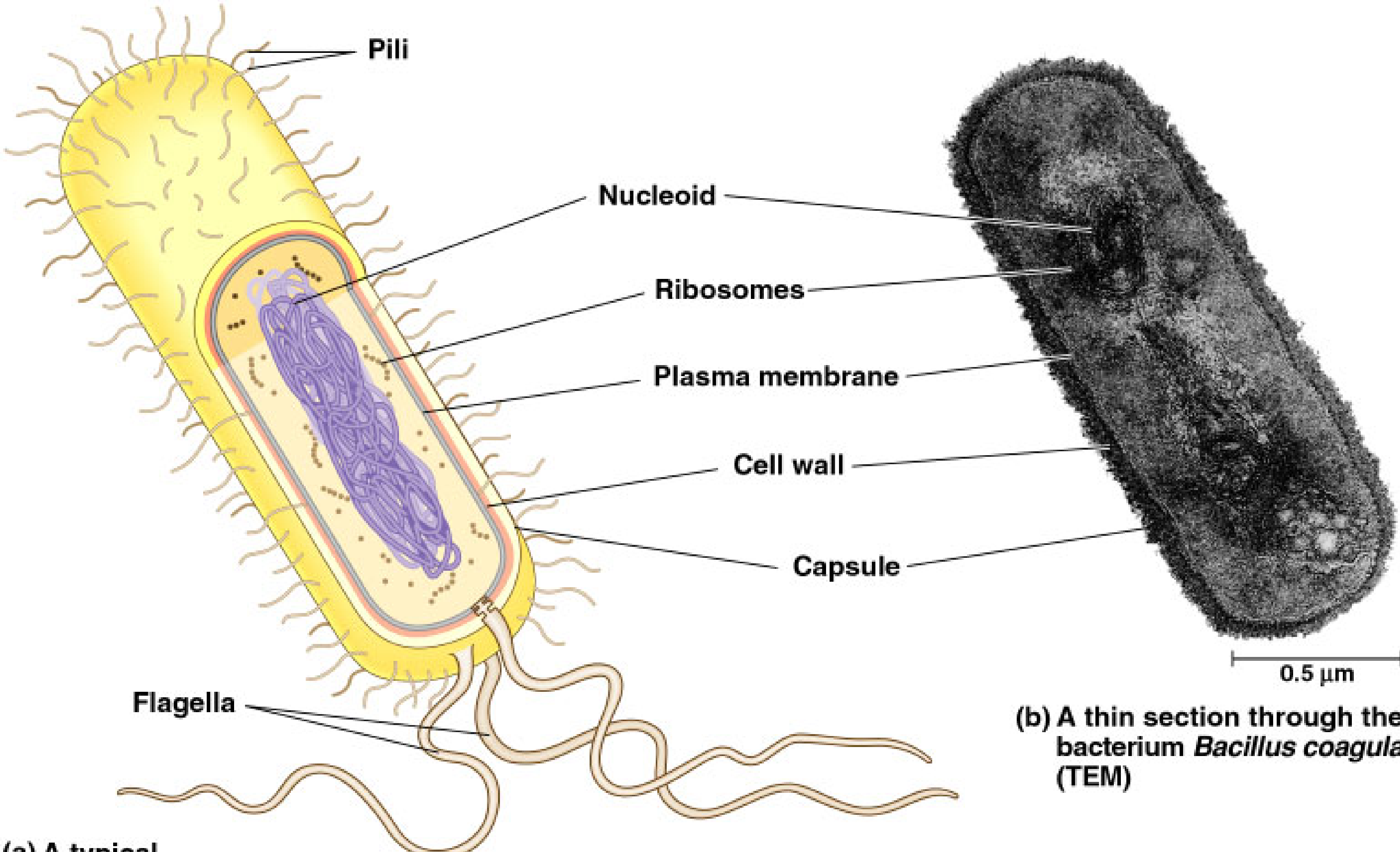
Comparing Prokaryotic and Eukaryotic Cells

Basic unit of living organisms is the cell; the smallest unit capable of life.

“Features” found in all cells:

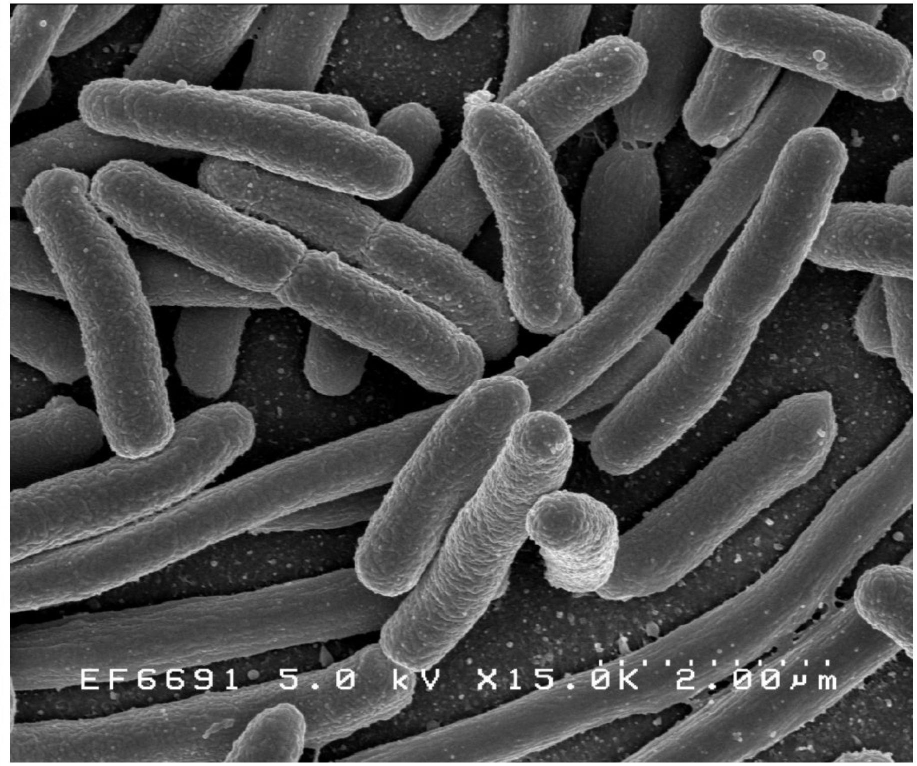
- **Ribosomes**
- **Cell Membrane**
- **Genetic Material**
- **Cytoplasm**
- **ATP Energy**
- **External Stimuli**
- **Regulate Flow**
- **Reproduce**

A prokaryotic cell



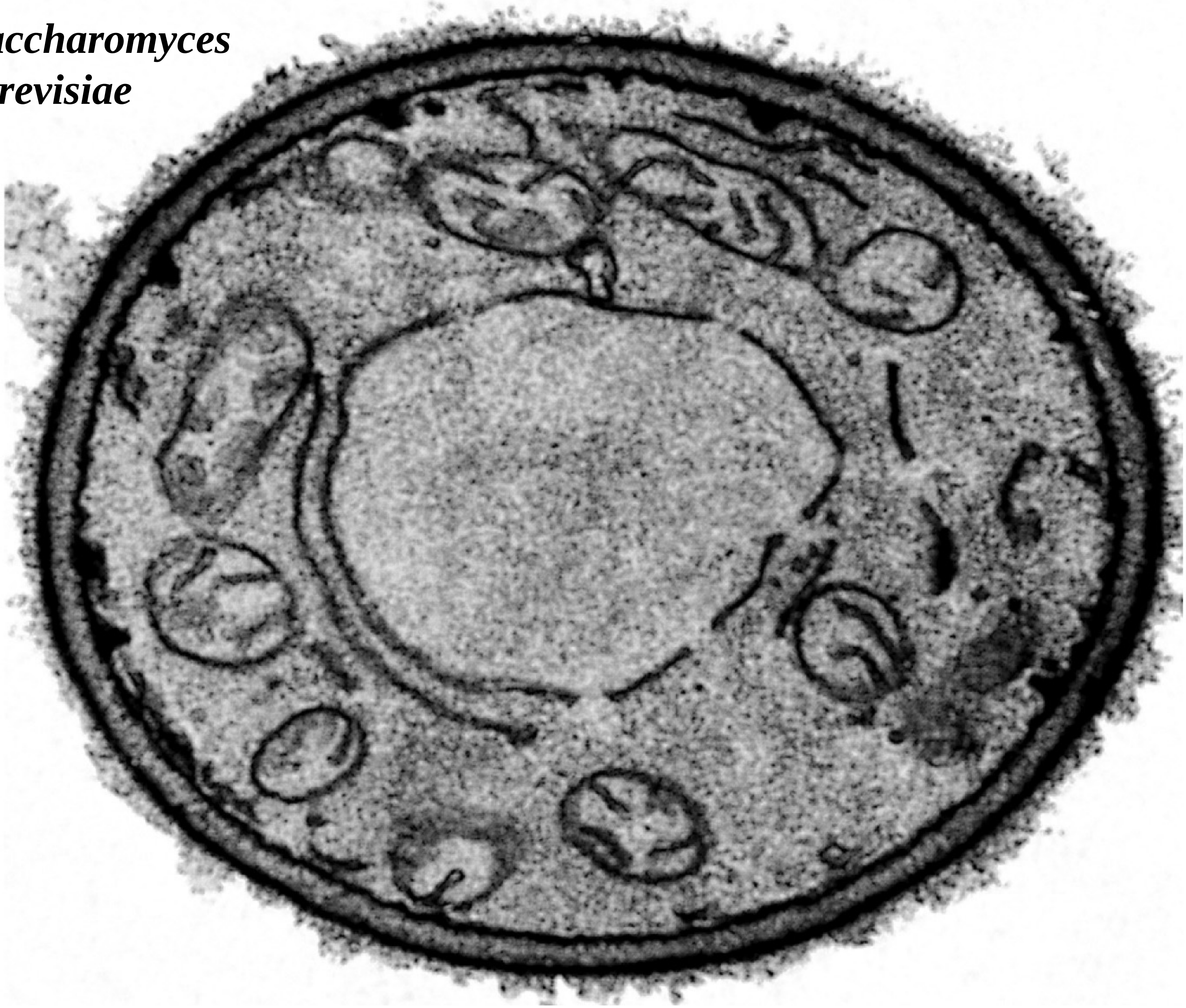
(a) A typical rod-shaped bacterium

(b) A thin section through the bacterium *Bacillus coagulans* (TEM)

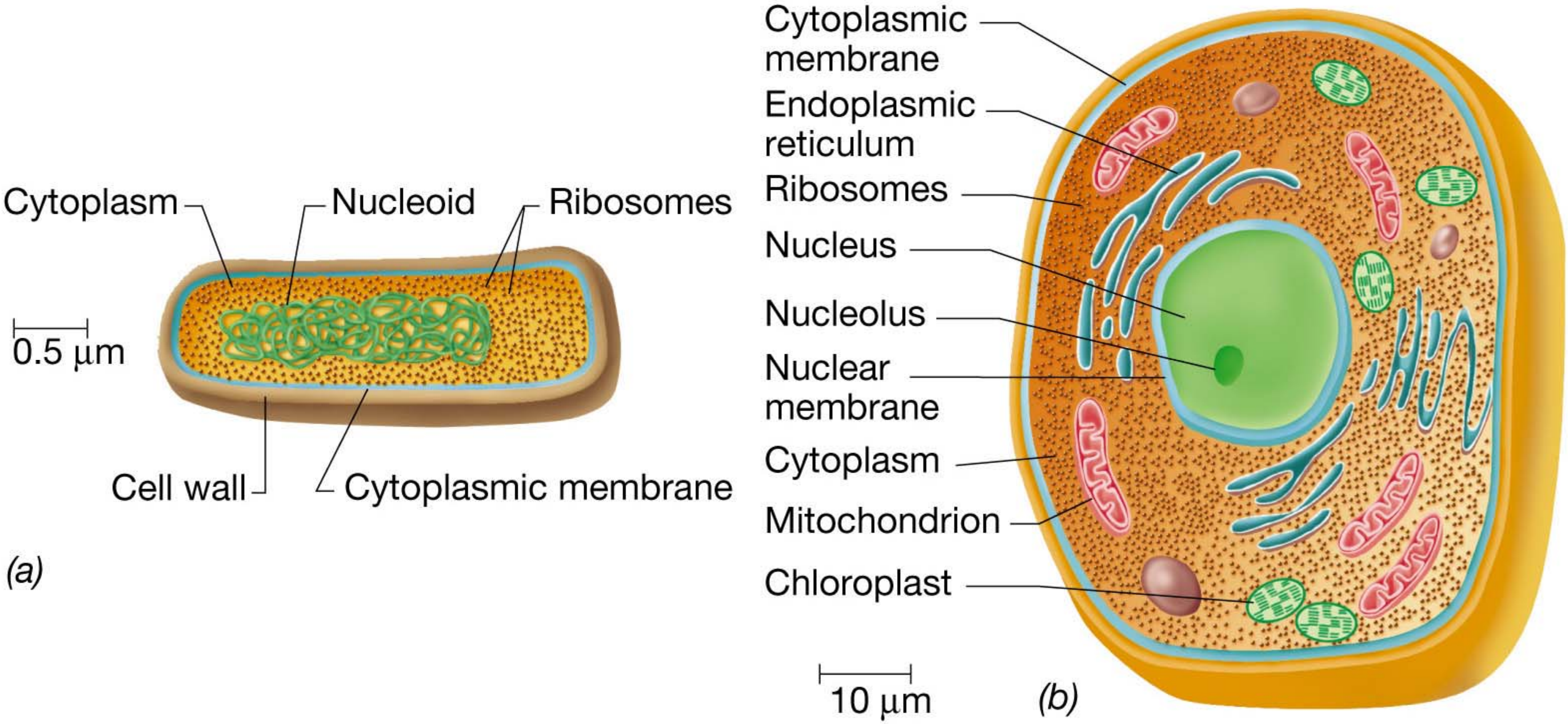


Escherichia coli

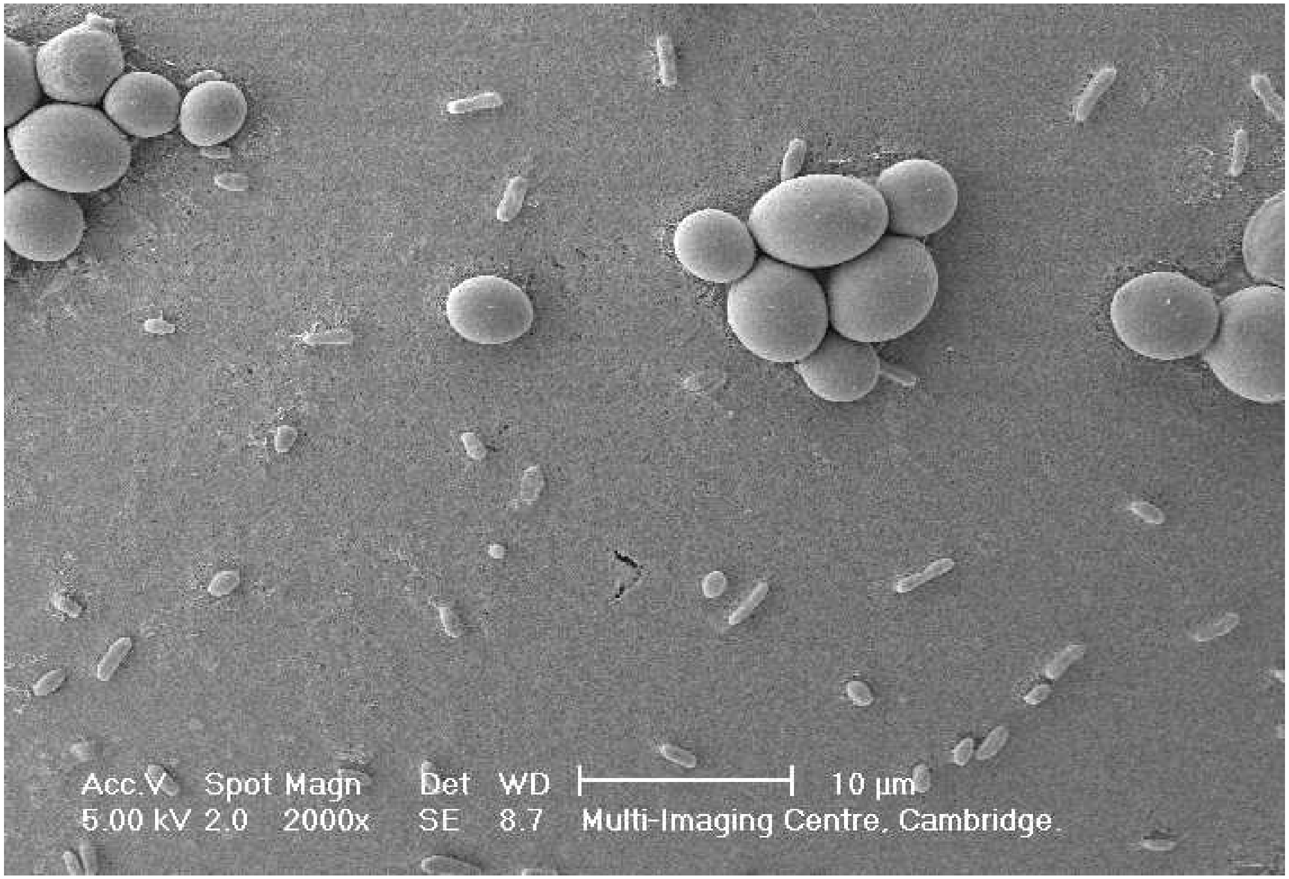
Saccharomyces cerevisiae



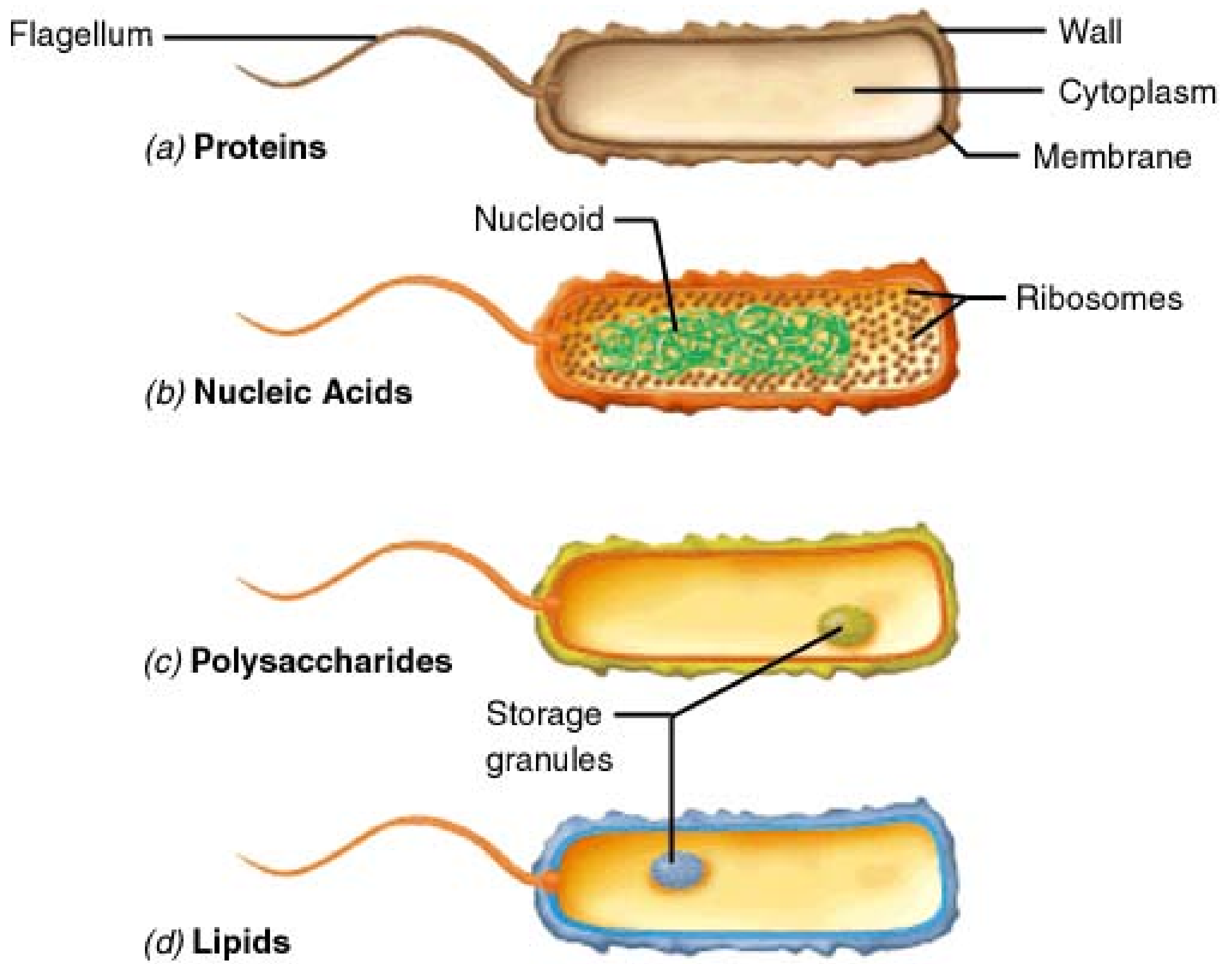
Elements of cellular structure



E. coli and S. cerevisiae



Locations of macromolecules in the cell



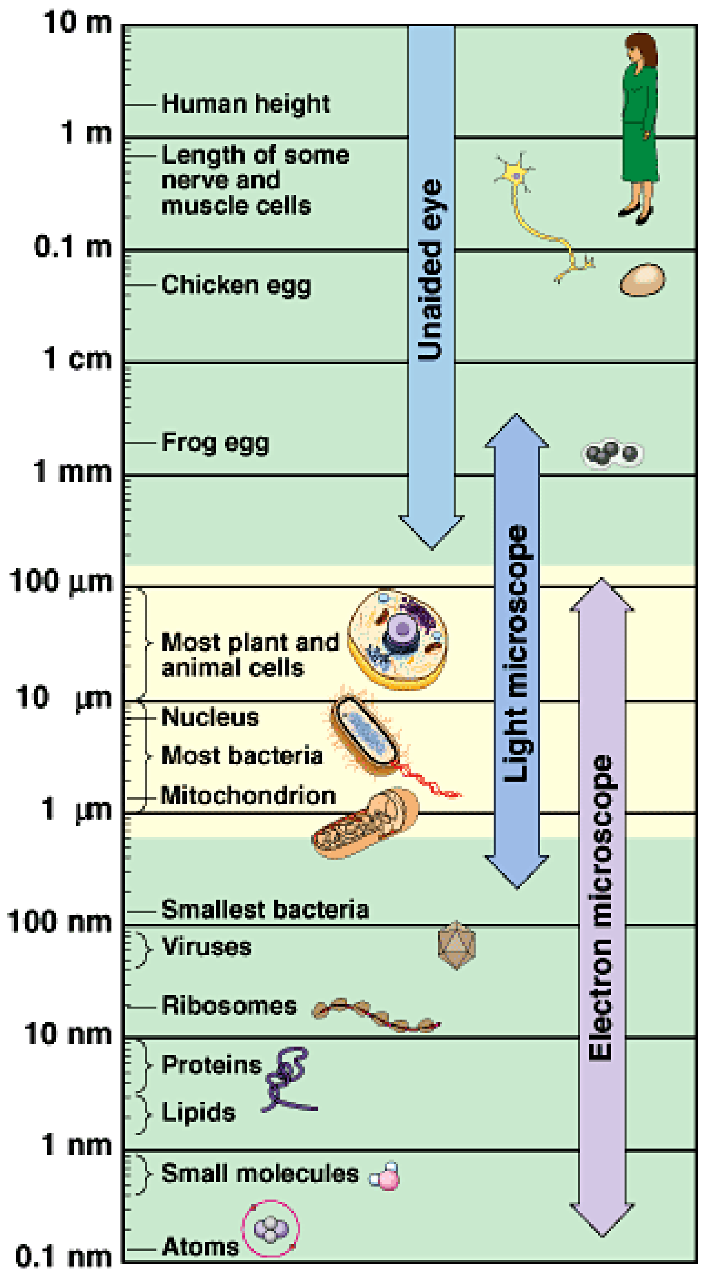
All over

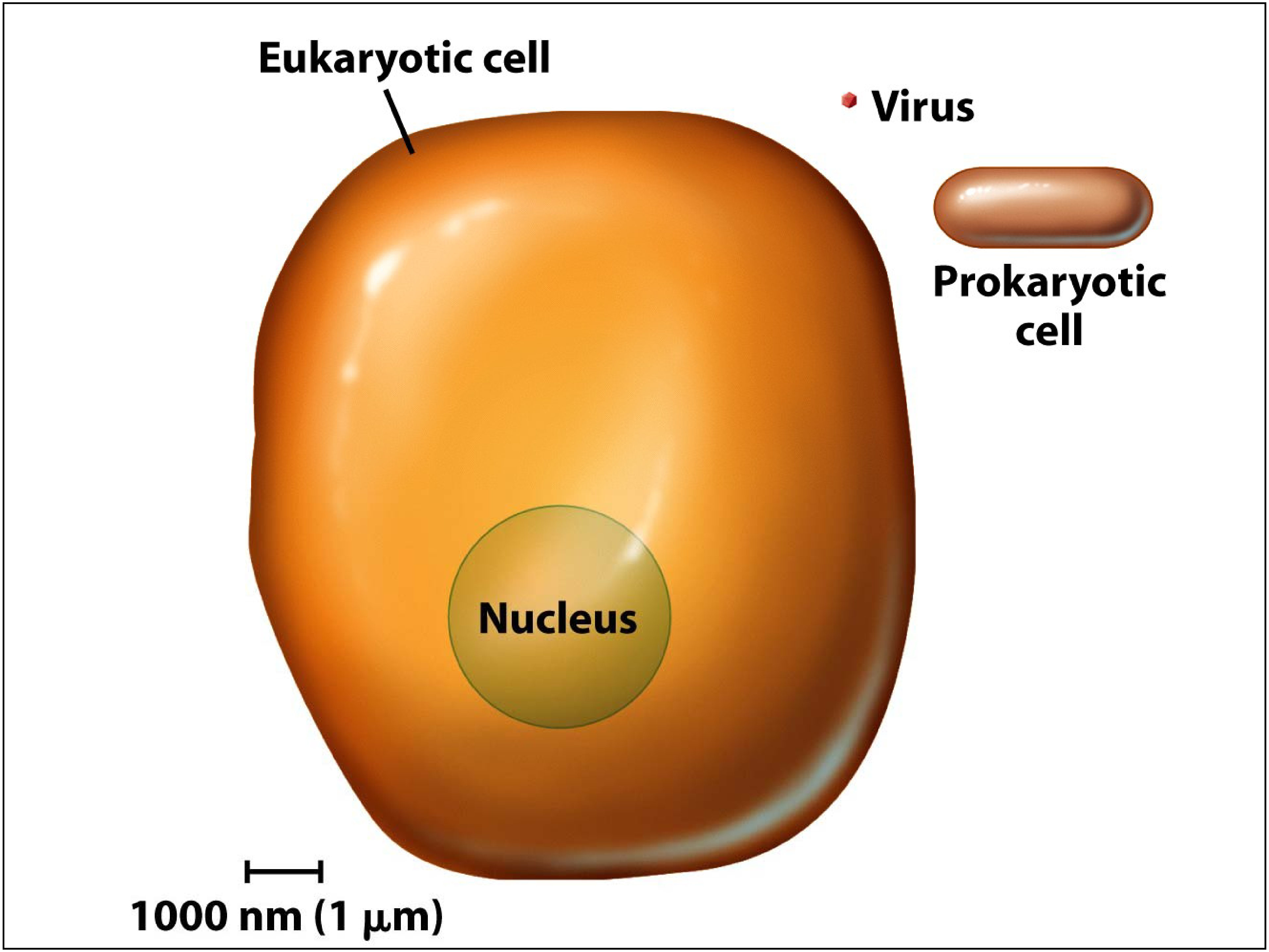
2 types
mostly

Cell Wall
mostly

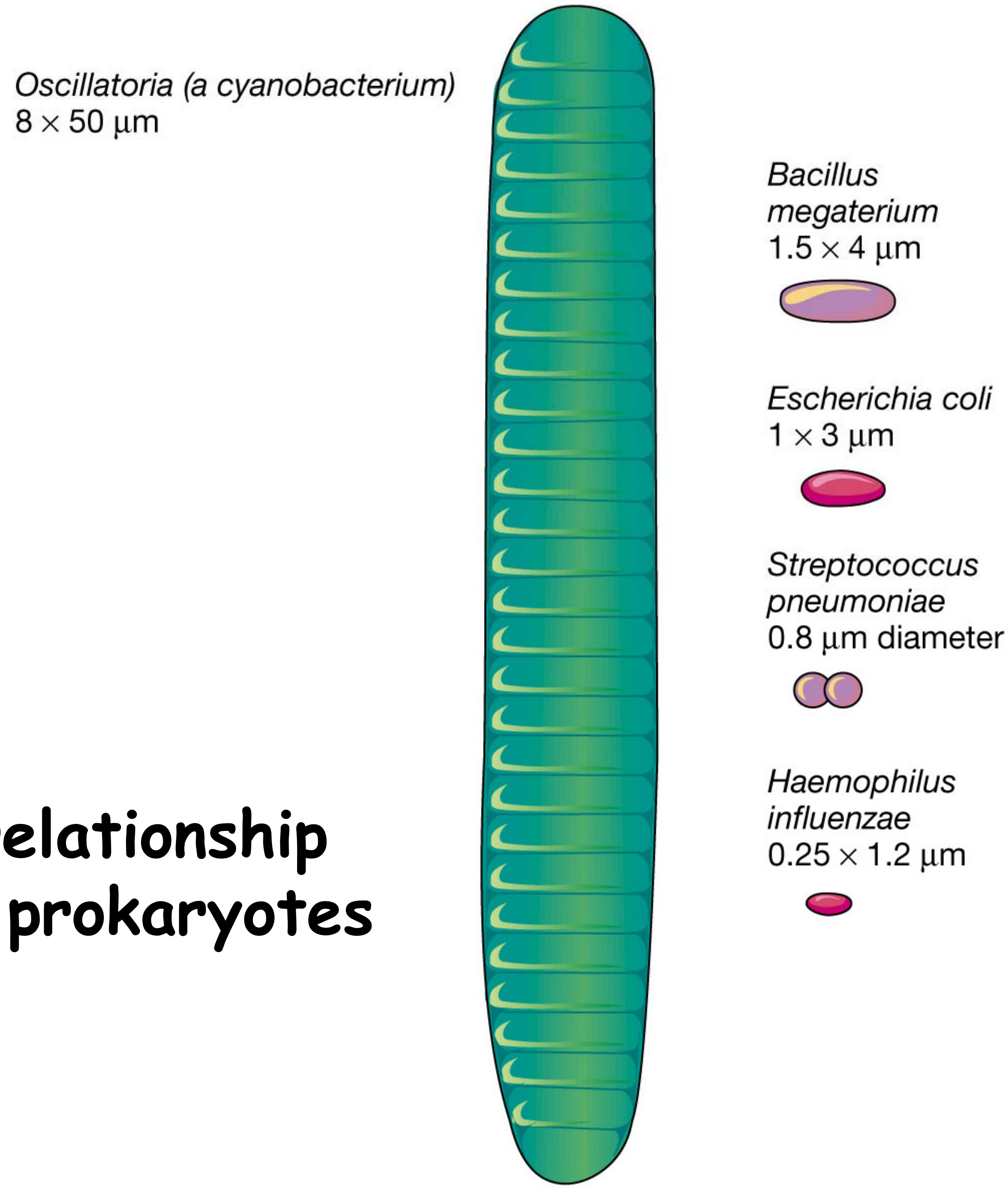
Cell Wall
Cell Mem

The size range of cells

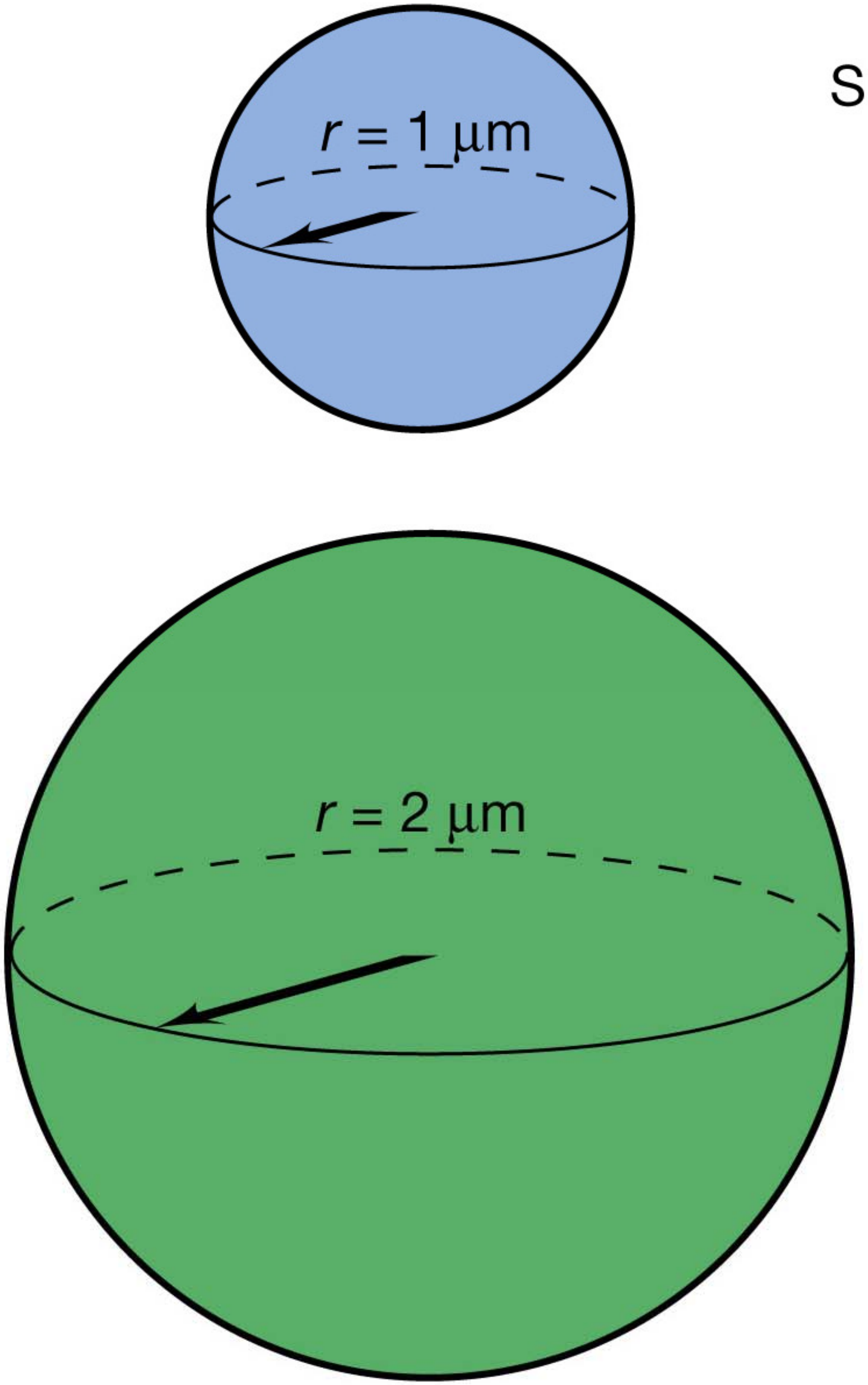




Eukaryotic cell
Virus
Prokaryotic cell
Nucleus
1000 nm (1 μm)



