, and chemical composition
  - **Slime layer** - a loose shield that protects some bacteria from loss of water and nutrients
  - **Capsule** - when the glycocalyx is bound more tightly to the cell and is denser and thicker

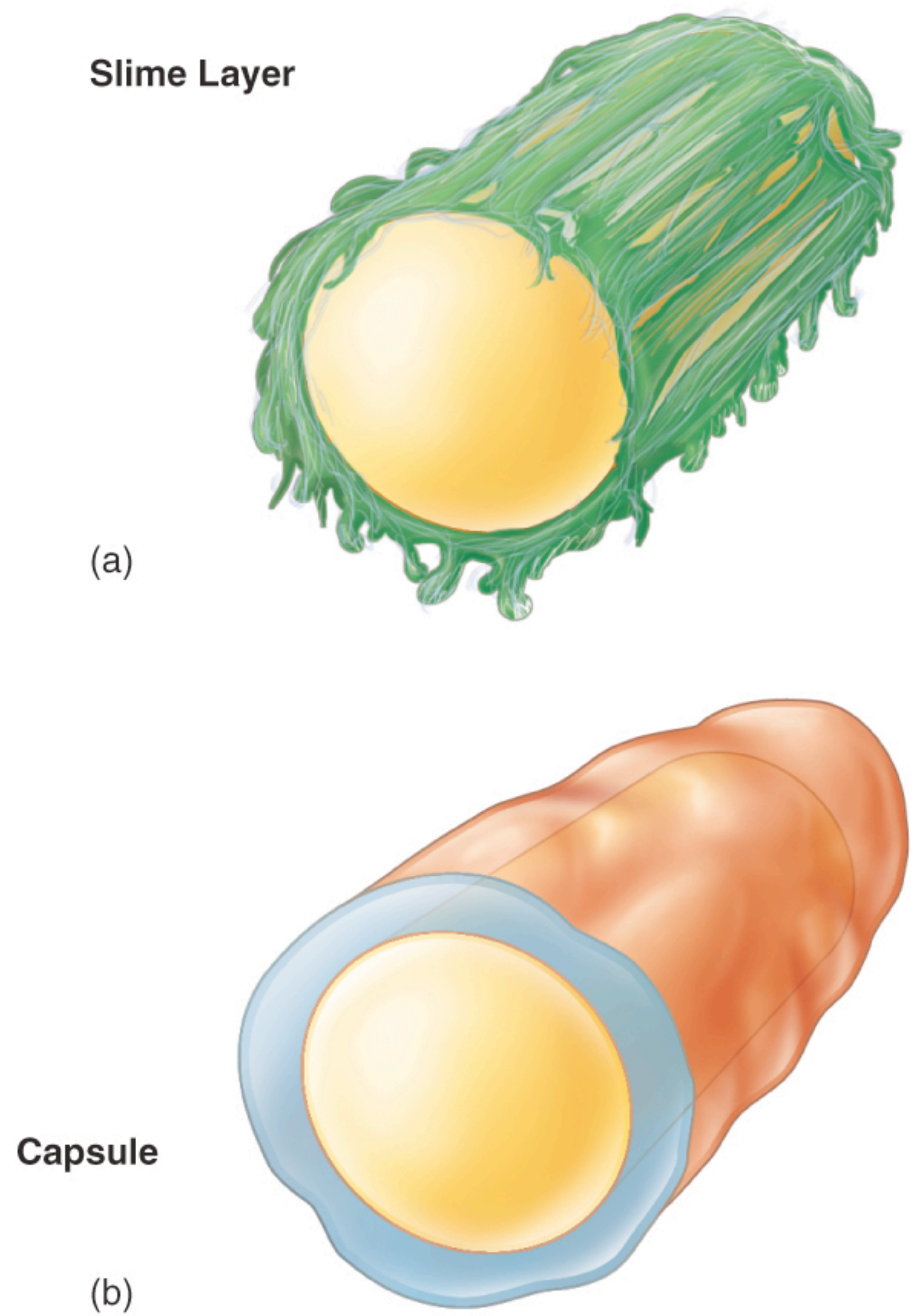


Figure 4.9

The capsule is tightly bound to the cell, and is associated with pathogenic bacteria.

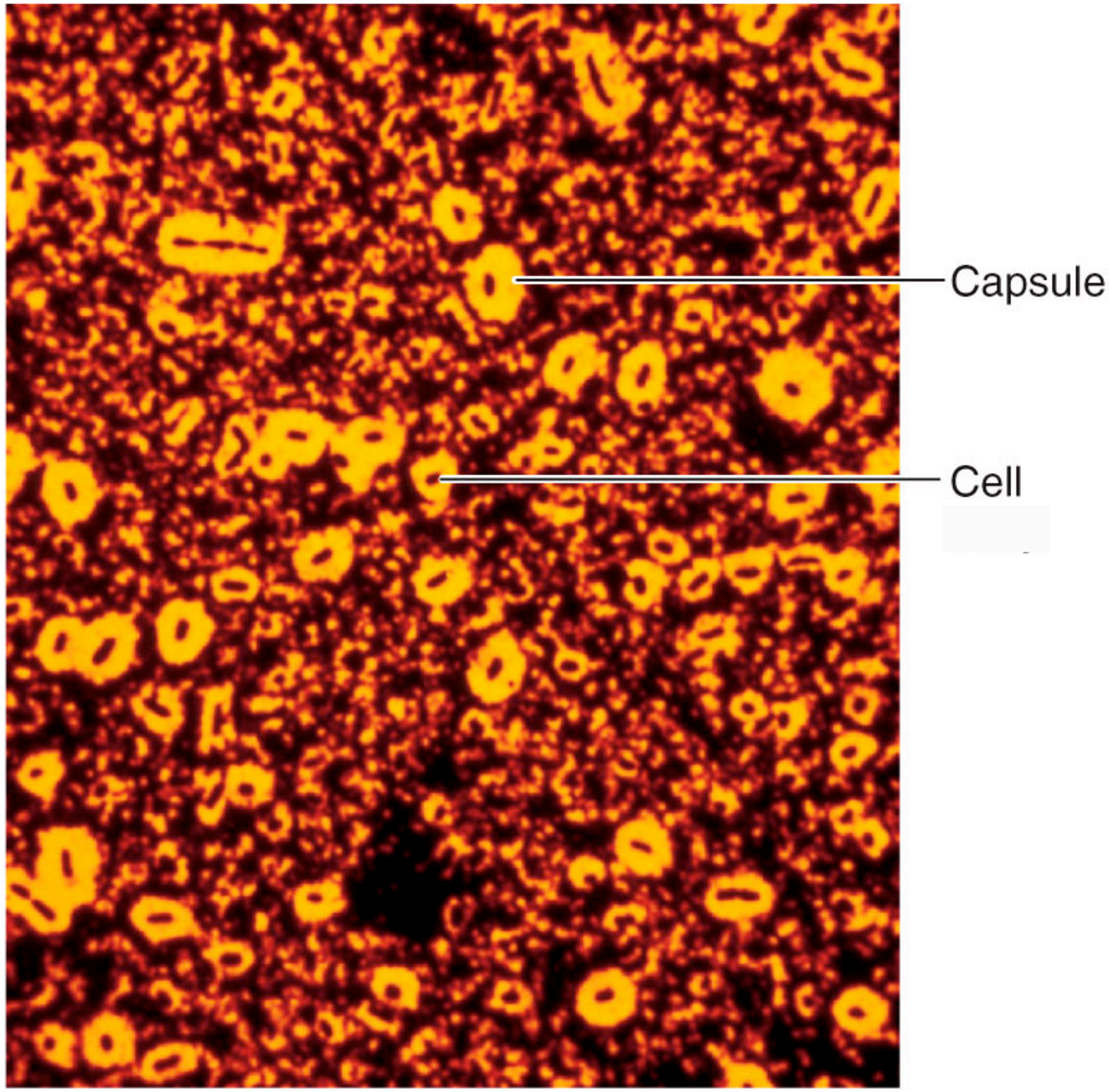


Fig. 4.10 Encapsulated bacteria

The slime layer is associated with the formation of biofilms, which are typically found on teeth.

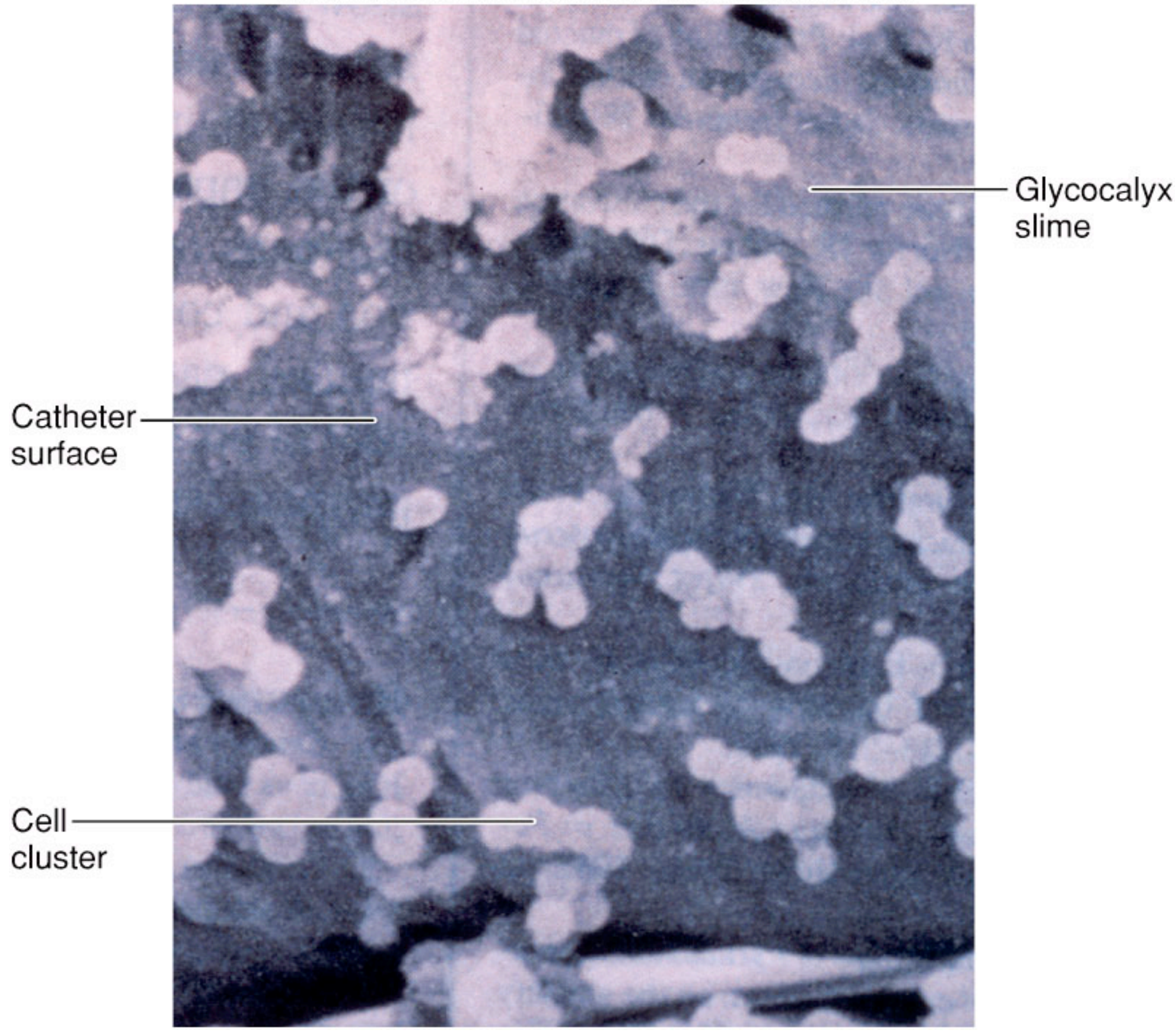


Fig. 4.11 Biofilm

Functions of the Glycocalyx

- Formed by many pathogenic bacteria- protect the bacteria against phagocytes
- Important in formation of biofilms

4.3 The Cell Envelope: The boundary layer of Bacteria

- Book says: "**Majority of bacteria have a cell envelope**
- Cell envelope lies outside of the cytoplasm
- Is composed of two or three basic layers
  - Cell wall
  - Cell membrane
  - In some bacteria, the outer membrane"
- **THIS IS WRONG!!!!!!!**

“Differences in Cell Envelope Structure

- The differences between **Gram-positive** and **Gram-negative** bacteria lie in the cell envelope
- Gram-positive
  - Two layers
  - Cell wall and cytoplasmic membrane
- Gram-negative
  - Three layers
  - Outer membrane, cell wall, and cytoplasmic membrane”
- **THIS IS WRONG!!!!!!!**

“Cell envelope” *in sensu stricto* is the **Cell Wall**

The Cytoplasmic (Cell, Plasma) **Membrane**

is an ESSENTIAL STRUCTURE that ALL cells (bacteria, archaea, eukaryotes) have to have!

