Microbiology: A Systems Approach, 2nd ed.

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

Chapter 5: Eukaryotic Microbes

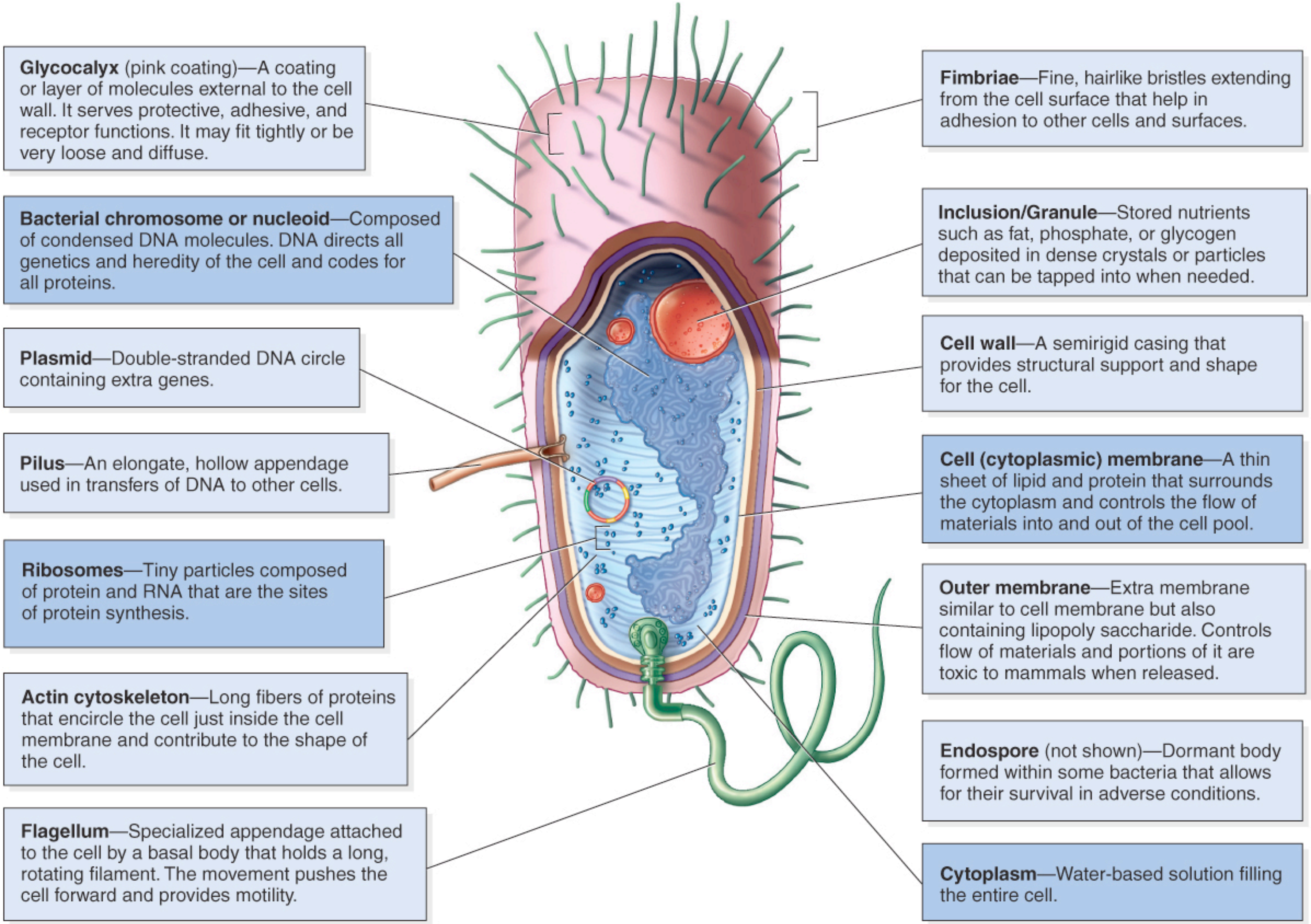
4.1 Prokaryotic Form and Function

- 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



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

Cell wall

- Typical 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

Cell Membrane

- Also known as the **cytoplasmic membrane**
- Very thin (5-10 nm)
- Contain primarily phospholipids, proteins and
  - Hopanes (hopanoids) or
  - sterols (mycoplasmas)

- 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 wall and glycocalyx 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)**

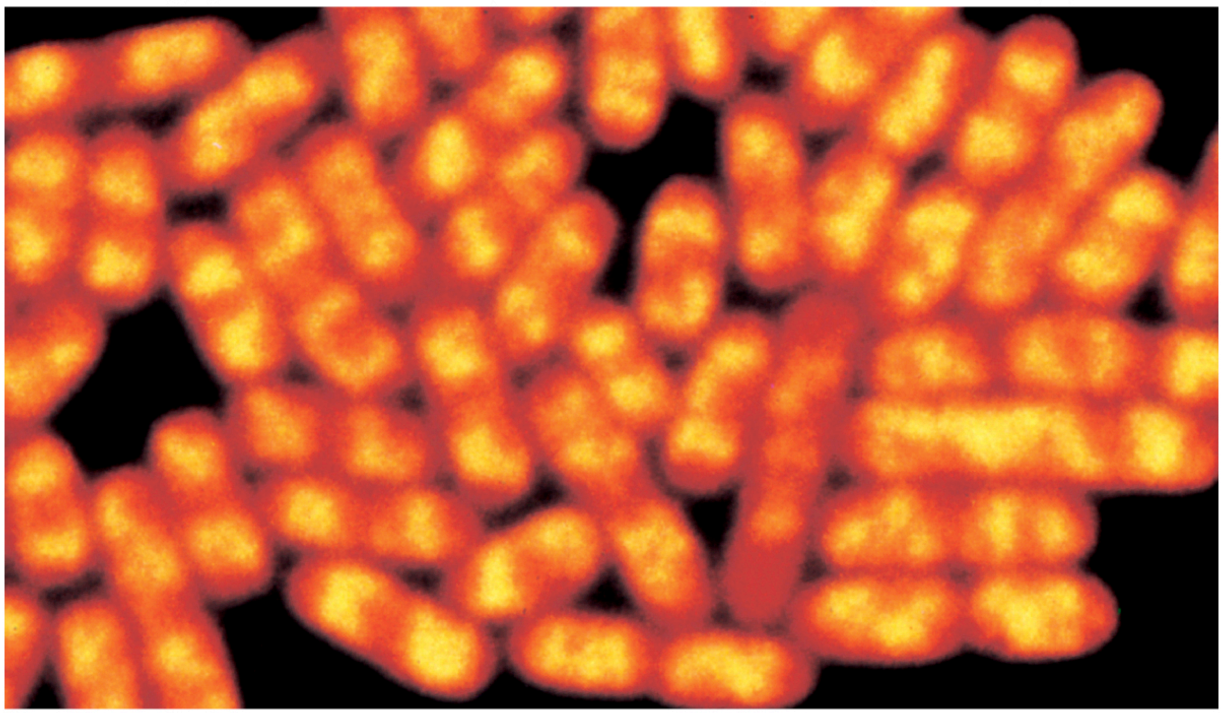


Figure 4.17

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

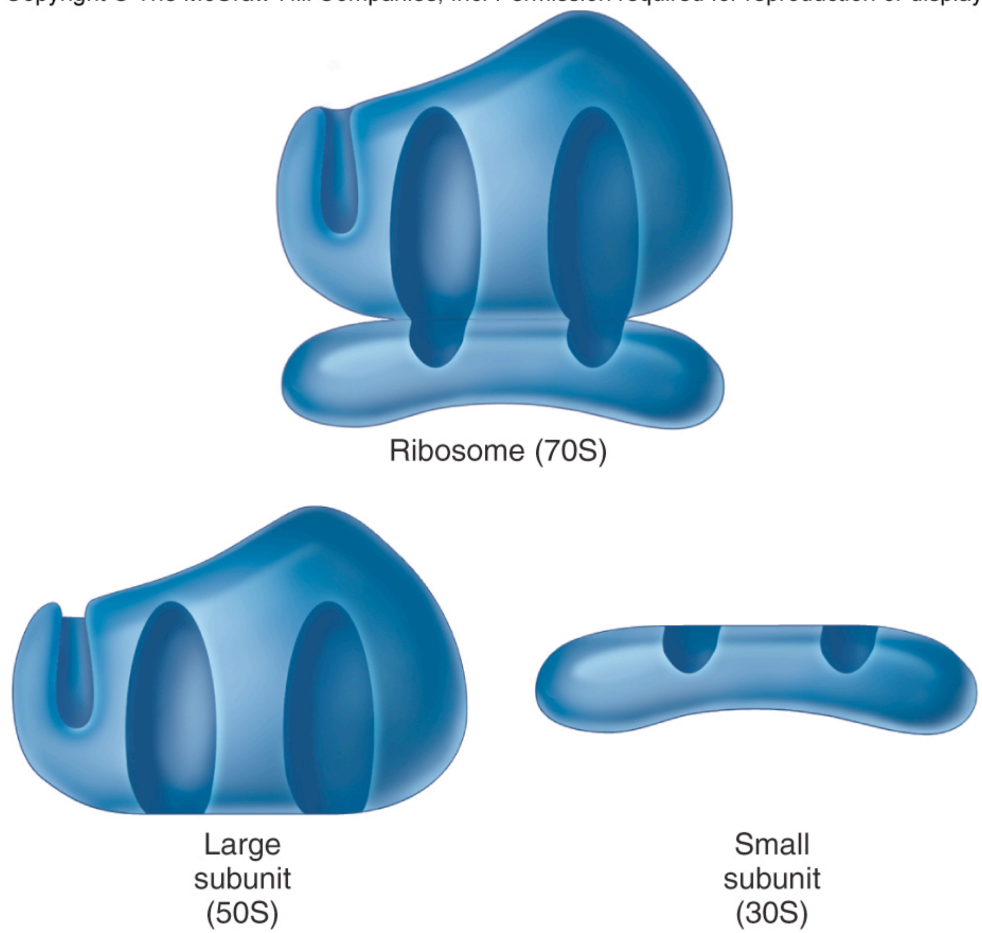


Figure 4.18

Inclusions

- Inclusions- also known as **inclusion bodies**
  - Some bacteria accumulate **polymer granules** in during periods of nutrient abundance
    - Serve as a storehouse when nutrients become depleted
    - Serve as a storehouse when energy becomes depleted

Examples: Granules

- Contain crystals of inorganic compounds
- Are not enclosed by membranes
- **Starch and glycogen granules**
- **Poly-hydroxybutyrate granules**
- **Sulfur granules** accumulated by 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; many other bacteria accumulate poly~Pi

© Paul W. Johnson/Biological Photo Service

Figure 4.19

Membrane-enclosed inclusions

- Protein membranes
  - Some aquatic bacterial inclusions include **gas vesicles** to provide buoyancy and flotation
  - Some inclusions contain entire **metabolic pathways** such as carbon fixation (carboxysome) or polymer lysis (cellulosome)

- Lipid membranes
  - Magnetotactic bacteria contain granules with iron oxide- give magnetic properties to the cell

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.