Size relationship among prokaryotes



Surface area $(4\pi r^2) = 12.6\ \mu m^2$

Volume $(\frac{4}{3}\pi r^3) = 4.2\ \mu m^3$

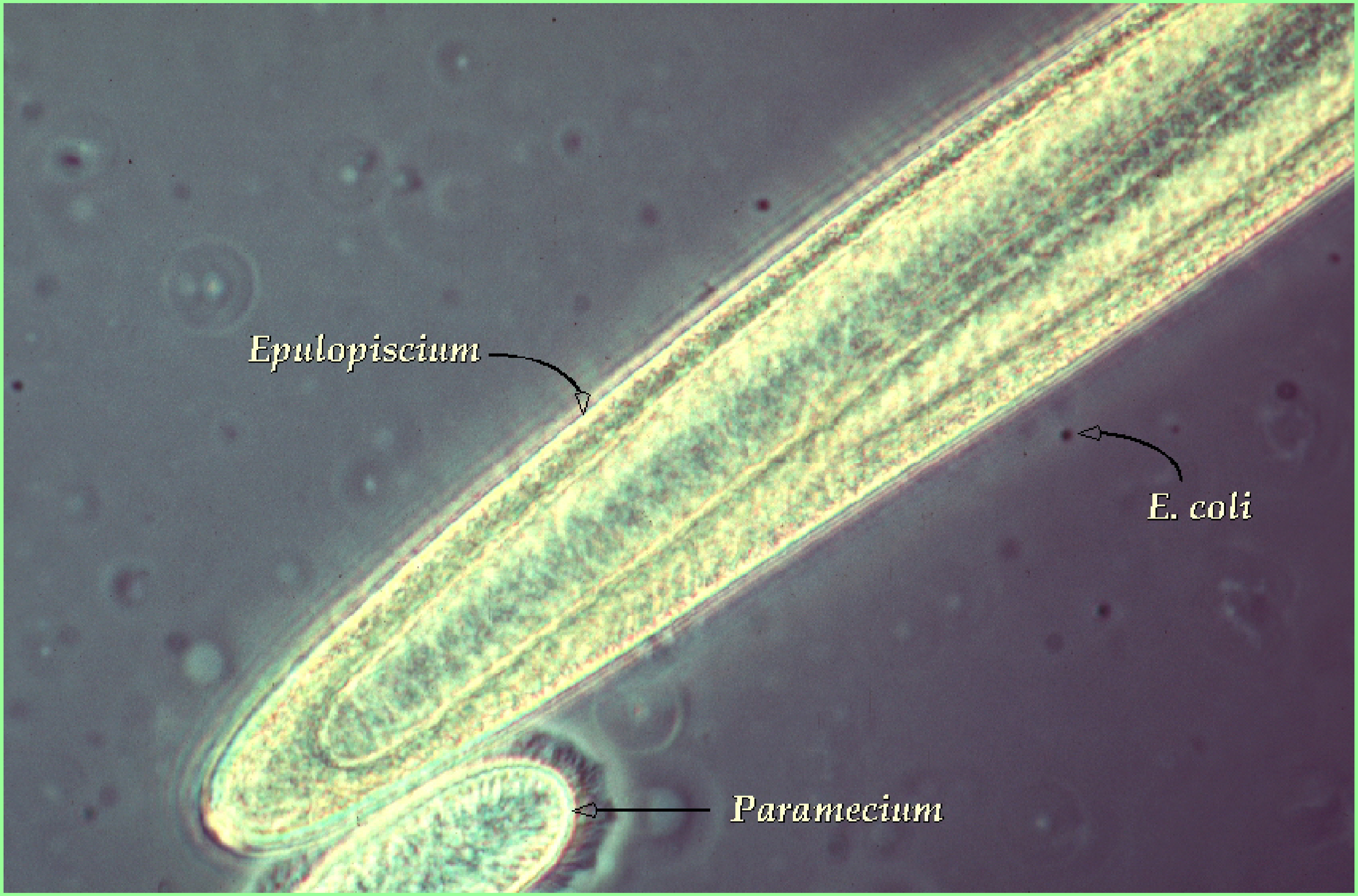
$$\mathbf{\frac{Surface}{Volume} = 3}$$

Surface area $= 50.3\ \mu m^2$

Volume $= 33.5\ \mu m^3$

$$\mathbf{\frac{Surface}{Volume} = 1.5}$$

A Million times bigger than E. coli!



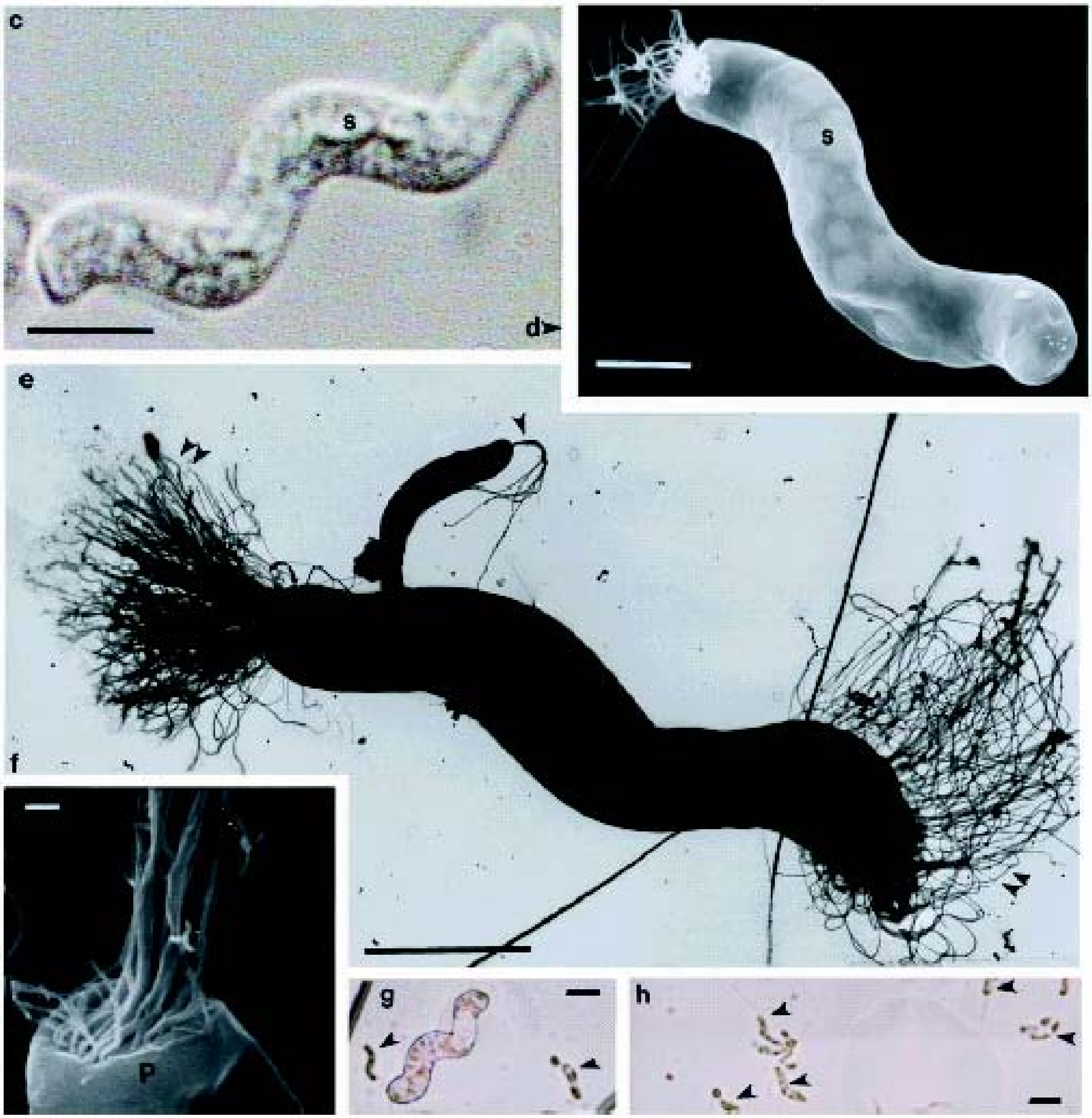


FIG. 1. (*a*) Mat surface at the Ebro Delta field site (3) showing lack of standing water. (Bar = 10 cm.) (*b*) Two spirilla cells (S, sulfur globule) shown by differential interference contrast (Nomarski). (Bar = 5 μm.) (*c*) Phase contrast microscopy of live spirillum cells. (Bar = 5 μm.) (*d*) Bipolar lophotrichous large spirillum in which only one pole has retained flagella. Sulfur globules are visible through the cell wall (scanning electron micrograph). (Bar = 5 μm.) (*e*) Negative-stain transmission electron micrograph of an entire bipolar lophotrichous large spirillum showing flagella "braids" (double arrowheads) compared with standard-sized spirilla (single arrowhead). (Bar = 5 μm.) (*f*) This scanning-electron micrograph of a cell terminus shows one vaulted end with residual flagella. The indentation coated by the polar organelle (P; see Fig. 2) is implied. (Bar = 0.5 μm.) (*g*) This Gram-stain brightfield preparation compares the two size classes, huge and standard, of Gram-negative spirilla. (Bar = 5 μm.) (*h*) Standard-sized spirillum Gram stain. The lighter spots are probably sulfur globules. (Bar = 5 μm.)

Titanospirillum velox

Up to 40 μm long

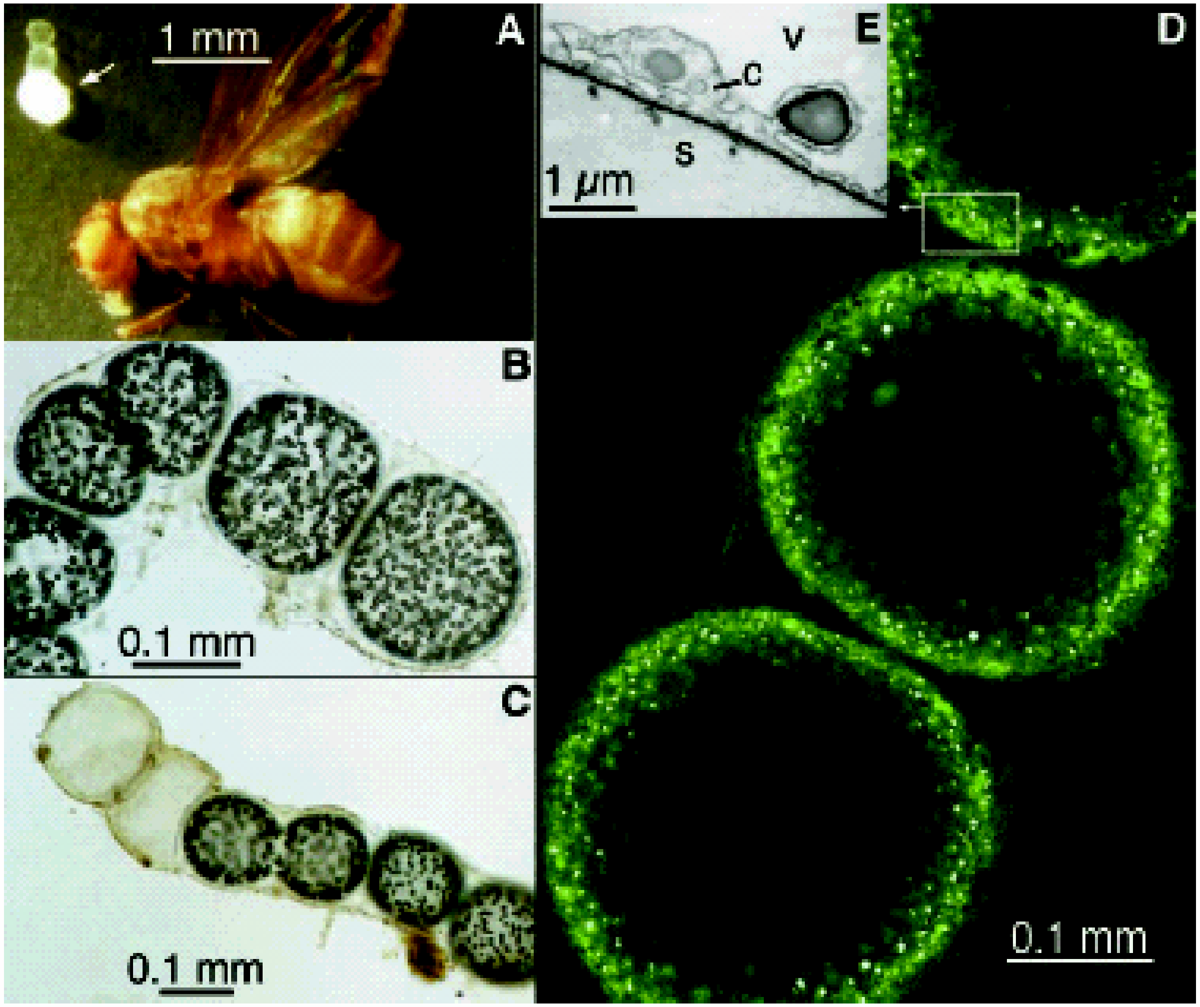
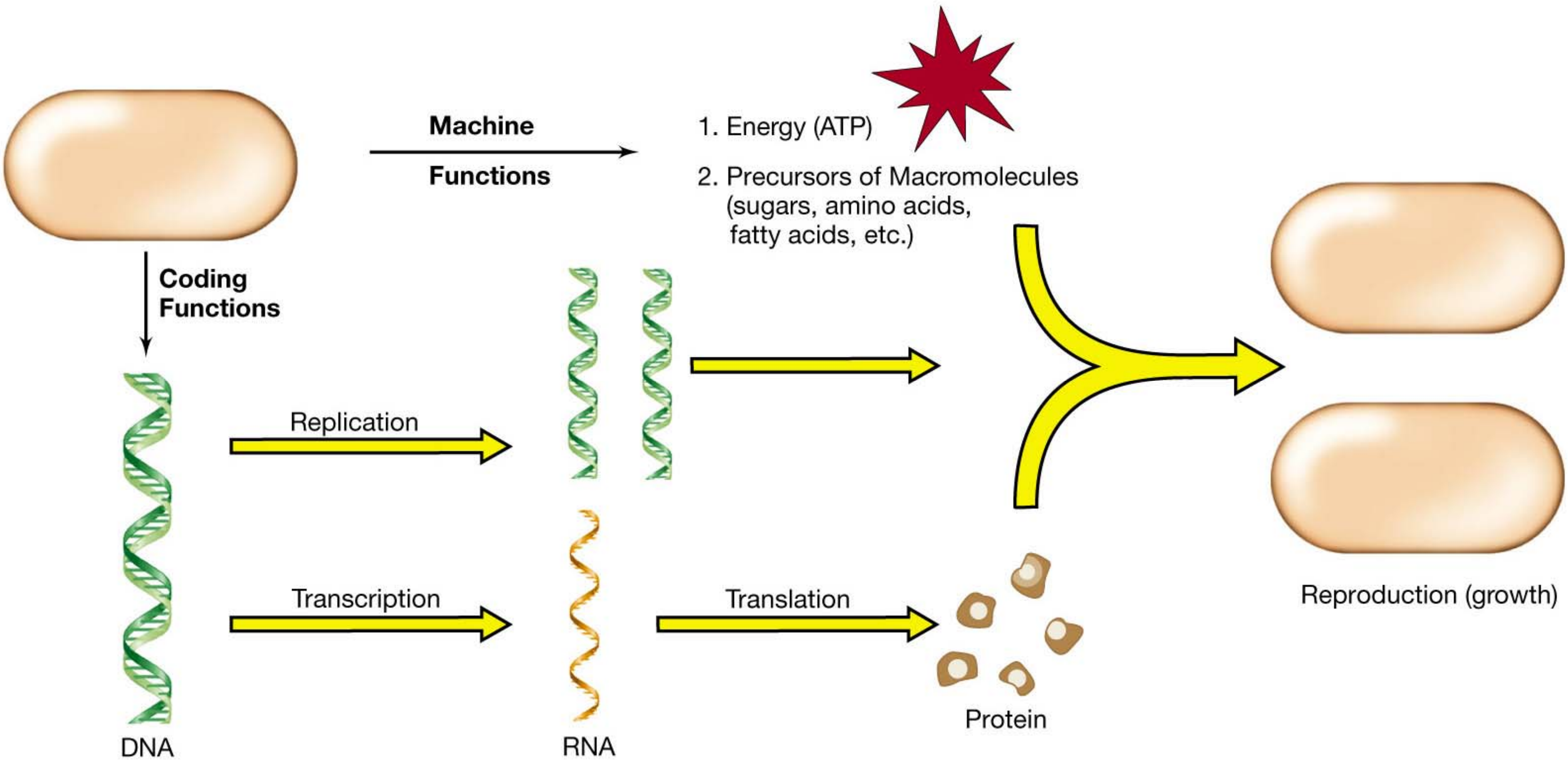


Fig. 1. *Thiomargarita namibiensis*. (A) The white arrow points to a single cell of *Thiomargarita*, 0.5 mm wide, which shines white because of internal sulfur inclusions. Above there is an empty part of the sheath, where the two neighboring cells have died. The cell was photographed next to a fruit fly (*Drosophila viriles*) of 3 mm length to give a sense of its size. (B) A typical chain of *Thiomargarita* as it appears under light microscopy. (C) At the left end of the chain there are two empty mucus sheaths, while in the middle a *Thiomargarita* cell is dividing. (D) Confocal laser scanning micrograph showing cytoplasm stained green with fluorescein isothiocyanate and the scattered light of sulfur globules (white). Most of the cells appear hollow because of the large central vacuole. (E) Transmission electron micrograph of the cell wall [enlarged area in (D)] showing the thin layer of cytoplasm (C), the vacuole (V), and the sheath (S).

Thiomargarita namibiensis

Up to 500 μm wide

The machine/coding functions of the cell



Central Dogma

TABLE 2.2 Chemical composition of a prokaryotic cell[a]

Rem: 70-85% Water

Molecule	Percent of dry weight[b]	Molecules per cell	Different kinds
Total macromolecules	96	24,610,000	~2500
Protein	55	2,350,000	~1850
Polysaccharide	5	4,300	2[c]
Lipid	9.1	22,000,000	4[d]
Lipopolysaccharide	3.4	1,430,000	1
DNA	3.1	2.1	1
RNA	20.5	255,500	~660
Total monomers	3.0		~350
Amino acids and precursors	0.5		~100
Sugars and precursors	2		~50
Nucleotides and precursors	0.5		~200
Inorganic ions	1		18
Total	100%		

a Data from Neidhardt, F. C., et al. (eds.), 1996. *Escherichia coli* and *Salmonella typhimurium—Cellular and Molecular Biology*, 2nd edition. American Society for Microbiology, Washington, DC.

b Dry weight of an actively growing cell of *E. coli* ≅ 2.8×10^{-13} g; total weight (70% water) = 9.5×10^{-13} g.

c Assuming peptidoglycan and glycogen to be the major polysaccharides present.

d There are several classes of phospholipids, each of which exists in many kinds because of variability in fatty acid composition between species and because of different growth conditions.

Protein ~50%
Lipid ~10%
RNA ~20%
DNA ~ 3-4%

Cell Wall 10–20%

Take Home Message:

Proteins are #1 by weight

Lipids are #1 by number

Peptidoglycan is 1 jumbo molecule

Comparing Prokaryotic and Eukaryotic Cells

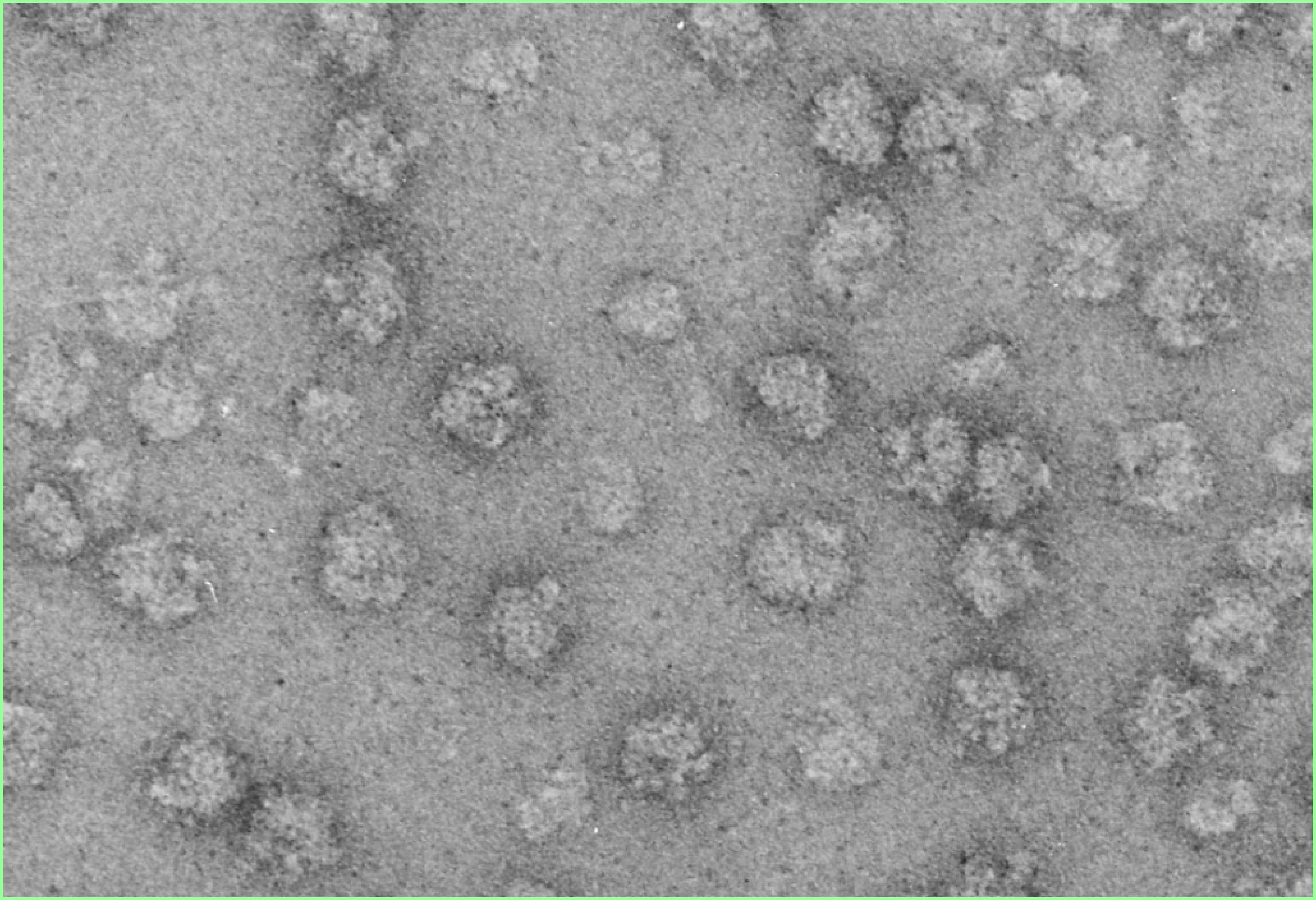
Classification of prokaryotic cellular features:
Invariant (or common to all)

⇨ ● **Ribosomes: Sites for protein synthesis – aka the grand translators.**

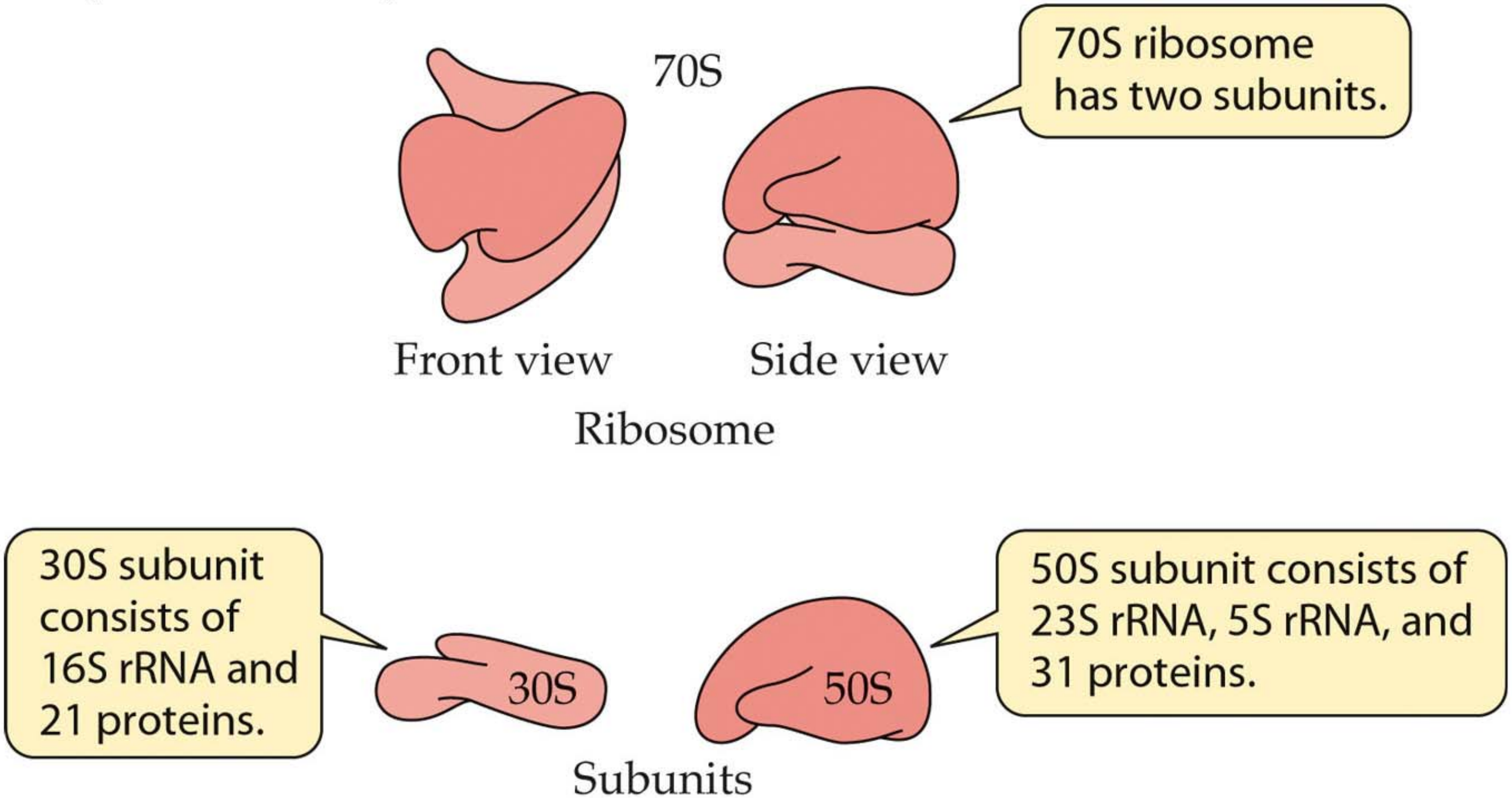
● **Cell Membranes: The barrier between order and chaos**.

● **Nucleoid Region: Curator of the Information**.