Bacteria may or may not have a Glycocalyx and/ or a Cell Wall

===>

- Cell wall
  - Gram-positive
  - Gram-negative
- Non cell wall

Architecture of the **Cell Wall**

- Helps determine the shape of a bacterium
- Provides strong structural support
- Most are rigid because of peptidoglycan scaffold

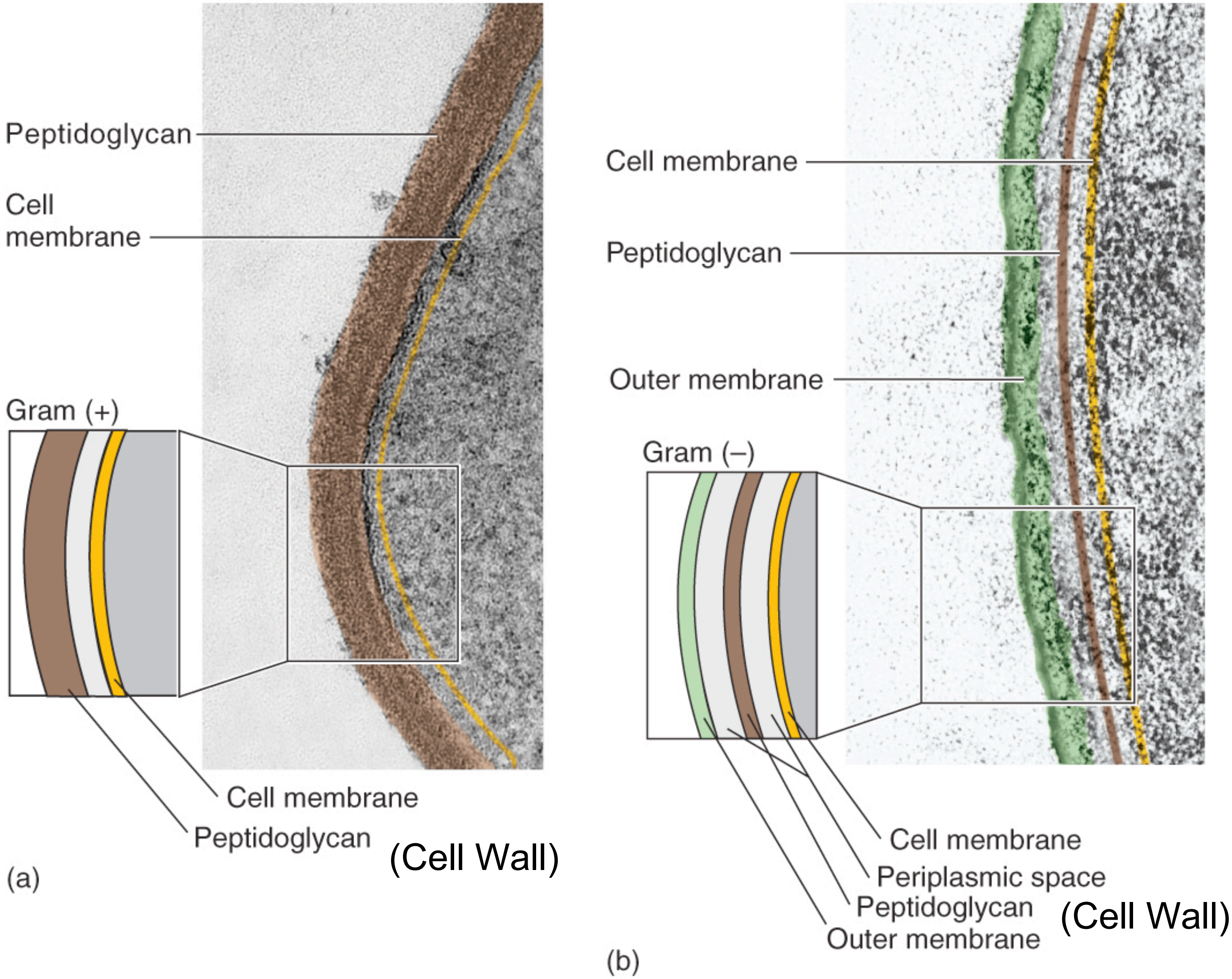
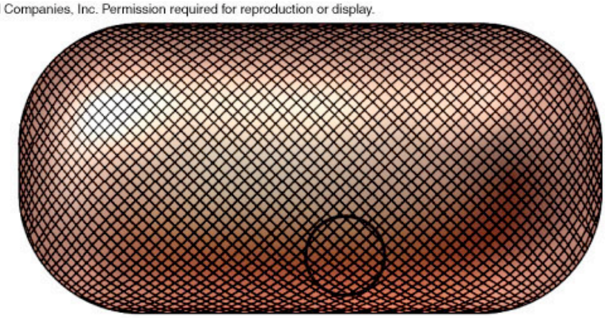

Peptidoglycan
Cell membrane
Gram (+)
Cell membrane
Peptidoglycan
(Cell Wall)
(a)
Cell membrane
Peptidoglycan
Outer membrane
Gram (–)
Cell membrane
Periplasmic space
Peptidoglycan
Outer membrane
(Cell Wall)
(b)

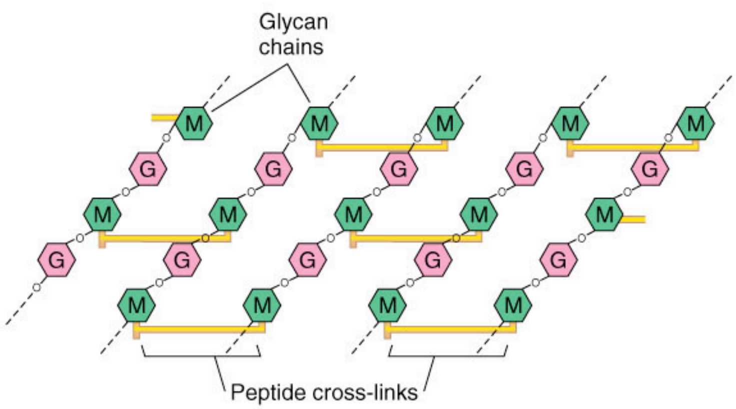
Figure 4.12

PG is a complex amino-sugar and peptide structure important for cell wall stability and shape.

(a) The peptidoglycan of a cell wall can be seen as a crisscross network pattern similar to a chain-link fence, forming a single massive molecule that molds the outer structure of the cell into a tight box.



(b) An idealized view of the molecular pattern of peptidoglycan. It contains alternating glycans (G and M) bound together in long strands. The G stands for N-acetyl glucosamine, and the M stands for N-acetyl muramic acid. A muramic acid molecule binds to an adjoining muramic acid on a parallel chain by means of a cross-linkage of peptides.



(c) A detailed view of the links between the muramic acids. Tetrapeptide chains branching off the muramic acids connect by interbridges also composed of amino acids. The types of amino acids in the interbridge can vary and it may be lacking entirely (gram-negative cells). It is this linkage that provides rigid yet flexible support to the cell and that may be targeted by drugs like penicillin.

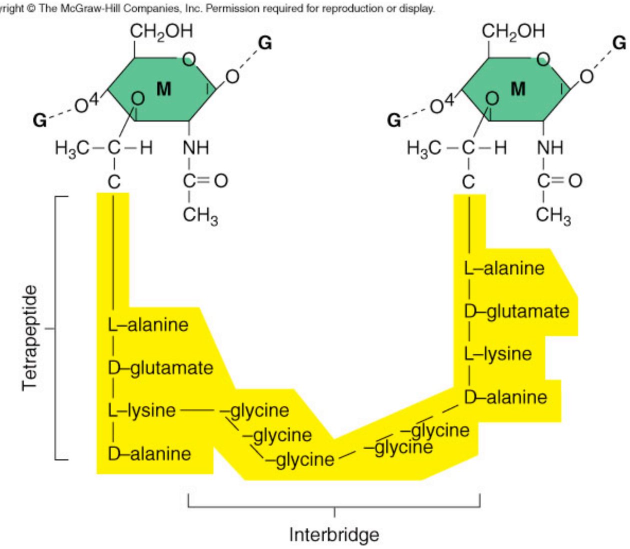


Fig. 4.13 Structure of peptidoglycan in the cell wall

Structure of the Cell Wall, cont.

- Keeps cells from rupturing because of changes in pressure due to osmosis
- Target of many antibiotics- disrupt the cell wall, and cells have little protection from **lysis**
- Gram-positive cell wall
  – A thick (20 to 80 nm), homogeneous sheath of petidoglycan
  – Contains tightly bound acidic polysaccharides
- Gram-negative Cell Wall
  – Single, thin (1 to 3 nm) sheet of peptidoglycan
  – Periplasmic space surrounds the peptidoglycan

Structures associated with Gram-positive and Gram-negative cell walls.

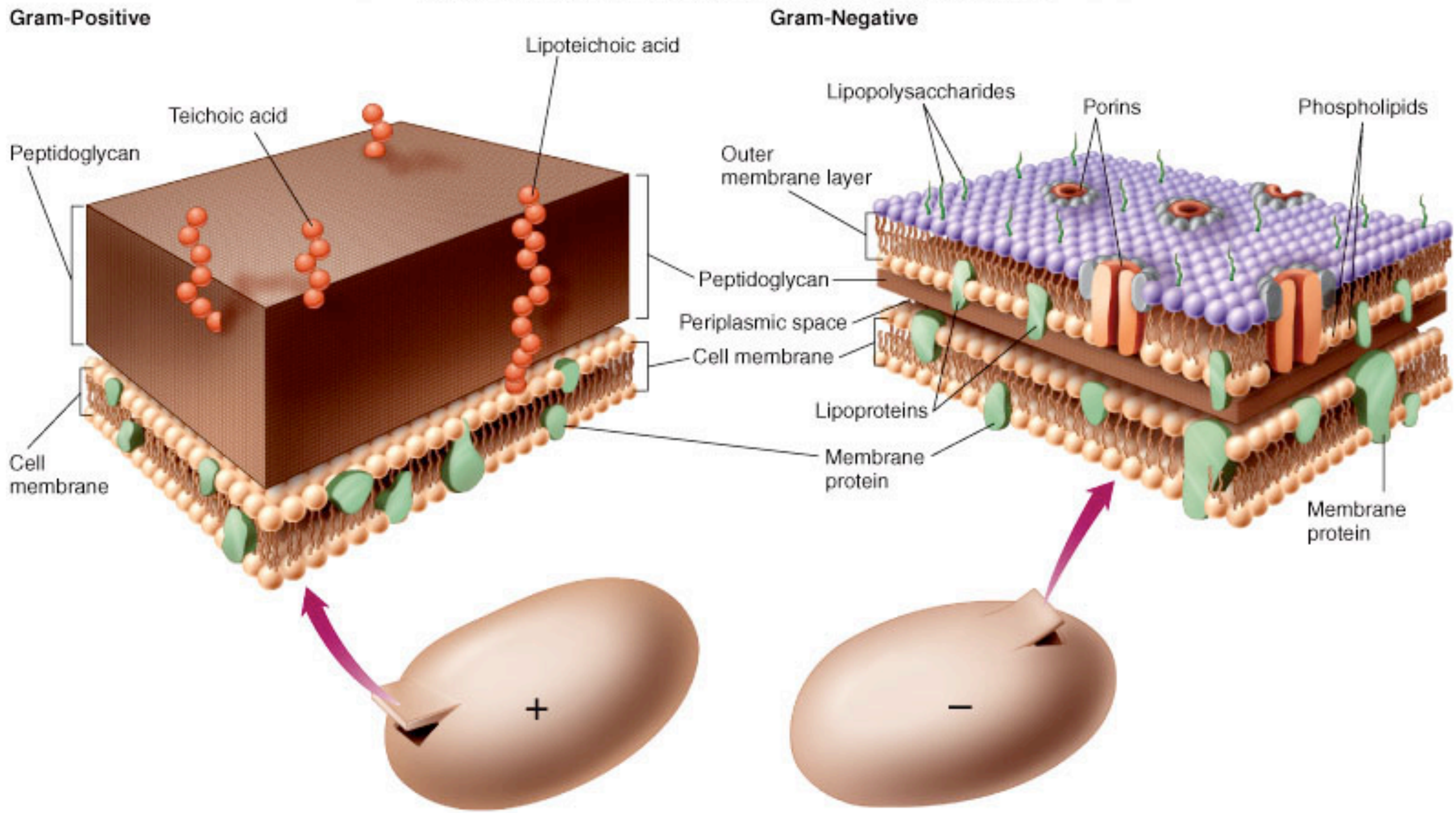


Fig. 4.14 A comparison of the detailed structure of Gram-positive and Gram-negative cell walls.