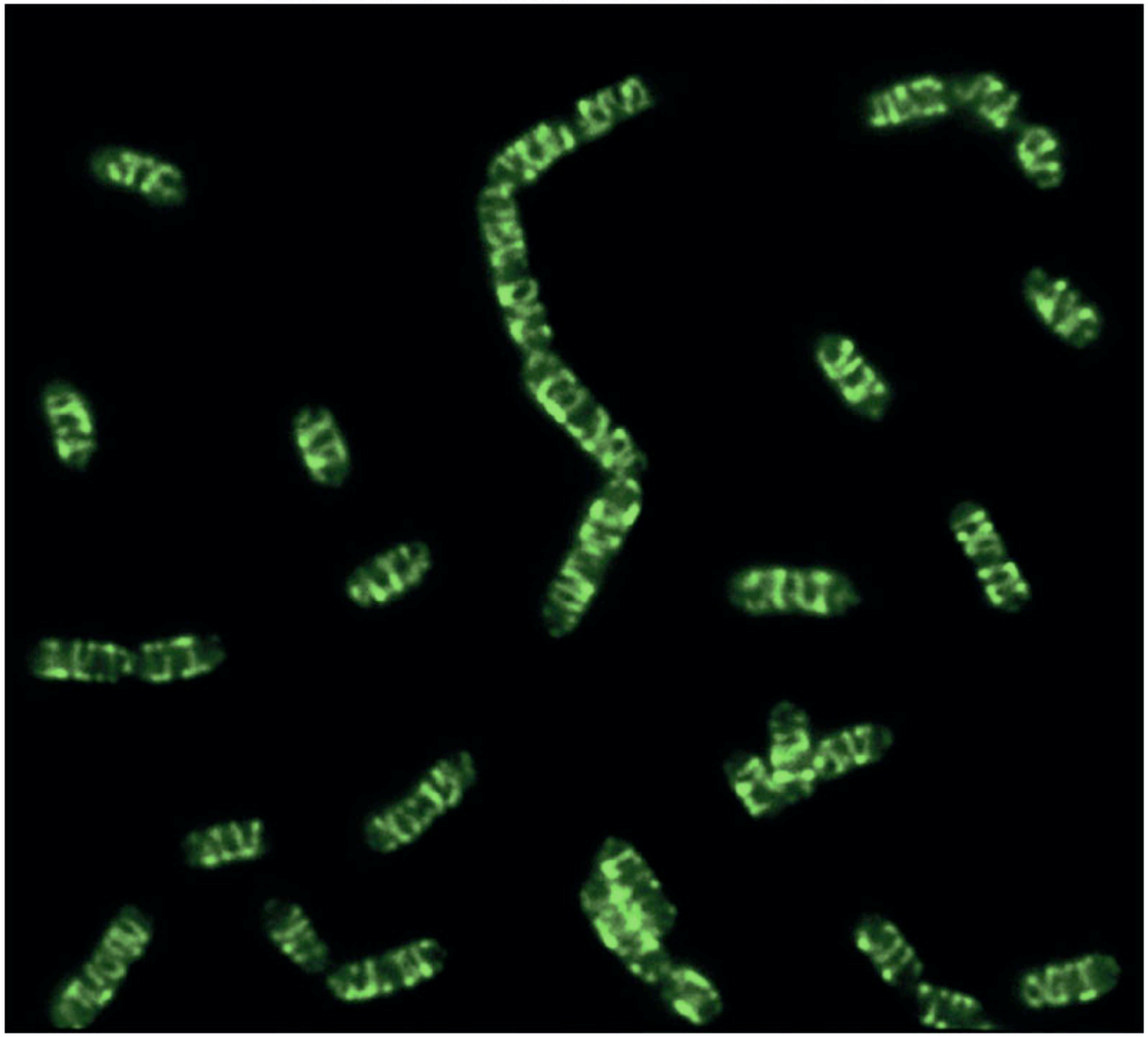


Fig. 4.20 Bacterial cytoskeleton

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

- Dormant structures produced by *Bacillus, Clostridium,* and *Sporosarcina* ==>

Gram-positive low G+C bacteria

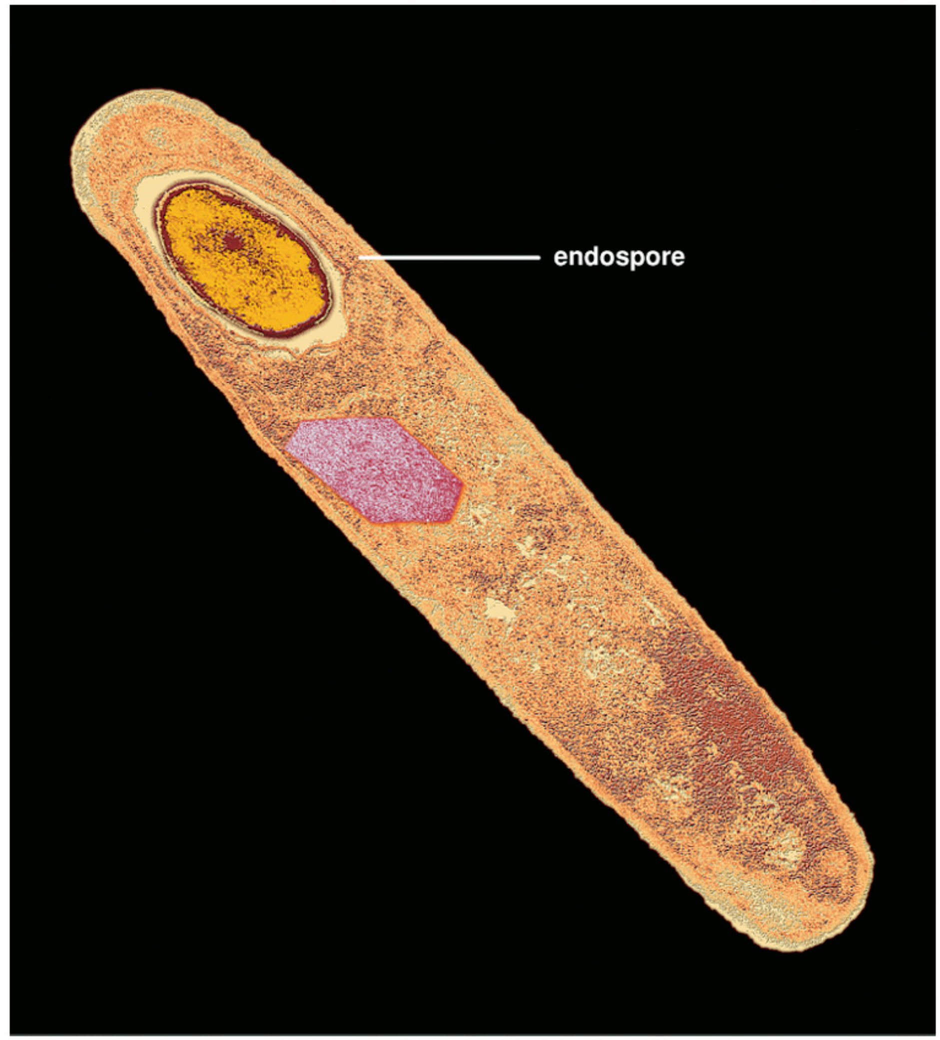


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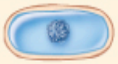
Figure 4.21

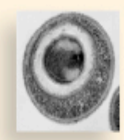
Endospore-Forming Bacteria

- These bacteria have a two-phase life cycle
  - Phase One - The 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.
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.
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