Ribosome structure



(B) Prokaryotic ribosome
(*Escherichia coli*)



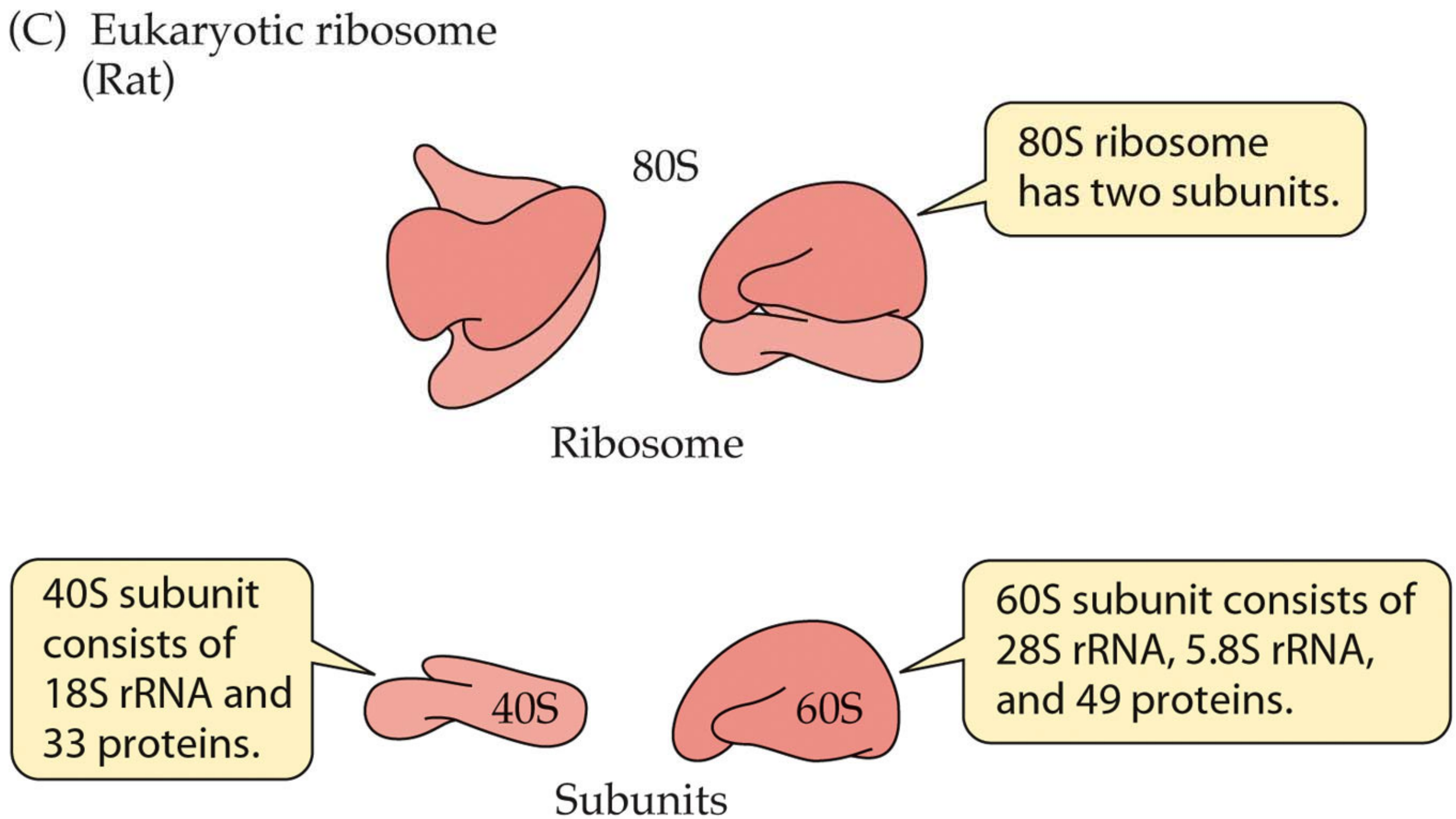

(C) Eukaryotic ribosome
(Rat)
80S
80S ribosome
has two subunits.
Ribosome
40S subunit
consists of
18S rRNA and
33 proteins.
40S
60S
60S subunit consists of
28S rRNA, 5.8S rRNA,
and 49 proteins.
Subunits

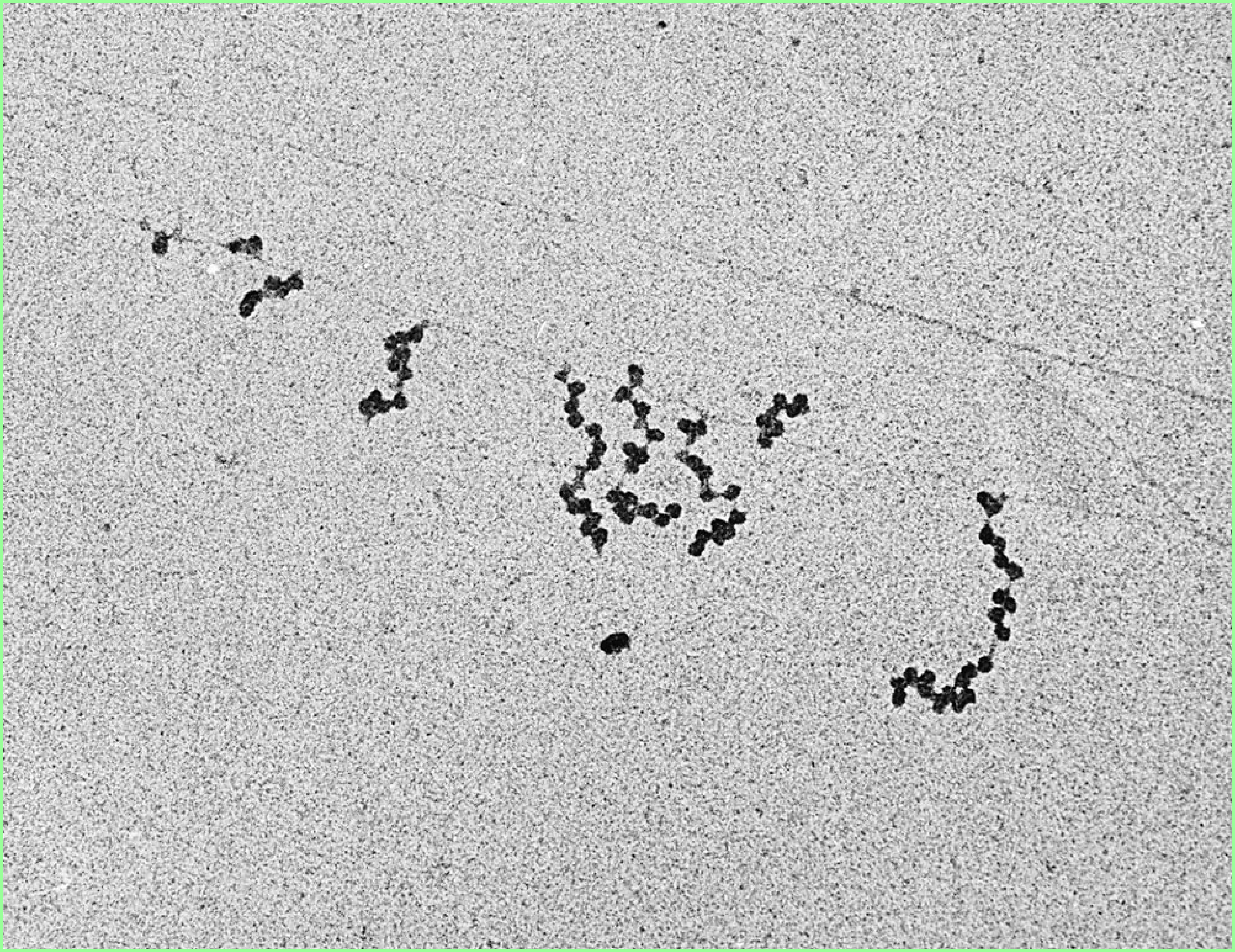
Table 7.6 Ribosome structure[a]

Property	Prokaryote	Eukaryote
Overall size	70S	80S
Small subunit	30S	40S
Number of proteins	~21	~30
RNA size (number of bases)	16S (1500)	18S (2300)
Large subunit	50S	60S
Number of proteins	~34	~50
RNA size (number of bases)	23S (2900)	28S (4200)
	5S (120)	5.8S (160)
		5S (120)

[a] Ribosomes of mitochondria and chloroplasts of eukaryotes are similar to prokaryotic ribosomes (Section 14.4).

S= Svedberg; a sedimentation coefficient that is NOT ADDITIVE!!!

Protein synthesis



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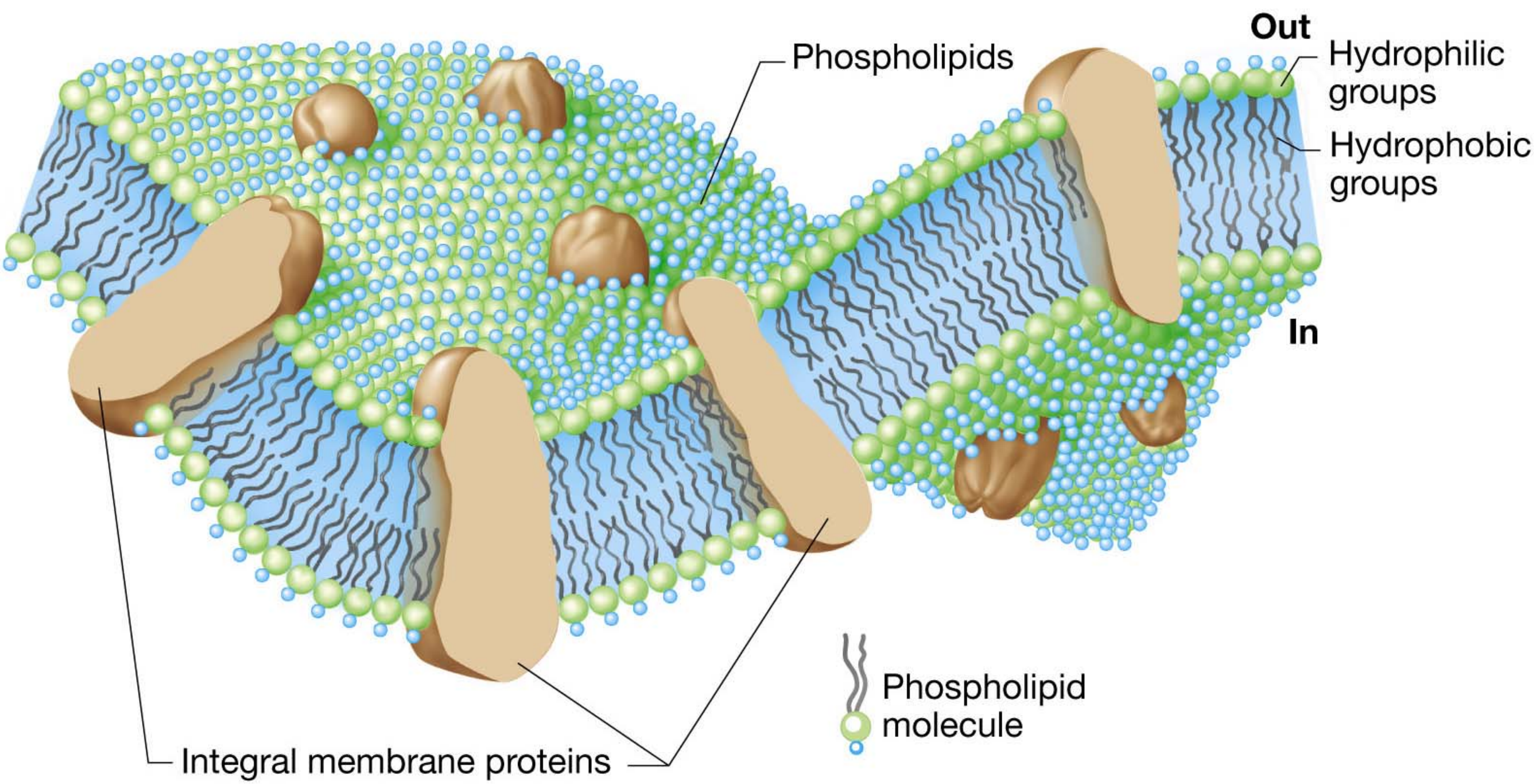
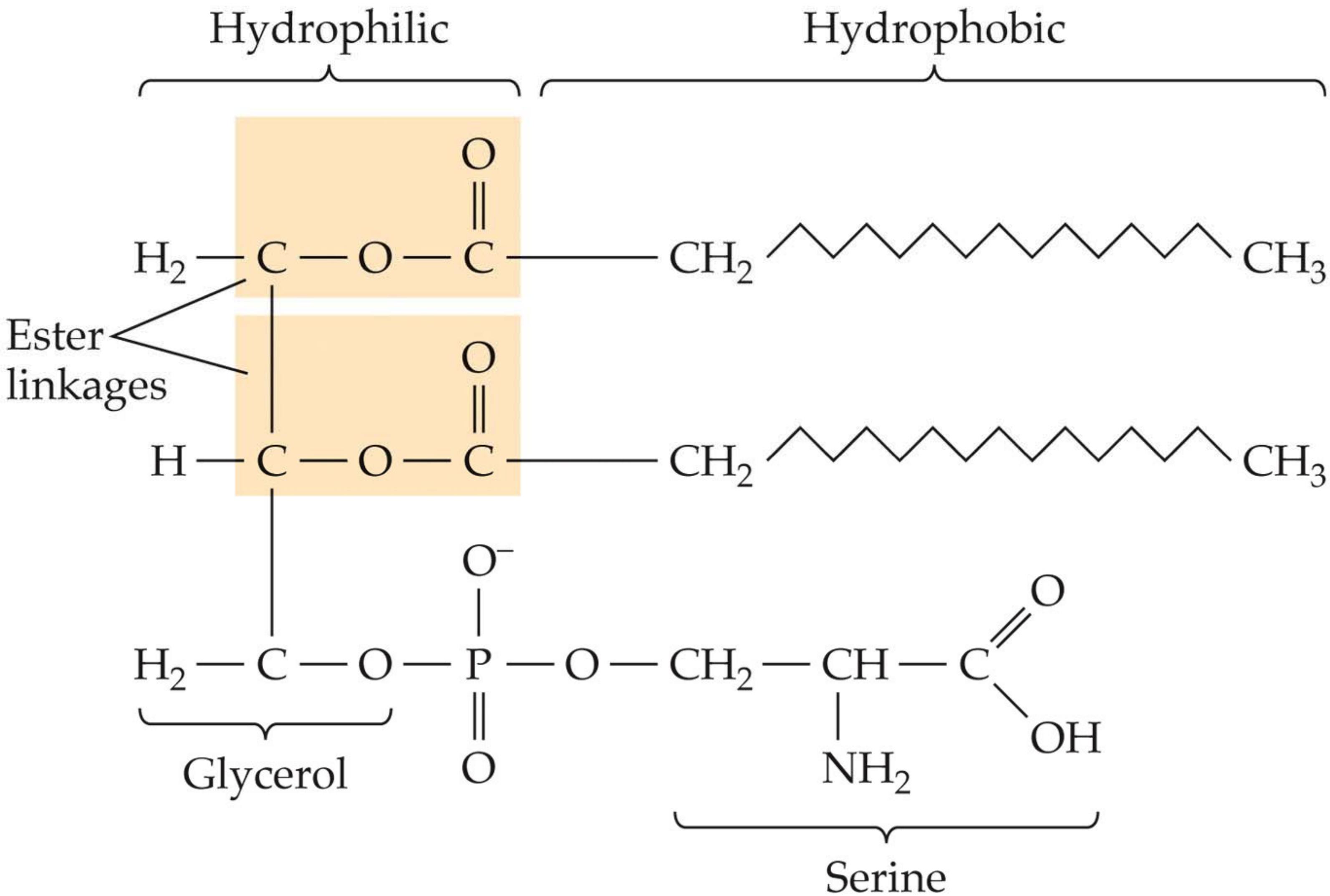
The cytoplasmic membrane

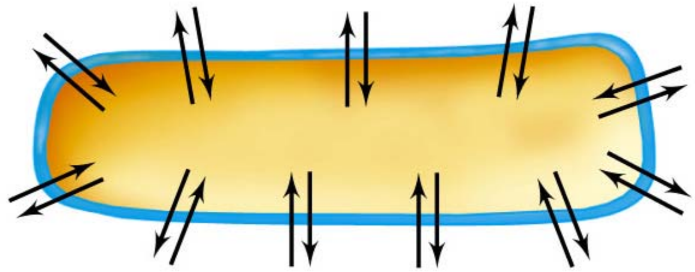


Rem: Fluid Mosaic Model

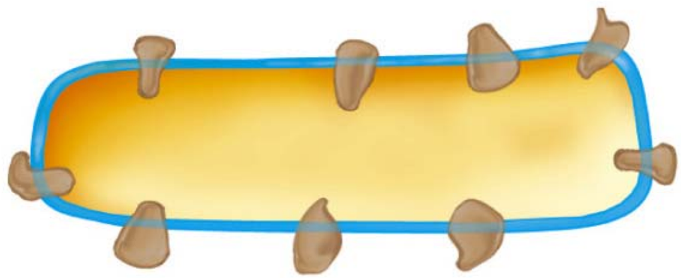


Amphipathic

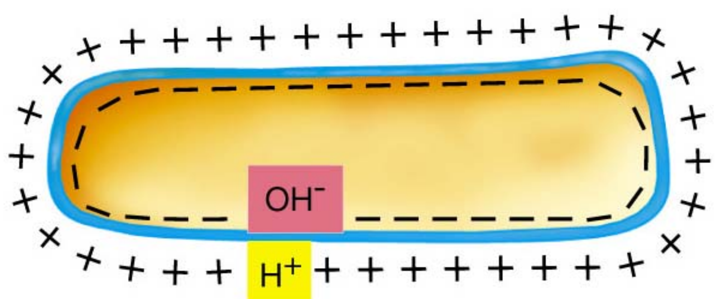
Functions of the cytoplasmic membrane



Permeability Barrier — Prevents leakage and functions as a gateway for transport of nutrients into and out of the cell



Protein Anchor — Site of many proteins involved in transport, bioenergetics, and chemotaxis



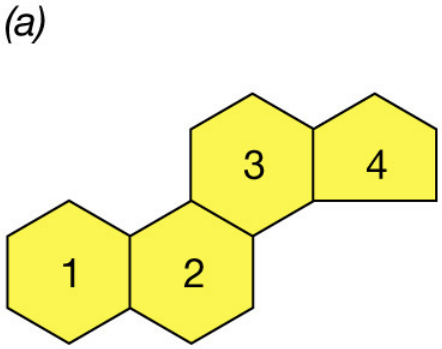
Energy Conservation — Site of generation and use of the proton motive force

Table 4.2 Comparative permeability of membranes to various molecules

Substance	Rate of permeability [a]
Water	100
Glycerol	0.1
Tryptophan	0.001
Glucose	0.001
Chloride ion (Cl^-)	0.000001
Potassium ion (K^+)	0.0000001
Sodium ion (Na^+)	0.00000001

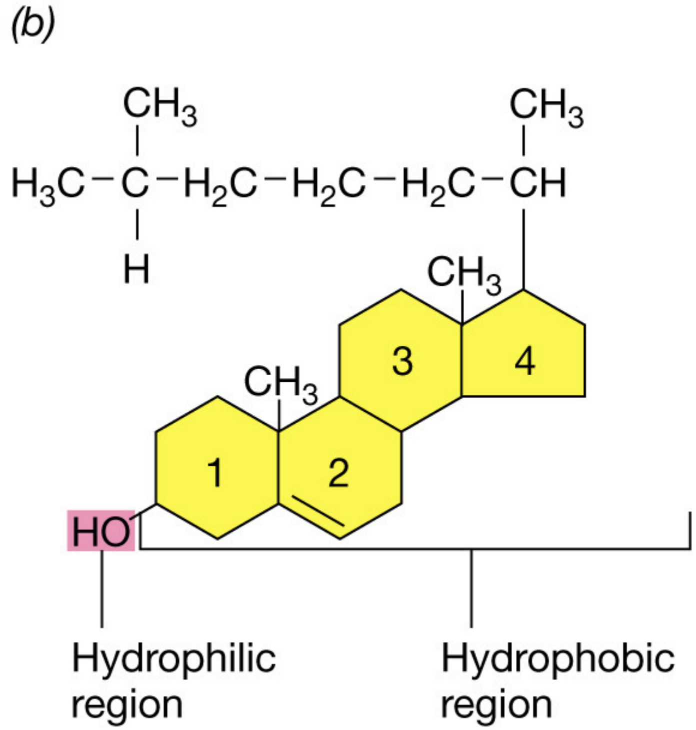
[a] Relative scale—permeability with respect to permeability of water given as 100. Permeability of the membrane to water may be affected by aquaporins (see text).

Sterol

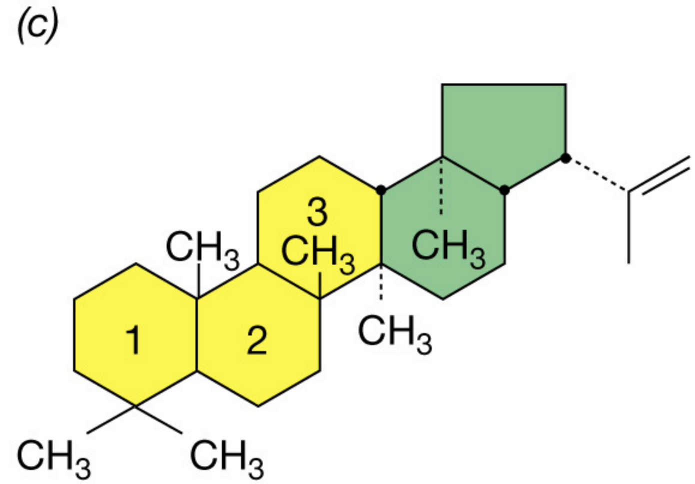


Few Bacteria

Cholesterol



Hopanoid (e.g., Diploptene)

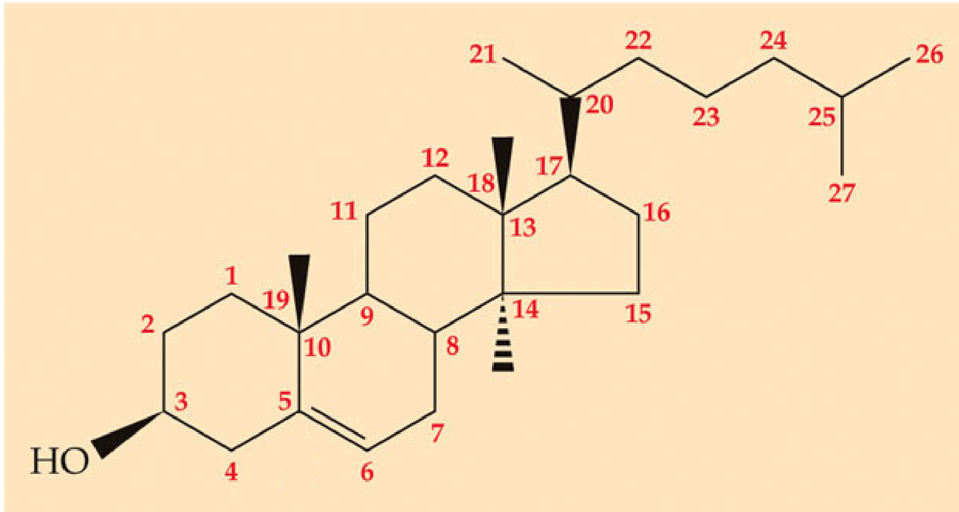


Many Bacteria

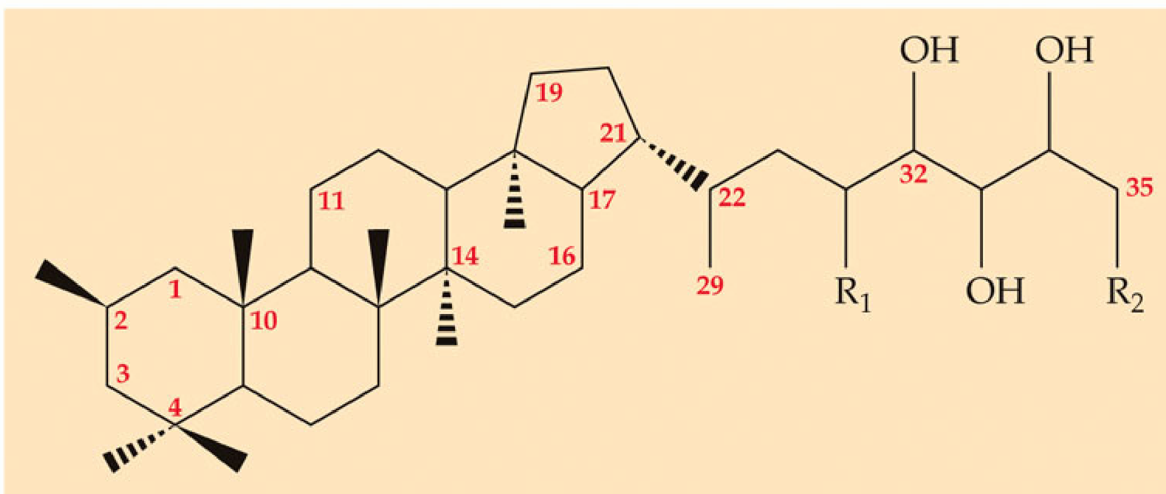
O_2 -

All rigid planar molecules

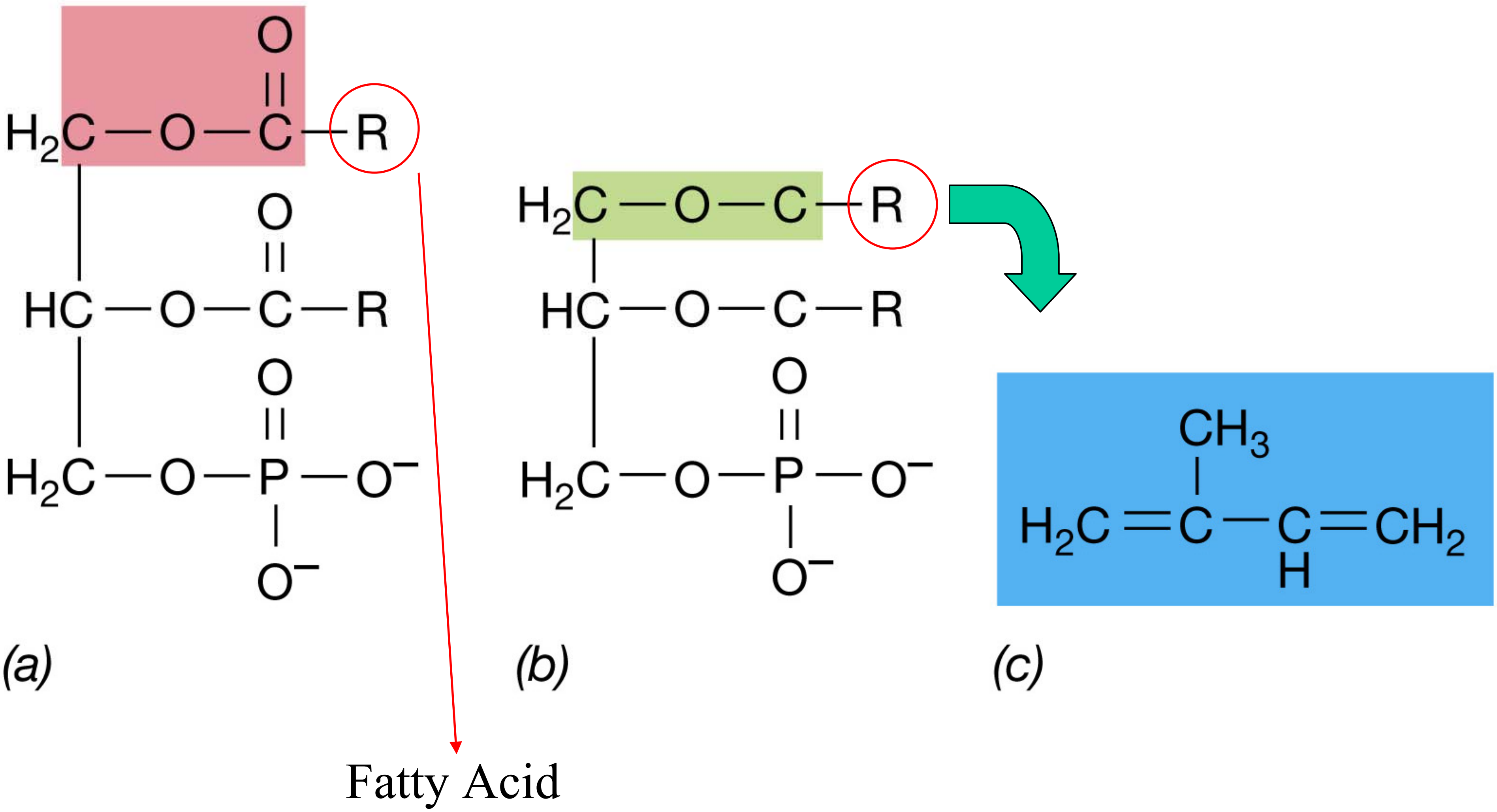
(A) Cholesterol



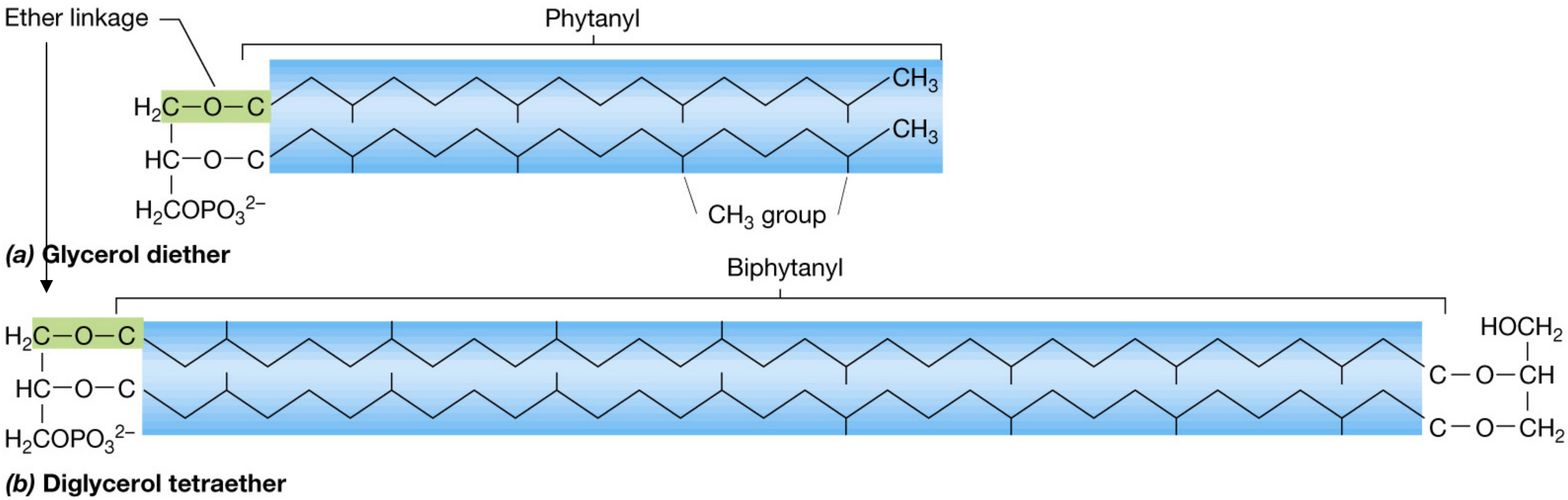
(B) A hopanoid from a cyanobacterium



Ester Linkage | Ether Linkage | Isoprene Unit



Major lipids of *Archaea* and the structure of archaeal membranes



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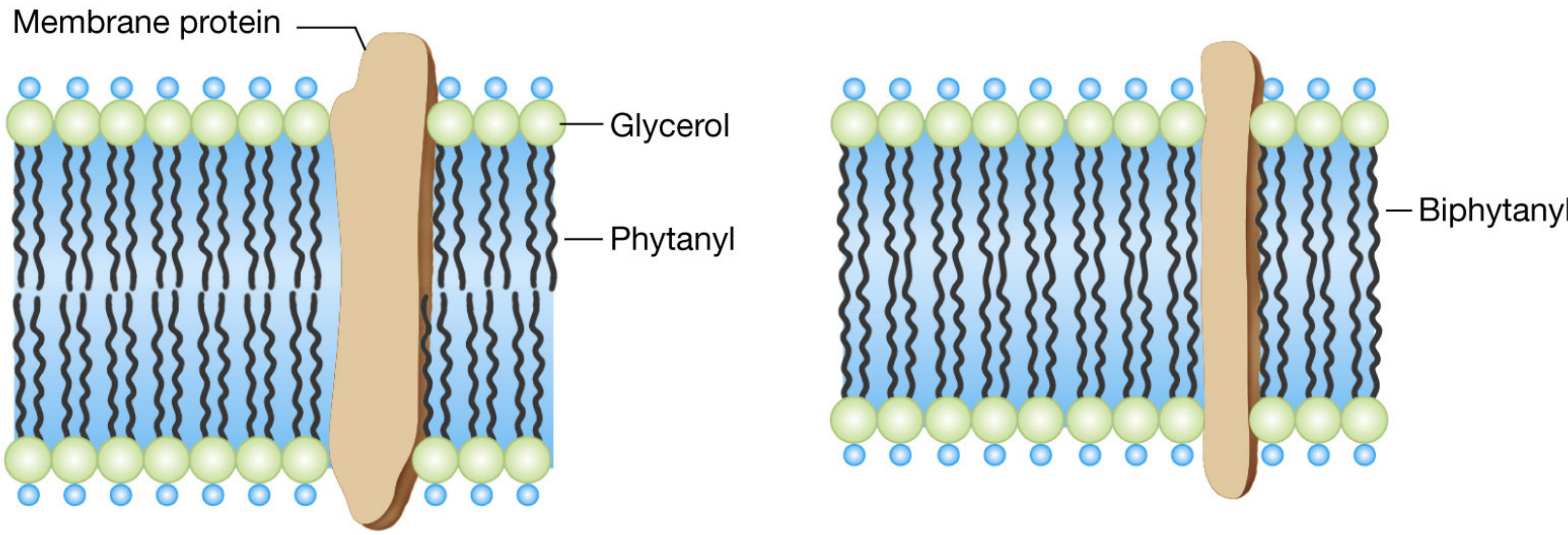
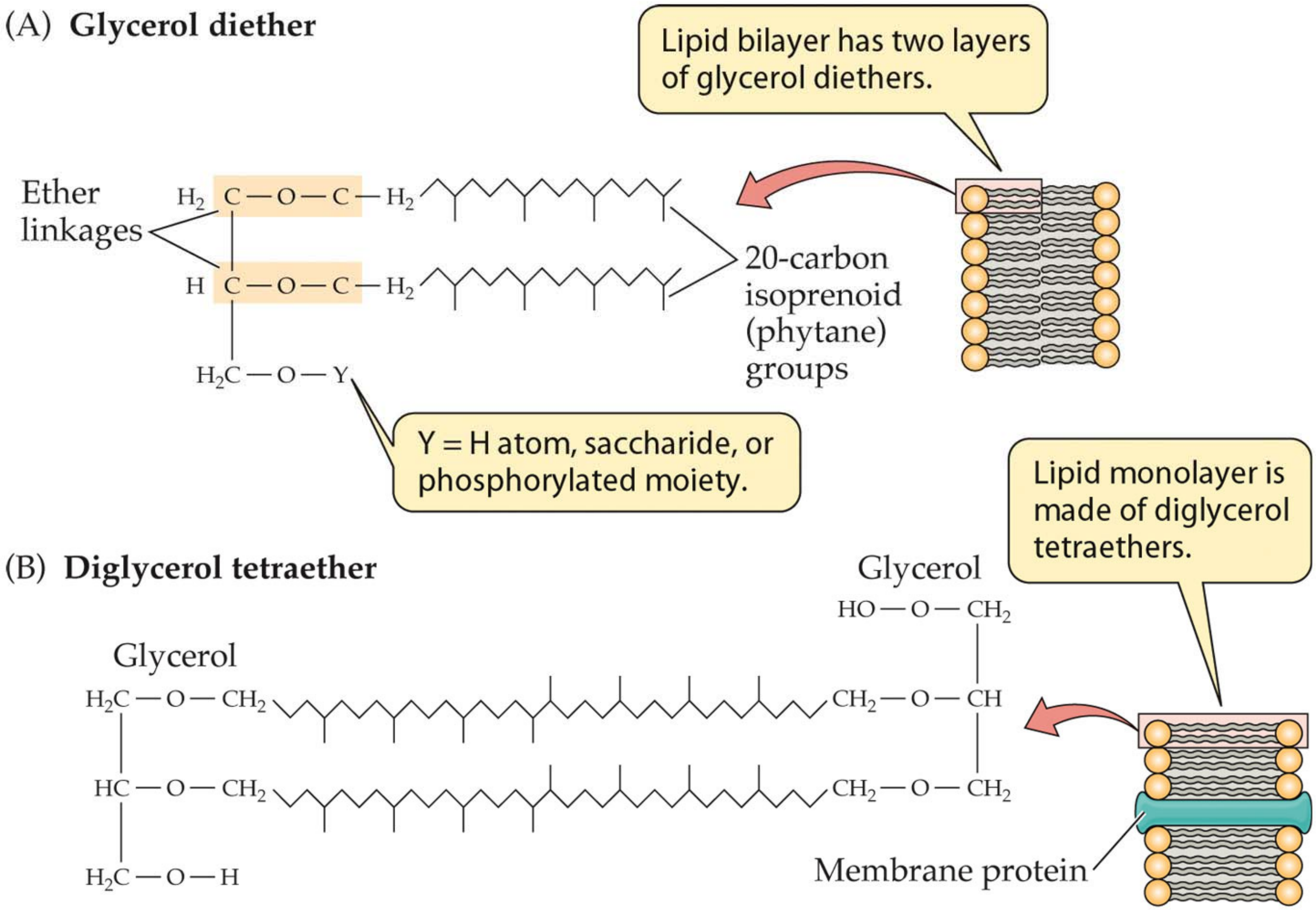