Cell wall

- Gram positive cell wall
  - Thick peptidoglycan (PG) layer (90%)
  - Acidic polysaccharides
  - (wall) teichoic acid and lipoteichoic acid
- Gram-negative cell wall
  - Thin PG layer (10%)
  - Outer membrane
  - Lipopolysaccharide (LPS = “Endotoxin”)
  - Porins

Nontypical Cell Walls

- Some aren't characterized as either gram-positive or gram-negative
- Some don't have a cell wall at all
- For example, *Mycobacterium* and *Nocardia* - have unique types of lipids in Outer Membrane but are classified as Gram-positive
- Archaea - unusual and chemically distinct cell walls
- **Mycoplasma(s)**- lack(s) cell wall entirely

Mycoplasmas and Other Cell-Wall-Deficient Bacteria

- Mycoplasma cell membrane is stabilized by sterols and is resistant to lysis
  - Very small bacteria (0.1 to 0.5 μm) !!!
  - Range in shape from filamentous to coccus !!!
  - Live in isotonic environments !!!
  - Non-obligate parasites

  - Can be grown on artificial media
  - Found in many habitats
  - Important medical species: *Mycoplasma pneumonia*

Mycoplasma bacteria have no cell wall, which contributes to varied shapes.

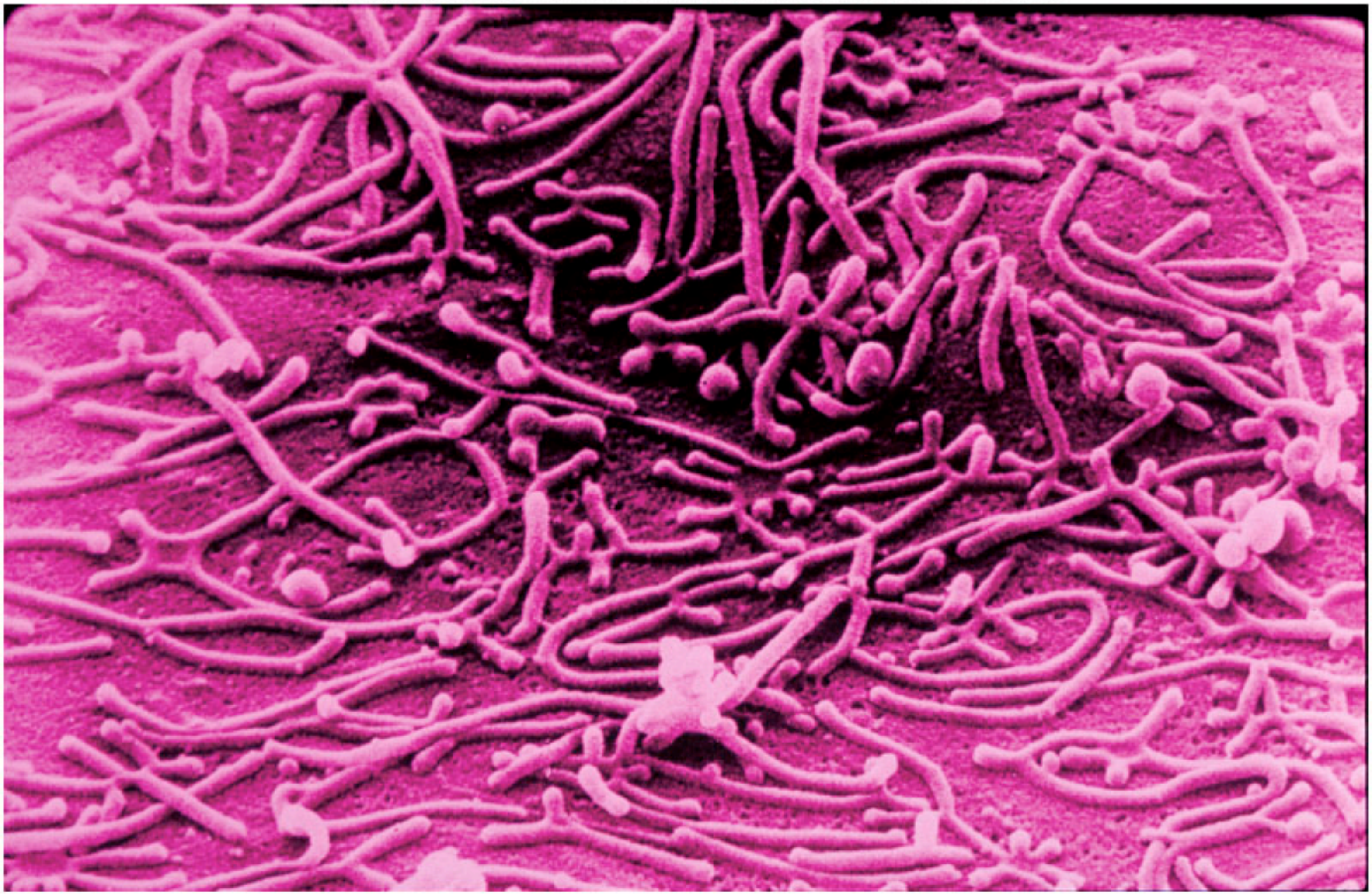


Fig. 4.15 Scanning electron micrograph of *Mycoplasma pneumoniae*

- Some bacteria lose their cell wall during part of their life cycle
  - **L-forms**
  - Arise naturally from a mutation in the cell wall-forming genes
  - Can be induced artificially by treatment with a chemical that disrupts the cell wall
    - When this occurs with Gram-positive cells, the cell becomes a **protoplast**
    - With Gram-negative cells, the cell becomes a **spheroplast**

Mutations can cause some bacteria to lose the ability to synthesize the cell wall, and are called L forms.

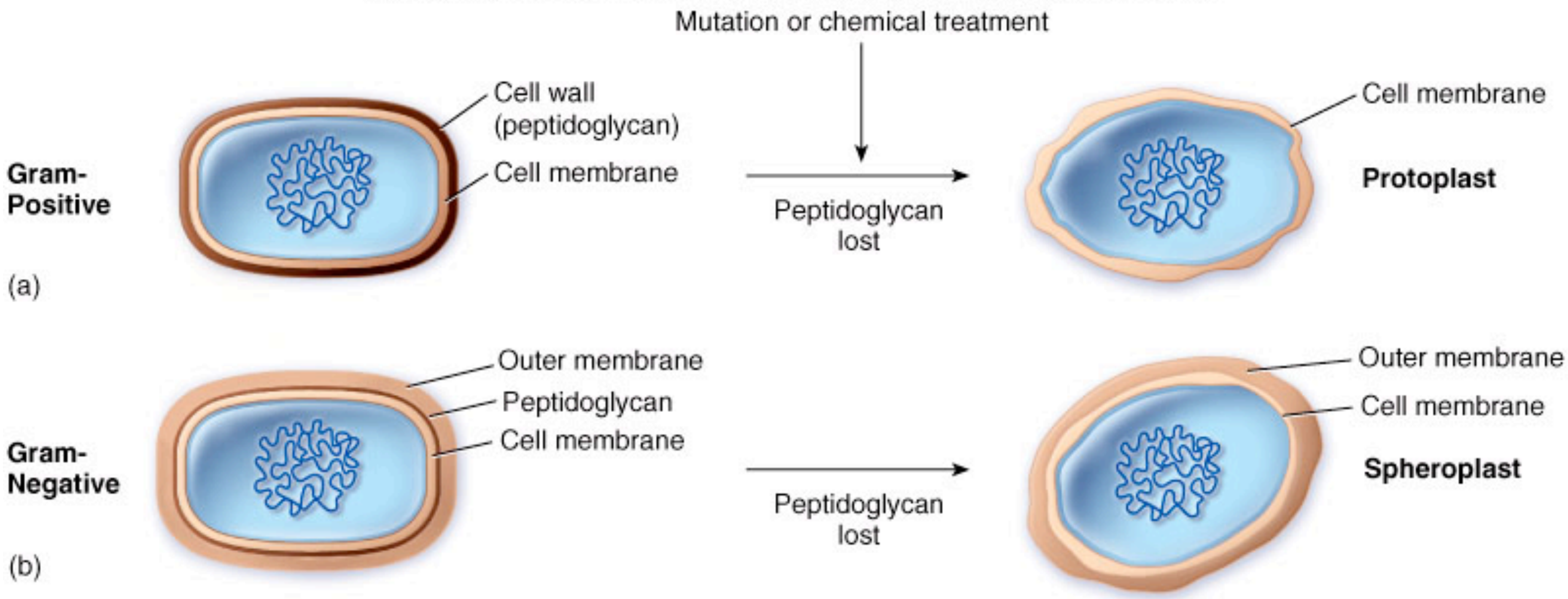


Fig. 4.16 The conversion of walled bacterial cells to L forms

The Gram-Negative **Outer Membrane (OM)**

- Bilayer like cell membrane, BUT it contains
  - specialized polysaccharides and proteins
  - outermost layer - contains lipopolysaccharide
  - Innermost layer - phospholipid layer anchored by lipoproteins to the peptidoglycan layer below
- OM serves as a chemical sieve (filter)
  - Only relatively small molecules can penetrate
  - Access provided by special membrane channels formed by porin proteins (gated or non-gated)

Cell Membrane

- Also known as the **cytoplasmic membrane**
- Very thin (5-10 nm)
- Contain primarily phospholipids, proteins and
  – Hopanes (hopanoids) or
  – sterols mycoplasmas
- The exceptions: mycoplasmas and archaea
- Functions
  – Provides a site for functions such as energy reactions, nutrient processing, and synthesis
  – Regulates transport (selectively permeable membrane)
  – Facilitates communication

Transport systems are essential to every living cell.

They

(1) allow the entry of all essential nutrients into the cell and its compartments,

(2) regulate the cytoplasmic concentrations of metabolites by excretion mechanisms,

(3) provide physiological cellular concentrations of ions that can differ by several orders of magnitude from those in the external medium,

(4) export macromolecules such as complex carbohydrates, proteins, lipids, and DNA,

(5) catalyze export and uptake of signaling molecules that mediate intercellular communications,

(6) prevent toxic effects of drugs and toxins by mediating active efflux, and

(7) participate in biological warfare by exporting biological active agents that insert into or permeate the membranes of target cells.