Fluorescent stain of *Bacillus subtilis*



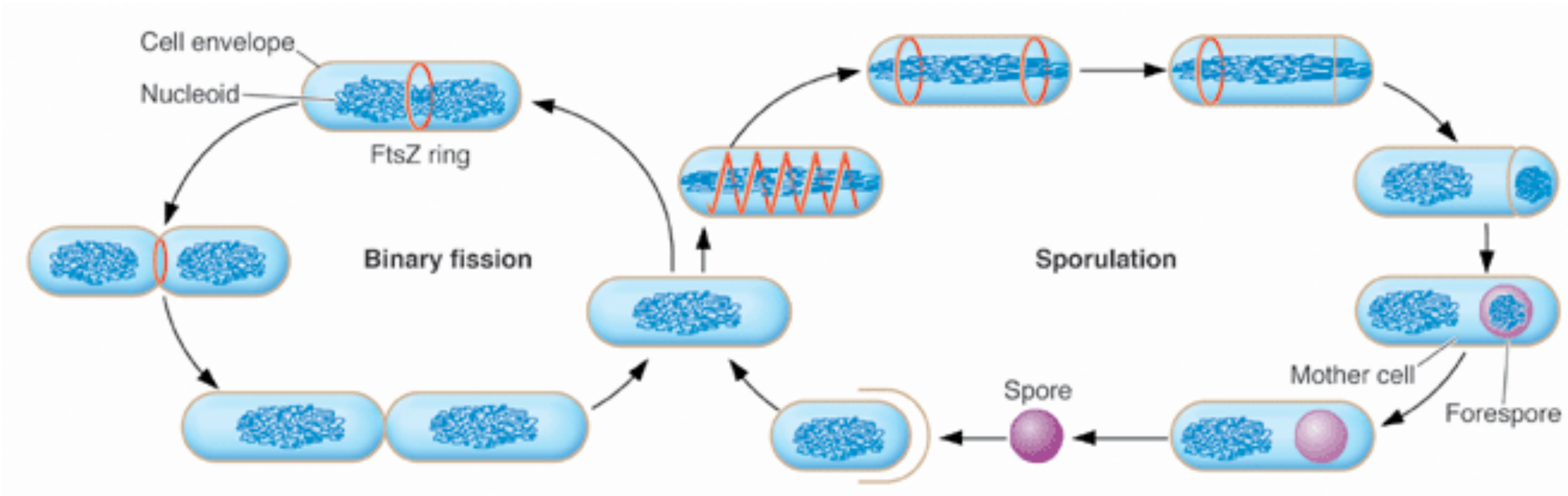
TEM of cross section of free endospore

Phase Two: Endospore

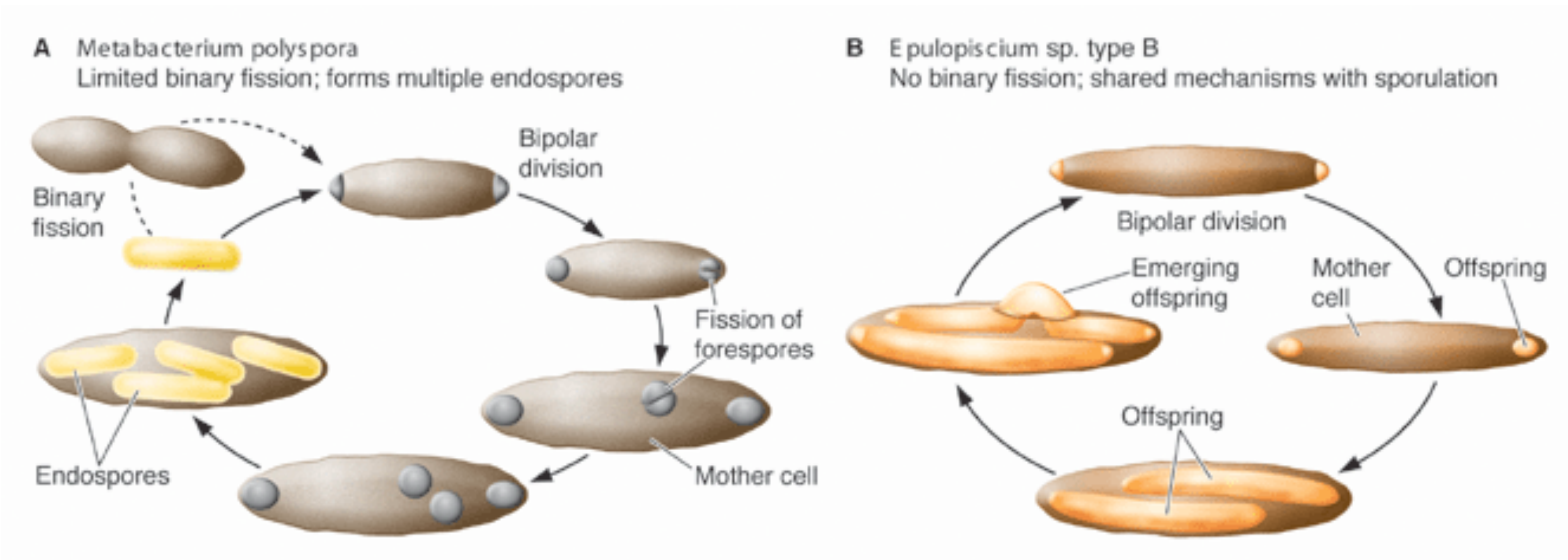
- Many stimuli for sporulation- the depletion of nutrients, heat, water shortage, UV, etc …
- Vegetative cell undergoes a conversion to a **sporangium**
- Sporangium transforms in to an endospore
- Hardiest of all life forms
  - Withstand extremes in heat, drying, freezing, radiation, and chemicals
  - 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 anthracis*
    - *Clostridium tetani*
    - *Clostridium perfingensl; Clostridium 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

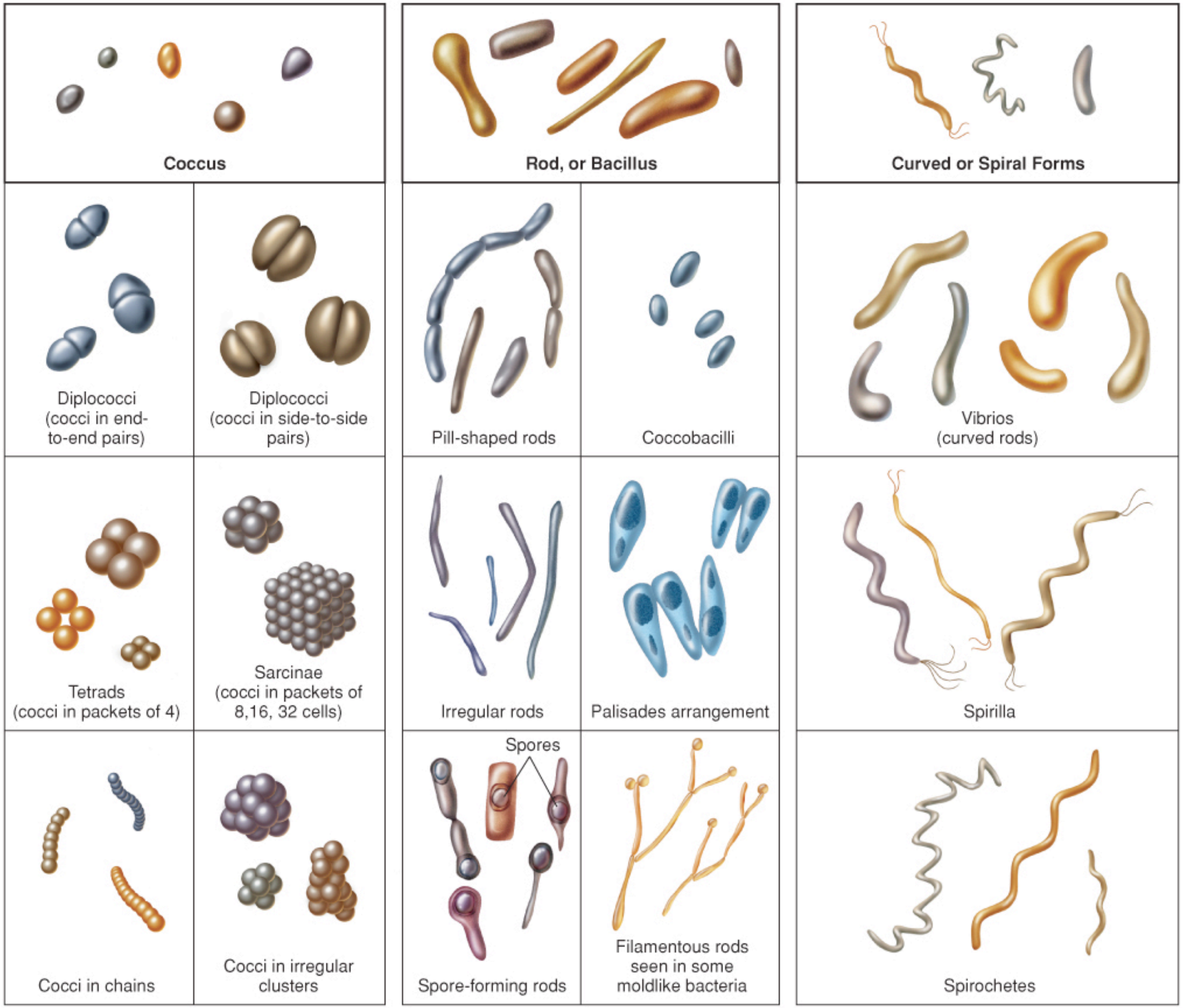
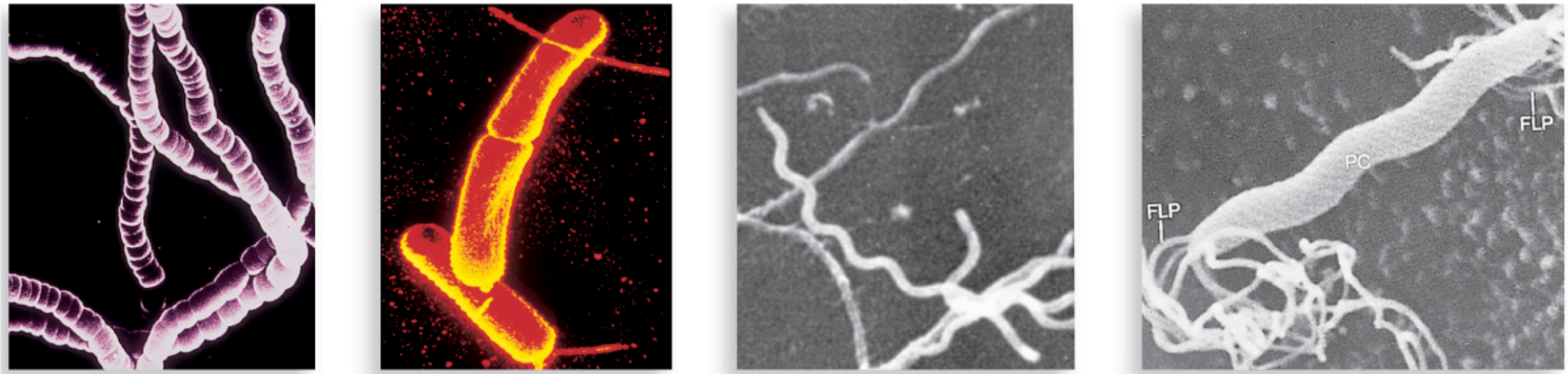

Coccus
Rod, or Bacillus
Curved or Spiral Forms
Diplococci
(cocci in end-
to-end pairs)
Diplococci
(cocci in side-to-side
pairs)
Pill-shaped rods
Coccobacilli
Vibrios
(curved rods)
Tetrads
(cocci in packets of 4)
Sarcinae
(cocci in packets of
8,16, 32 cells)
Irregular rods
Palisades arrangement
Spirilla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

Figure 4.22



(a) (b) (c) (d)