(c) **Lipid bilayer**

(d) **Lipid monolayer**

Archaeal cell membrane structure



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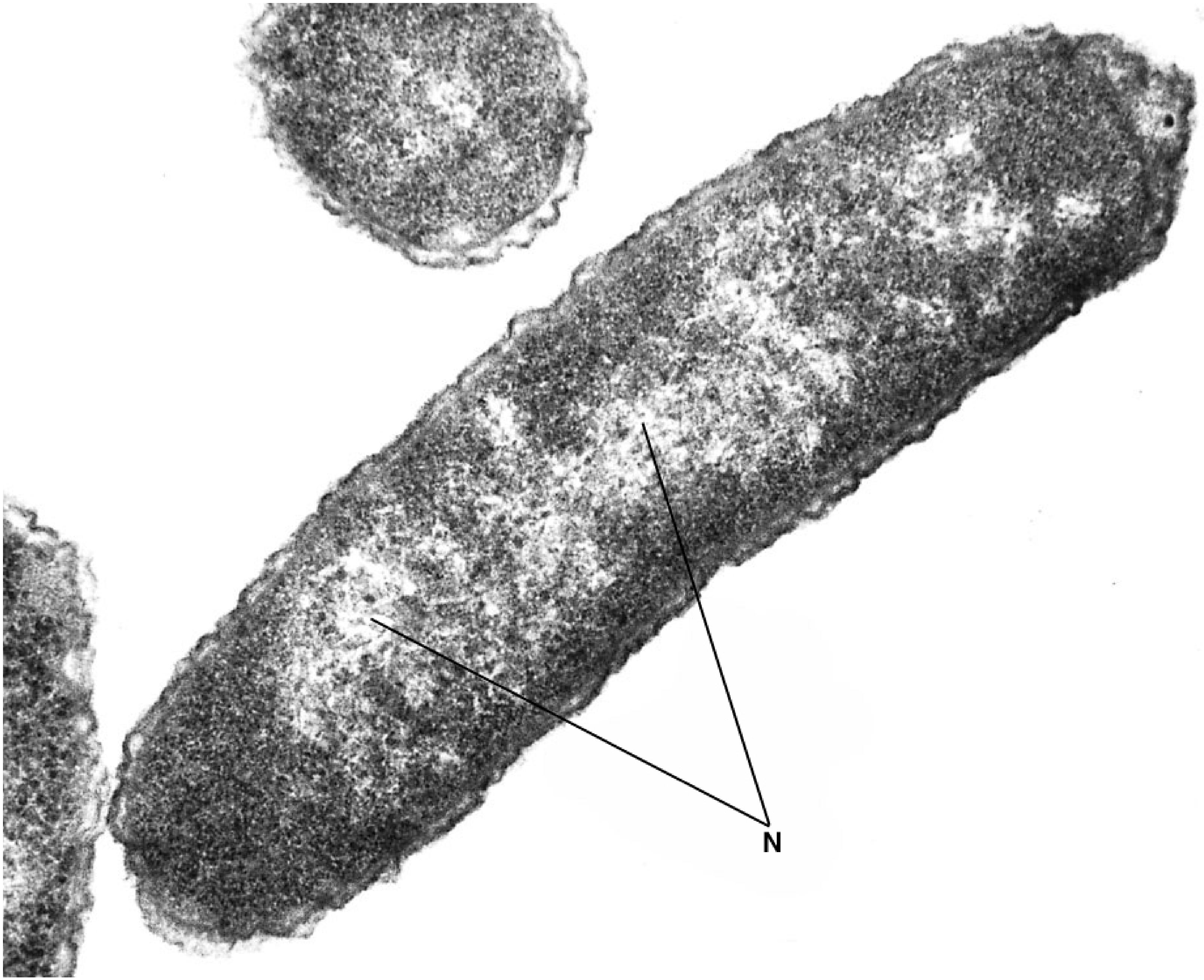
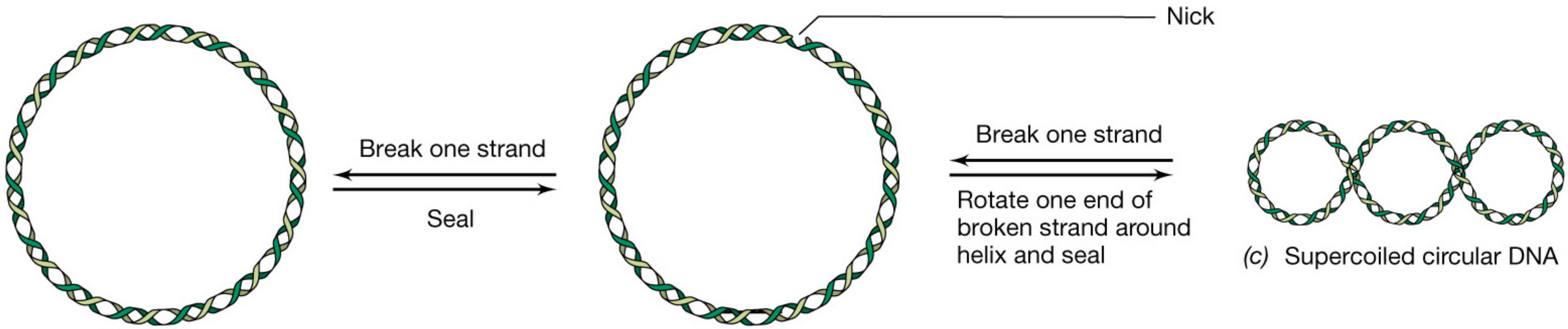
- **Cell Membranes: The barrier between order and chaos.**

➡ **Nucleoid Region: Curator of the Information.**

Appearance of DNA by EM



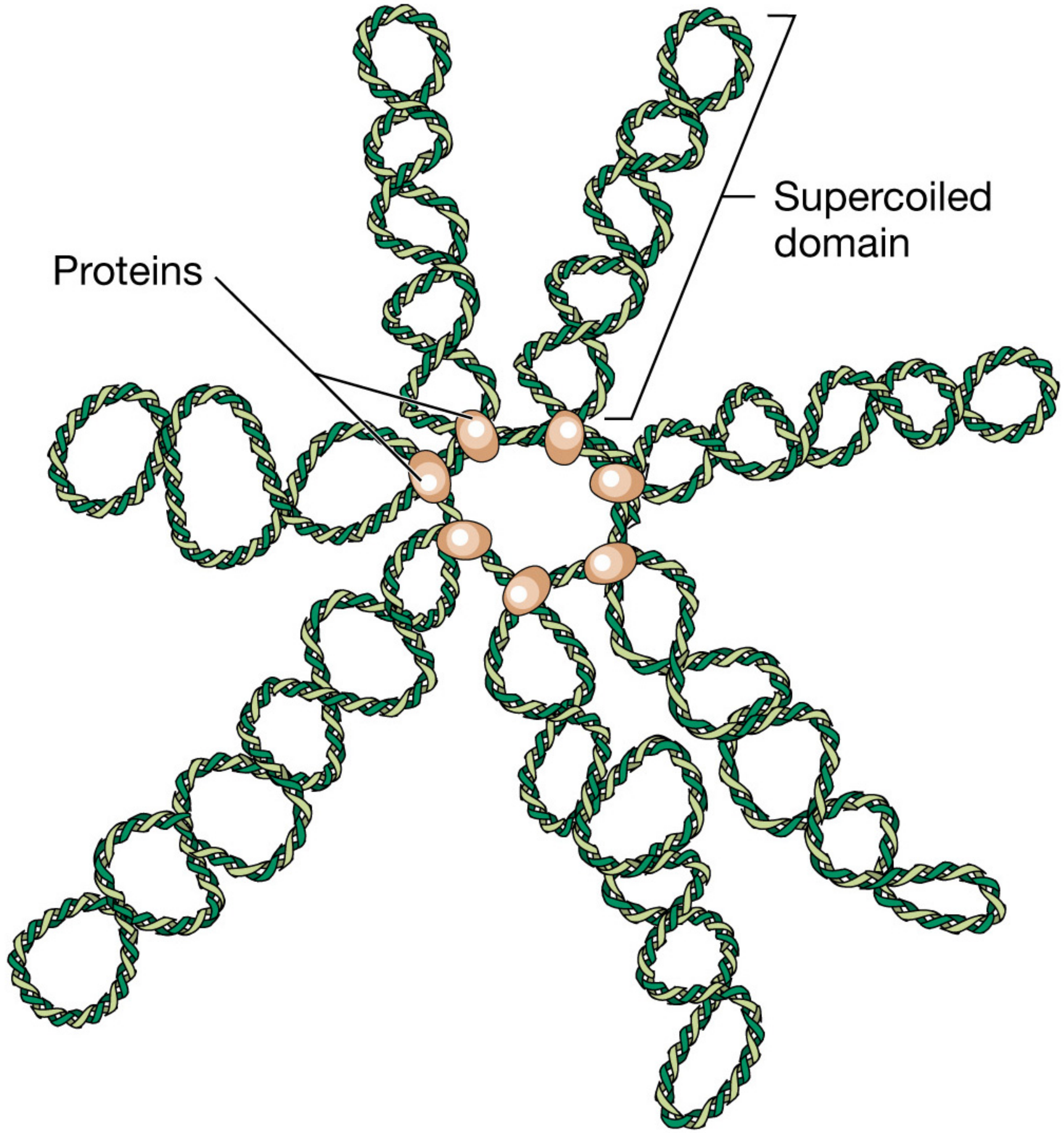
DNA strands released from cell



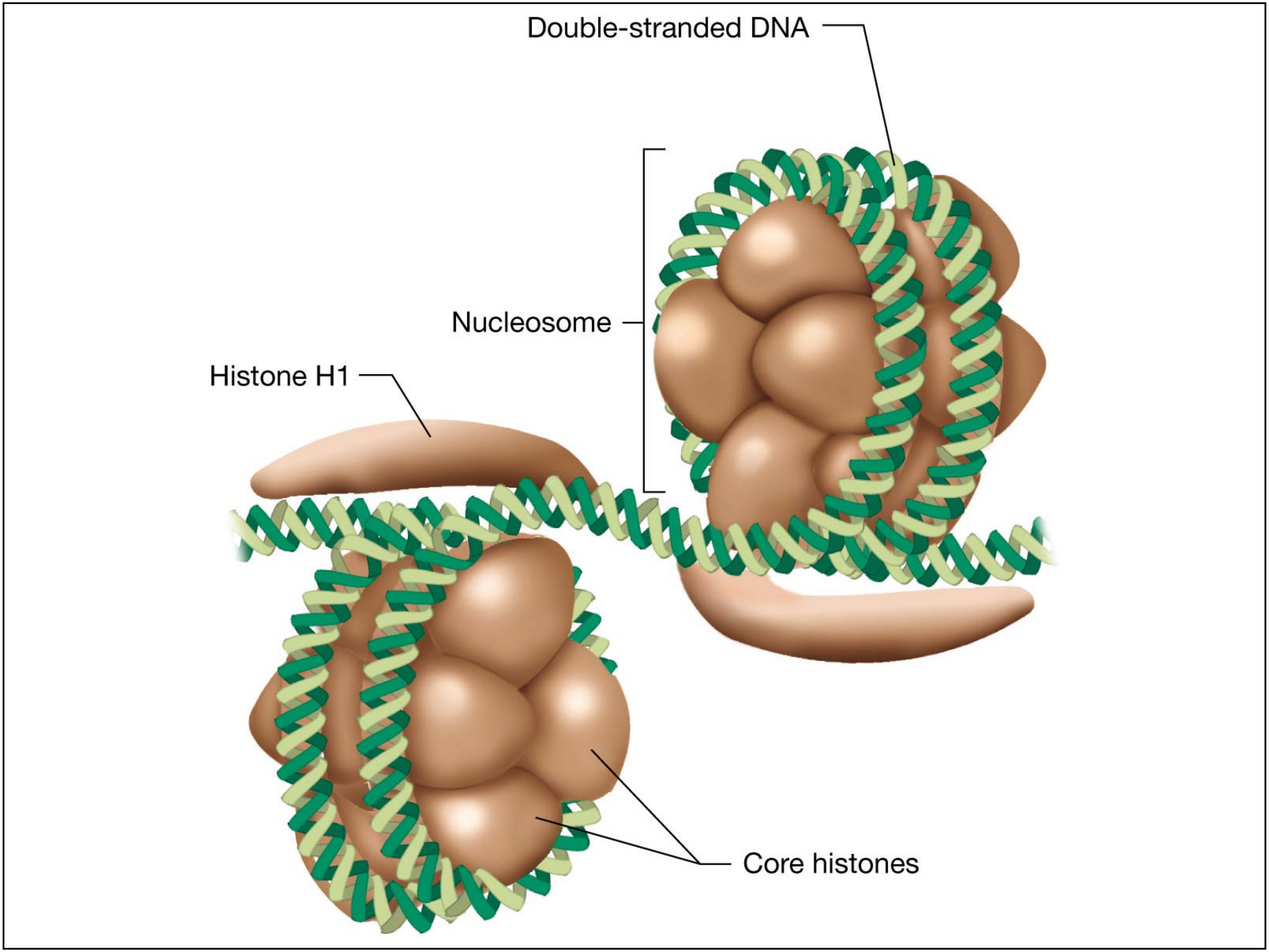
(a) Relaxed, covalently closed circular DNA

(b) Relaxed, nicked circular DNA

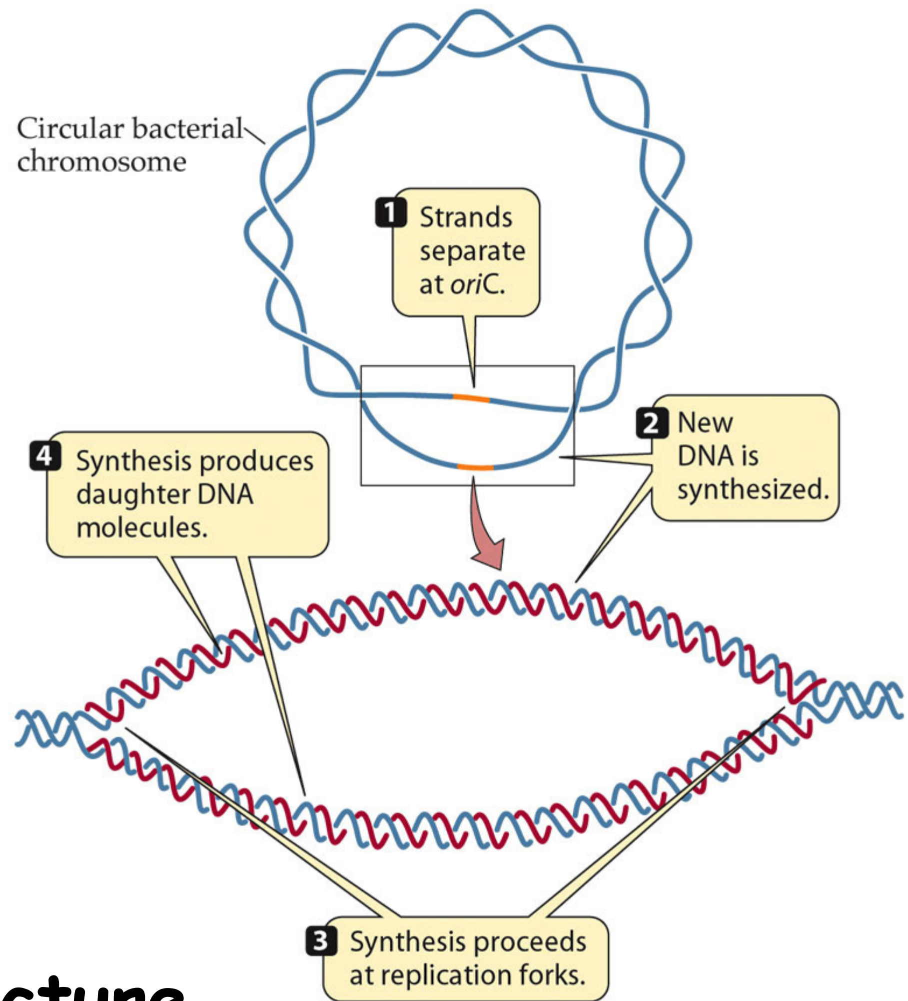
(c) Supercoiled circular DNA



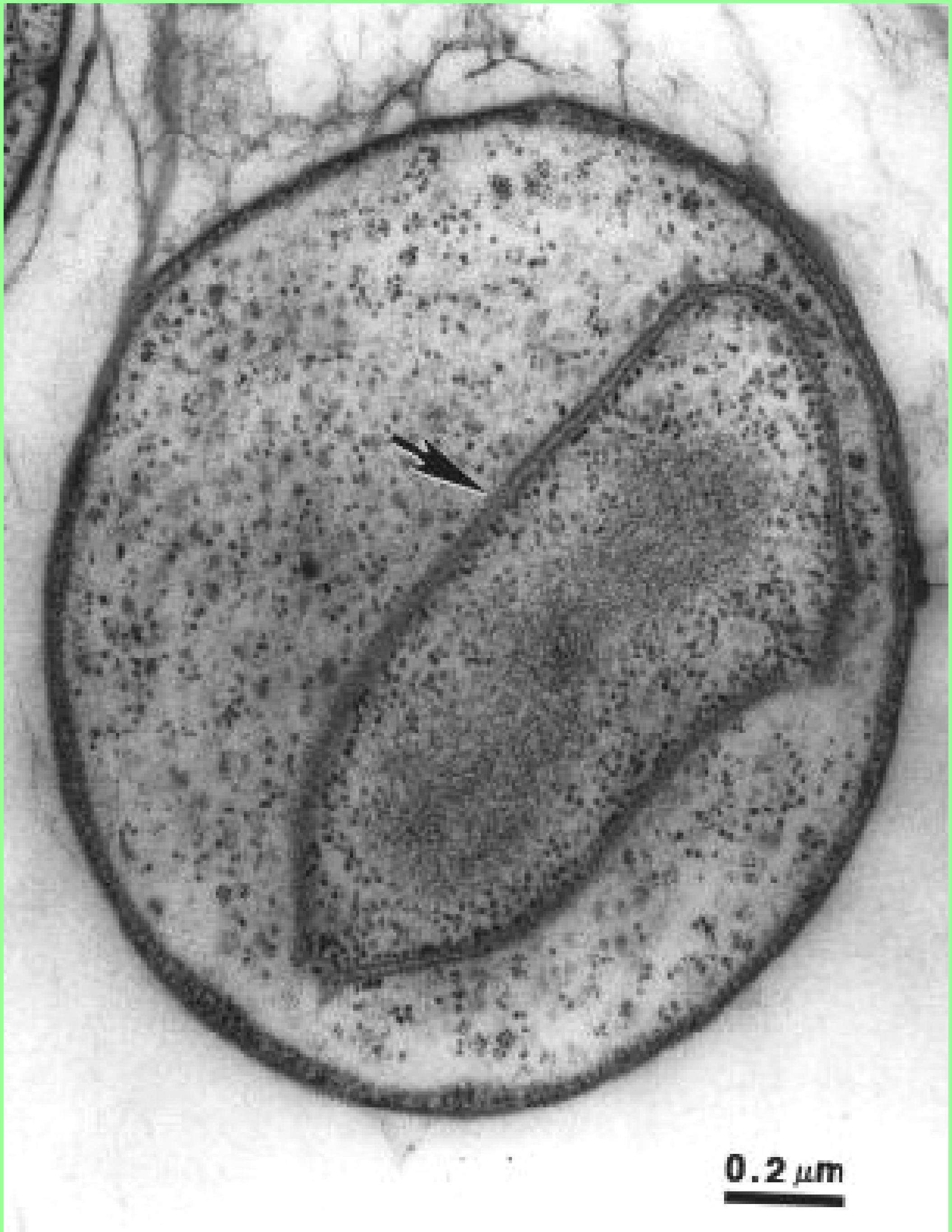
(d) Chromosomal DNA with supercoiled domains


Double-stranded DNA
Nucleosome
Histone H1
Core histones

Overview of DNA replication



Theta Structure



Gemmata obscuriglobus

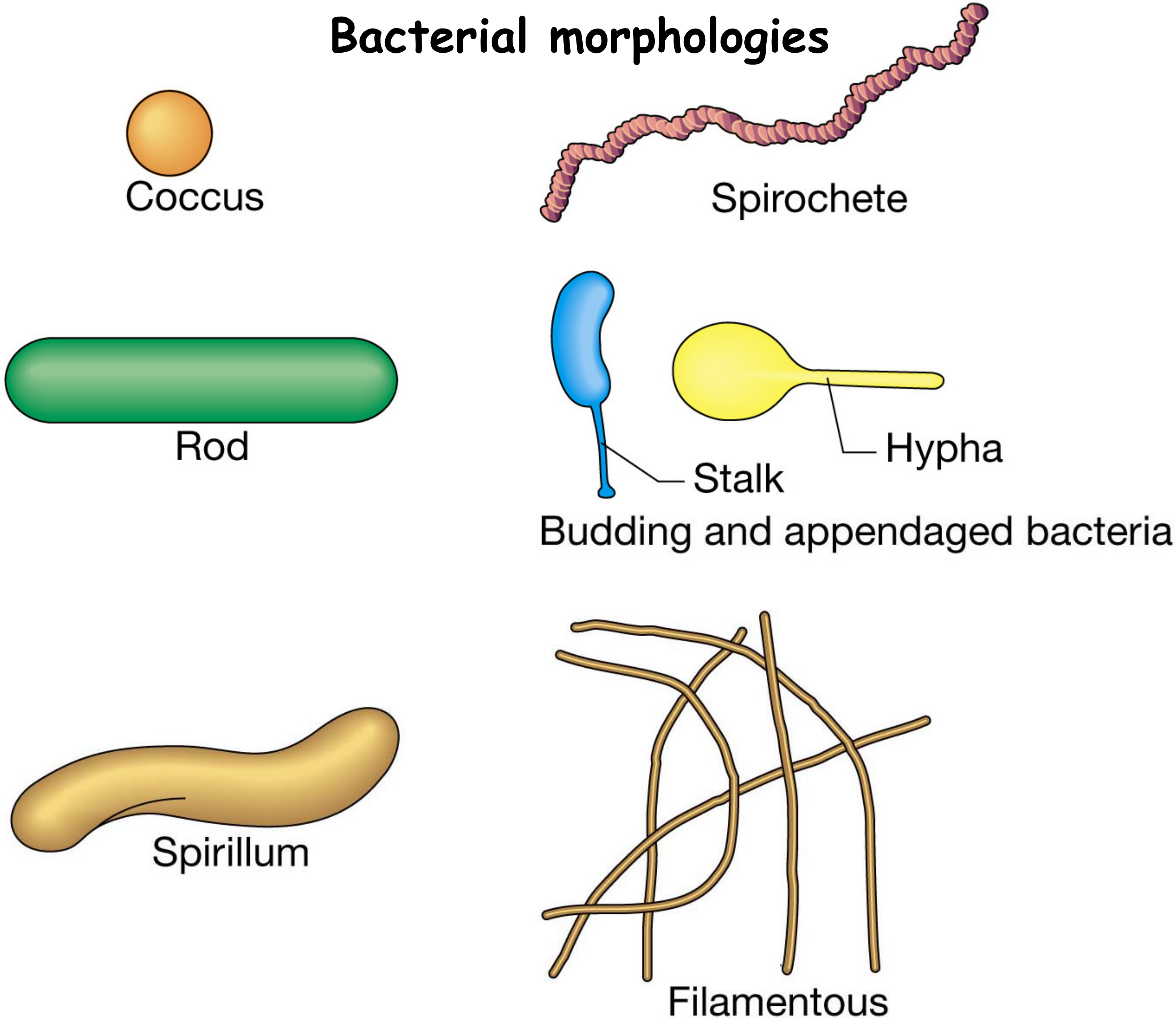
Membrane encompassed nucleoid

Comparing Prokaryotic and Eukaryotic Cells

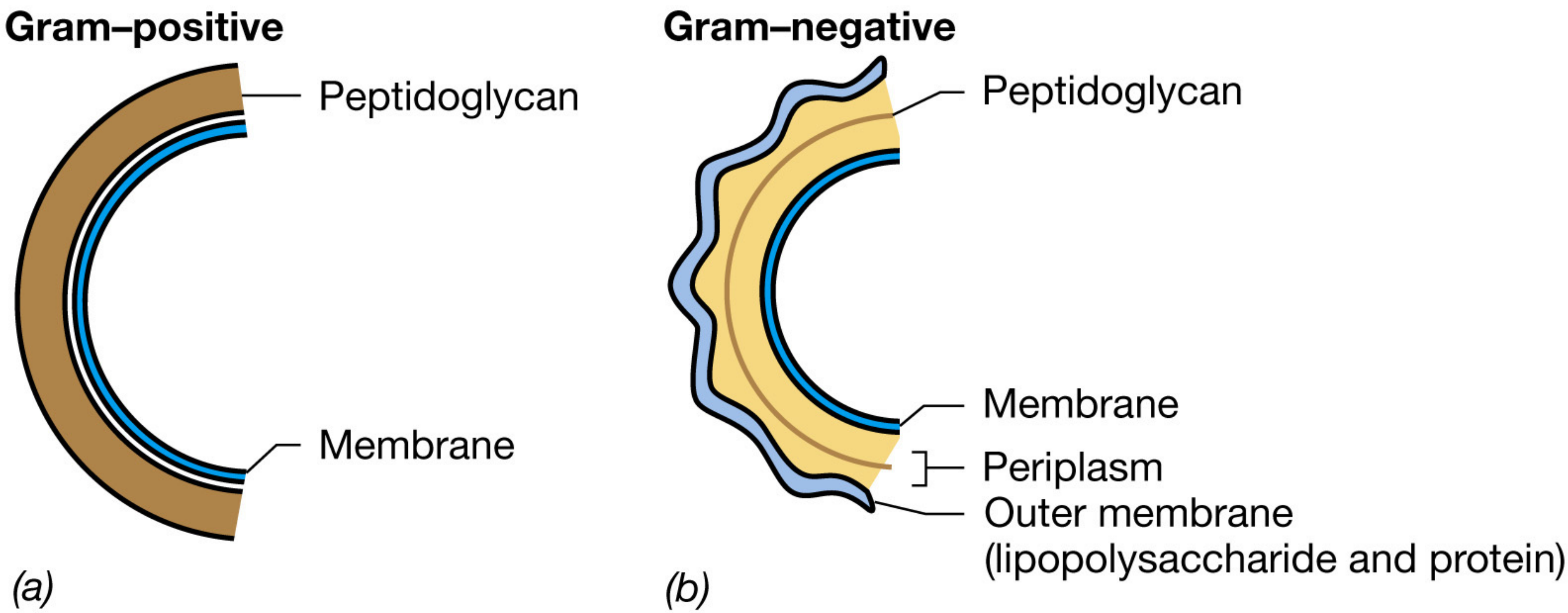
Classification of prokaryotic cellular features: Variant (or NOT common to all)

- Cell Wall (multiple barrier support themes)
- Endospores (heavy-duty life support strategy)
- Bacterial Flagella (appendages for movement)
- Gas Vesicles (buoyancy compensation devices)
- Capsules/Slime Layer (exterior to cell wall)
- Inclusion Bodies (granules for storage)
- Pili (conduit for genetic exchange)