Transport is an essential aspect of all life-endowing processes: **catabolism, biosynthesis, communication, reproduction, and both cooperative and antagonistic inter-organismal behaviors.**

Practical Considerations of Differences in Cell Envelope Structure

- OM - an extra barrier in Gram-negative bacteria
  - Makes them impervious to some antimicrobials
  - Generally, makes Gram-negative bacteria more difficult to injure or kill than Gram-positive bacteria
- “Cell envelope” can interact with host cell and tissues surfaces and facilitate infection
  - *Corynebacterium diphtheriae*
  - *Streptococcus pyogenes*

4.4 Bacterial Internal Structure

- Cytoplasm
- Genetic element
- Inclusion bodies
- Actin
- Endospore

Cytoplasm

- Contents of the Cell **Cytoplasm**
  - Gelatinous solution
  - Site for many biochemical and synthetic activities
  - 70%-80% water
  - 20% - 30% nutrients, proteins, and genetic material (i.e., chromatin, ribosomes, macromolecular storage granules, and actin strands)

Bacterial Chromosome

- Circular or linear double strands of DNA
- Aggregated in a dense area of the cell - called the **nucleoid (chromosome)**

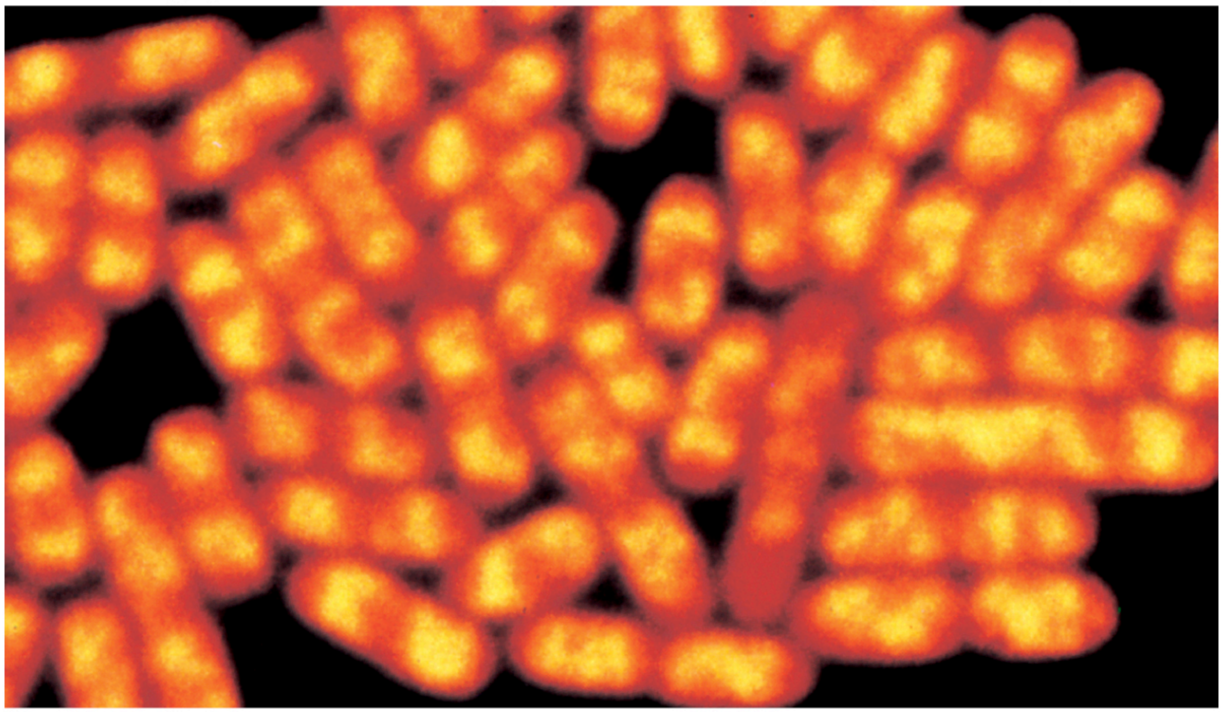


Figure 4.17

Plasmids

- extrachromosomal pieces of DNA
- Double-stranded circles or strands of DNA
- Often confer protective traits such as drug resistance or the production of toxins and enzymes

Ribosomes

- Made of RNA and protein
- Special type of RNA- ribosomal RNA (rRNA)
- Characterized by S units- the prokaryotic ribosome is 70S

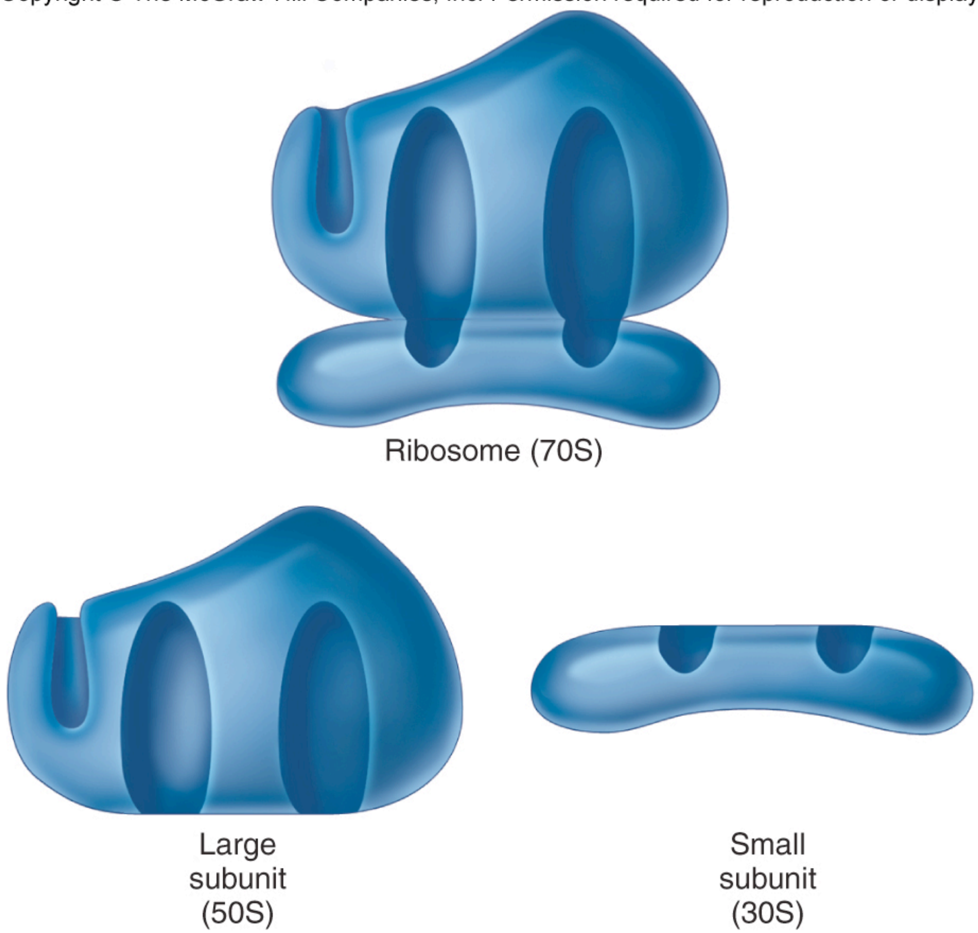


Figure 4.18

Inclusions

- Inclusions- also known as **inclusion bodies**
  - Some bacteria accumulate polymers in these inclusions during periods of nutrient abundance
    - Serve as a storehouse when nutrients become depleted
    - Serve as a storehouse when energy becomes depleted
  - Some aquatic bacterial inclusions include gas vesicles to provide buoyancy and flotation
  - Some inclusions contain entire metabvolic pathways such as carbon fixation (carboxysome) or polymer lysis (cellulosome)

Granules

- A type of inclusion body
- Contain crystals of inorganic compounds
- Are not enclosed by membranes
- Example- sulfur granules of photosynthetic bacteria (serve as storage for reductant)
- Polyphosphate granules of *Corynebacterium* and *Mycobacterium* are called **metachromatic granules** because they stain a contrasting color in methylene blue
- Magnetotactic bacteria contain granules with iron oxide- give magnetic properties to the cell

Figure 4.19

The Actin Cytoskeleton

- Long polymers of **actin**
- Arranged in helical ribbons around the cell just under the cell membrane
- Contribute to cell shape

Actin is a protein fiber (cytoskeleton) present in some bacteria, and is involved in maintaining cell shape.

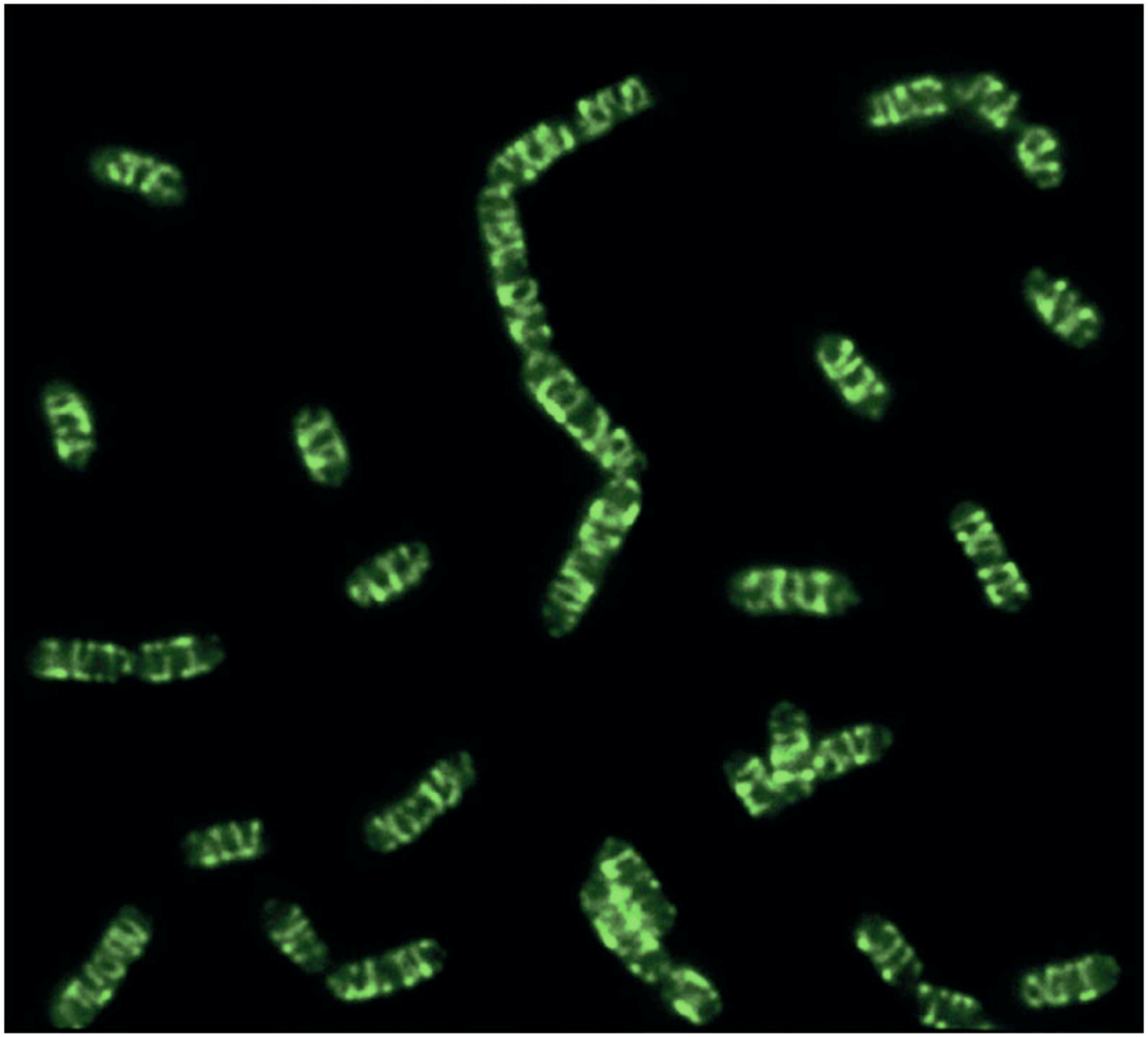


Fig. 4.20 Bacterial cytoskeleton

Bacterial **Endospores**: An Extremely Resistant Resting Stage

- Dormant bodies produced by *Bacillus, Clostridium,* and *Sporosarcina* - Gram-positive low G+C bacteria