Figure 4.23

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

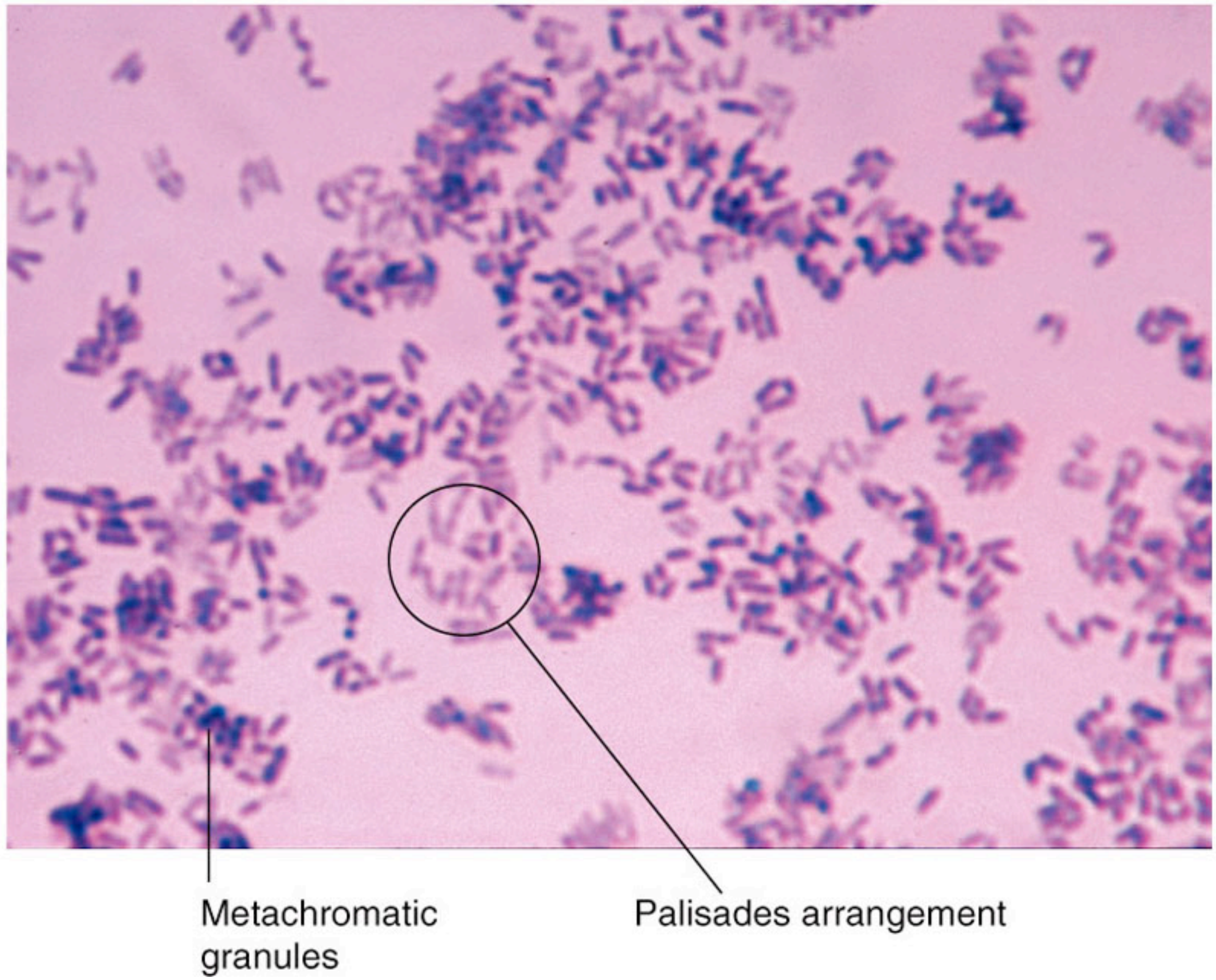


Fig. 4.24 Pleomorphism in *Corynebacterium*

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.

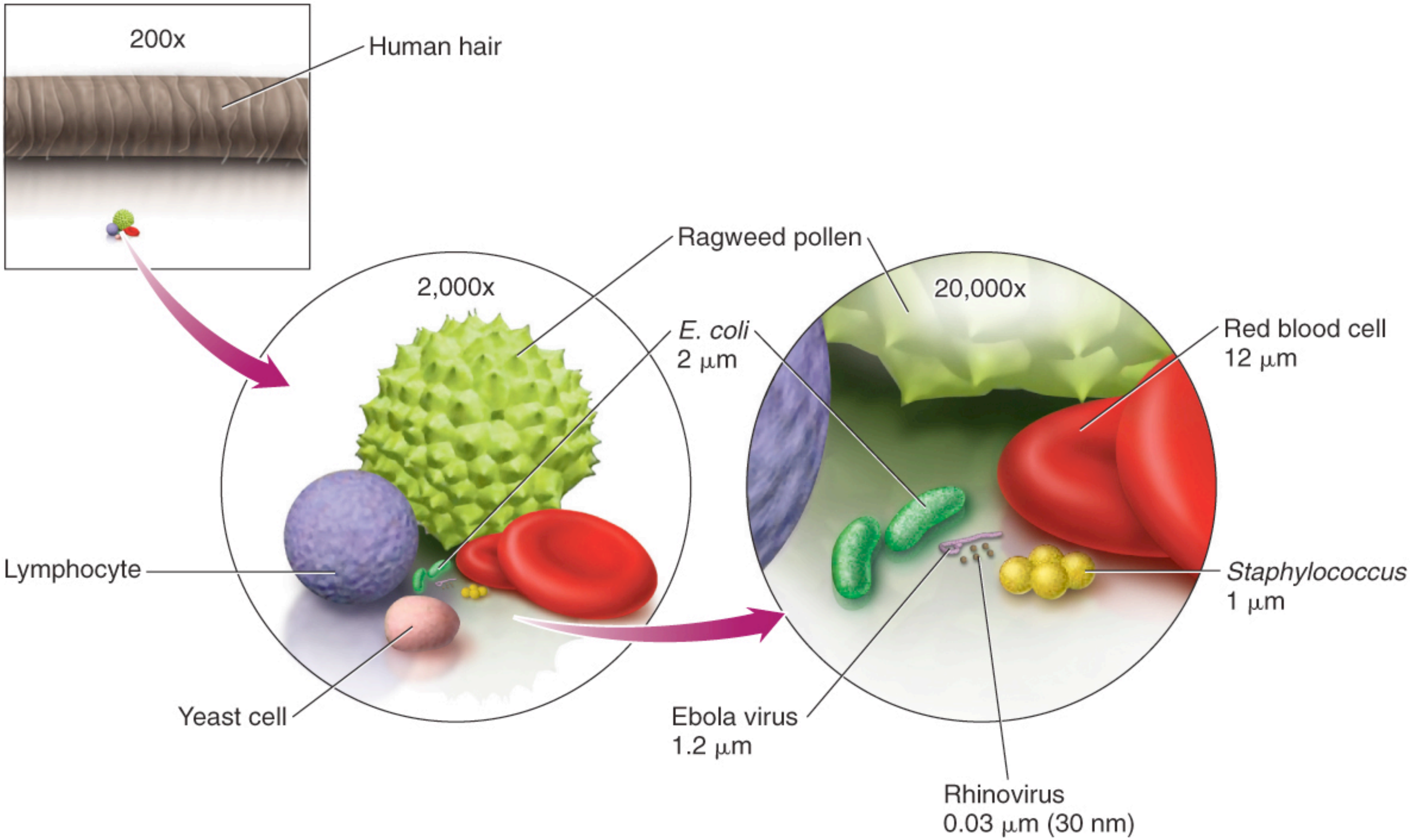


Fig. 4.25 The dimension of bacteria

4.6 Classification Systems in the "Prokaryotae"

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

Phenotypic methods

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

Classification

- 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 nucleotide sequences 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 ("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 **Isolate**: bacteria of the same species that have differing characteristics
    - Biovar(iety) - representatives that have similar metabolism
    - Pathovar(iety) - representative that cause a particular disease
    - Serovar(iety) or serotype- representatives of a species that stimulate a distinct pattern of immune responses in their hosts

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.

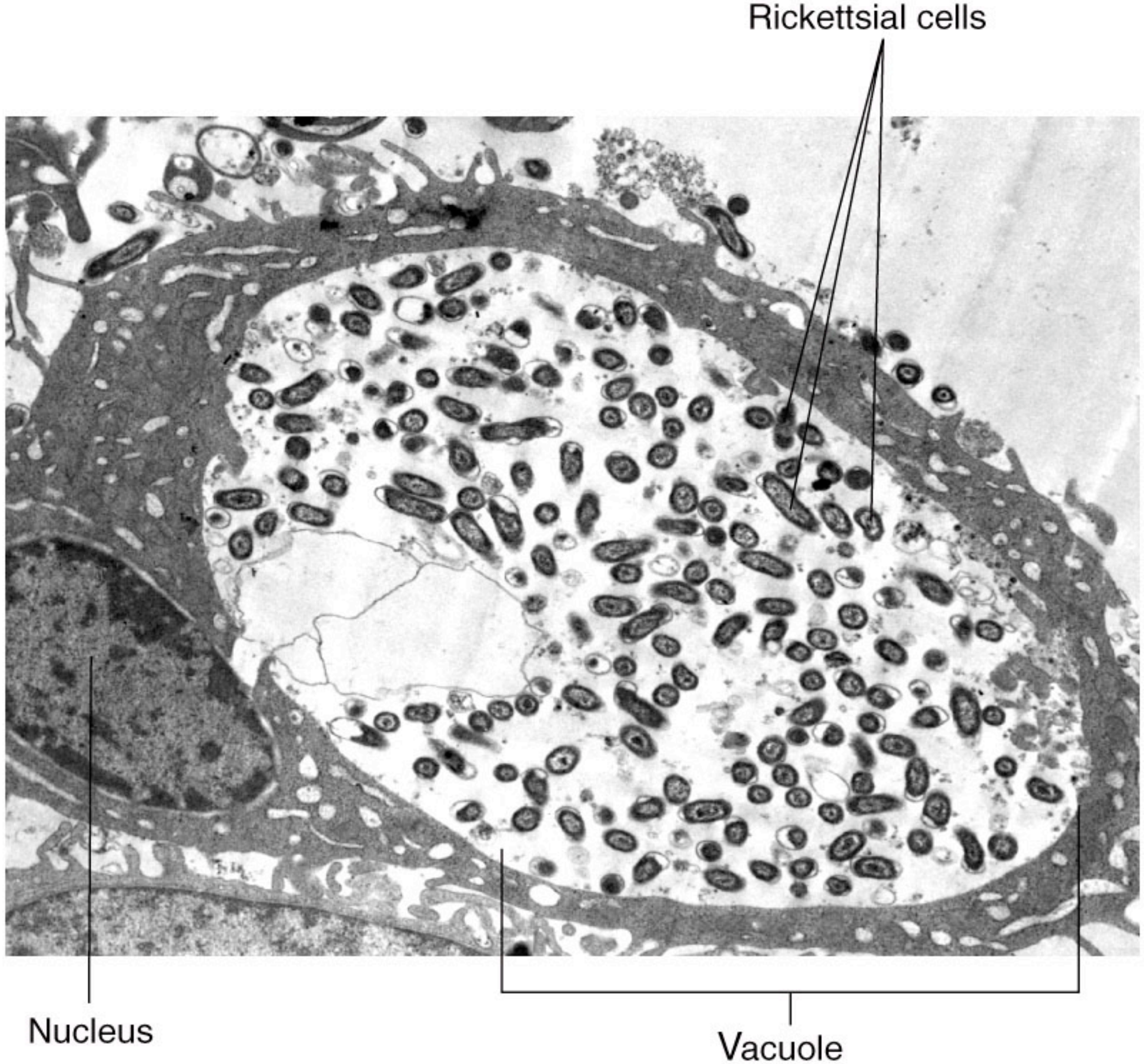


Fig. 4.26 Transmission electron micrograph of Rickettsia.