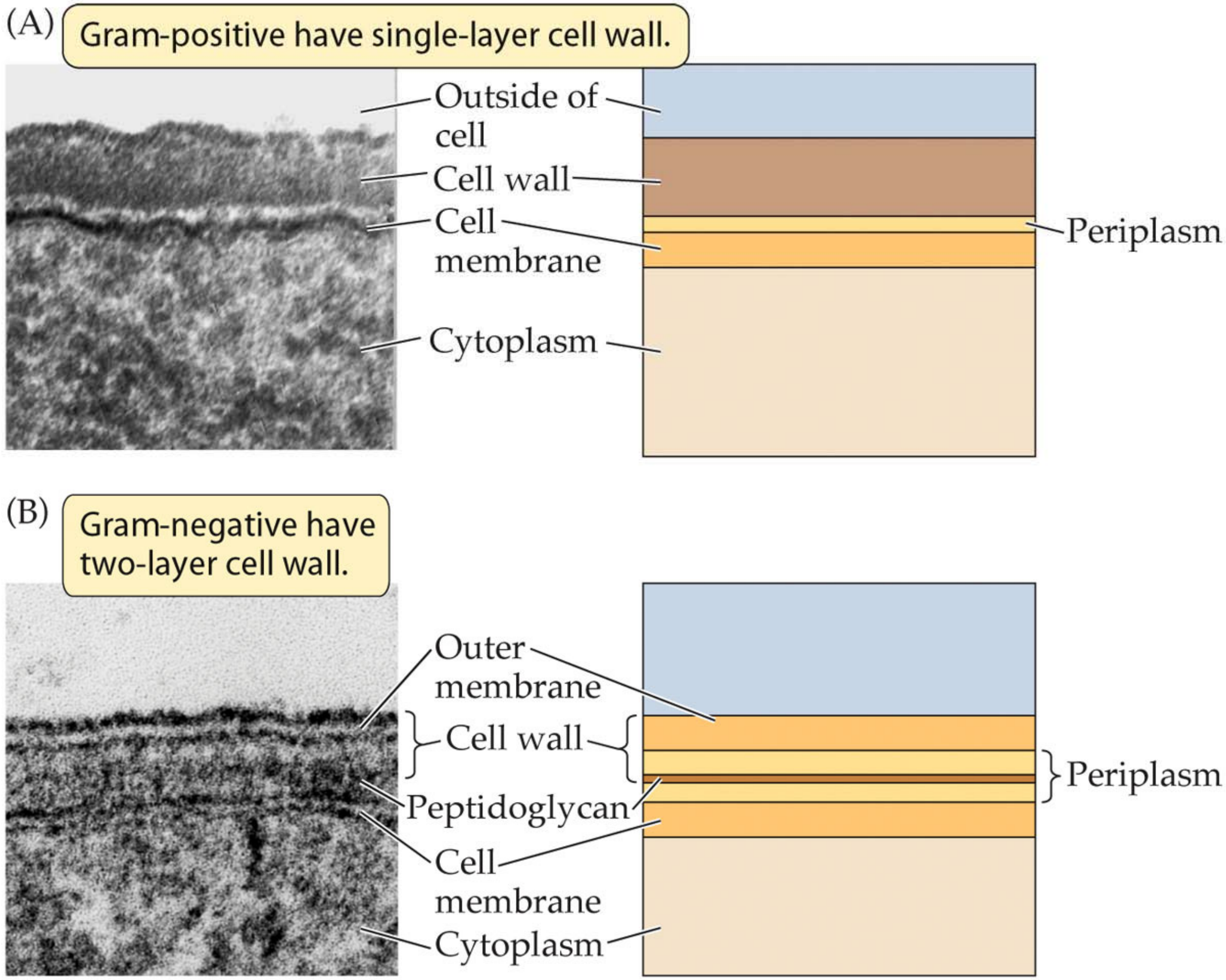
Bacterial morphologies

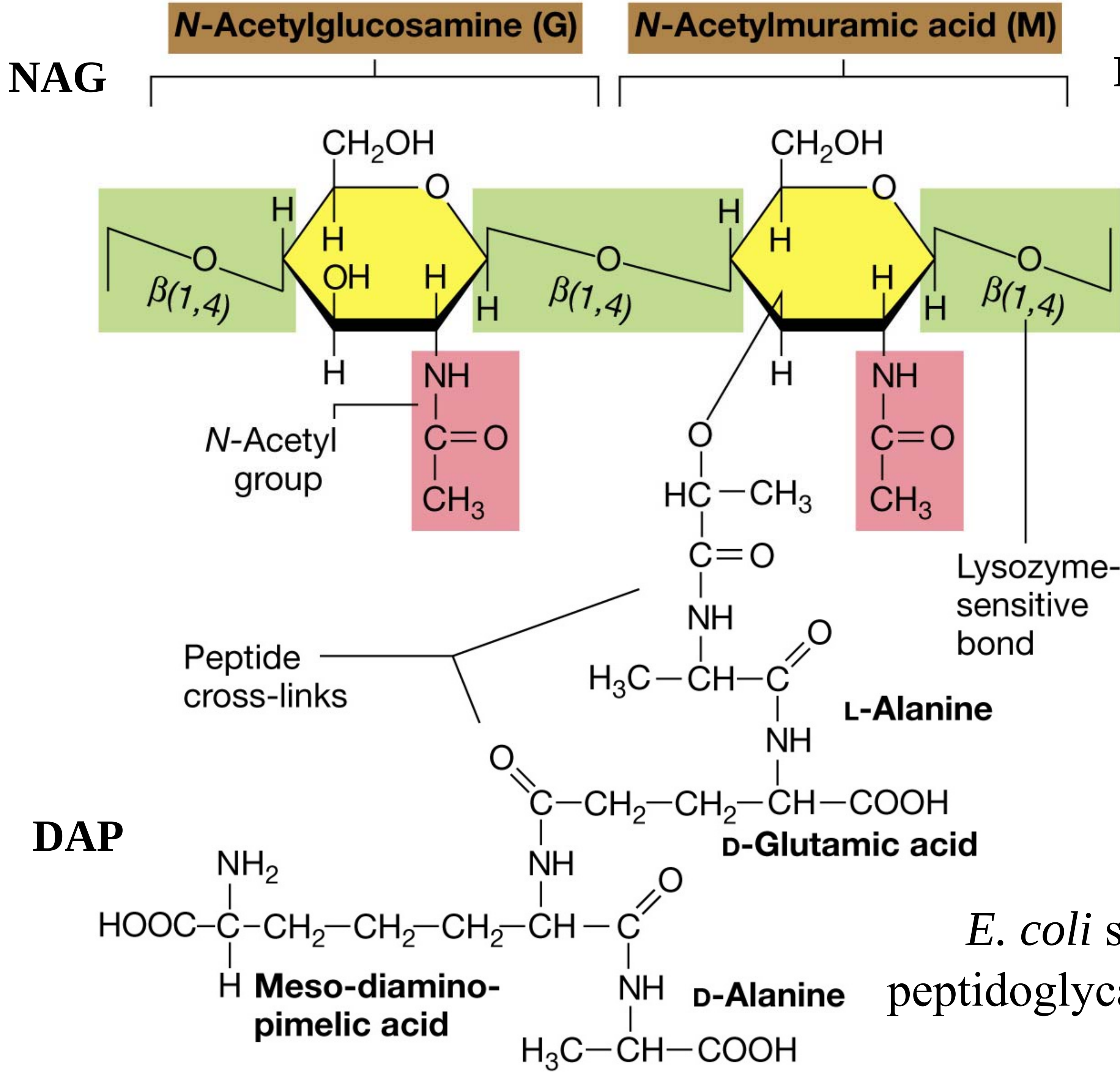


Cell walls of *Bacteria*



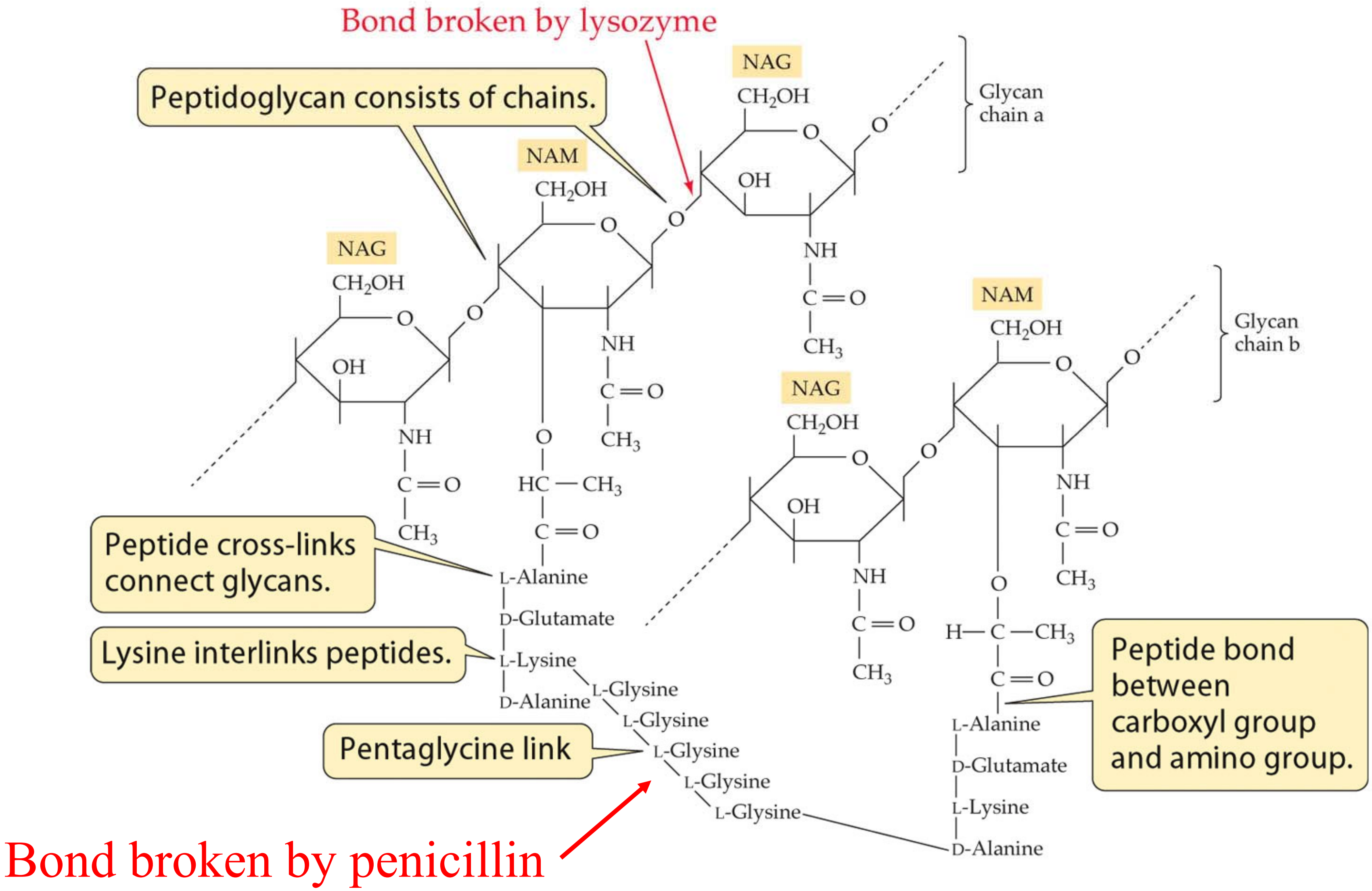
Cell wall structure



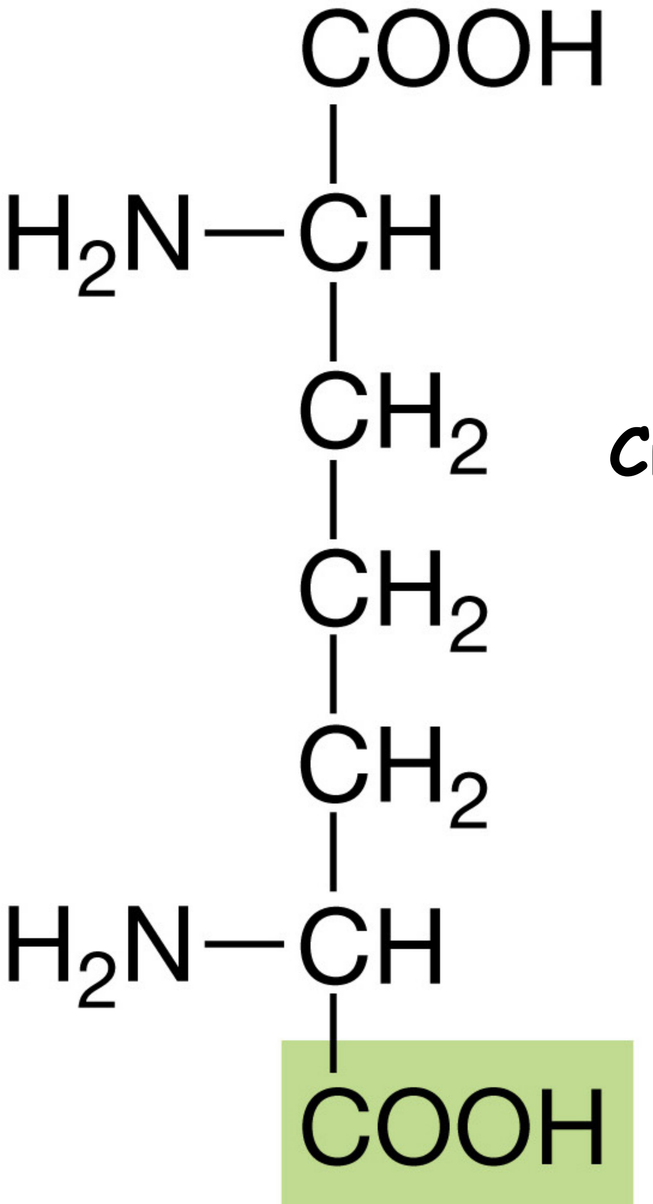


E. coli structure of peptidoglycan aka murein

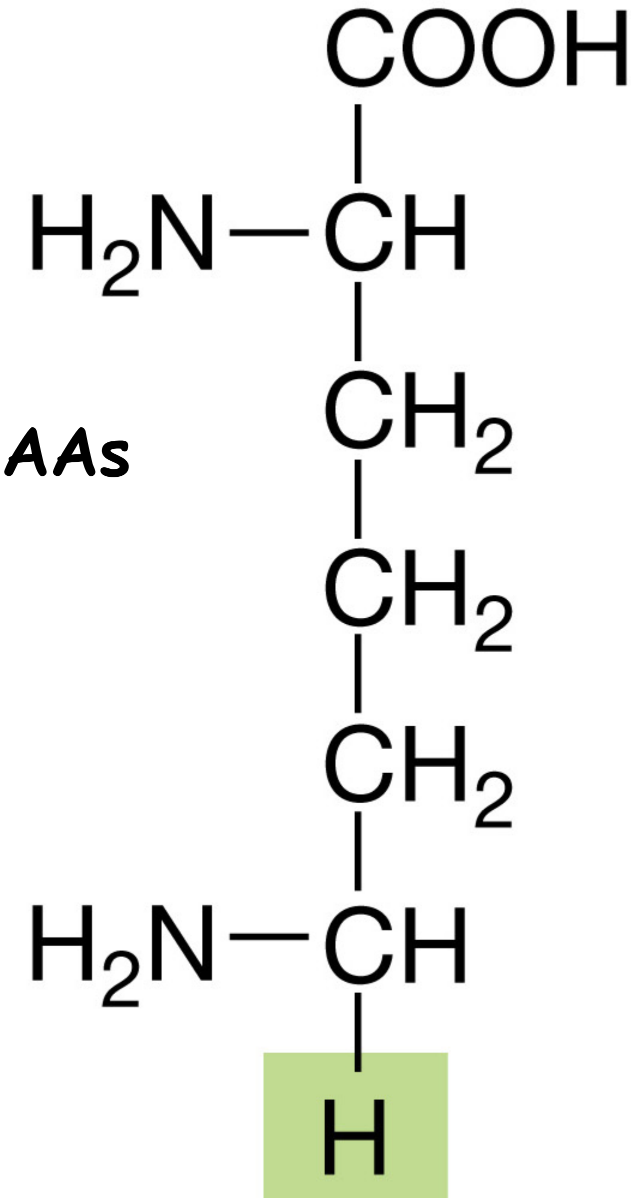
Peptidoglycan of a gram-positive bacterium



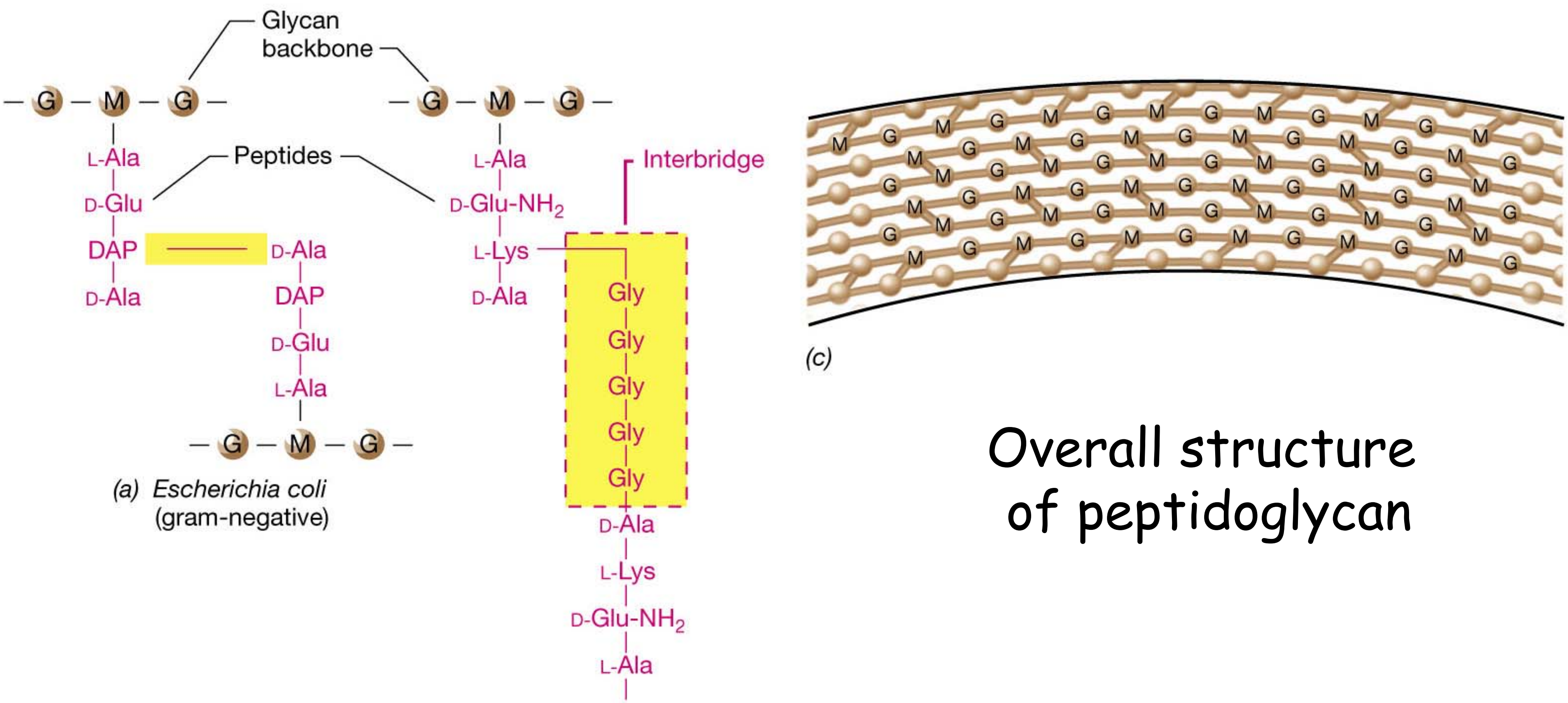
Crossing linking AAs



(a) DAP or Diaminopimelic acid



(b) Lysine



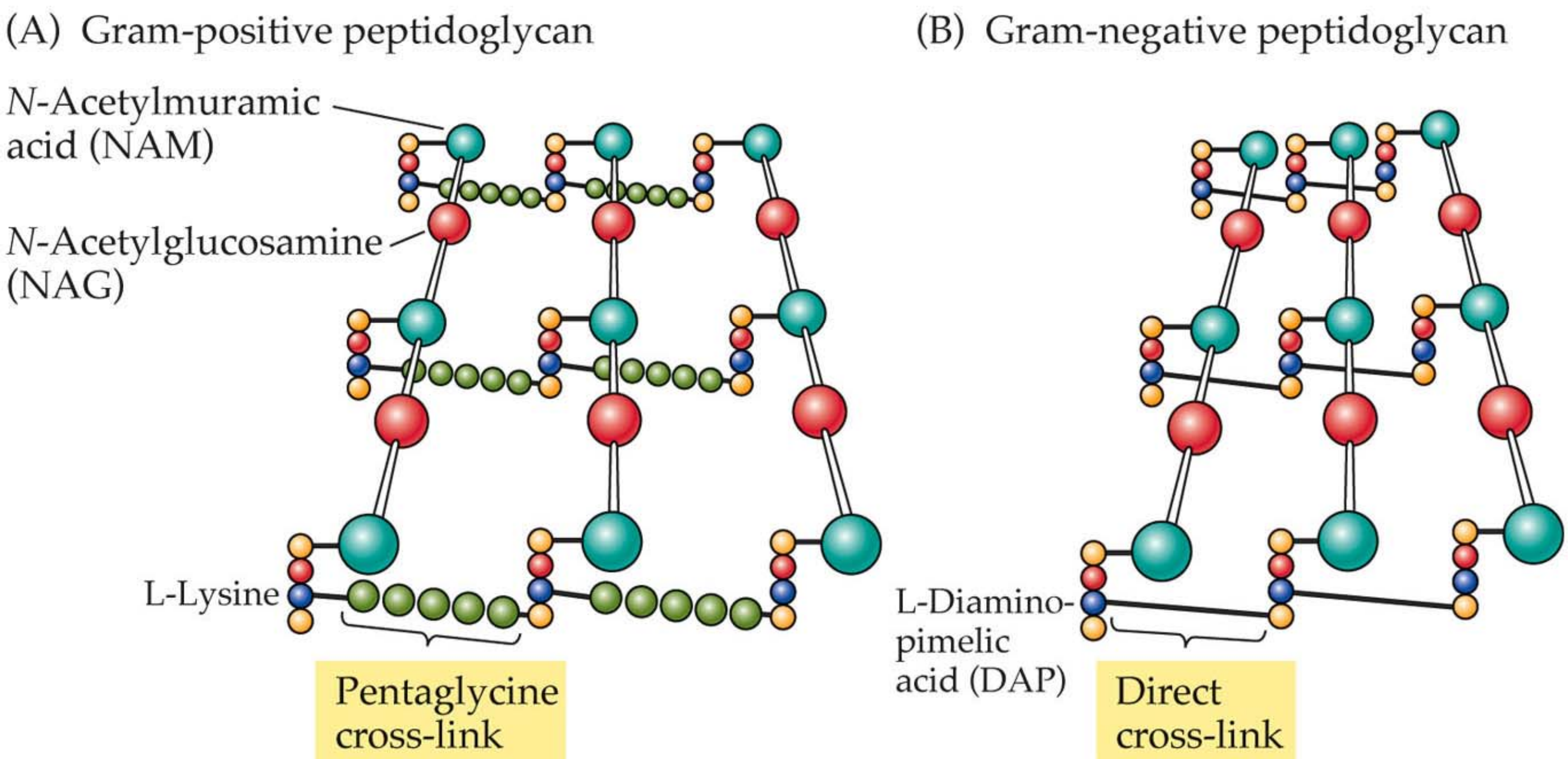
(a) *Escherichia coli* (gram-negative)

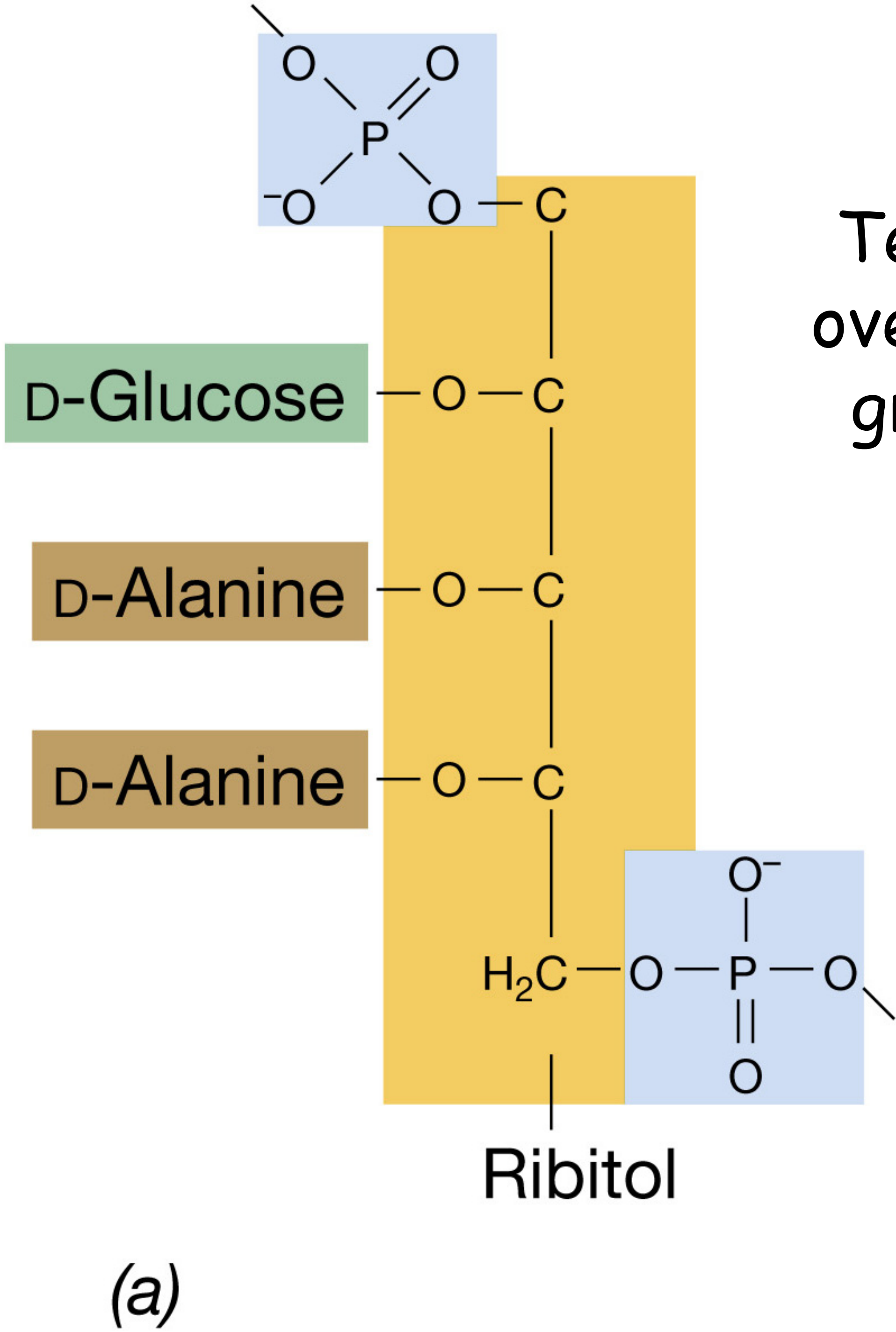
(b) *Staphylococcus aureus* (gram-positive)

(c)

Overall structure of peptidoglycan

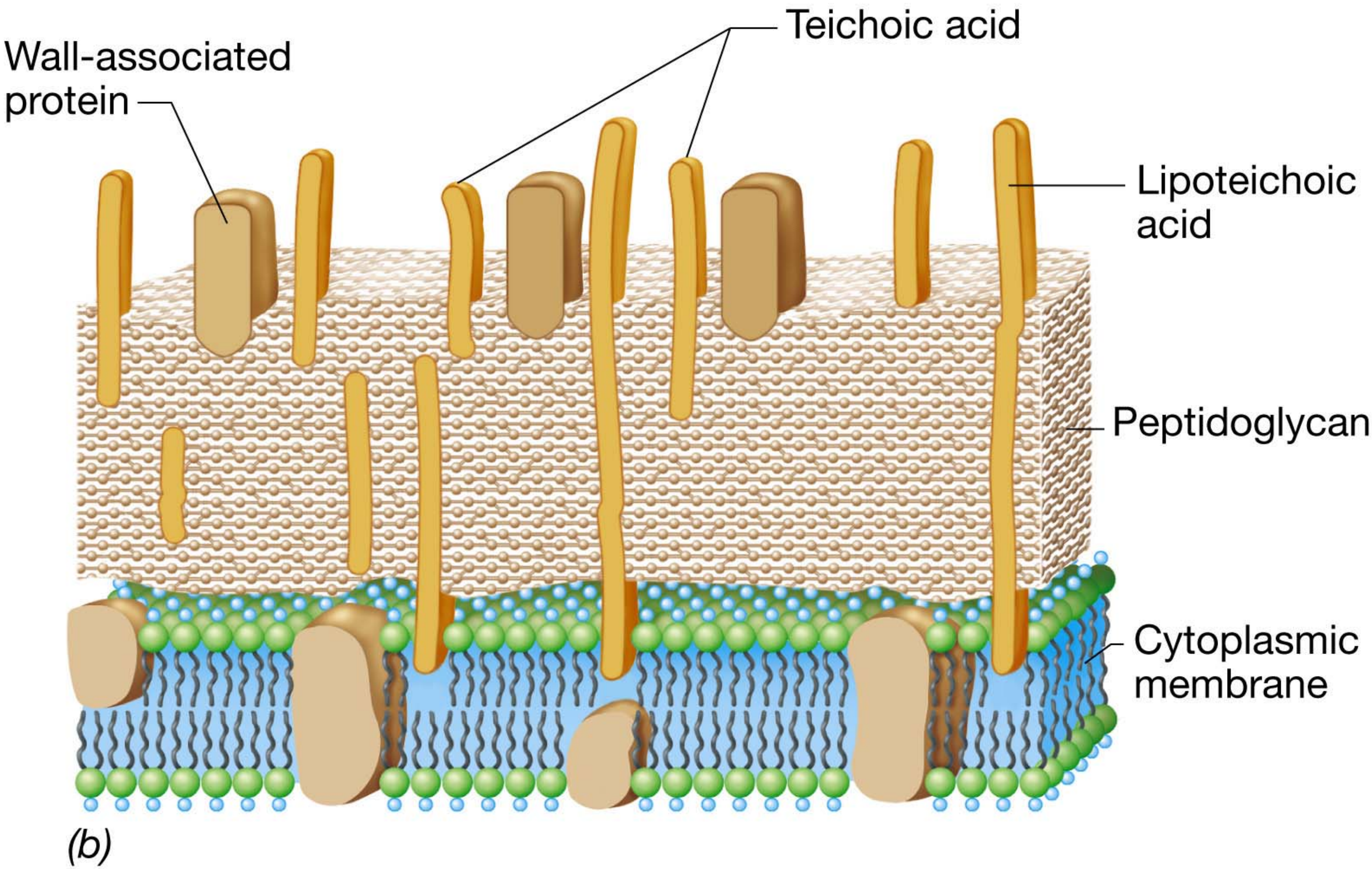
Cell walls of gram-positive and gram-negative bacteria