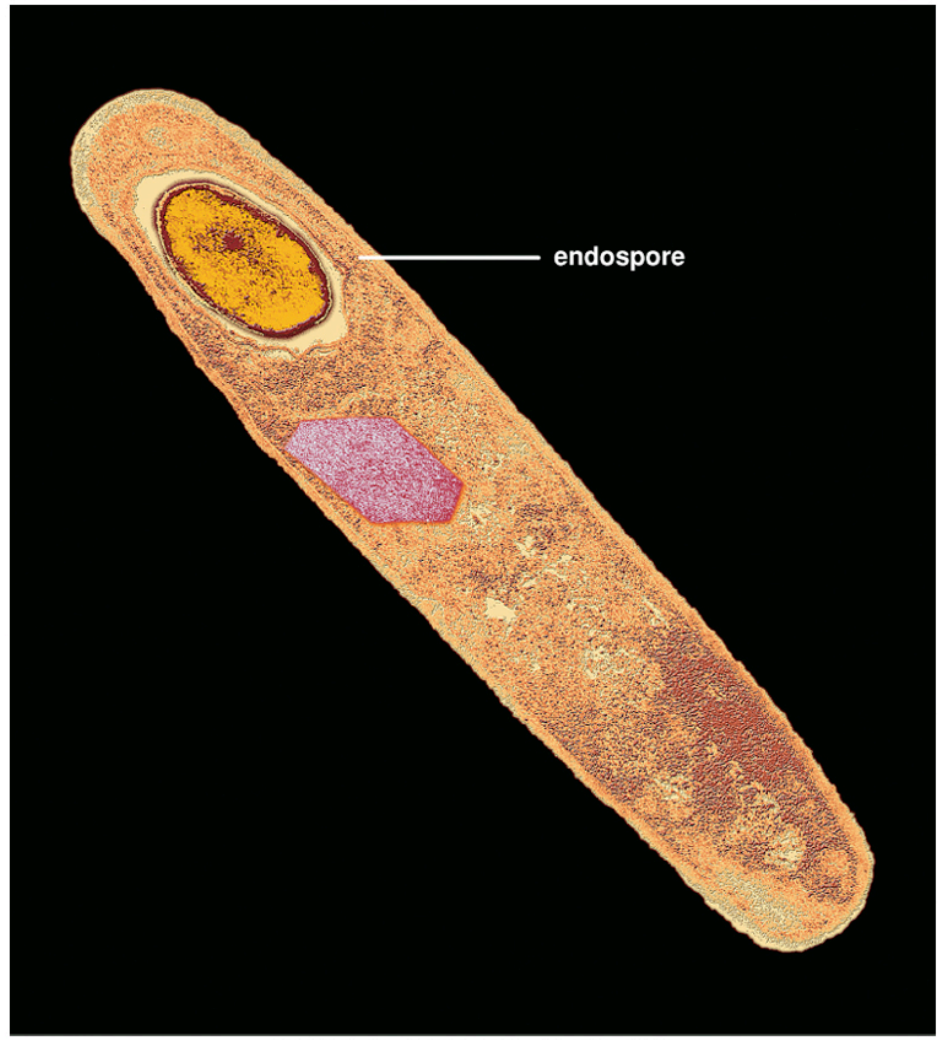
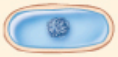
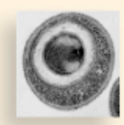
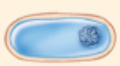


Figure 4.21

Endospore-Forming Bacteria

- These bacteria have a two-phase life cycle
  - Phase One - Vegetative cell
    - Metabolically active and growing
    - Can be induced by the environment to undergo spore formation (**sporulation**)

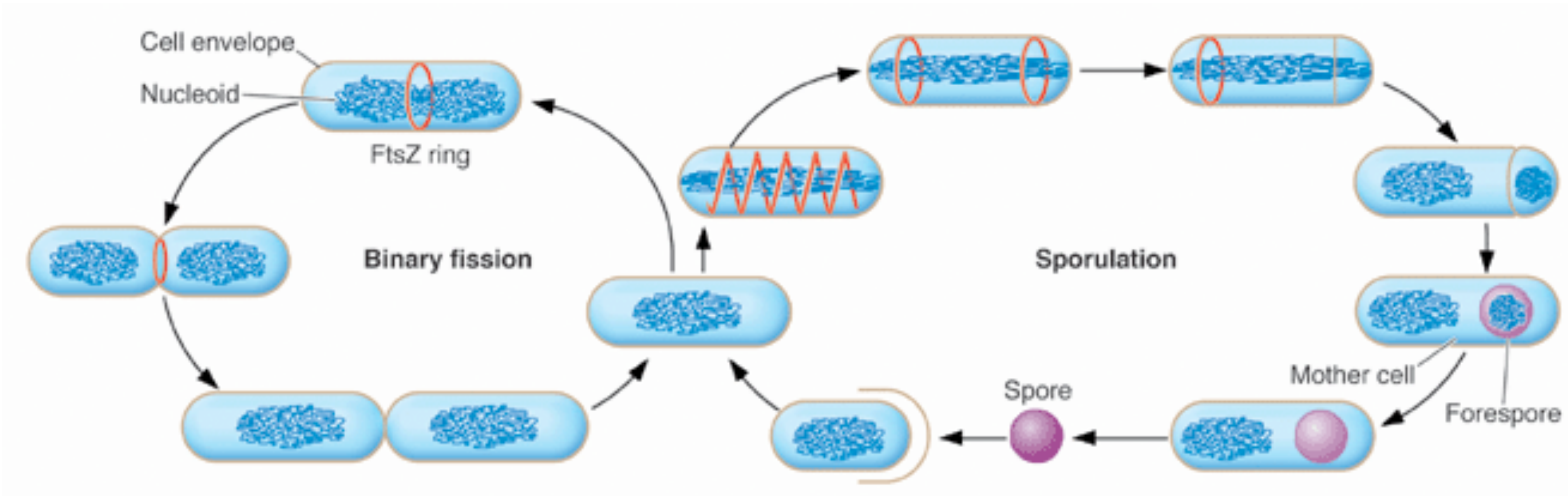
TABLE 4.1 General Stages in Endospore Formation

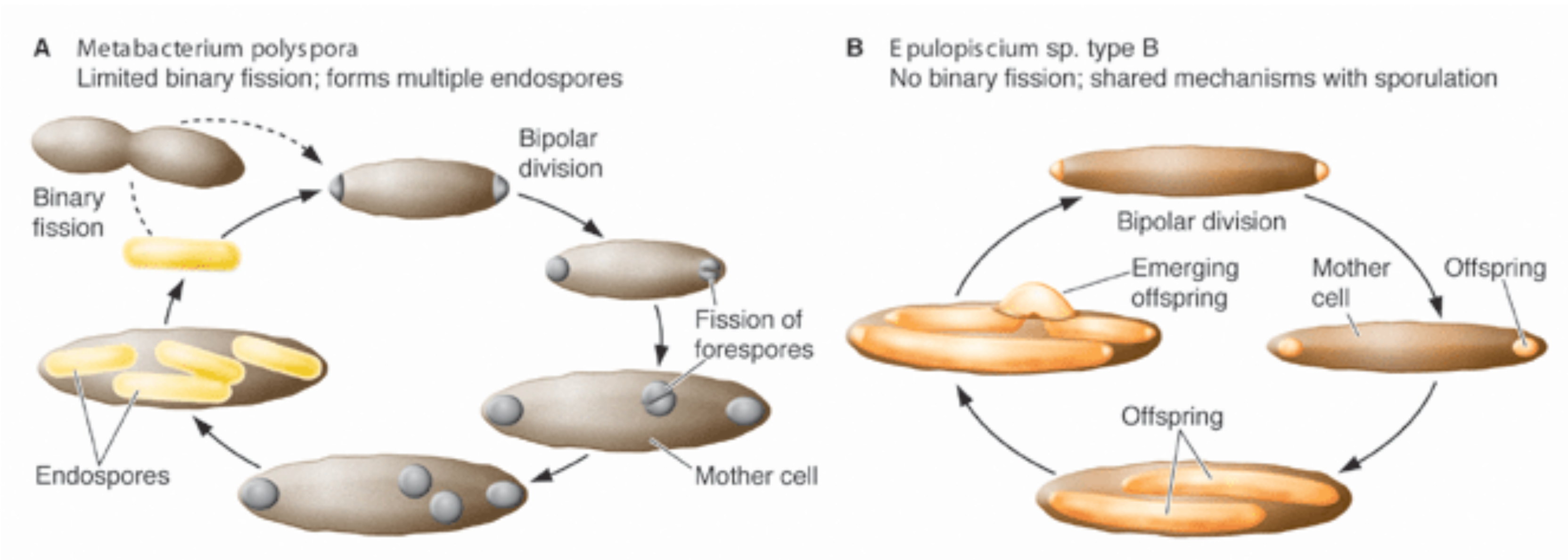
Stage	State of Cell	Process/Event
1 	Vegetative cell	Cell in early stage of binary fission doubles chromosome.
2 	Vegetative cell becomes **sporangium** in preparation for sporulation.	One chromosome and a small bit of cytoplasm are walled off as a protoplast at one end of the cell. This core contains the minimum structures and chemicals necessary for guiding life processes. During this time, the sporangium remains active in synthesizing compounds required for spore formation.
3 	Sporangium	The protoplast is engulfed by the sporangium to continue the formation of various protective layers around it.
4 	Sporangium with prospore	Special peptidoglycan is laid down to form a cortex around the spore protoplast, now called the prospore; calcium and dipicolinic acid are deposited; core becomes dehydrated and metabolically inactive.  Fluorescent stain of *Bacillus subtilis*
5 	Sporangium with prospore	Three heavy and impervious protein spore coats are added.
6 	Mature endospore	Endospore becomes thicker, and heat resistance is complete; sporangium is no longer functional and begins to deteriorate.
7 	Free spore	Complete lysis of sporangium frees spore; it can remain dormant yet viable for thousands of years.  TEM of cross section of free endospore
8 	Germination	Addition of nutrients and water reverses the dormancy. The spore then swells and liberates a young vegetative cell.
9 	Vegetative cell	Restored vegetative cell

Phase Two: Endospore

- Stimulus for sporulation- the depletion of nutrients
- Vegetative cell undergoes a conversion to a **sporangium**
- Sporangium transforms in to an endospore
- Hardiest of all life forms
  - Withstand extremes in heat, drying, freezing, radiation, and chemicals
  - Heat resistance- high content of calcium and dipicolinic acid
  - Some viable endospores have been found that were more than 250 million years old

- Germination
  - Breaking of dormancy
  - In the presence of water and a specific germination agent
  - Quite rapid (1 ½ hours)
  - The agent stimulates the formation of hydrolytic enzymes, digest the cortex and expose the core to water
- Medical Significance
  - Several bacterial pathogens
    - *Bacillus antracis*
    - *Clostridium tetani*
    - *Clostridium perfingensClostridium botulinum*
  - Resist ordinary cleaning methods


Cell envelope
Nucleoid
FtsZ ring
Binary fission
Sporulation
Mother cell
Forespore
Spore


A Metabacterium polyspora
Limited binary fission; forms multiple endospores
Binary fission
Bipolar division
Fission of forespores
Mother cell
Endospores
B Epulopiscium sp. type B
No binary fission; shared mechanisms with sporulation
Bipolar division
Emerging offspring
Mother cell
Offspring
Offspring

4.5 Bacterial Shapes, Arrangements, and Sizes

- Three general shapes
  - **Coccus**- roughly spherical
  - **Bacillus**- rod-shaped
    - **Coccobacillus**- short and plump
    - **Vibrio**- gently curved
  - **Spirillum**- curviform or spiral-shaped
    - **Pleomorphism**- when cells of a single species vary to some extent in shape and size