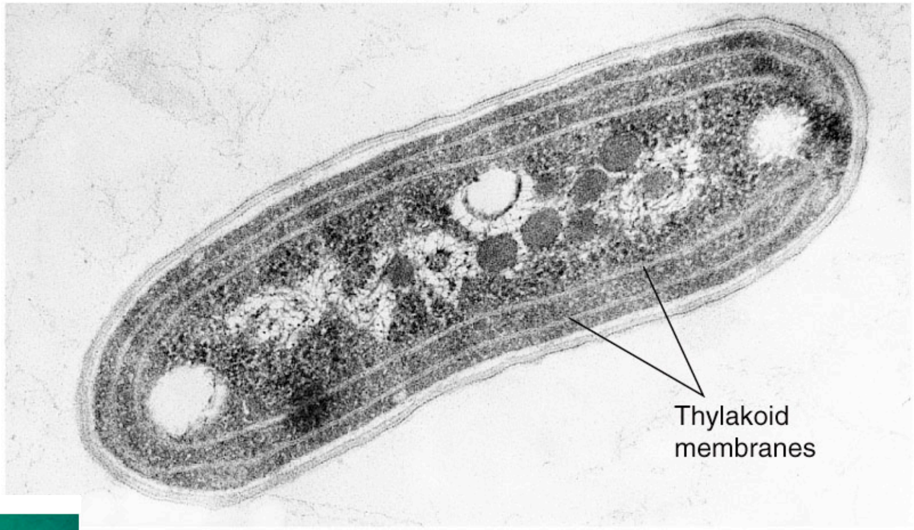
- **Chlamydias**
  - Genera *Chalmydia* and *Chalmydophila*
  - Require host cells for growth and metabolism (cannot synthesize ATP)
  - Not closely related to Rickettsia
  - Not transmitted by arthropods
  - Human diseases
    - *Chlamydia trachomatis*- causes a severe eye infection and the STD
   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

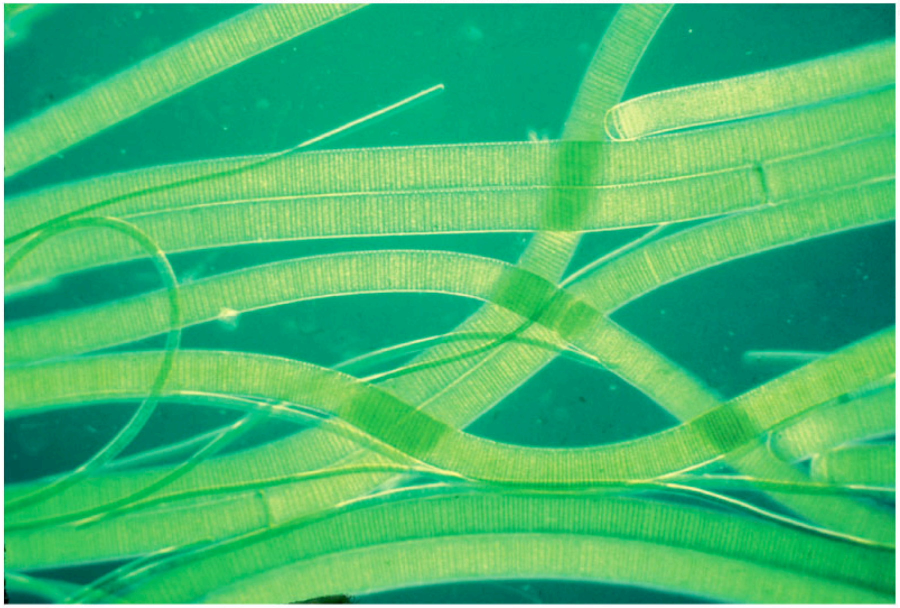
Free-Living Nonpathogenic Bacteria

- 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
  - General prokaryotic structure
  - Gram-negative cell wall
  - 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.





(b)

(c)

Fig. 4.27 Structure and examples of cyanobacteria

Green and Purple Sulfur Bacteria

- Green and Purple Sulfur Bacteria
  - Photosynthetic
  - Contain variety of pigments
  - Different chlorophylls than cyanobacteria: bacteriochlorophyll
  - Do not give off oxygen (“anoxygenic”)
  - Live in areas with low oxygen 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.

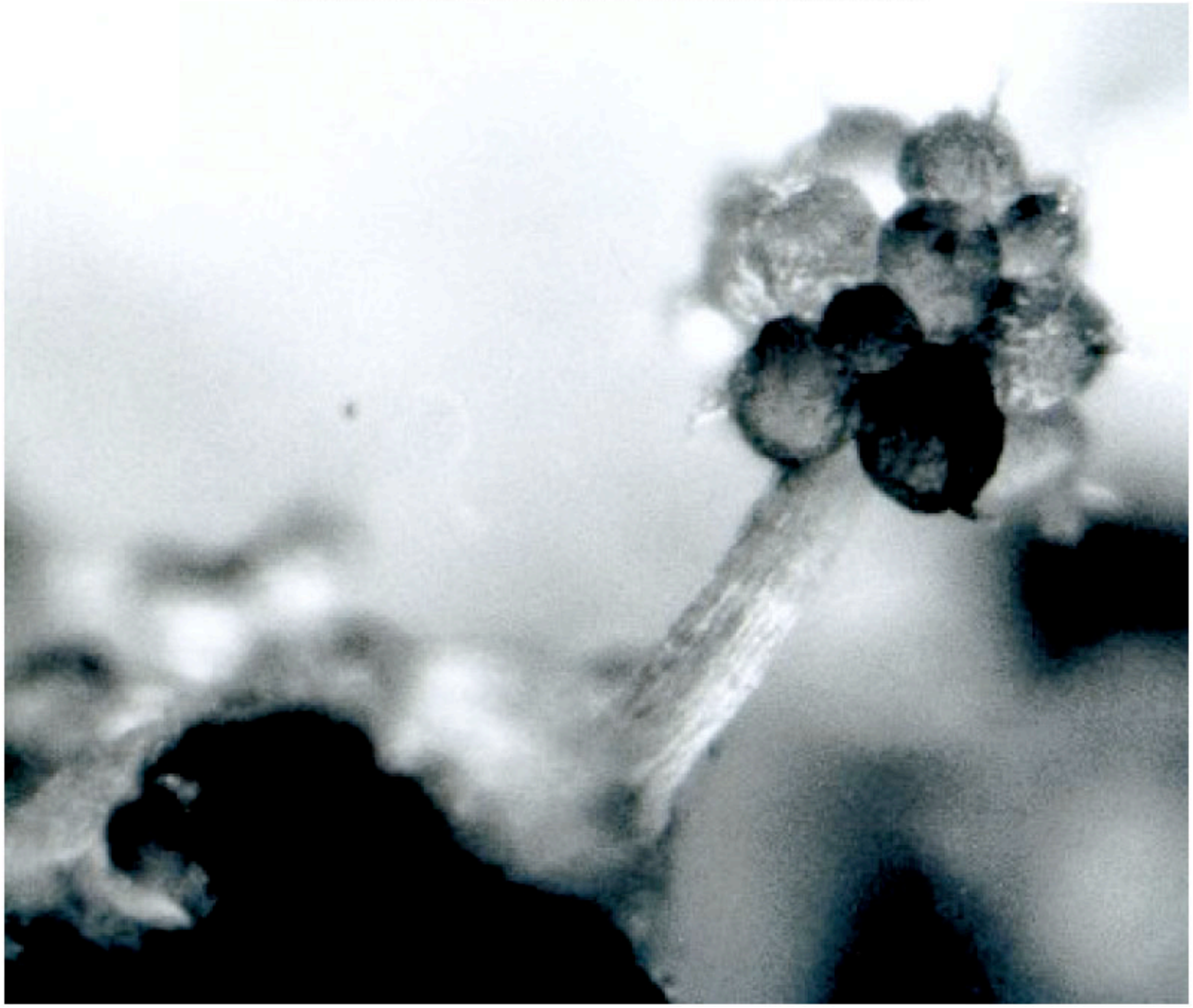


Fig. 4.29 Myxobacterium

Archaea: The Other Prokaryotes

- Domain Archaea
- Prokaryotic in general structure
- Share many characteristics with bacteria
- Universal tree of life (based on ssu rRNA) 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
- Thought to be the 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 live only in extreme environments and be most closely related to the first cells that originated on earth **- wrong!!!!**

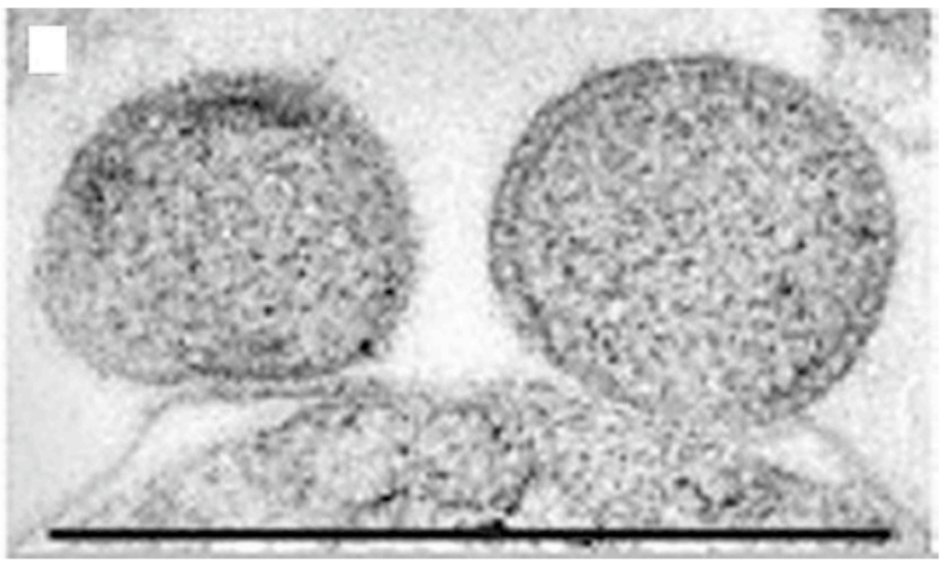
- Most live in temperate environments!!!