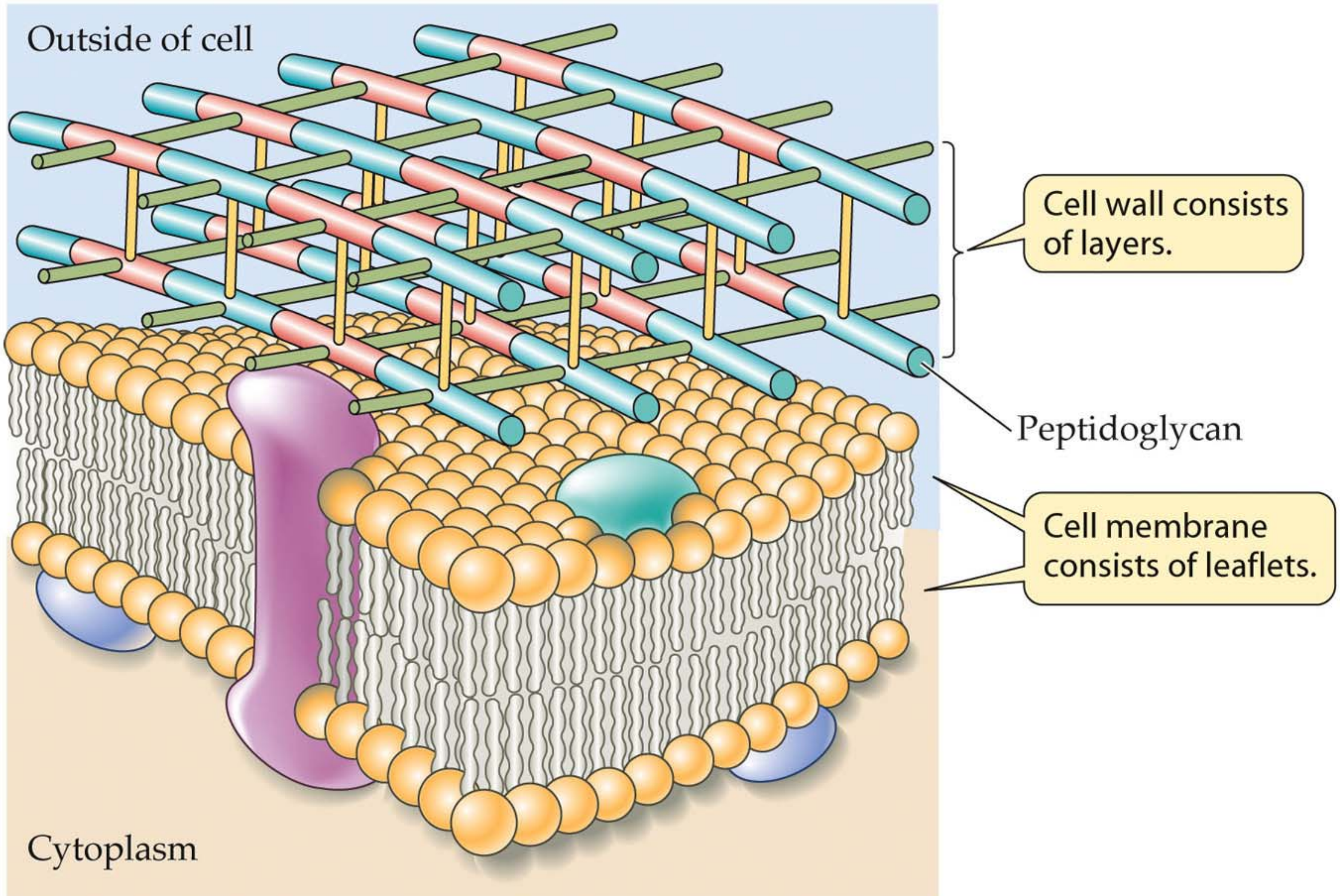
Teichoic acids and the overall structure of the gram-positive cell wall

Summary diagram of the gram-positive cell wall



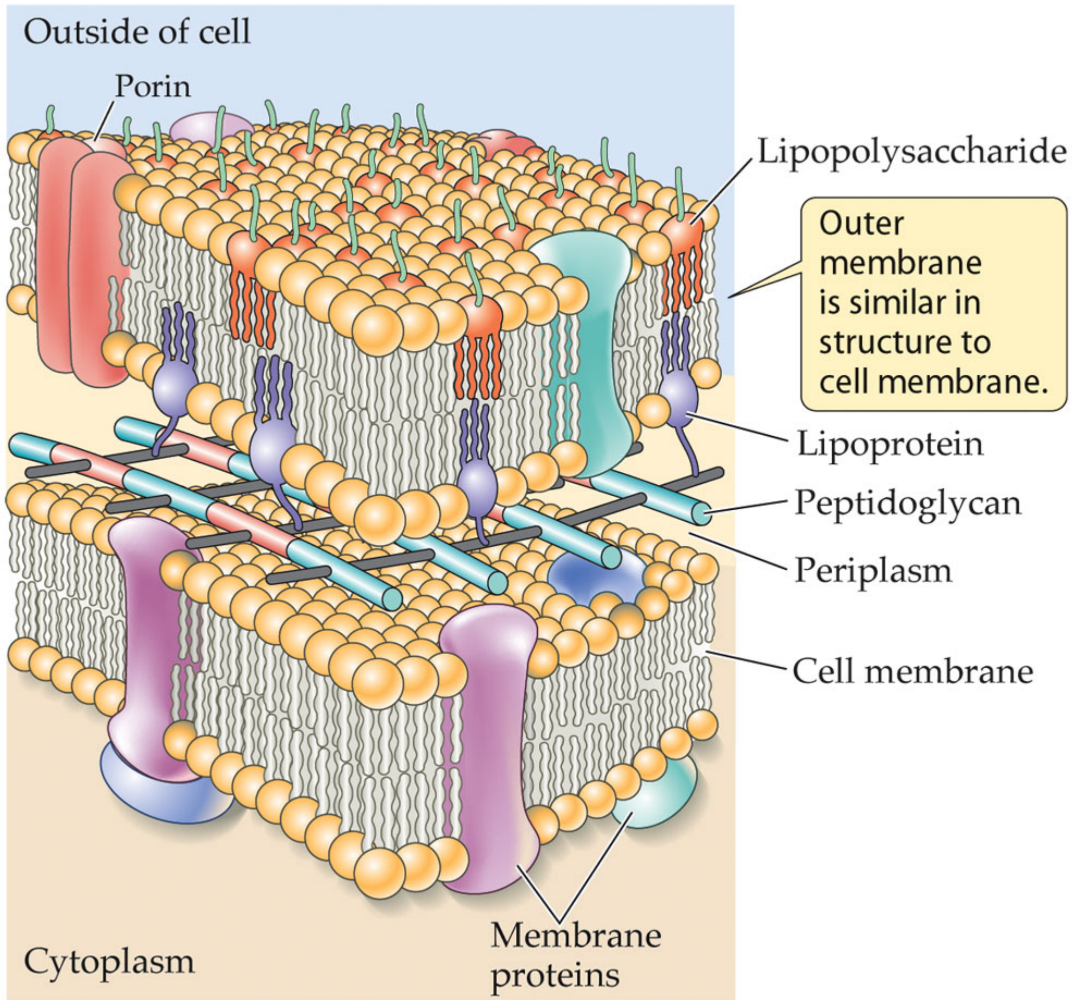
Cell envelopes of *Bacteria*

(A) Gram-positive cell envelope

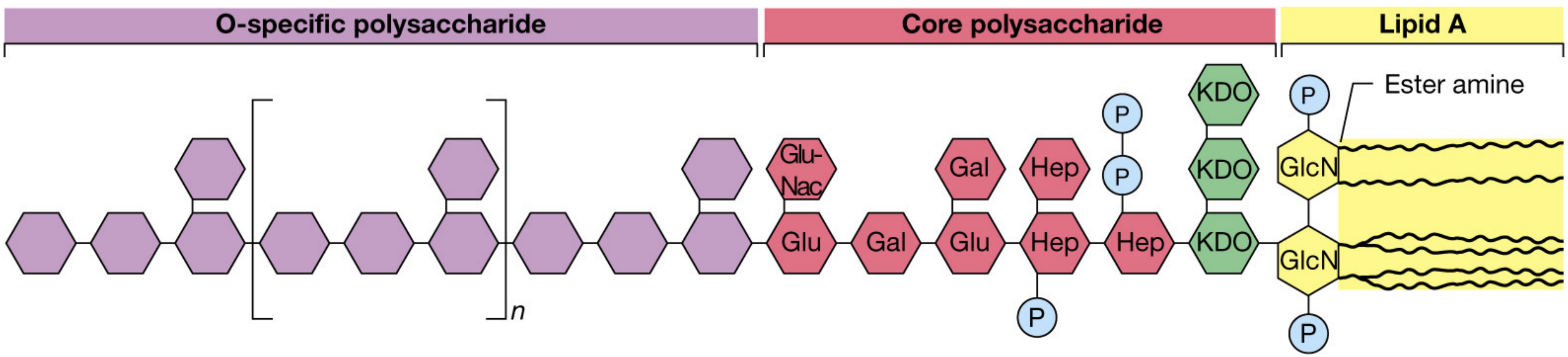


Cell envelopes of *Bacteria*

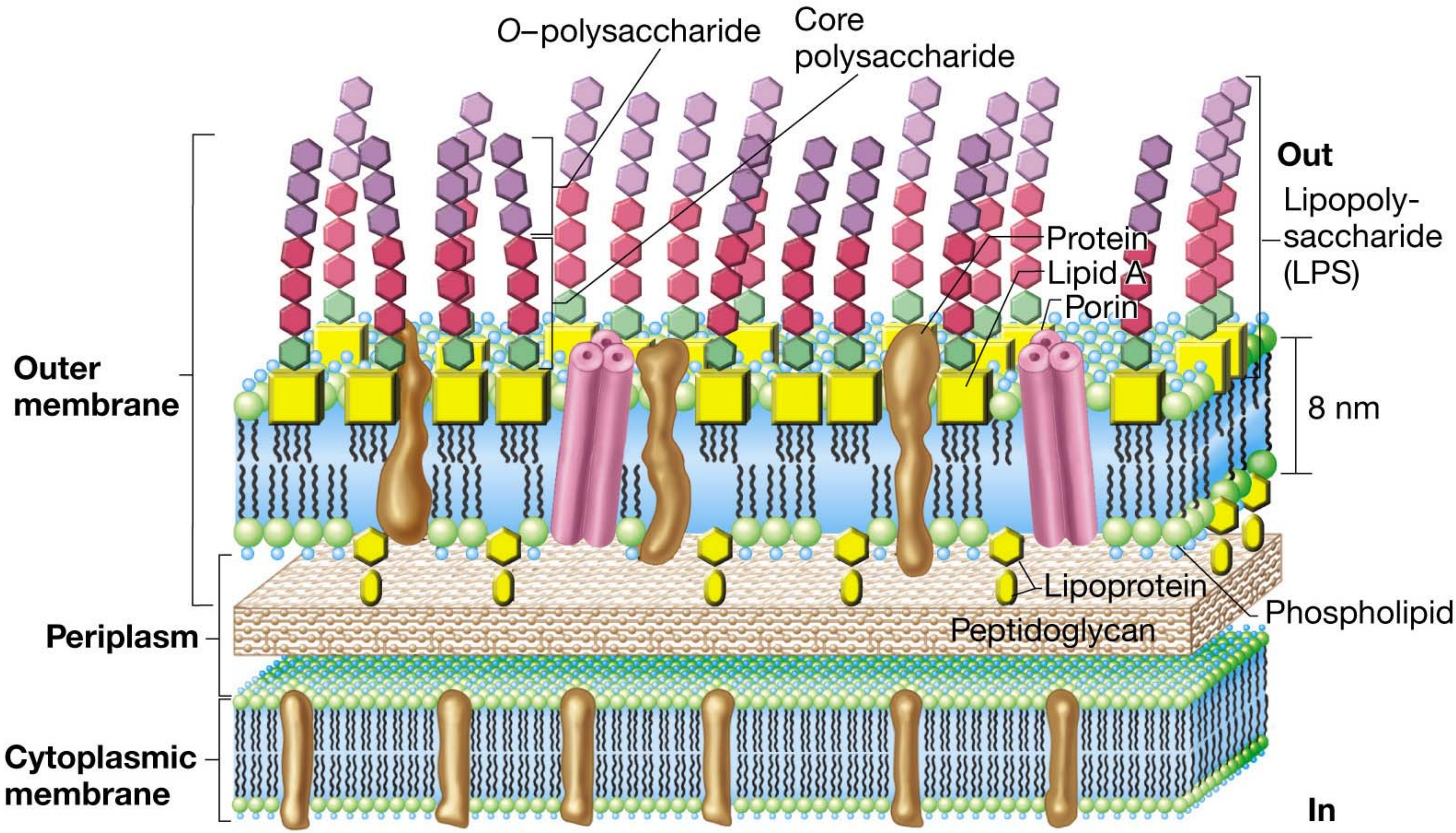
(B) Gram-negative cell envelope

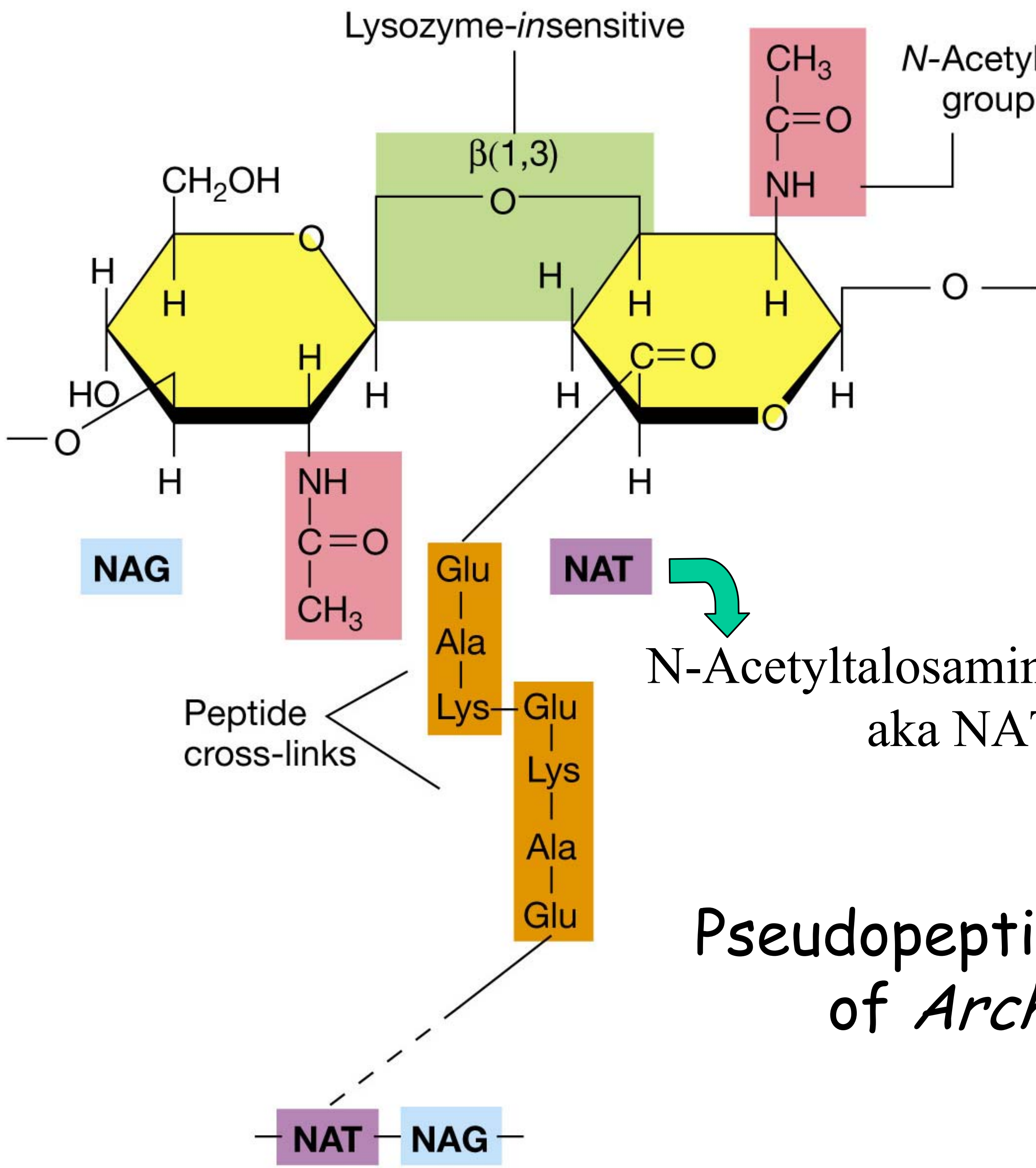


Structure of the lipopolysaccharide of gram-negative *Bacteria*



The gram-negative cell wall

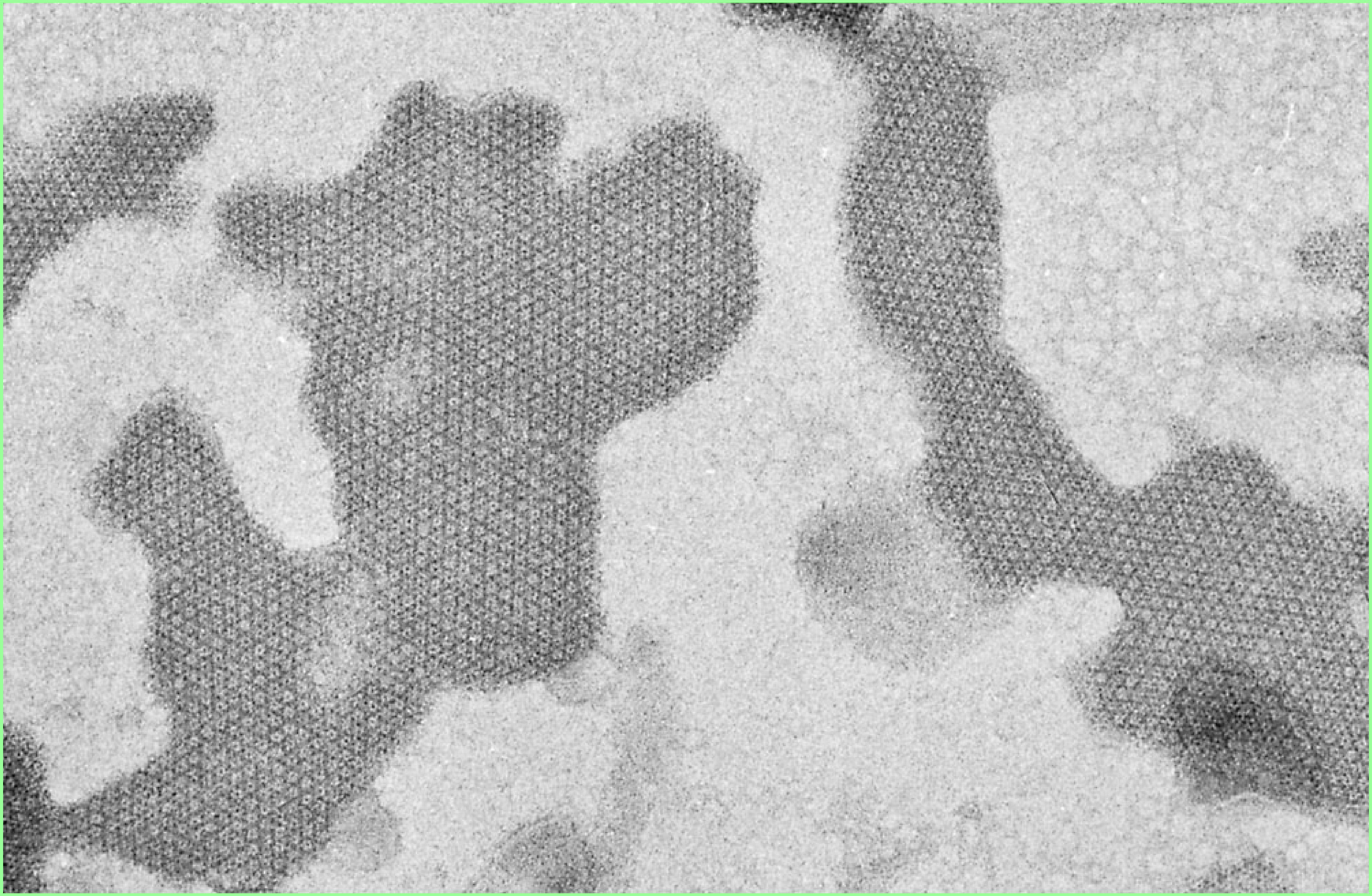




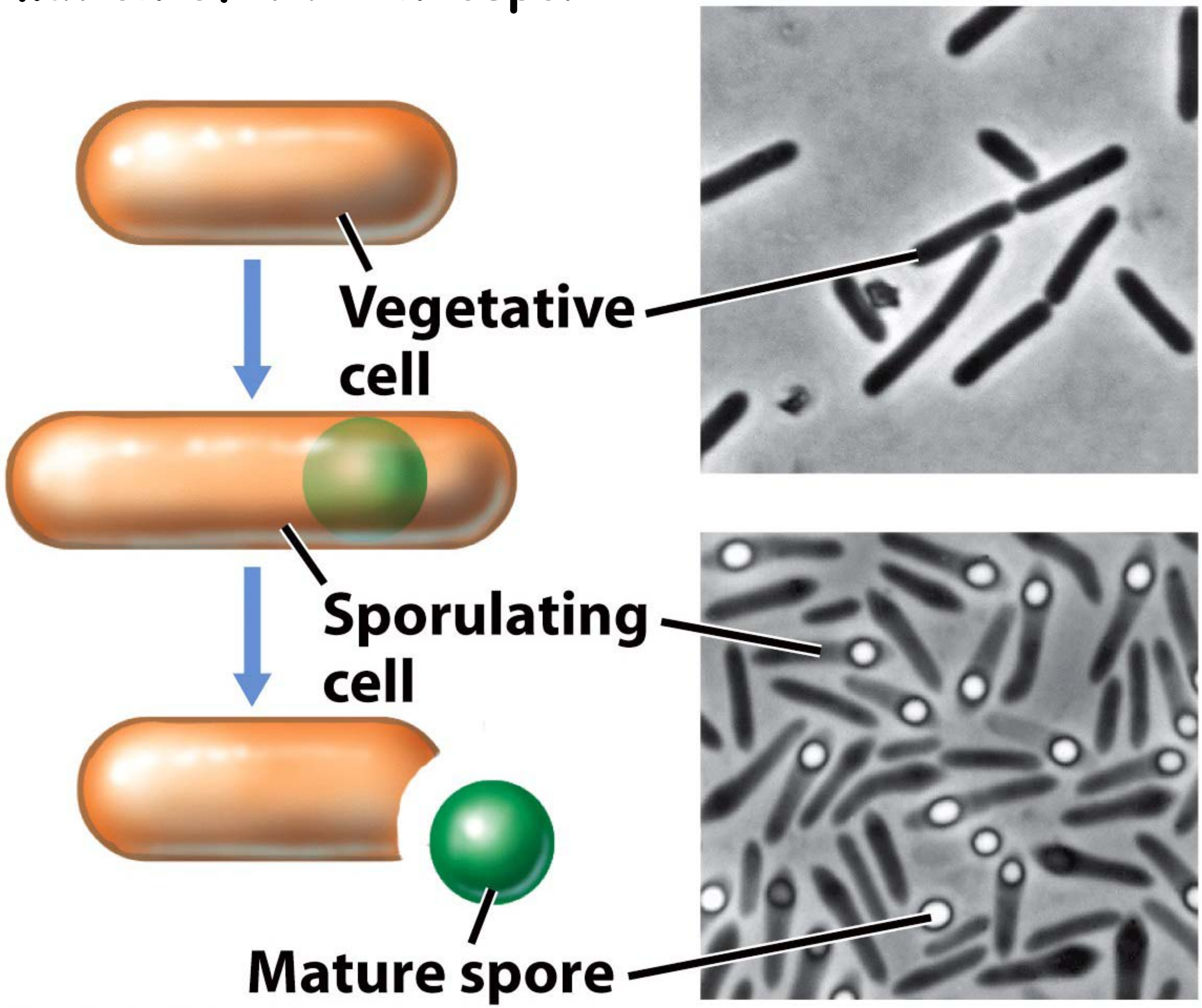
N-Acetyltalosaminuronic acid
aka NAT

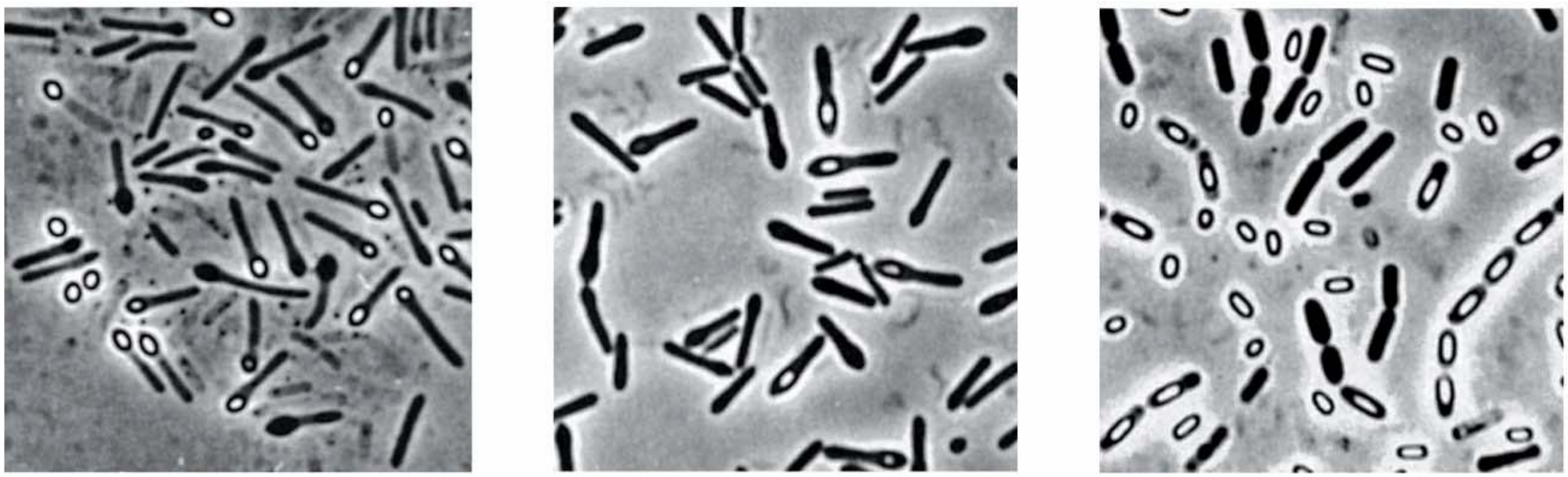
Pseudopeptidoglycan of *Archaea*

Paracrystalline S-layer: A protein jacket for *Bacteria* & *Archaea*



Formation of the endospore

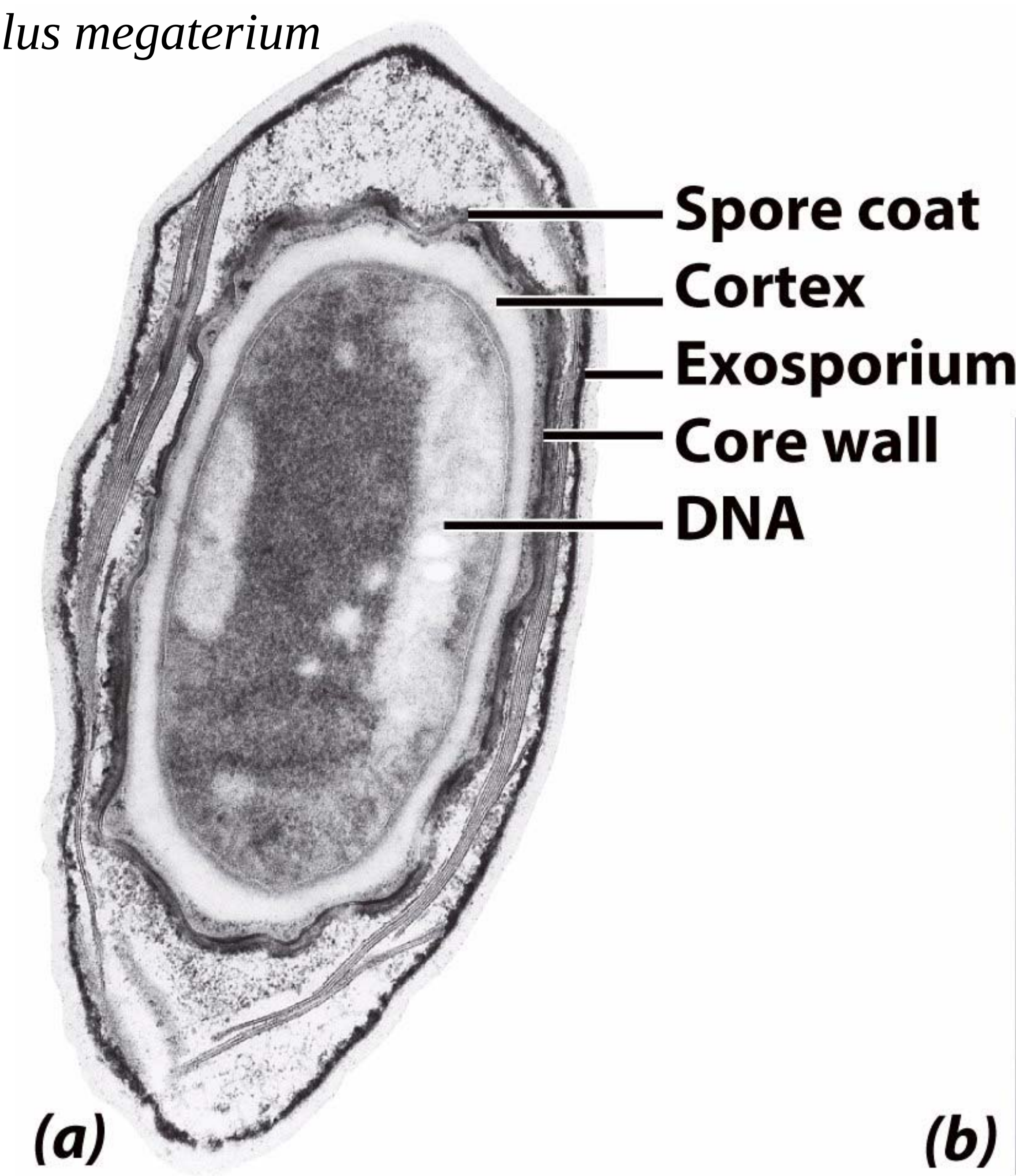




(a) (b) (c)

Morpology of the bacterial endospore
(a) Terminal (b) Subterminal (c) Central

Bacillus megaterium



Bacillus subtilis

(b)

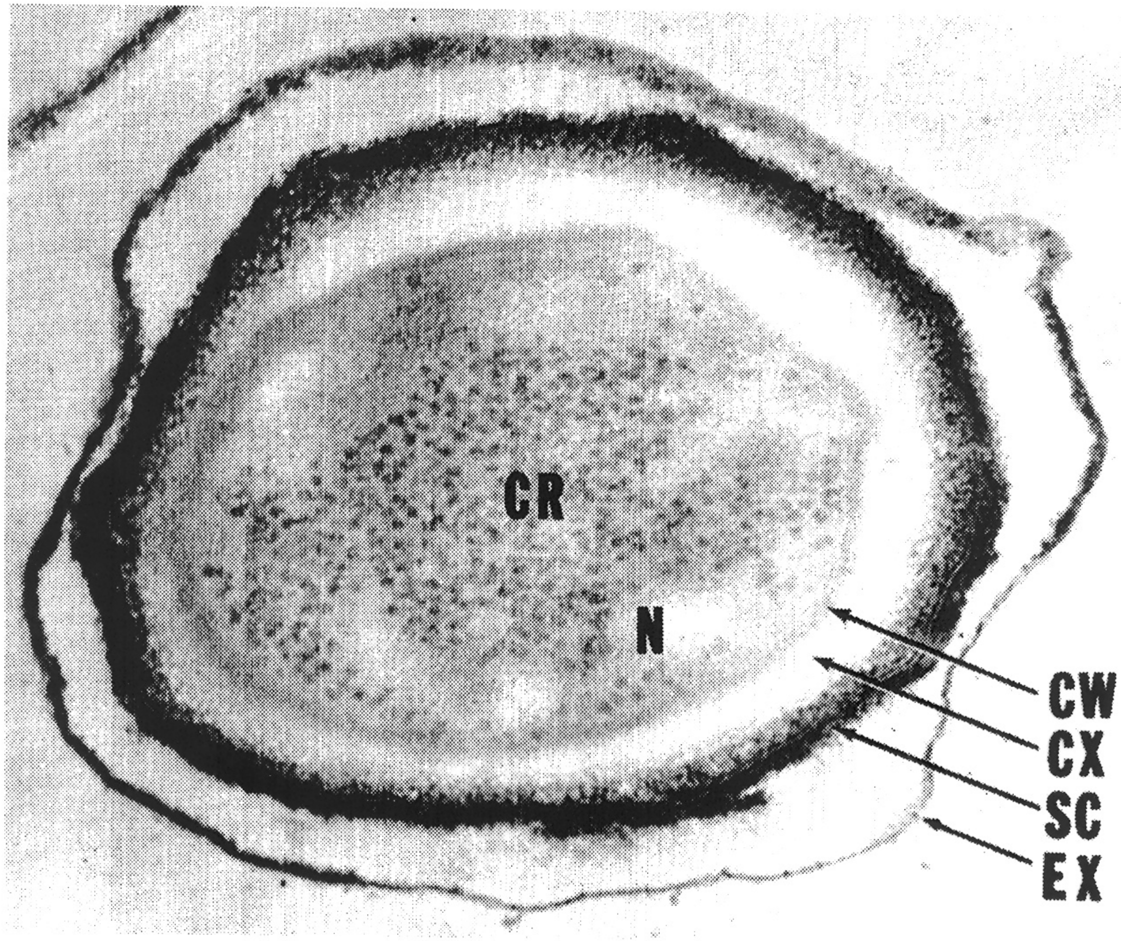
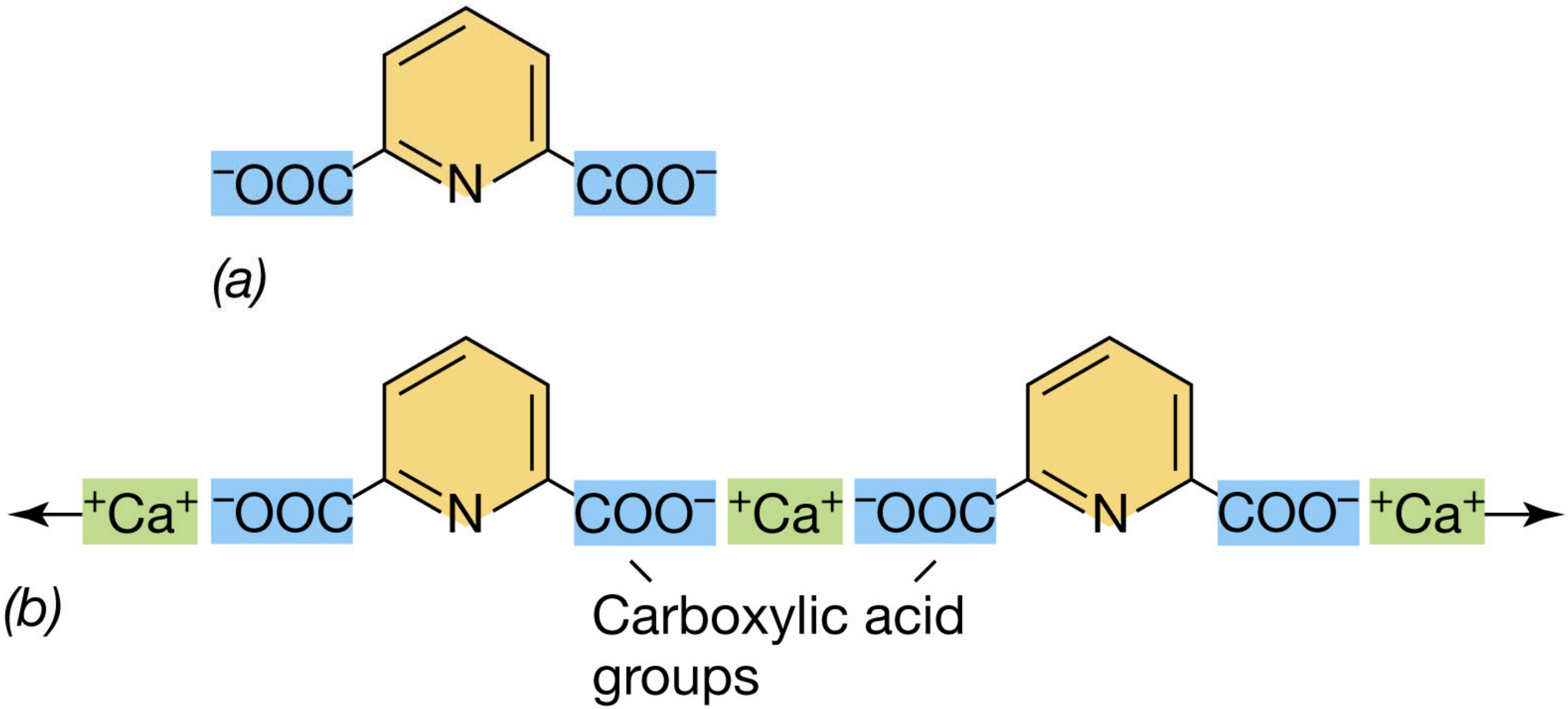


Figure 3.45 Endospore Structure. *Bacillus anthracis* endospore (×151,000). Note the following structures: exosporium, EX; spore coat, SC; cortex, CX; core wall, CW; and the protoplast or core with its nucleoid, N, and ribosomes, CR.