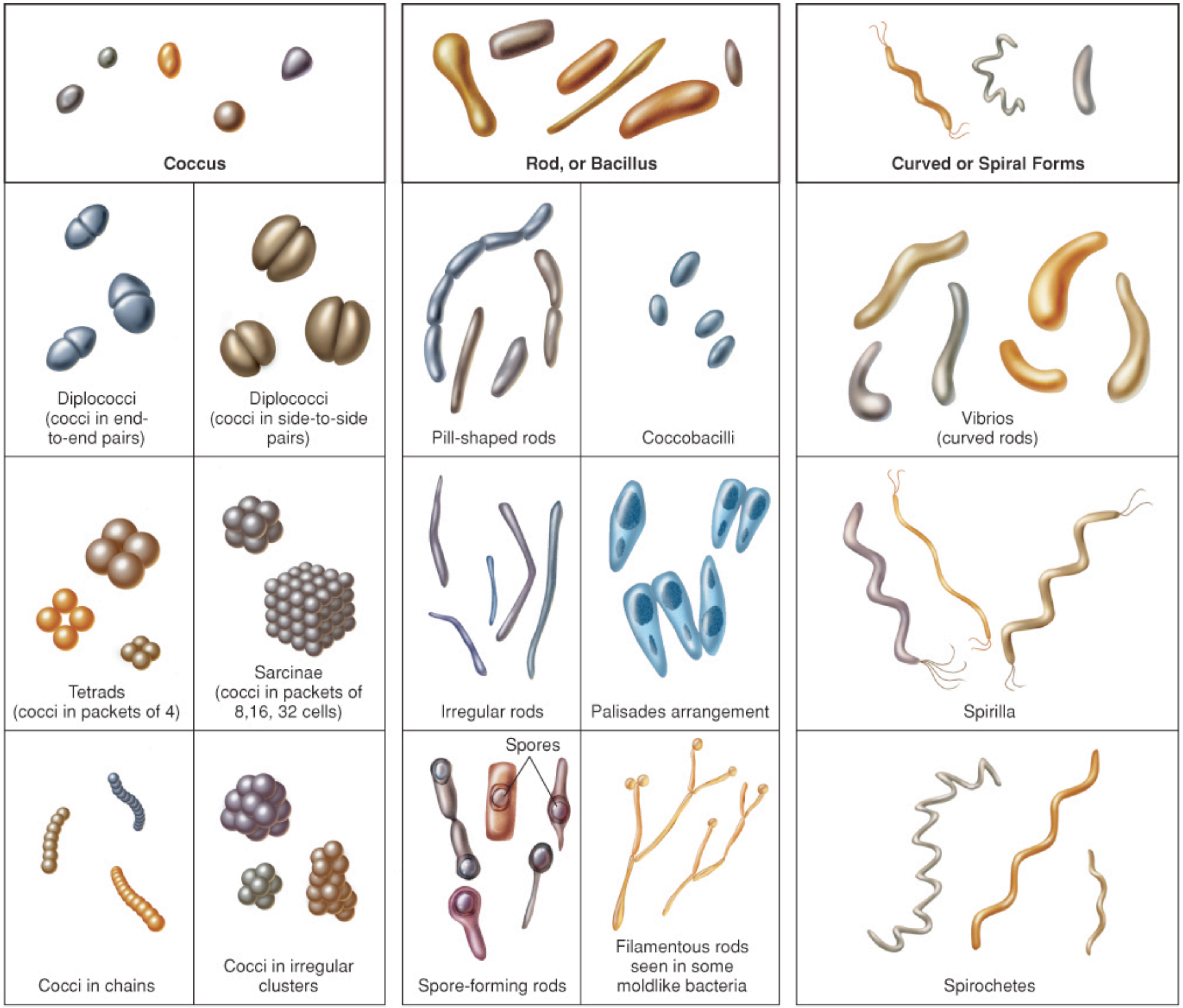

Coccus
Rod, or Bacillus
Curved or Spiral Forms
Diplococci
(cocci in end-
to-end pairs)
Diplococci
(cocci in side-to-side
pairs)
Pill-shaped rods
Coccobacilli
Vibrios
(curved rods)
Tetrads
(cocci in packets of 4)
Sarcinae
(cocci in packets of
8,16, 32 cells)
Irregular rods
Palisades arrangement
Spirilla
Cocci in chains
Cocci in irregular
clusters
Spores
Spore-forming rods
Filamentous rods
seen in some
moldlike bacteria
Spirochetes

Figure 4.22

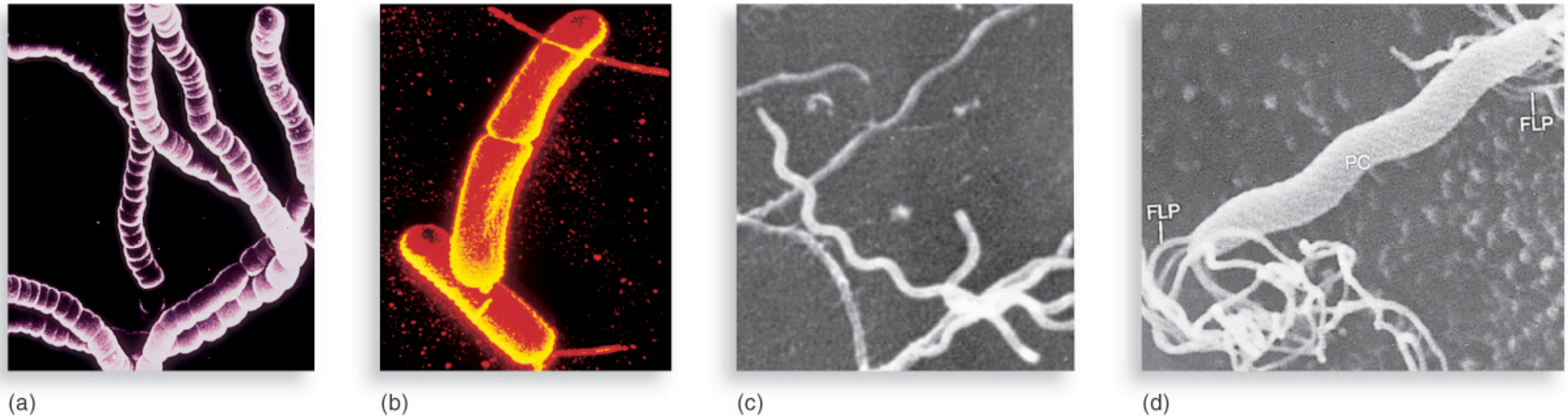


Figure 4.23

Some bacteria (ex. *Corynebacterium*) have varied shapes called pleomorphism.

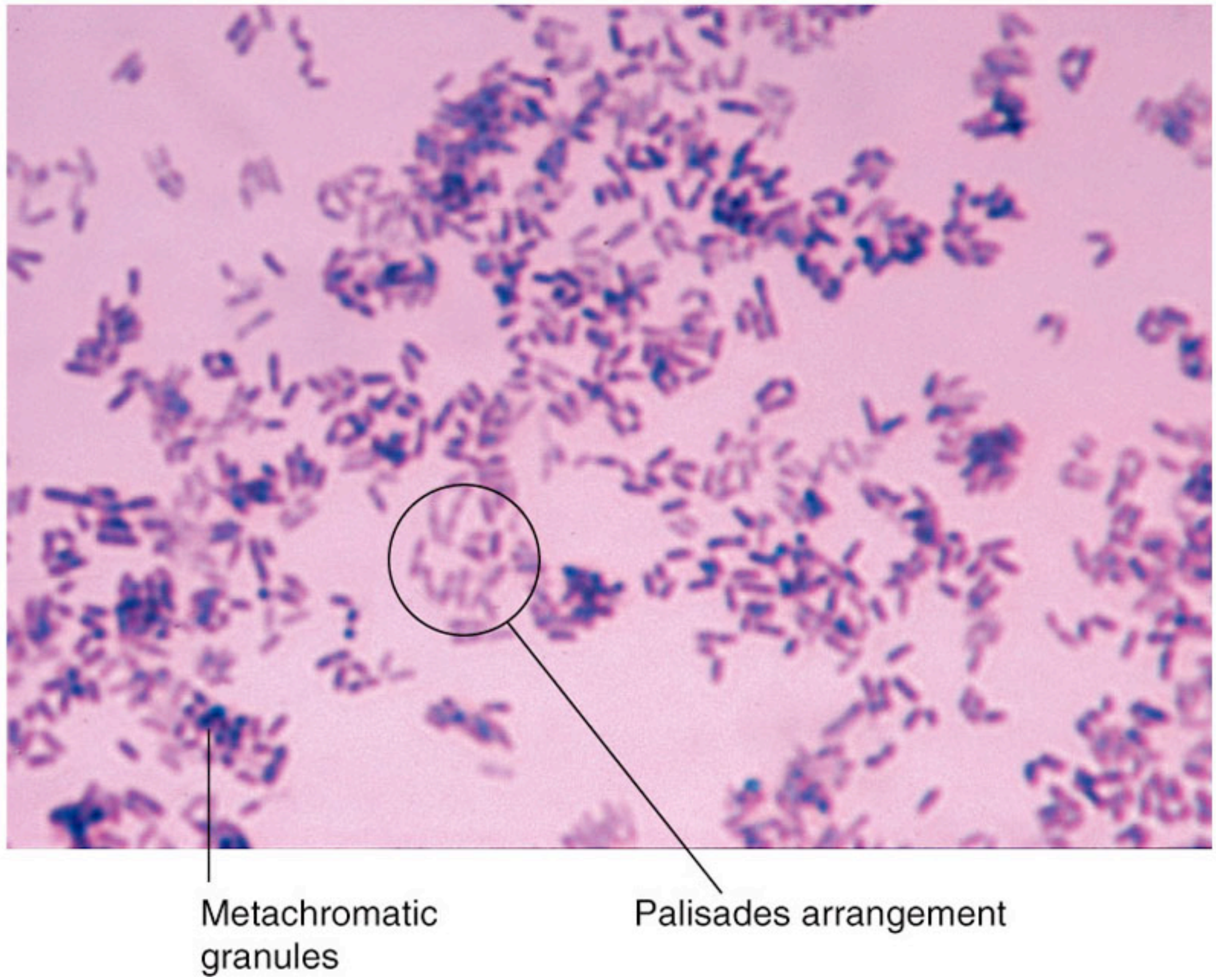


Fig. 4.24 Pleomorphism in *Corynebacterium*

Arrangement, or Grouping

- Cocci- greatest variety in arrangement
  - Single
  - Pairs (diplococcic)
  - **Tetrads**
  - Irregular clusters (staphylococci and micrococci)
  - Chains (streptococci)
  - Cubical packet (**sarcina**)
- Bacilli- less varied
  - Single
  - Pairs (diplobacilli)
  - Chain (streptobacilli)
  - Row of cells oriented side by side (**palisades**)
- Spirilla
  - Occasionally found in short chains

Relative size of a bacterial cell compared to other cells and viruses.

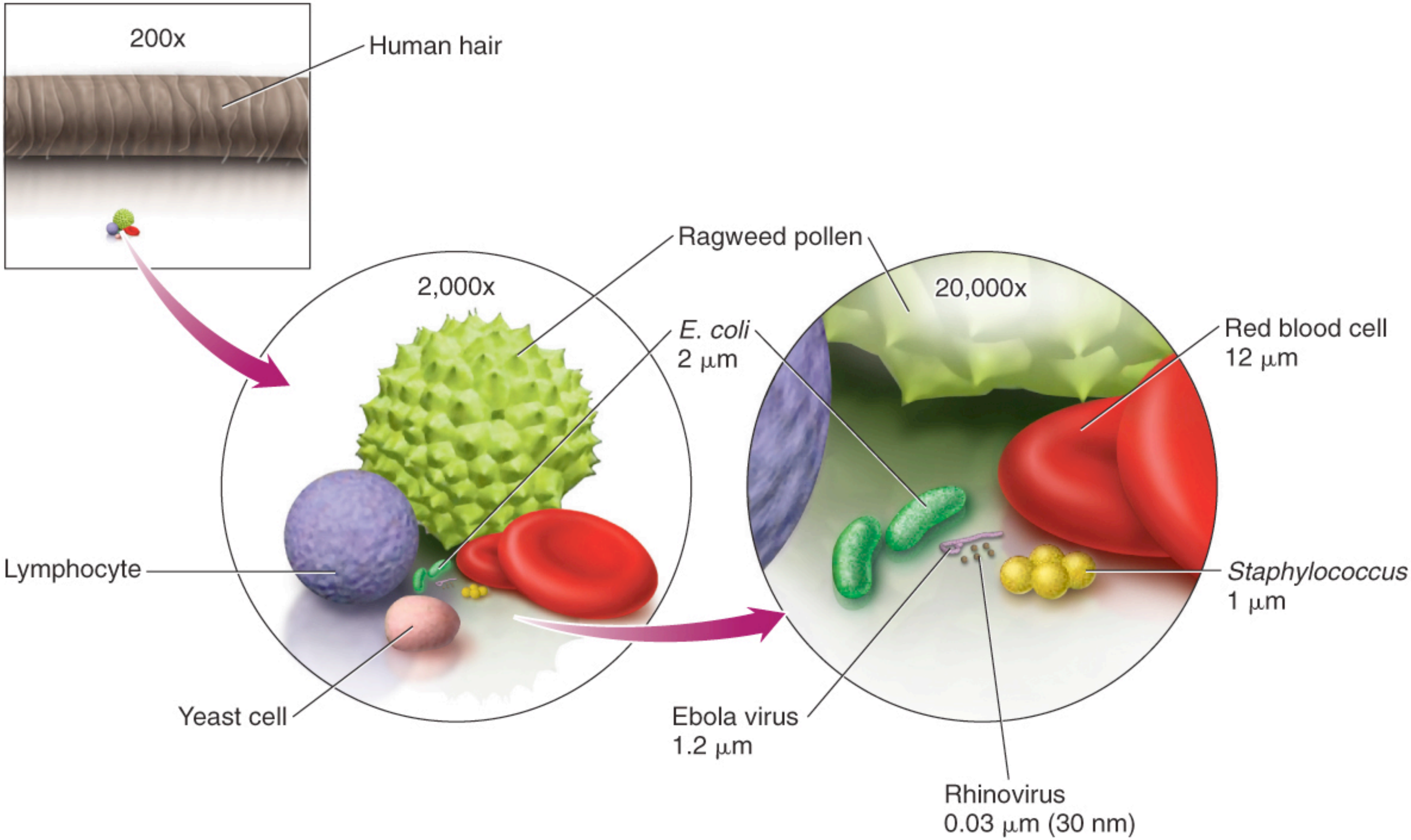


Fig. 4.25 The dimension of bacteria

Classification

- Phenotypic methods
- Molecular methods
- Taxonomic scheme
- Unique groups

Phenotypic methods

- Cell morphology - staining & microscopy
- Biochemical test – enzyme test

4.6 Classification Systems in the Prokaryotae

- One of the original classification systems- shape, variations in arrangement, growth characteristics, and habitat
- Definitive published source for bacterial classification
  - *Bergey's Manual*
  - Since 1923
  - Early classification- the **phenotypic** traits of bacteria
  - Current version- combines phenotypic information with rRNA sequencing