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

(a) (b)

Fig. 4.30 Halophile around the world

Archaea Also come in very different sizes and engage in symbiotic associations with one another and with other organisms.



An electron microscopic depiction of an *Ignicoccus* cell (bottom), showing the inner and outer membranes, in symbiotic association with two *Nanoarchaeum* cells (top). (Reproduced from H. Huber, M. Hohn, R. Rachel, T. Fuchs, V. Wimer, and K. Stetter, A new phylum of Archaea represented by a nanosized hyperthermophilic symbiont. Nature **417**:63–67, 2002).

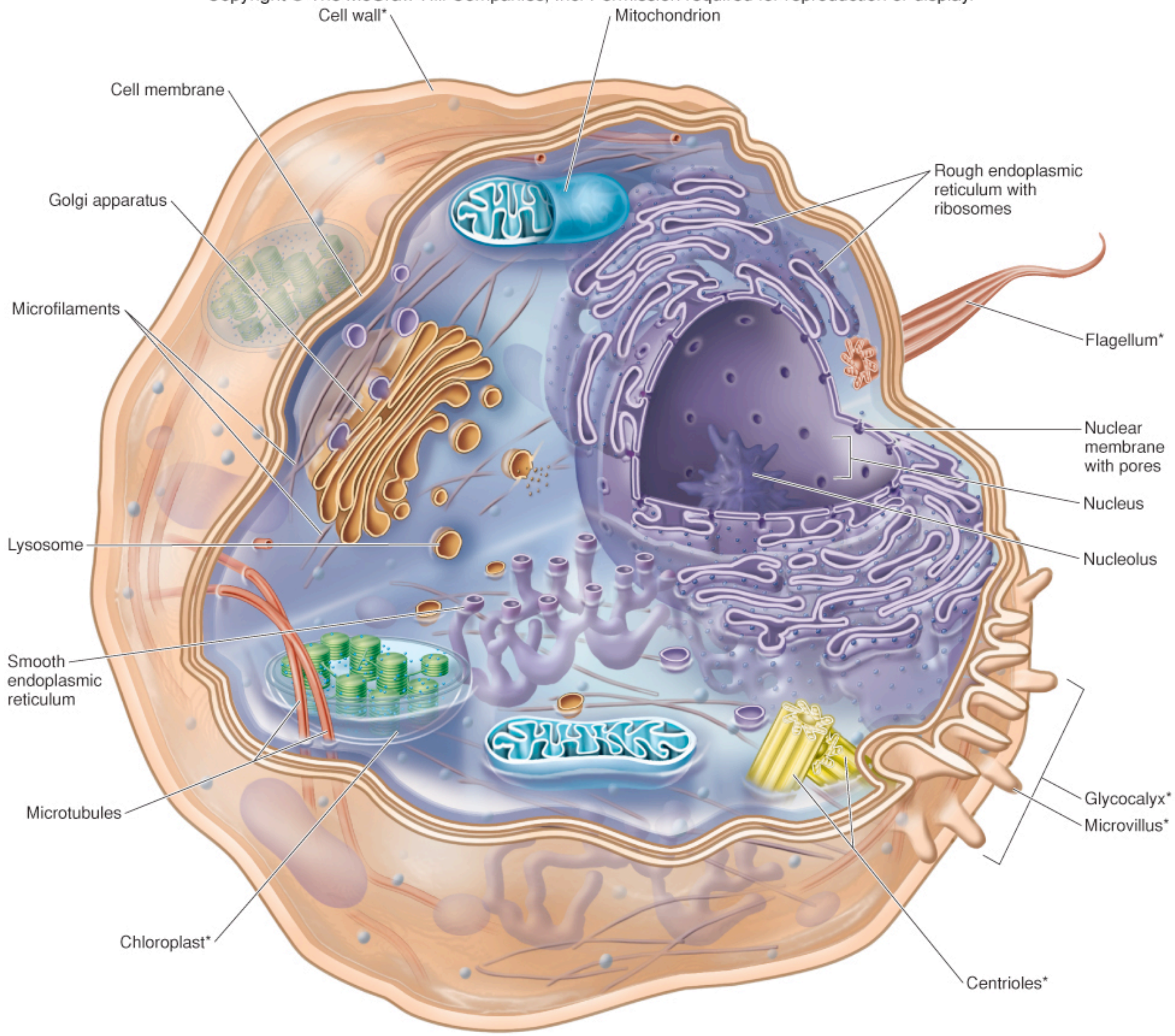
TABLE 4.3 Comparison of Three Cellular Domains

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)	−	+

5.1 The History of Eukaryotes

- First eukaryotic cells emerged on Earth approximately 2 billion years ago
- Evidence points to these eukaryotic cells evolving from prokaryotic organisms through intercellular and intracellular **symbioses**
  - First eukaryotes- single-celled and independent
  - Thought to be a merger of an Archaeon engulfed by a Bacterium
  - Eventually formed colonies
  - Cells within colonies became specialized
  - Eukaryotic **organelles** originated from prokaryotic cells trapped inside of them
  - Evolved in to multicellular organisms
- Extant ("today's") Eukaryotes have many levels of cellular complexity

5.2 Form and Function of the Eukaryotic Cell: External Structures

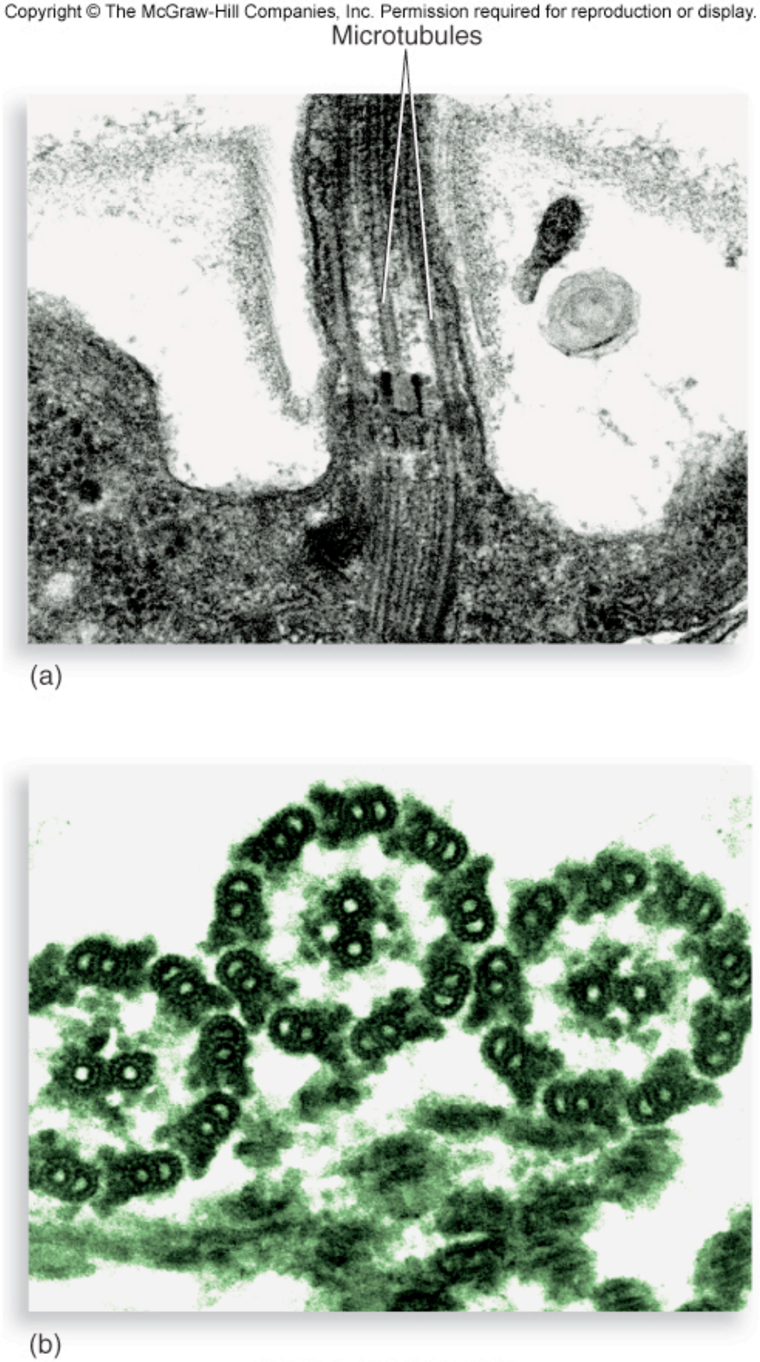


*Structure not present in all cell types

Figure 5.2

Locomotor Appendages: Cilia and Flagella

- Eukaryotic flagella are much different from those of prokaryotes
  - 10X thicker
  - Structurally more complex
  - Covered by an extension of the cell membrane
- A single flagellum contains regularly spaced microtubules along its length
  - 9 pairs surrounding a single pair
  - The 9 + 2 arrangement



9 + 2

Figure 5.3

- Cilia- similar to flagella but some differences
  - Shorter
  - More numerous
  - Can also function as feeding and filtering structures

The Glycocalyx

- Most eukaryotic cells have this outermost boundary that comes into direct contact with the environment
- Usually composed of polysaccharides
- Appears as a network of fibers, a slime layer, or a capsule
- Functions
  - Protection
  - Adhesion
  - Reception of signals
- The layer beneath the glycocalyx varies among eukaryotes
  - Fungi, plants and most algae have a thick, rigid cell wall
  - Protozoa and animal cells do not have this cell wall

Form and Function of the Eukaryotic Cell: Boundary Structures

- Cell Wall
  - Rigid
  - Provide support and shape
  - Different chemically from prokaryotic cell walls
  - Fungi
    - Thick, inner layer of chitin or cellulose
    - Thin outer layer of mixed glycans
  - Algae
    - Varied in chemical composition
    - May contain cellulose, pectin, mannans, and minerals