(a) Structure of Dipicolinic Acid & (b) crosslinked with Ca^{++}

Table 4.3 **Differences between endospores and vegetative cells**

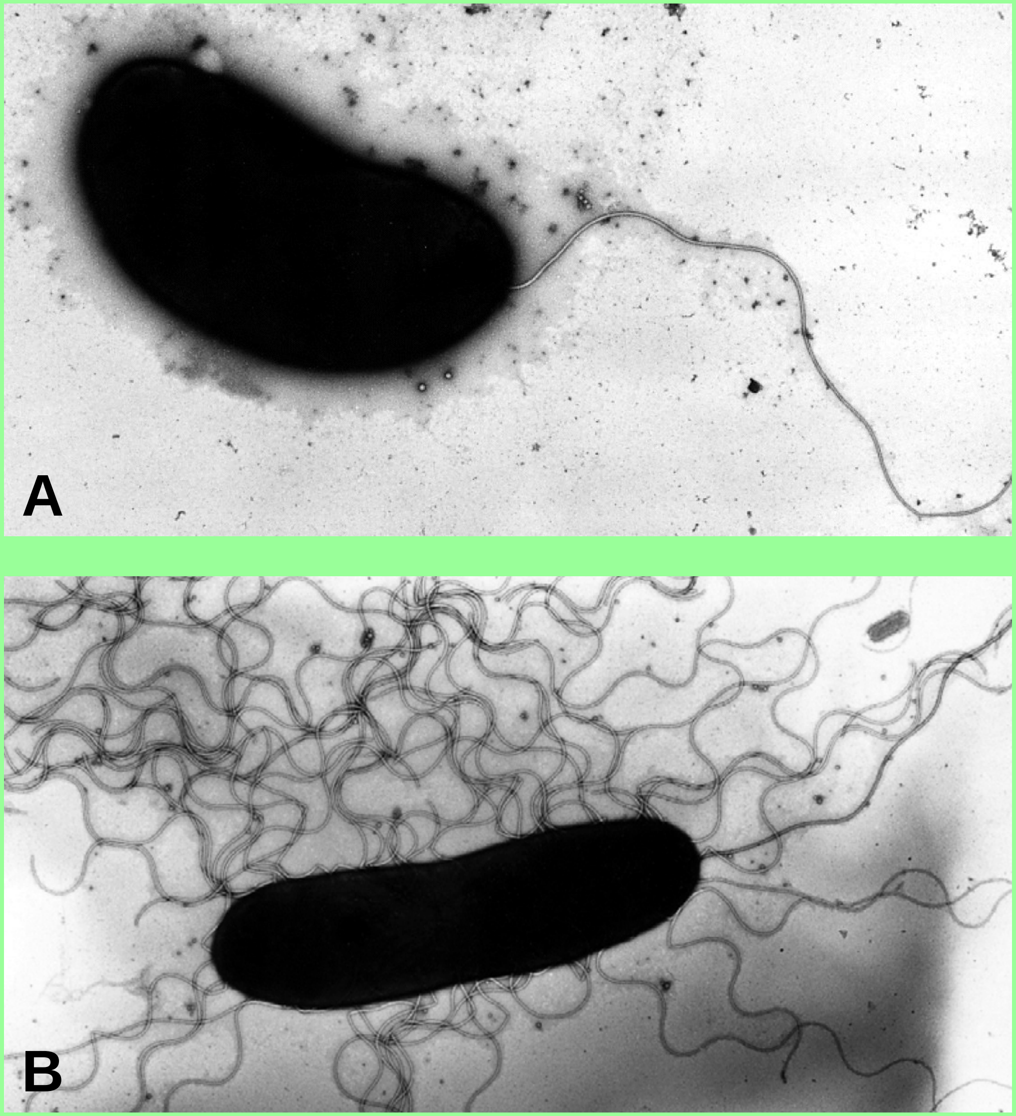
Characteristic	Vegetative cell	Endospore
Structure	Typical gram-positive cell; a few gram-negative cells	Thick spore cortex Spore coat Exosporium
Microscopic appearance	Nonrefractile	Refractile
Calcium content	Low	High
Dipicolinic acid	Absent	Present
Enzymatic activity	High	Low
Metabolism (O_2 uptake)	High	Low or absent
Macromolecular synthesis	Present	Absent
mRNA	Present	Low or absent
Heat resistance	Low	High
Radiation resistance	Low	High
Resistance to chemicals (for example, H_2O_2) and acids	Low	High
Stainability by dyes	Stainable	Stainable only with special methods
Action of lysozyme	Sensitive	Resistant
Water content	High, 80–90%	Low, 10–25% in core
Small acid-soluble proteins (product of *ssp* genes)	Absent	Present
Cytoplasmic pH	About pH 7	About pH 5.5–6.0 (in core)

Characteristics of Endospore: Take Home Message

- The endospore is a highly resistant differentiated bacterial cell produced by certain gram-positive *Bacteria*.

- Endospore formation leads to a highly dehydrated structure that contains essential macromolecules and a variety of substances such as calcium dipicolinate and small acid-soluble proteins, absent from vegetative cells.

- Endospores can remain dormant indefinitely but germinate quickly when the appropriate trigger is applied.



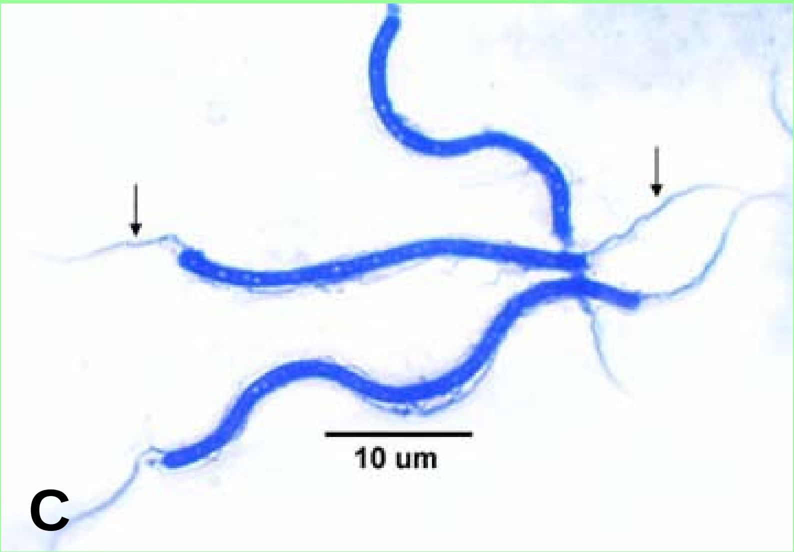
Bacterial flagella

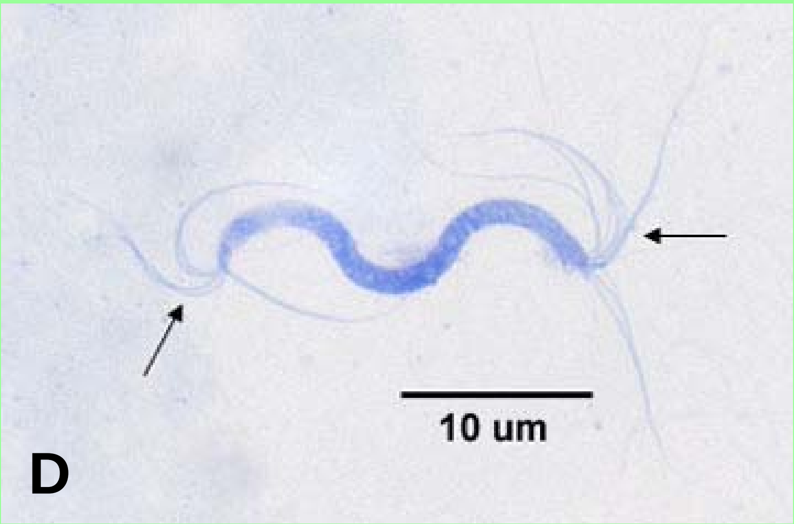
(a) Polar

(aka monotrichous)

&

(b) Peritrichous

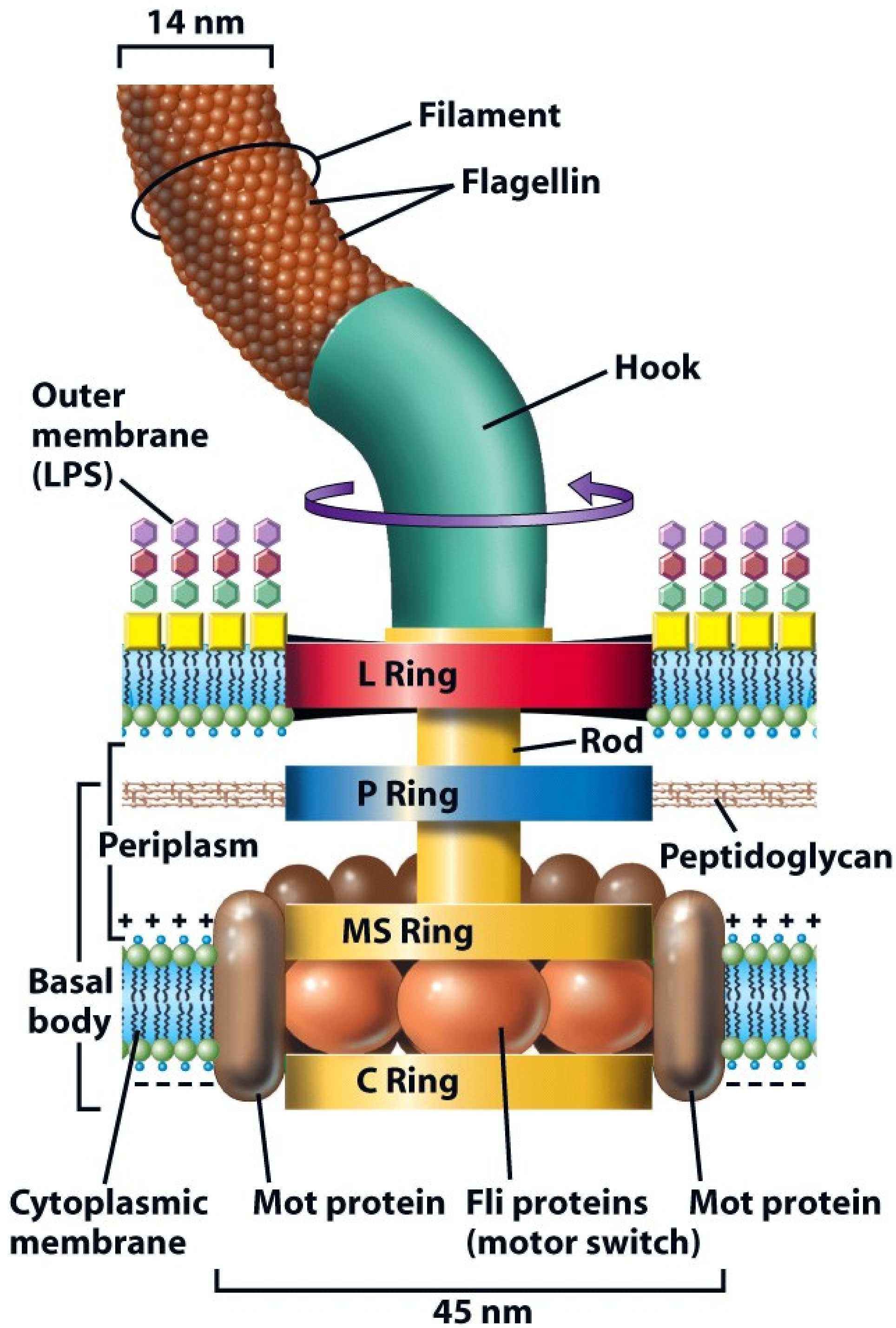


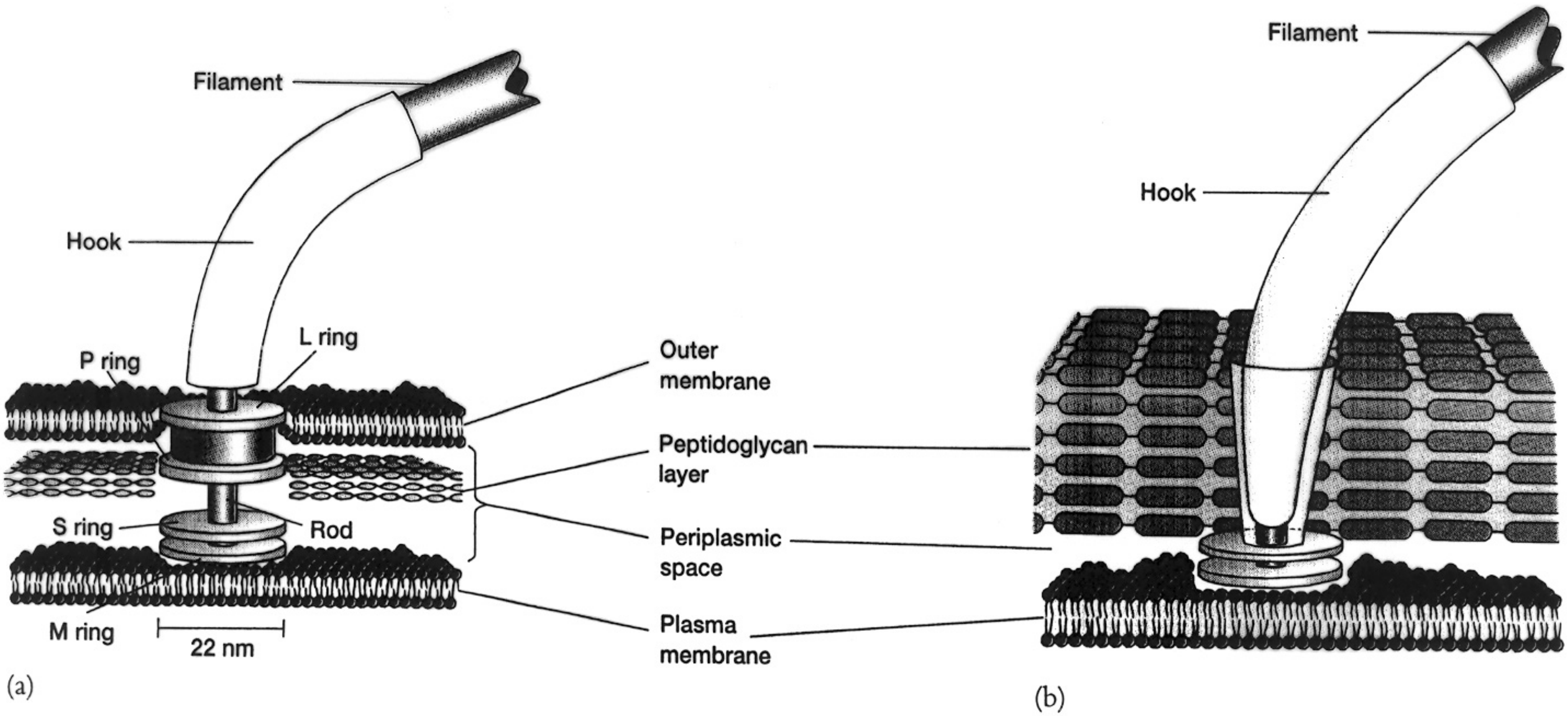


Bacterial flagella cont.

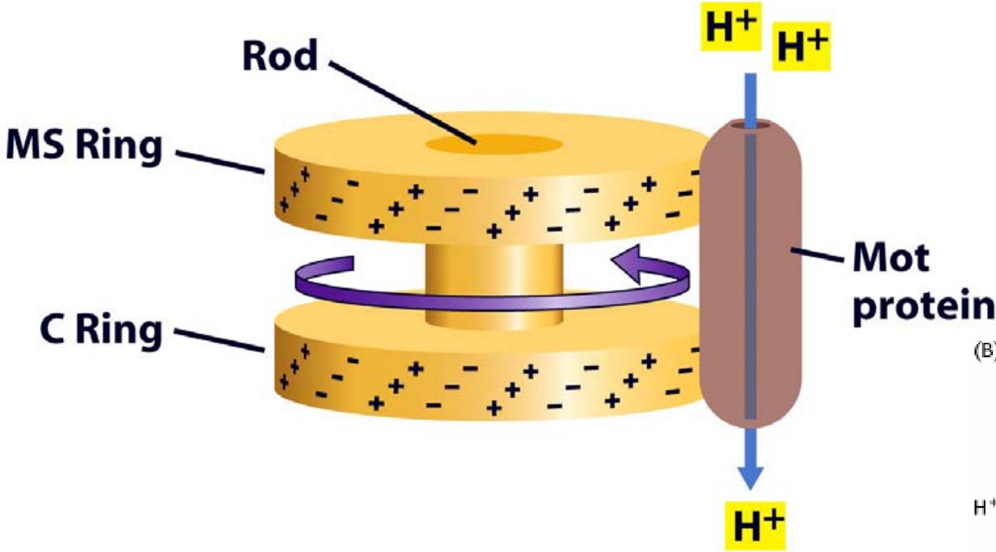
Also:
(c) Amphitrichous (bipolar)
&
(d) Lophotrichous (tuft)

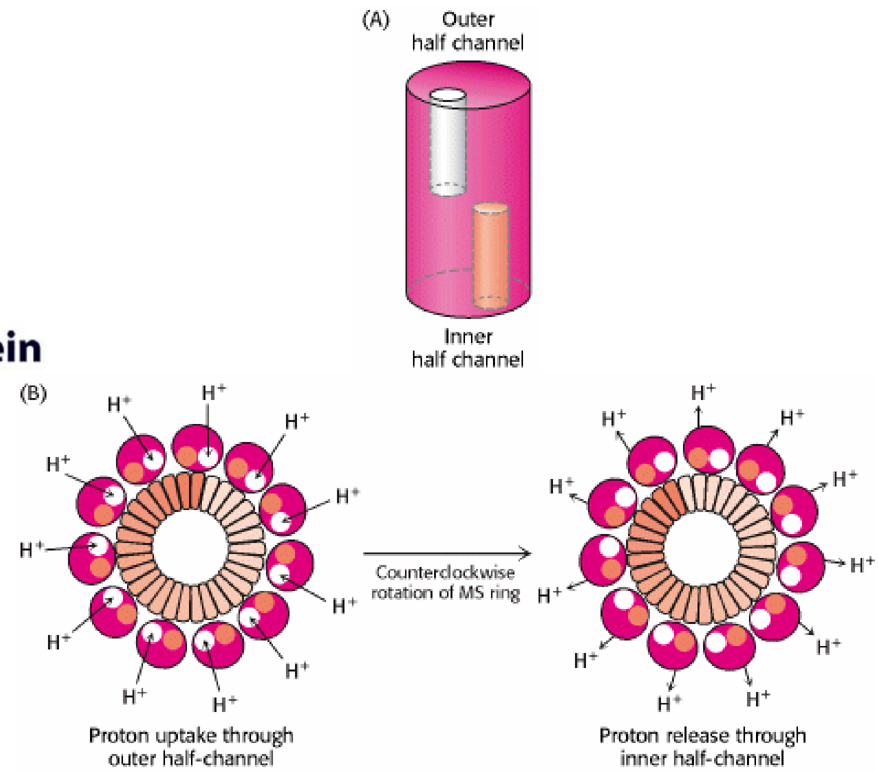
Structure of the bacterial flagellum



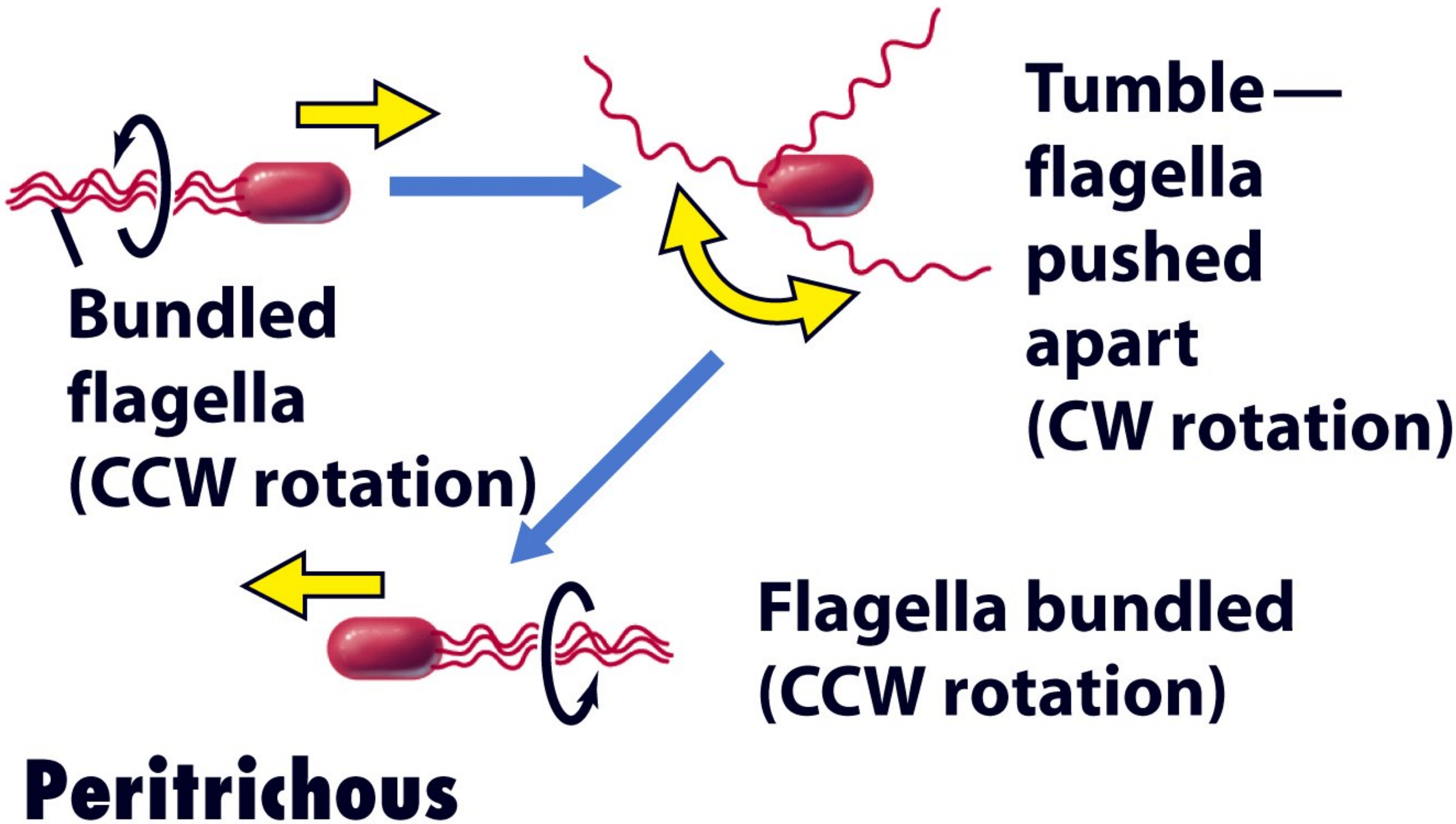


The Ultrastructure of Bacterial Flagella. Flagellar basal bodies and hooks in (*a*) gram-negative and (*b*) gram-positive bacteria.

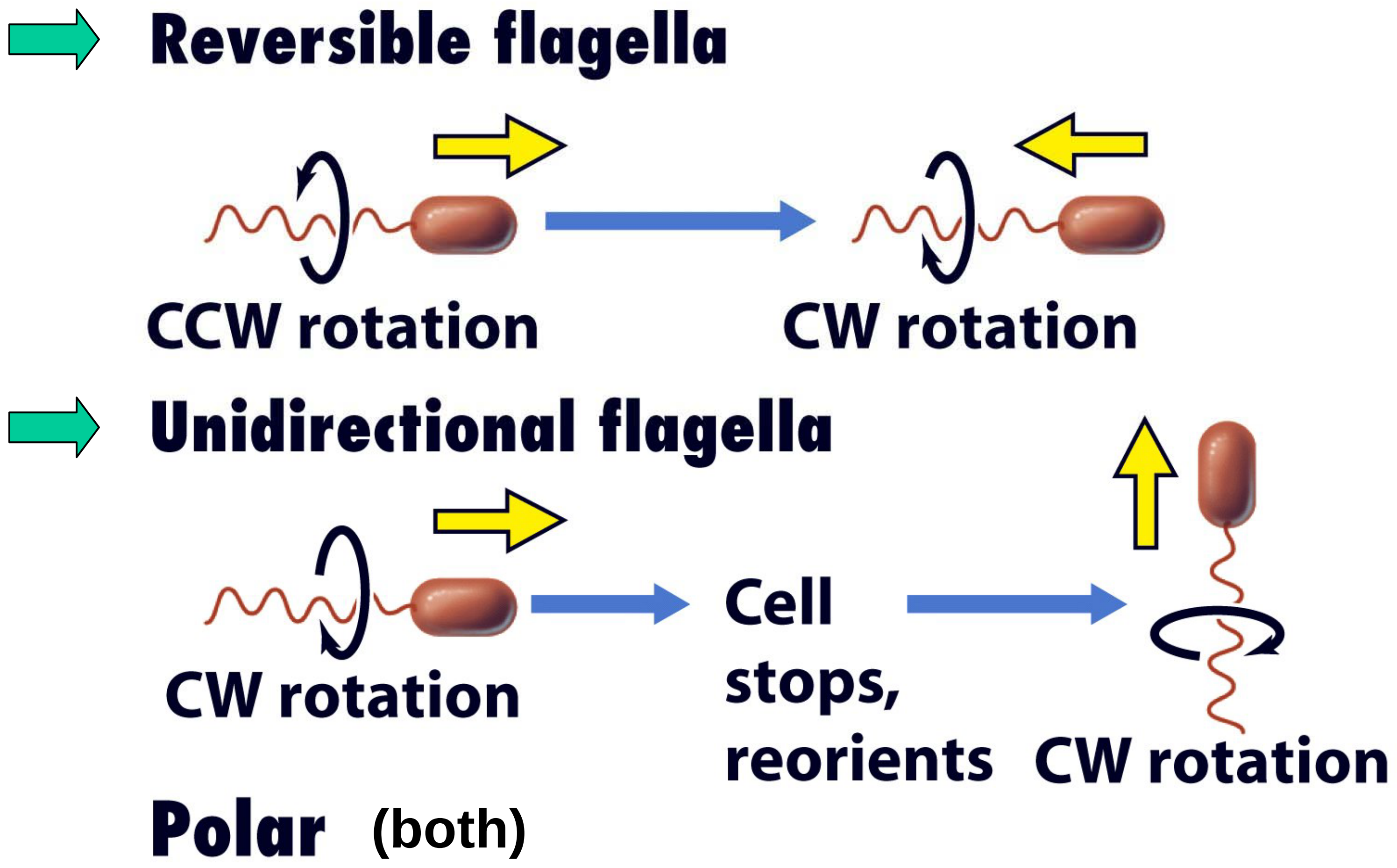




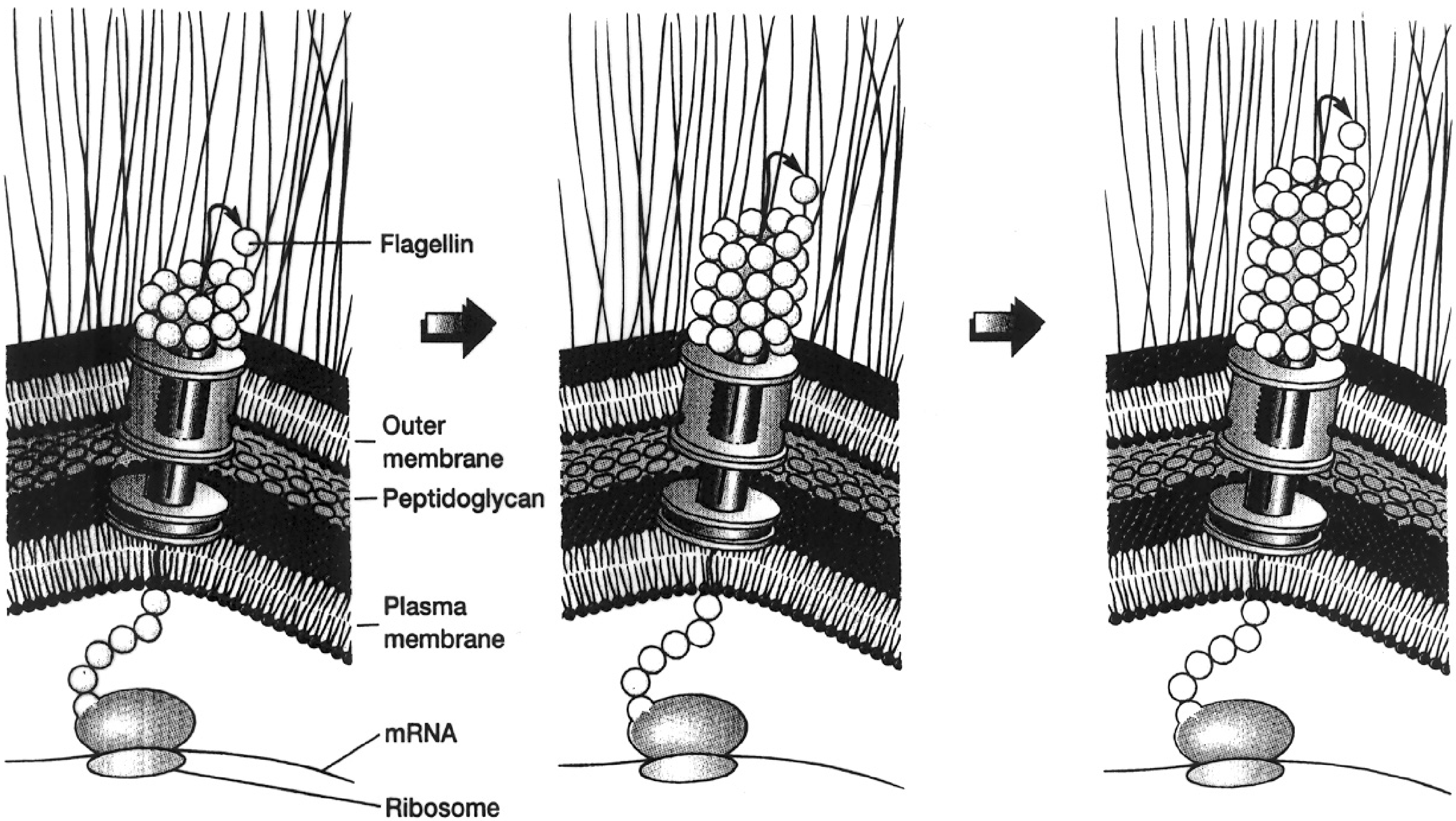
Proton Transport-Coupled Rotation of the Flagellum. (A) Mot protein may form a structure having two half-channels. (B) One model for the mechanism of coupling rotation to a proton gradient requires protons to be taken up into the outer half-channel and transferred to the MS ring. The MS ring rotates in a CCW direction, and the protons are released into the inner half-channel. The flagellum is linked to the MS ring and so the flagellum rotates as well.