- Modern Taxonomy is based on molecular methods, i.e., comparing the sequence of nucleotides in rRNA

Molecular methods

Analyze:

- DNA sequence
- 16S rRNA sequence
- Protein sequence

OLD Taxonomic Scheme

- Kingdom Prokaryotae - 4 divisions based upon the nature of the cell wall
  - **Gracilicutes**- Gram-negative
  - **Firmicutes**- Gram-positive
  - **Tenericutes**- lack cell wall
  - **Mendosicutes**- the archaea

The methods of classification have allowed bacteria to be grouped into different divisions and classes.

TABLE 4.3 Major Taxonomic Groups of Bacteria per *Bergey's Manual*

Division I. Gracilicutes: Gram-Negative Bacteria	
Class I.	Scotobacteria: Gram-negative non-photosynthetic bacteria
Class II.	Anoxyphotobacteria: Gram-negative photosynthetic bacteria that do not produce oxygen (purple and green bacteria)
Class III.	Oxyphotobacteria: Gram-negative photosynthetic bacteria that evolve oxygen (cyanobacteria)
Division II. Firmicutes: Gram-Positive Bacteria	
Class I.	Firmibacteria: Gram-positive rods or cocci (examples in table 4.4)
Class II.	Thallobacteria: Gram-positive branching cells (the actinomycetes)
Division III. Tenericutes	
Class I.	Mollicutes: Bacteria lacking a cell wall (the mycoplasmas)
Division IV. Mendosicutes	
Class I.	Archaebacteria: Procaryotes with atypical compounds in the cell wall and membranes

Source: Data from *Bergey's Manual of Determinative Bacteriology,* 9th ed. Williams & Wilkins Company, Baltimore, 1994.

Table 4.3 Major taxonomic groups of bacteria

Diagnostic Scheme

- Many medical microbiologists prefer
- Informal working system
- See Table 4.2

Species and Subspecies

- Common definition of species used for animals (can produce viable offspring only when it mates with others of its own kind) does not work for bacteria
- Bacteria do not exhibit a typical mode of sexual reproduction
- For bacteria- a species is a collection of bacterial cells, all of which share an overall similar pattern of traits
- Individual members of a bacterial species can show variations
  - Subspecies, strain, or type- bacteria of the same species that have differing characteristics
  - Serotype- representatives of a species that stimulate a distinct pattern of antibody responses in their hosts

An example of how medically important families and genera of bacterial are characterized.

TABLE 4.4 Medically Important Families and Genera of Bacteria, with Notes on Some Diseases*

I. Bacteria with gram-positive cell wall structure
- Cocci in clusters or packets that are aerobic or facultative
  - Family Micrococcaceae: *Staphylococcus* (members cause boils, skin infections)
- Cocci in pairs and chains that are facultative
  - Family Streptococcaceae: *Streptococcus* (species cause strep throat, dental caries)
- Anaerobic cocci in pairs, tetrads, irregular clusters
  - Family Peptococcaceae: *Peptococcus*, *Peptostreptococcus* (involved in wound infections)
- Spore-forming rods
  - Family Bacillaceae: *Bacillus* (anthrax), *Clostridium* (tetanus, gas gangrene, botulism)
- Non-spore-forming rods
  - Family Lactobacillaceae: *Lactobacillus*, *Listeria* (milk-borne disease), *Erysipelothrix* (erysipeloid)
  - Family Propionibacteriaceae: *Propionibacterium* (involved in acne)
  - Family Corynebacteriaceae: *Corynebacterium* (diphtheria)
  - Family Mycobacteriaceae: *Mycobacterium* (tuberculosis, leprosy)
  - Family Nocardiaceae: *Nocardia* (lung abscesses)
  - Family Actinomycetaceae: *Actinomyces* (lumpy jaw), *Bifidobacterium*
  - Family Streptomycetaceae: *Streptomyces* (important source of antibiotics)

II. Bacteria with gram-negative cell wall structure
- Aerobic cocci
  - *Neisseria* (gonorrhea, meningitis), *Branhamella*
- Aerobic coccobacilli
  - *Moraxella*, *Acinetobacter*
- Anaerobic cocci
  - Family Veillonellaceae
  - *Veillonella* (dental disease)
- Miscellaneous rods
  - *Brucella* (undulant fever), *Bordetella* (whooping cough), *Francisella* (tularemia)
- Aerobic rods
  - Family Pseudomonadaceae: *Pseudomonas* (pneumonia, burn infections)
  - Miscellaneous: *Legionella* (Legionnaires' disease)
- Facultative or anaerobic rods and vibrios
  - Family Enterobacteriaceae: *Escherichia*, *Edwardsiella*, *Citrobacter*, *Salmonella* (typhoid fever), *Shigella* (dysentery), *Klebsiella*, *Enterobacter*, *Serratia*, *Proteus*, *Yersinia* (one species causes plague)
  - Family Vibronaceae: *Vibrio* (cholera, food infection), *Campylobacter*, *Aeromonas*
  - Miscellaneous genera: *Chromobacterium*, *Flavobacterium*, *Haemophilus* (meningitis), *Pasteurella*, *Cardiobacterium*, *Streptobacillus*
- Anaerobic rods
  - Family Bacteroidaceae: *Bacteroides*, *Fusobacterium* (anaerobic wound and dental infections)
- Helical and curviform bacteria
  - Family Spirochaetaceae: *Treponema* (syphilis), *Borrelia* (Lyme disease), *Leptospira* (kidney infection)
- Obligate intracellular bacteria
  - Family Rickettsiaceae: *Rickettsia* (Rocky Mountain spotted fever), *Coxiella* (Q fever)
  - Family Bartonellaceae: *Bartonella* (trench fever, cat scratch disease)
  - Family Chlamydiaceae: *Chlamydia* (sexually transmitted infection)

III. Bacteria with no cell walls
- Family Mycoplasmataceae: *Mycoplasma* (pneumonia), *Ureaplasma* (urinary infection)

*Details of pathogens and diseases in chapters 18 through 23.

Table 4.4 Medically important families and genera of bacteria.

Unique groups of prokaryotes

- Intracellular parasites
- Photosynthetic bacteria
- Green and purple sulfur bacteria
- Gliding and fruiting bacteria
- Archaeobacteria (Archaea)

Obligate Intracellular Parasites

- **Rickettsias**
  - Very tiny
  - Gram-negative
  - Atypical in lifestyle and other adaptations
    - Most-pathogens that alternate between a mammalian host and blood-sucking arthropods
    - Cannot survive or multiply outside a host cell
    - Cannot carry out metabolism completely on their own
  - Human diseases
    - Rocky Mountain Spotted Fever by *Rickettsia rickettsii*
    - Endemic typhus by *Rickettsia typhi*

Intracellular bacteria must live in host cells in order to undergo metabolism and reproduction.

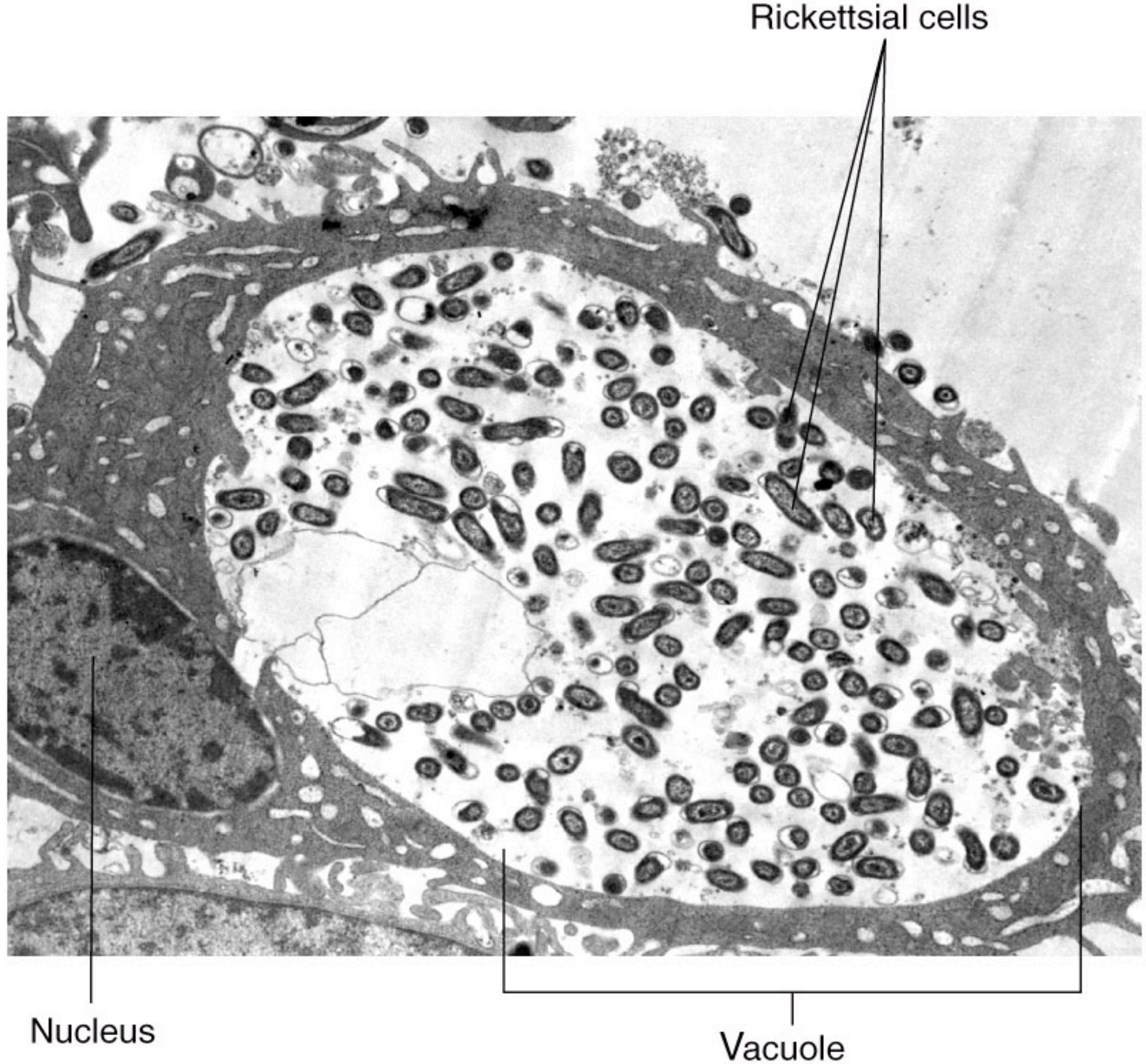


Fig. 4.26 Transmission electron micrograph of rickettsia.