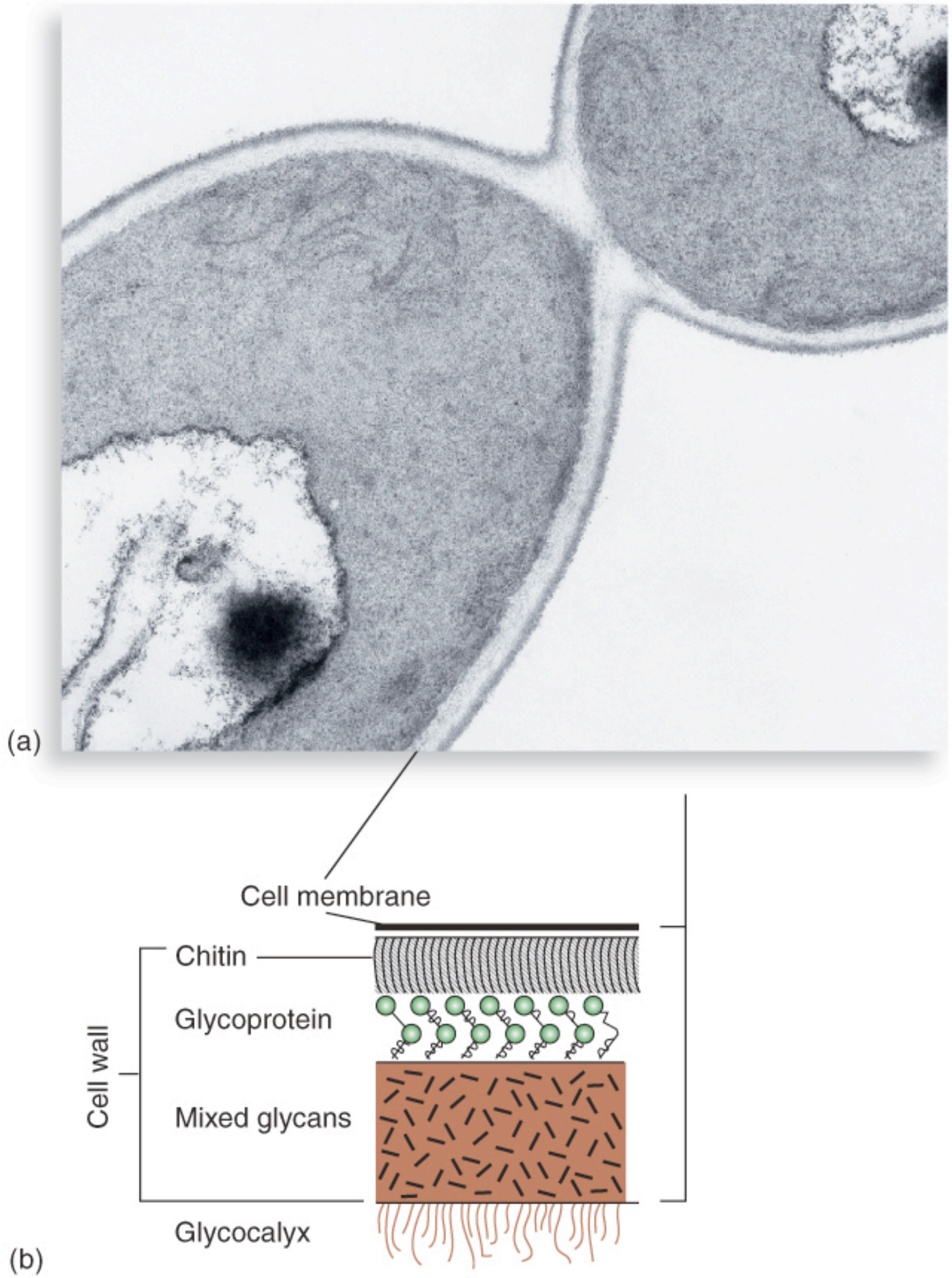

(a)
Cell membrane
Chitin
Glycoprotein
Mixed glycans
Cell wall
Glycocalyx
(b)

Figure 5.5

- Cytoplasmic (plasma) Membrane
  - Bilayer of phospholipids with protein molecules embedded
  - Also contain sterols
    - Gives stability
    - Especially important in cells without a cell wall
  - Selectively permeable

5.3 Form and Function of the Eukaryotic Cell: Internal Structures

- The Nucleus: The Control Center
  - Separated from the cytoplasm by a nuclear double membrane
    - Two parallel membranes separated by a narrow space
    - Perforated with nuclear pores
  - Filled with nucleoplasm
  - Contains area of dense NAs, called the **nucleolus**
    - rRNA synthesis
    - High density of ribosomal subunits
  - **Chromatin**
    - Comprises the **chromosomes**
      - Long, linear DNA molecules
      - Bound to **histone** proteins
      - Visible during **mitosis**

Endoplasmic Reticulum (ER): A Passageway in the Cell

- Microscopic series of tunnels
- Used in transport and storage
- Two kinds
  - **Rough endoplasmic reticulum (RER)**
    - Extension of the outer membrane of the nuclear envelope
    - Extends through the cytoplasm
    - Spaces in the RER - cisternae - transport materials from the nucleus to the cytoplasm
    - “Rough” because of ribosomes attached to its surface
    - Proteins synthesized by the ribosomes shunted into the lumen of the RER and held for later sorting, targeting and transport

Golgi Apparatus: A Packaging Machine

- Where proteins are modified and sent to their final destinations
- A stack of cisternae
- Do not form a continuous network
- Closely associated with ER both in location and function
  - The ER buds off transitional vesicles (packets of protein) where it meets the Golgi apparatus
  - The Golgi apparatus picks up the transitional vesicles
  - The proteins are often modified by addition of polysaccharides and lipids
  - Then the apparatus pinches off condensing vesicles
    - Sent to **lysosomes**
    - Or transported outside the cell

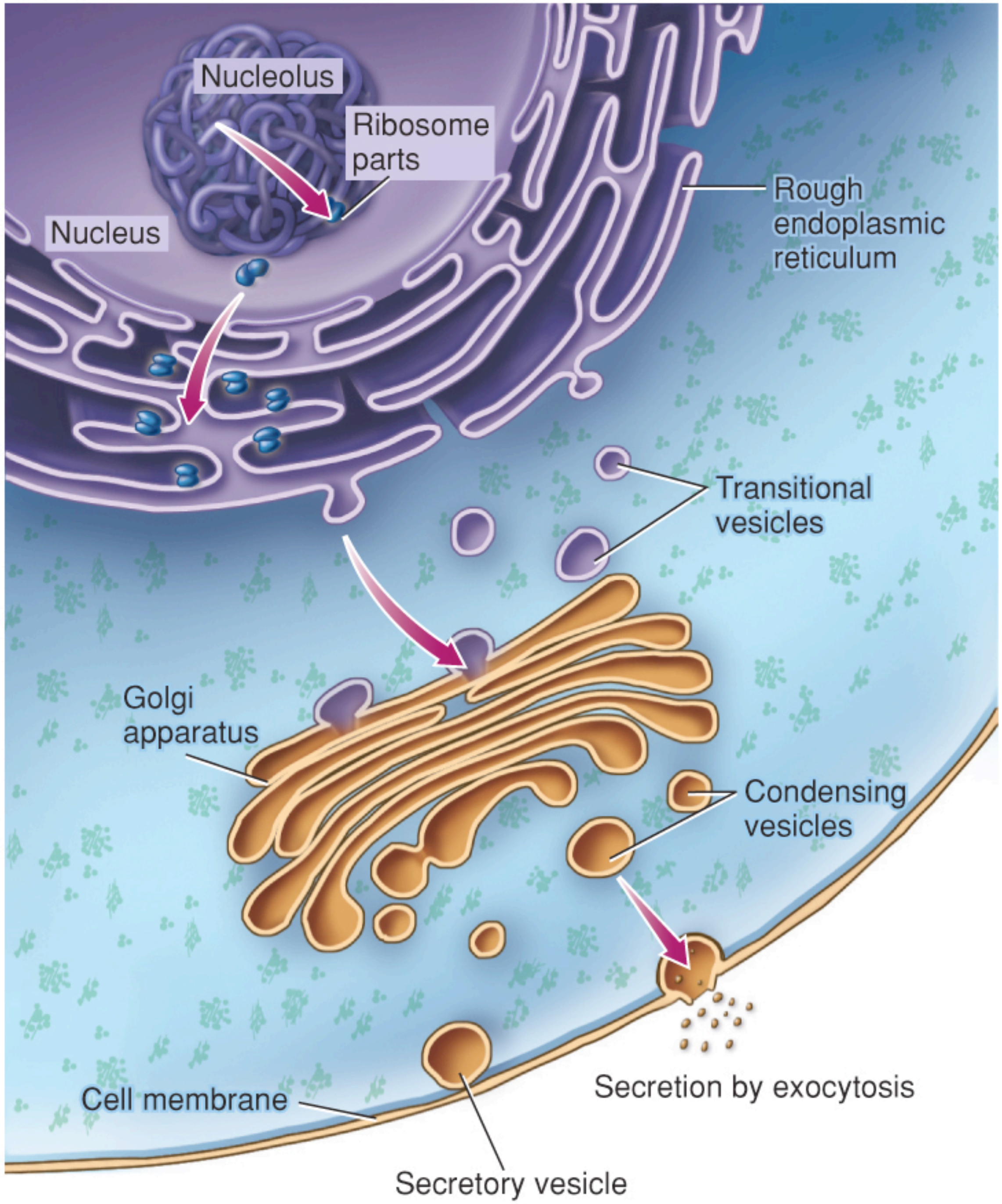

Nucleolus
Ribosome parts
Nucleus
Rough endoplasmic reticulum
Transitional vesicles
Golgi apparatus
Condensing vesicles
Cell membrane
Secretion by exocytosis
Secretory vesicle

Figure 5.10

Mitochondria: Energy Generators

- Cellular activities require a constant supply of energy
- The bulk of this energy generated by mitochondria
- Smooth, continuous outer membrane
- Inner folded membrane (folds are **cristae**)
  - Cristae hold enzymes and electron carriers of aerobic respiration
  - Spaces inside the cristae filled with a **matrix**
    - Ribosomes
    - DNA
    - Enzymes and other compounds involved in the metabolic cycle
- Divide independently of the cell
- Contain circular strands of DNA
- Contain prokaryotic-sized 70S ribosomes

Ribosomes: Protein Factories

- Some scattered in the cytoplasm and cytoskeleton
- Others associated with (R)ER
- Often found in chains of polyribosomes (polysomes)
- Composed of large and small subunits of ribonucleoprotein
- Larger 80S variety, composed of 60S and 40S subunits

The Cytoskeleton: A Support Network

- Flexible framework of molecules criss-crossing the cytoplasm
- Several functions
  - Anchoring organelles
  - Moving RNA and vesicles
  - Permitting shape changes and movement in some cells
- Two types: Microfilaments and microtubules

TABLE 5.2 A General Comparison of Prokaryotic and Eukaryotic Cells and Viruses*

Function or Structure	Characteristic	Procaryotic Cells	Eucaryotic Cells	Viruses**
Genetics	Nucleic acids	+	+	+
	Chromosomes	+	+	−
	True nucleus	−	+	−
	Nuclear envelope	−	+	−
Reproduction	Mitosis	−	+	−
	Production of sex cells	+/−	+	−
	Binary fission	+	+	−
Biosynthesis	Independent	+	+	−
	Golgi apparatus	−	+	−
	Endoplasmic reticulum	−	+	−
	Ribosomes	+***	+	−
Respiration	Enzymes	+	+	−
	Mitochondria	−	+	−
Photosynthesis	Pigments	+/−	+/−	−
	Chloroplasts	−	+/−	−
Motility/locomotor structures	Flagella	+/−***	+/−	−
	Cilia	−	+/−	−
Shape/protection	Membrane	+	+	+/−
	Cell wall	+***	+/−	− (have capsids instead)
	Capsule	+/−	+/−	−
Complexity of function		+	+	+/−
Size (in general)		0.5–3 μm****	2–100 μm	< 0.2 μm

*+ means most members of the group exhibit this characteristic; − means most lack it; +/− means some members have it and some do not.