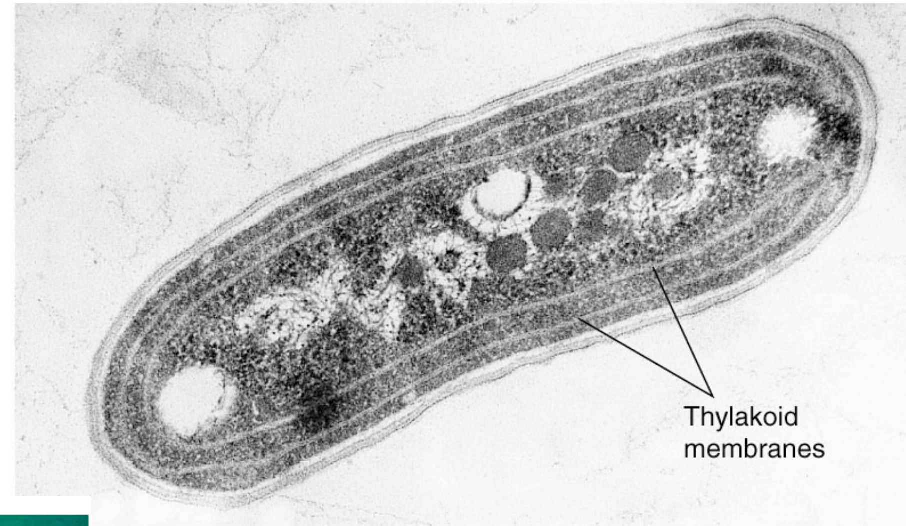
- **Chlamydias**
  - Genera *Chalmydia* and *Chalmydophila*
  - Require host cells for growth and metabolism
  - Not closely related
  - Not transmitted by arthropods
  - Human diseases
    - *Chlamydia trachomatis*- causes a severe eye infection and the STD
    - *Chlamydophila pneumonia*- causes lung infections
    - *Chlamydia psittaci* - heart inflammation

Free-Living Nonpathogenic Bacteria

- Photosynthetic Bacteria
  - May or may not produce oxygen during photosynthesis
  - Some produce oxidized substances during photosynthesis, such as sulfur granules or sulfates

- Cyanobacteria: the Blue-Green Bacteria
  - For many years, called Blue-Green Algae
  - Gram-negative cell wall
  - General prokaryotic structure
  - Can be unicellular or can occur in colonial or filamentous groupings
  - Specialized adaptation- **thylakoids**
    - Chlorophyll a
    - Other photosynthetic pigments
  - Gas inclusions
  - Widely distributed in nature

Cyanobacteria are important photosynthetic bacteria associated with oxygen production.



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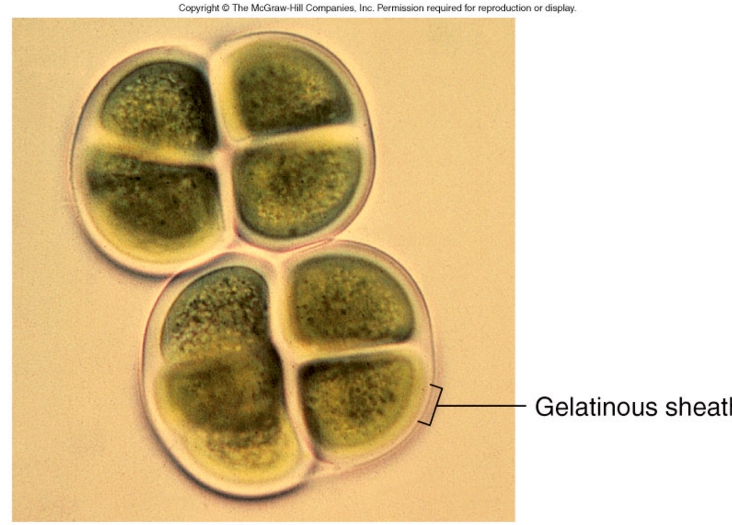


(c)

Fig. 4.27 Structure and examples of cyanobacteria

Green and Purple Sulfur Bacteria

- Green and Purple Sulfur Bacteria
  - Photosynthetic
  - Contain pigments
  - Different chlorophyll than cyanobacteria- bacteriochlorophyll
  - Do not give off oxygen
  - Live in areas deep enough for anaerobic conditions but yet where their pigments can absorb light
    - Sulfur springs
    - Freshwater lakes
    - Swamps

Green and purple sulfur bacteria are photosynthetic, do not give off oxygen, and are found in sulfur springs, freshwater, and swamps.

Fig. 4.28 Behavior of purple sulfur bacteria

An example of a fruiting body bacteria in which reproductive spores are produced.

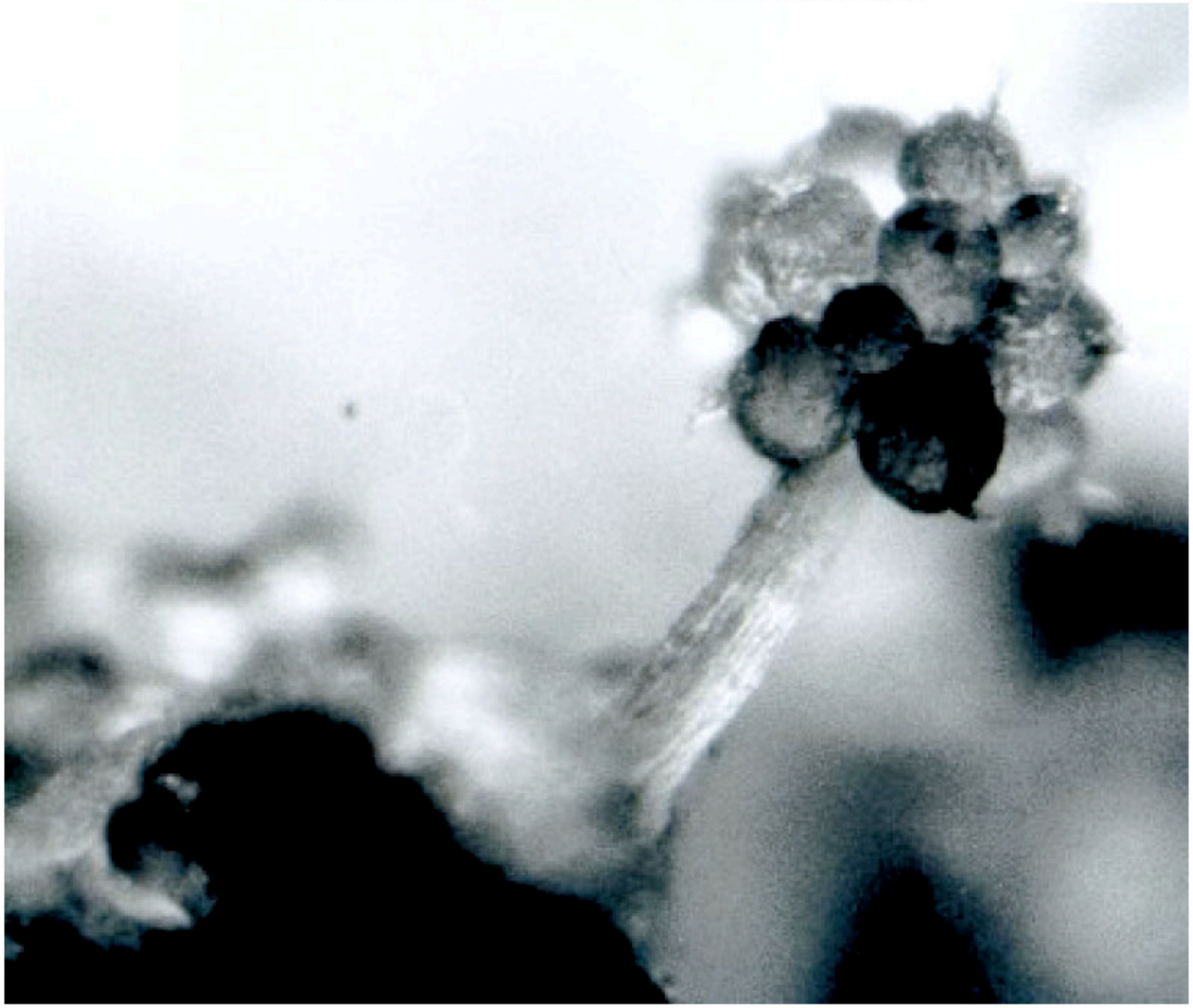


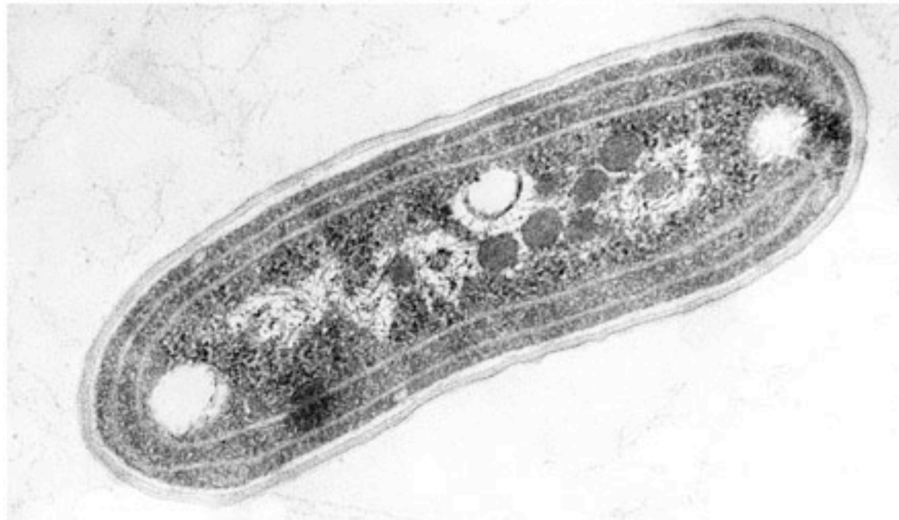
Fig. 4.29 Myxobacterium

Archae: The Other Prokaryotes

- Domain Archaea
- Prokaryotic in general structure
- Share many bacterial characteristics
- Molecular evidence reveals that they are more closely related to Domain Eukarya than to Domain Bacteria; nevertheless, they are clearly a different Domain by themselves …..

- How they differ from other cell types
  - Unique rRNA sequences
  - Unique membrane lipids and cell wall construction
  - Not susceptible to antibiotics
  - No nucleus
- Least evolved of all life forms
- Many archaea live in habitats that share conditions as the ancient earth
  - Methane producers
  - Hyperthermophiles
  - Extreme halophiles
  - Sulfur reducers
- ==> Thought to be most closely related to the first cells that originated on earth **- wrong!!!!**
- Most live in temperate environments!!!

Archaea are found in hot springs (thermophiles) and high salt content areas (halophiles) as well in temperate environments.



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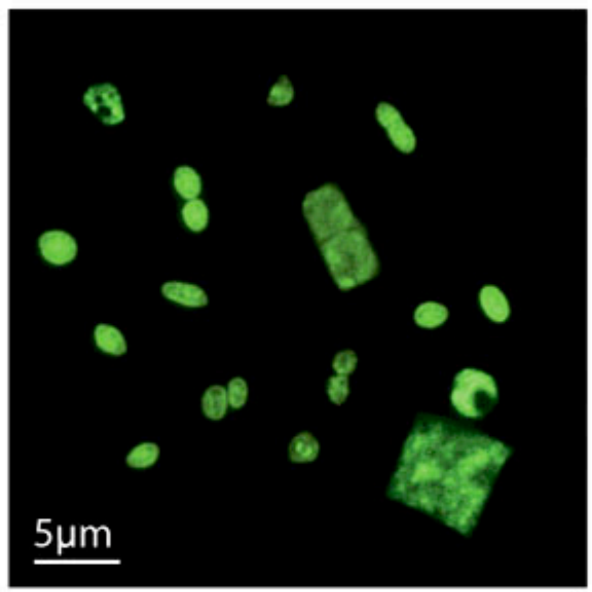

(b)

Fig. 4.30 Halophile around the world

TABLE 4.3 Comparison of Three Cellular Domains

Characteristic	Bacteria	Archaea	Eukarya
Cell type	Prokaryotic	Prokaryotic	Eukaryotic
Chromosomes	Single, or few, circular	Single, circular	Several, linear
Types of ribosomes	70S	70S but structure is similar to 80S	80S
Contains unique ribosomal RNA signature sequences	+	+	+
Number of sequences shared with Eukarya	1	3	(all)
Protein synthesis similar to Eukarya	−	+	
Presence of peptidoglycan in cell wall	+	−	−
Cell membrane lipids	Fatty acids with ester linkages	Long-chain, branched hydrocarbons with ether linkages	Fatty acids with ester linkages
Sterols in membrane	− (some exceptions)	−	+