**Viruses cannot participate in metabolic or genetic activity outside their host cells.

***The prokaryotic type is functionally similar to the eukaryotic, but structurally unique.

****Much smaller and much larger bacteria exist; see Insight 4.3.

5.4 The Kingdom of the **Fungi**

- Myceteae
- Great variety and complexity
- Approximately 100,000 species
- Can be divided in to two groups
  - Macroscopic fungi
  - Microscopic fungi
    - Yeasts
      - Round oval shape
      - Unique mode of asexual reproduction
    - **Hyphae**
      - Long, threadlike cells
    - Some are **dimorphic**
- Majority are unicellular or colonial
- Some form a **pseudohypha**

Fungal Nutrition

- Heterotrophic
- Acquire nutrients from **substrates**
- Most fungi are **saprophytes (saprotrophs)**
- Can be benign, **parasitic, pathogenic**
- General method of obtaining nutrition
  - Penetrates the substrate
  - Secretes enzymes
  - Breaks down the polymers into small molecules
  - Absorbs the small molecules
- Can absorb a wide variety of substrates
- Large medical and agricultural importance

Organization of Microscopic Fungi

- Most grow in loose associations or colonies
- **Yeasts**: unicellular, uniform texture and appearance
- **Molds** (Filamentous fungal colonies): cottony, hairy, or velvety textures
- **Mycelium**- the woven, intertwining mass of hyphae that makes up the body or colony of a mold
- Unique organizational features of hyphae
  - **Septa**- divide the hyphae in to segments (most fungi have so called septate hyphae)
  - Nonseptate hypha (coenocytic) - long, continuous cell
- Functions of hyphae
  - Vegetative hyphae (mycelium): visible mass of growth on the substrate surface; penetrates the substrate to digest and absorb nutrients
  - Reproductive (fertile) hyphae: form vegetative hyphae; responsible for the production of **spores**

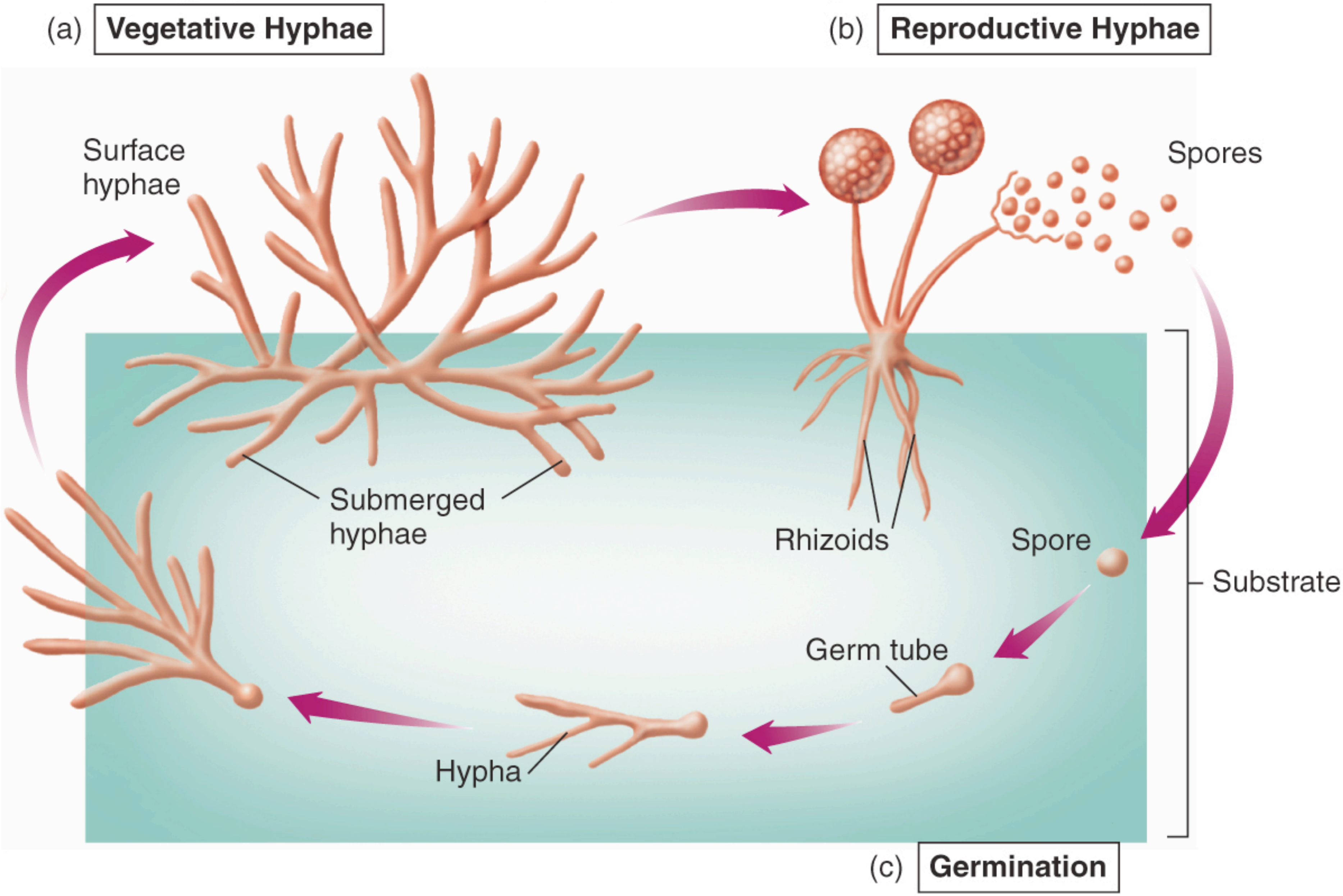

(a) Vegetative Hyphae
(b) Reproductive Hyphae
Surface hyphae
Spores
Submerged hyphae
Rhizoids
Spore
Substrate
Germ tube
Hypha
(c) Germination

Figure 5.18

5.5 The Protists

- Traditionally contains the algae and protozoa
- Two major taxonomic categories
  - Subkingdom Algae
  - Subkingdom Protozoa
- Any unicellular or colonial organism that lacks true tissues

The **Algae**: Photosynthetic protists

- Vary in length from a few micrometers to 100 meters
- Unicellular, colonial, and filamentous forms
- Larger forms can possess tissues and simple organs
- Exhibit all eukaryotic organelles
- Chloroplasts contain chlorophyll as well as other pigments
- One of the main components of **plankton**
- Rarely infectious
- Primary medical threat: shellfish exposed to red tide

Biology of the Protozoa

- About 65,000 species
- Most are harmless, free-living inhabitants of water and soil
- Few are parasites

Important Protozoan Pathogens

TABLE 5.4 Major Pathogenic Protozoa, Infections, and Primary Sources

Protozoan/Disease	Reservoir/Source
Amoeboid Protozoa	
Amoebiasis: *Entamoeba histolytica*	Human/water and food
Brain infection: *Naegleria, Acanthamoeba*	Free-living in water
Ciliated Protozoa	
Balantidiosis: *Balantidium coli*	Zoonotic in pigs
Flagellated Protozoa	
Giardiasis: *Giardia lamblia*	Zoonotic/water and food
Trichomoniasis: *T. hominis, T. vaginalis*	Human
Hemoflagellates	
Trypanosomiasis: *Trypanosoma brucei, T. cruzi*	Zoonotic/vector-borne
Leishmaniasis: *Leishmania donovani, L. tropica, L. brasiliensis*	Zoonotic/vector-borne
Apicomplexan Protozoa	
Malaria: *Plasmodium vivax, P. falciparum, P. malariae*	Human/vector-borne
Toxoplasmosis: *Toxoplasma gondii*	Zoonotic/vector-borne
Cryptosporidiosis: *Cryptosporidium*	Free-living/water, food
Cyclosporiasis: *Cyclospora cayetanensis*	Water/fresh produce

5.6 The Parasitic Helminths

- Tapeworms, flukes, and roundworms
- Adults large enough to be seen with the naked eye
- From 1 mm to 25 m in length
- Microscope is necessary to identify eggs and larvae
- Two major groups: Flatworms and Roundworms

TABLE 5.5 Examples of Helminths and Their Modes of Transmission

Classification	Common Name of Disease or Worm	Life Cycle Requirement	Spread to Humans By
Roundworms			
Nematodes			
Intestinal Nematodes			Ingestion
Infective in egg (embryo) stage			
Ascaris lumbricoides	Ascariasis	Humans	Fecal pollution of soil with eggs
Enterobius vermicularis	Pinworm	Humans	Close contact
Infective in larval stage			
Trichinella spiralis	Trichina worm	Pigs, wild mammals	Consumption of meat containing larvae
Tissue Nematodes			Burrowing of larva into tissue
Onchocerca volvulus	River blindness	Humans, black flies	Fly bite
Dracunculus medinensis	Guinea worm	Humans and *Cyclops* (an aquatic invertebrate)	Ingestion of water containing *Cyclops*
Flatworms			
Trematodes			
Schistosoma japonicum	Blood fluke	Humans and snails	Ingestion of fresh water containing larval stage
Cestodes			
T. solium	Pork tapeworm	Humans, swine	Consumption of undercooked or raw pork
Diphyllobothrium latum	Fish tapeworm	Humans, fish	Consumption of undercooked or raw fish

Distribution and Importance of Parasitic Worms

- About 50 species parasitize humans
- Distributed in all areas of the world
- Yearly estimate of worldwide infections- in the billions