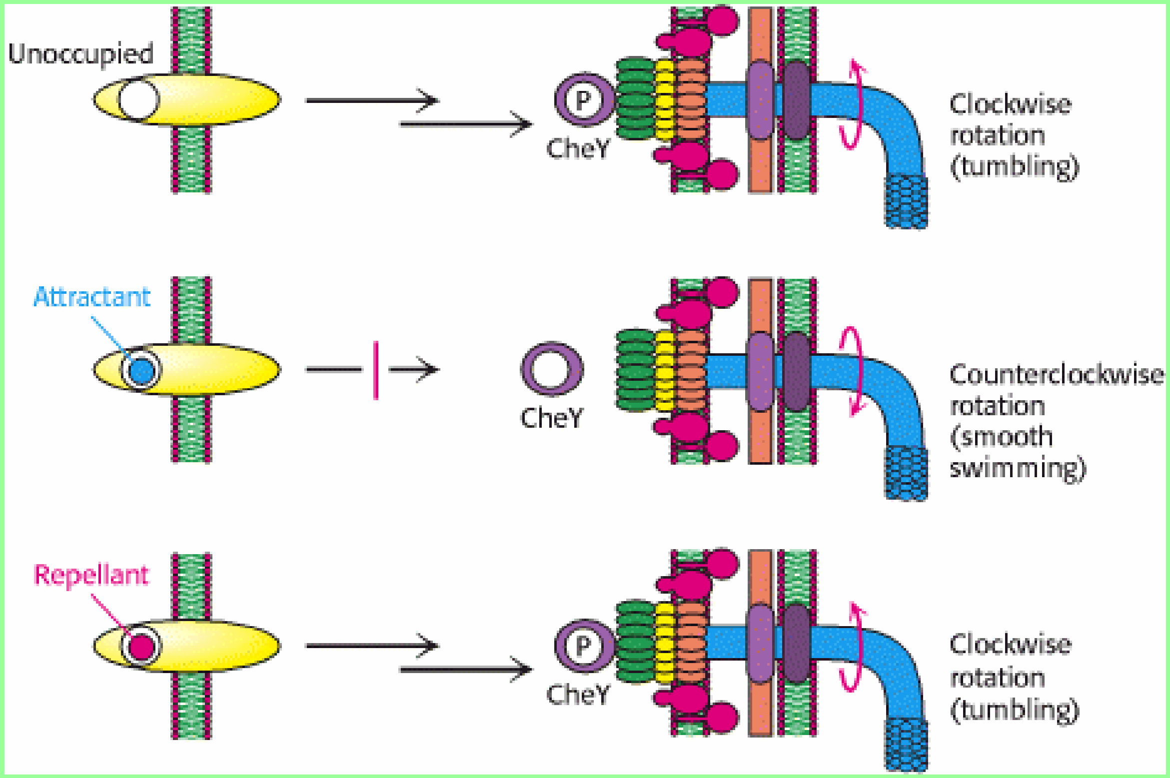
Flagellar Motility: Relationship of flagellar rotation to bacterial movement.



Flagellar Motility: Relationship of flagellar rotation to bacterial movement.



Growth of Flagellar Filaments. Flagellin subunits travel through the flagellar core and attach to the growing tip.



Chemotaxis Signaling Pathway. Receptors in the plasma membrane initiate a signaling pathway leading to the phosphorylation of the CheY protein. Phosphorylated CheY binds to the flagellar motor and favors CW rotation. When an attractant binds to the receptor, this pathway is blocked, and CCW flagellar rotation and, hence, smooth swimming results. When a repellant binds, the pathway is stimulated, leading to an increased concentration of phosphoylated CheY and, hence, more frequent CW rotation and tumbling.

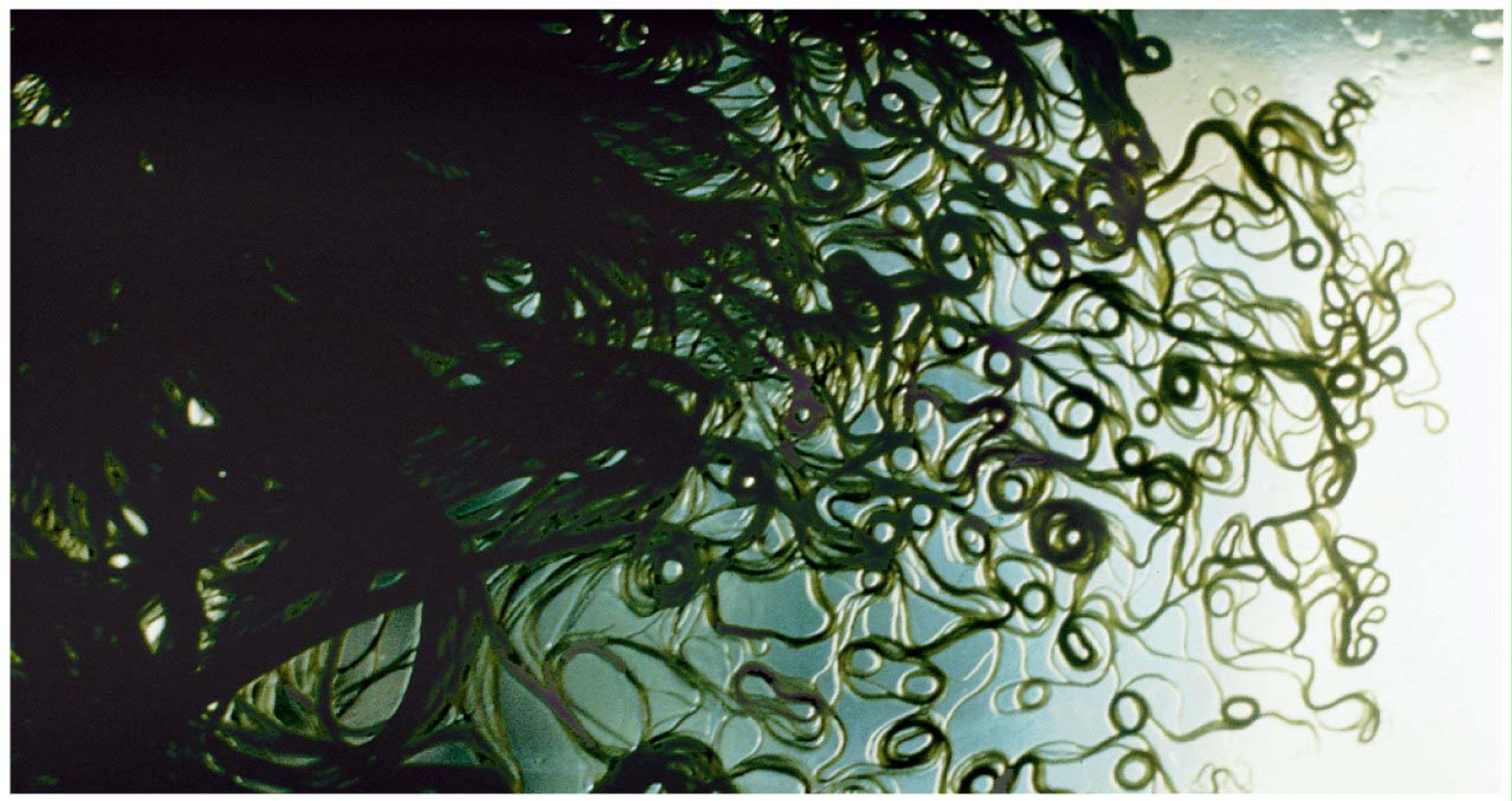
Flagellar Motility: Take Home Message

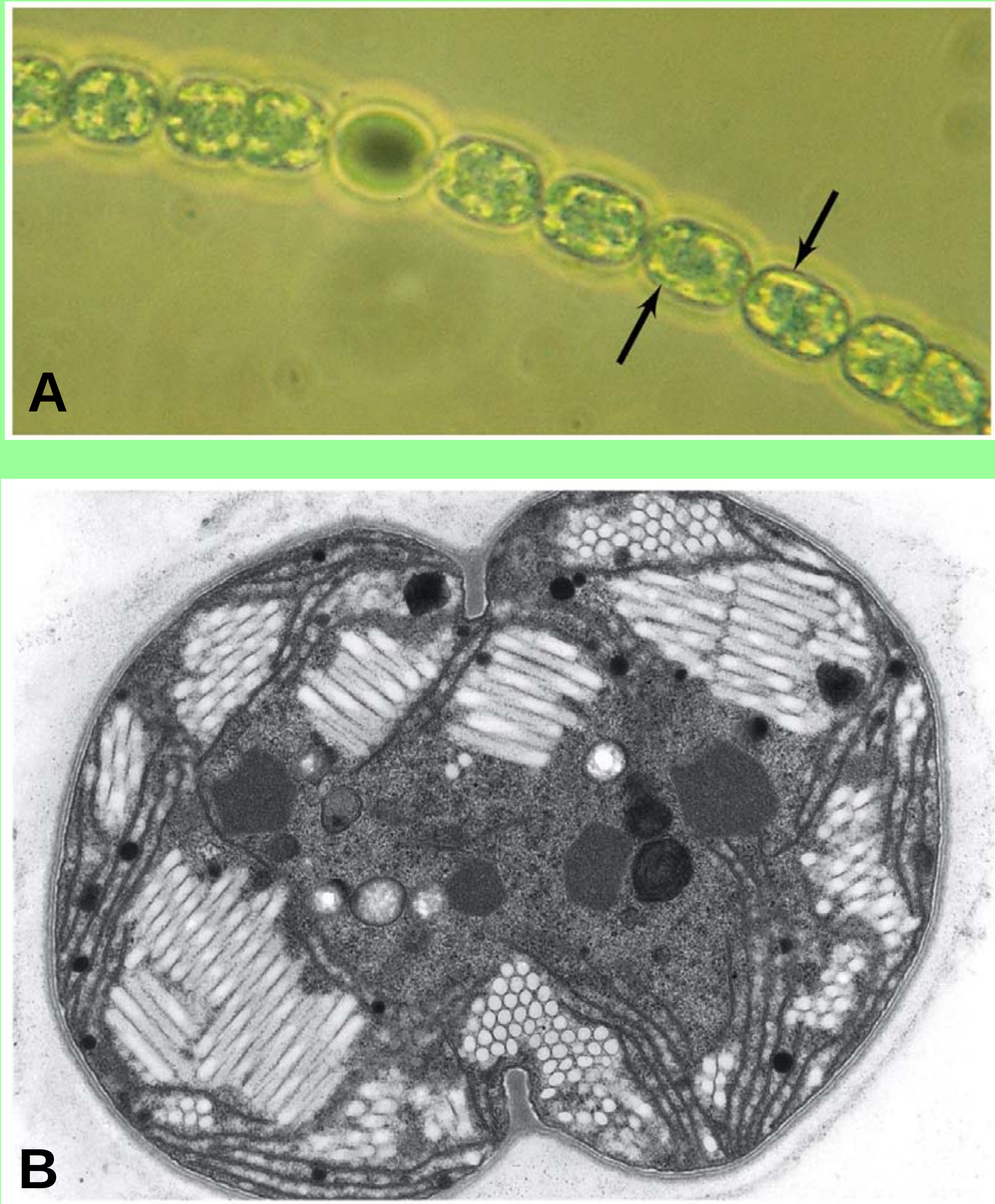
- Motility in most microorganisms is due to flagella.

- In prokaryotes the flagellum is a complex structure made of several proteins, most of which are anchored in the cell wall and cytoplasmic membrane.

- The flagellum filament, which is made of a single kind of protein, rotates at the expense of the proton motive force, which drives the flagellar motor.

Gliding Motility: Mechanism??

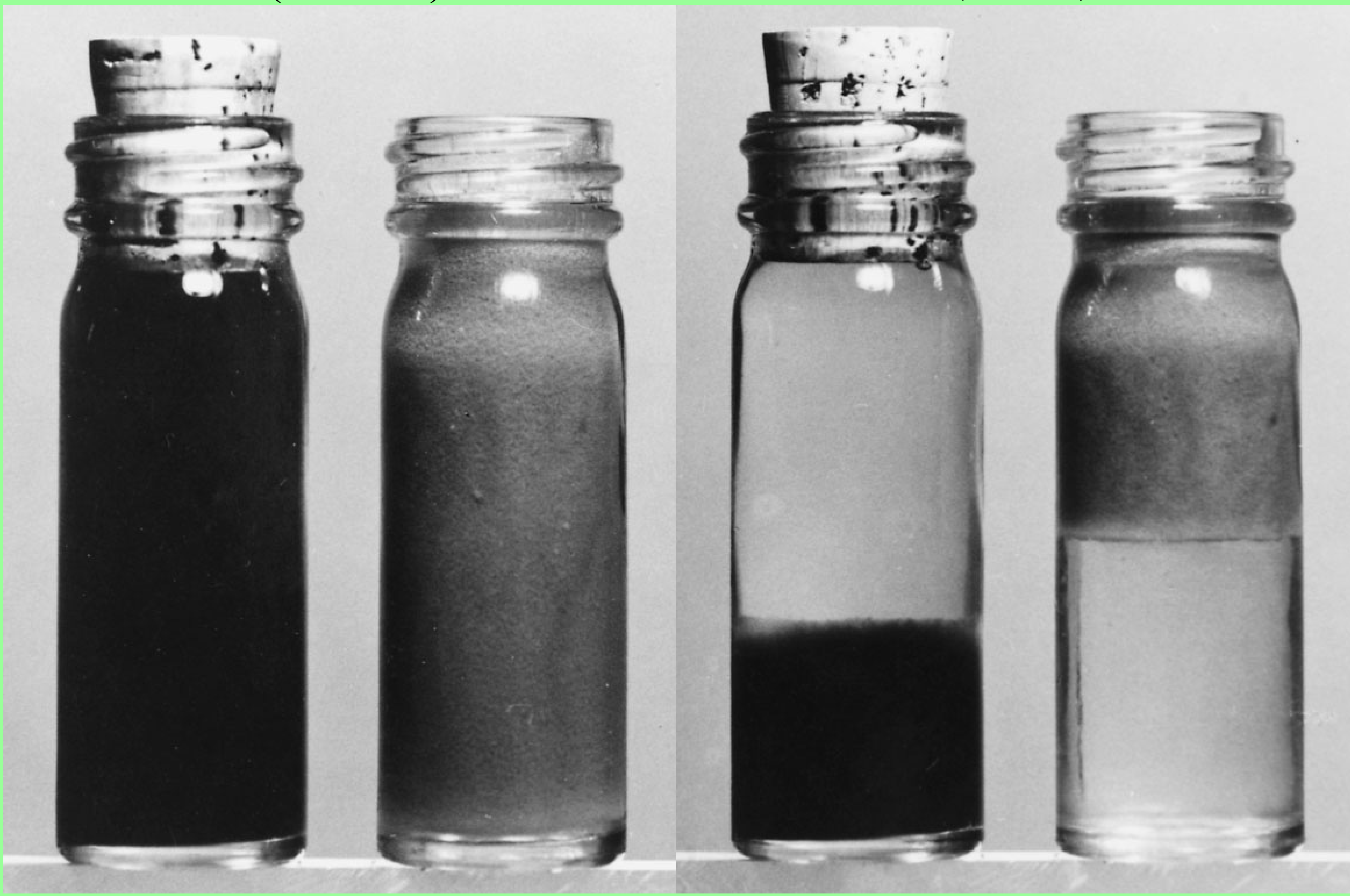




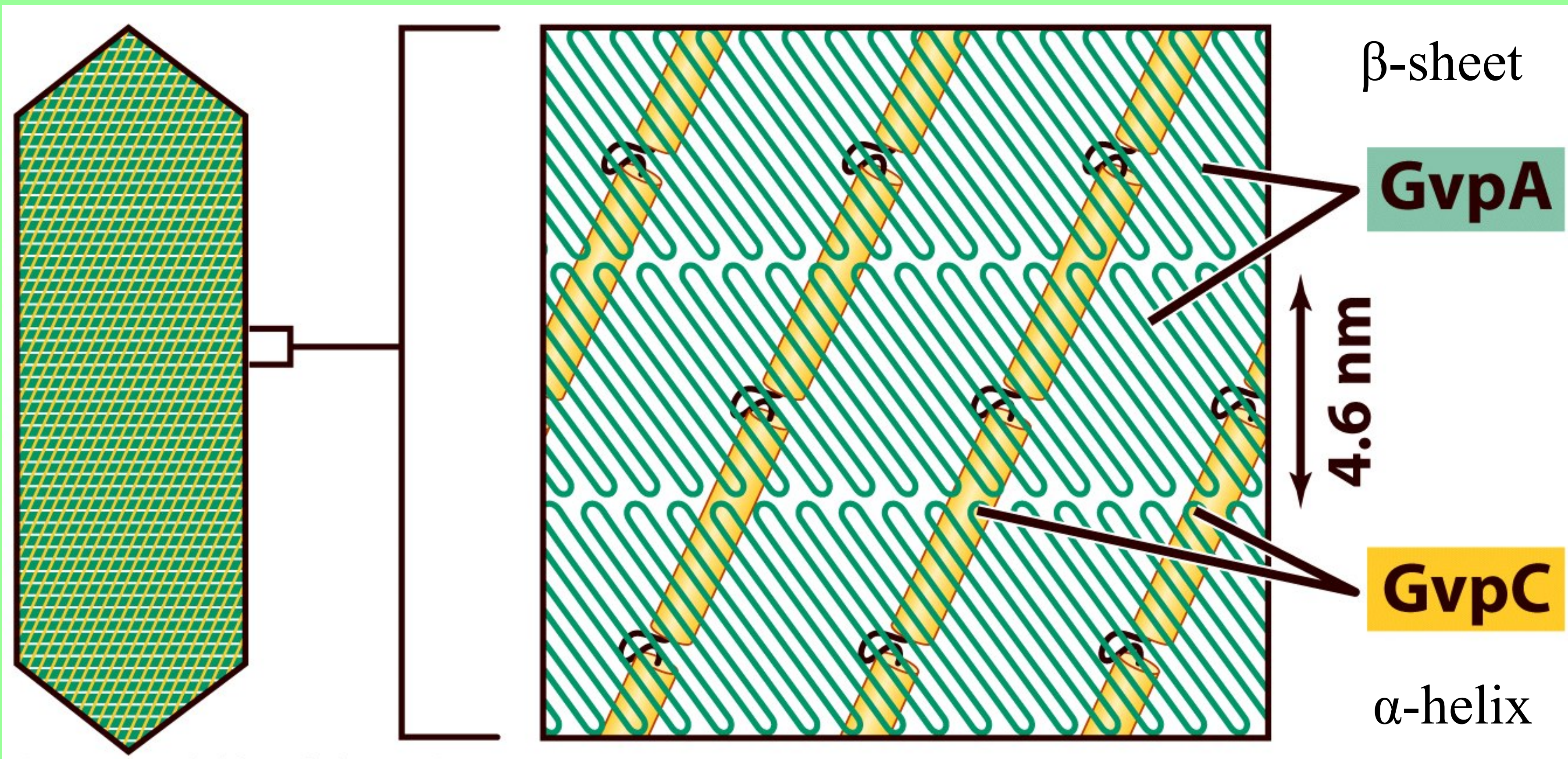
Gas Vesicles
(a) *Anabaena flos-aquae*
(b) *Microcystis* sp.

The Hammer, Cork, and Bottle Experiment

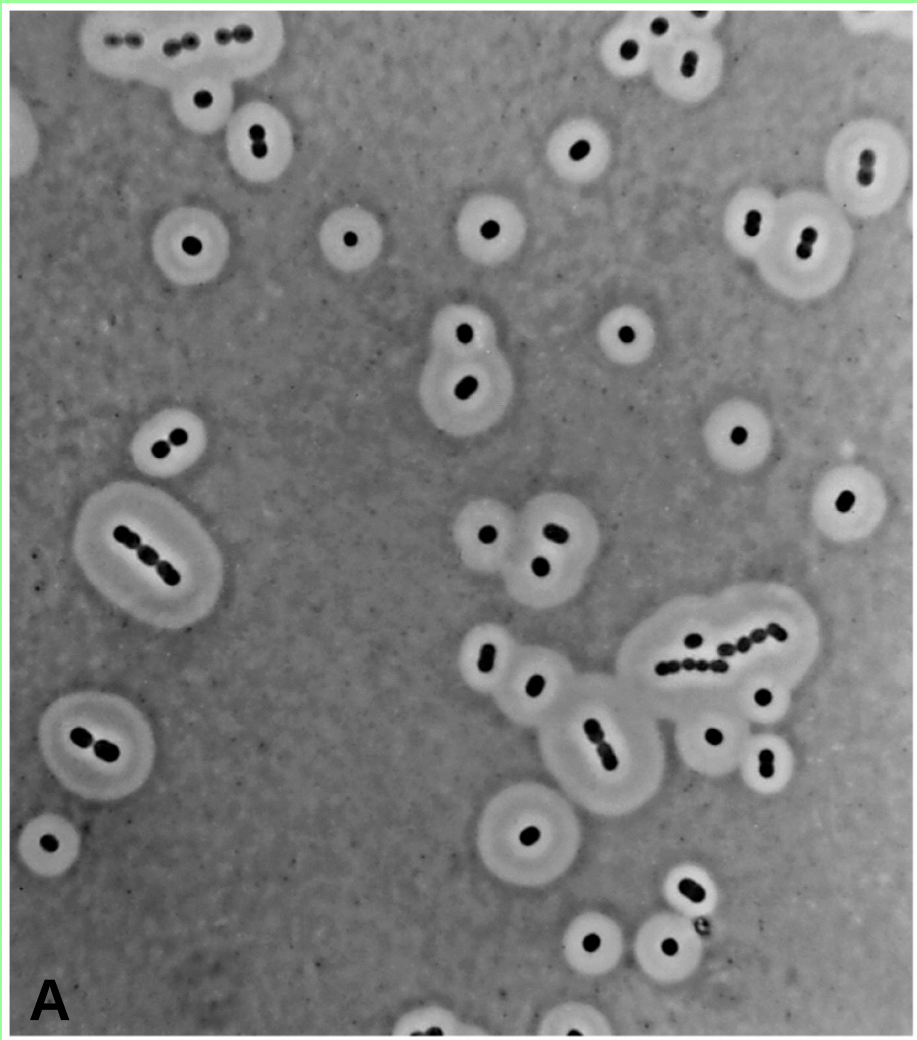
(Before) (After)

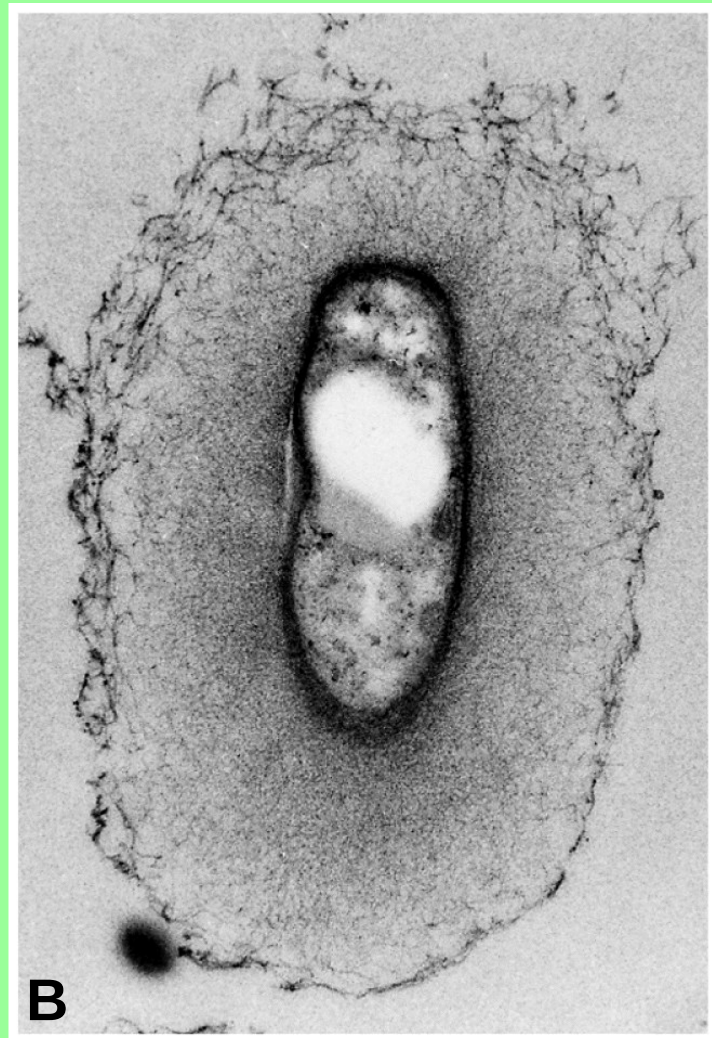


Model of how the two proteins that make up the gas vesicle, GvpA and GvpC, interact to form a watertight but gas-permeable structure.



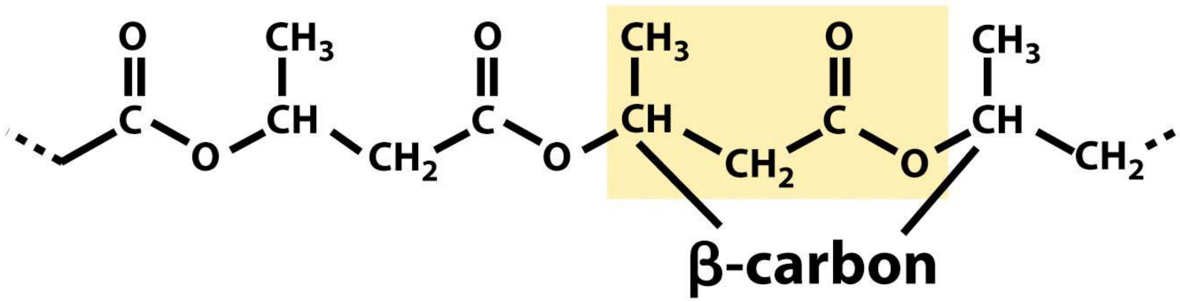
Bacterial Capsules: (a) *Acinetobacter* sp. (b) *Rhizobium trifolii*

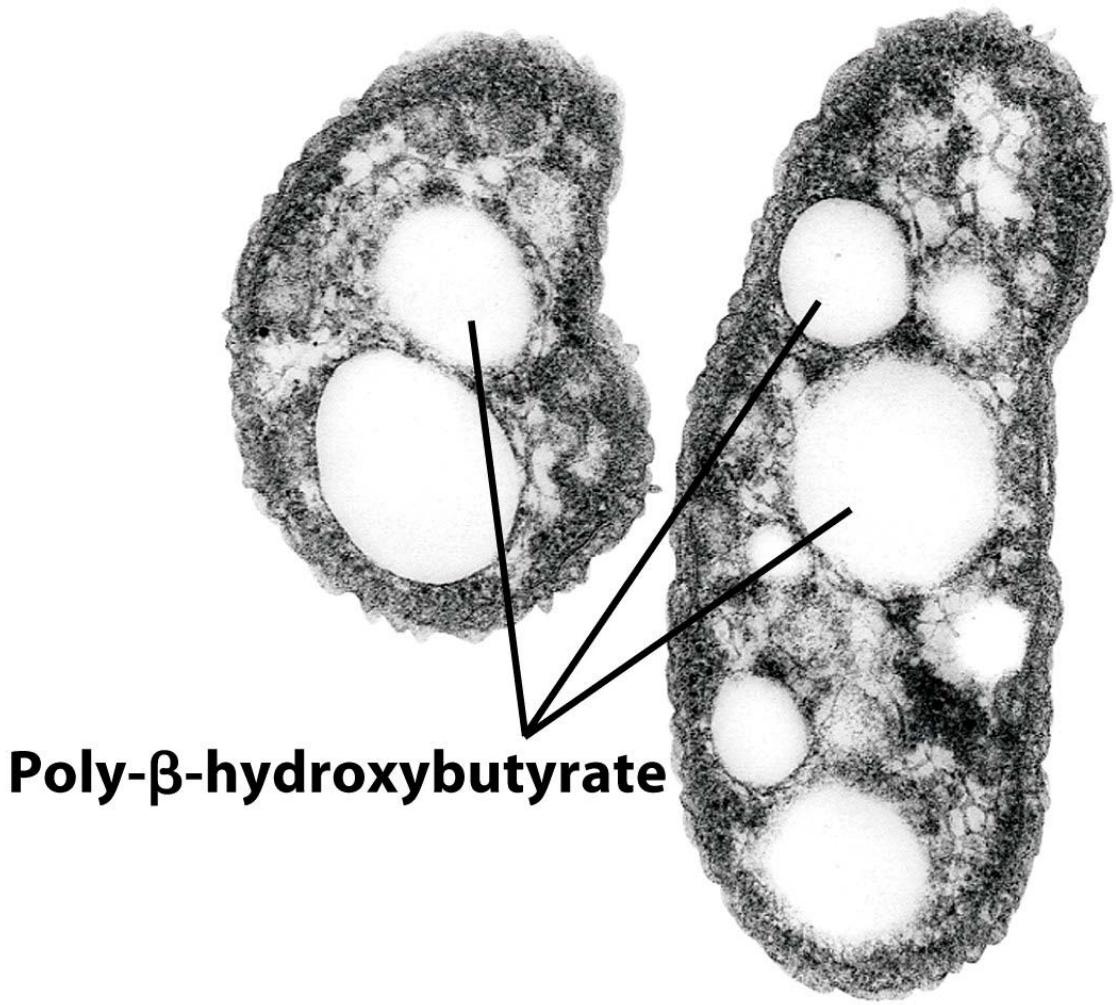


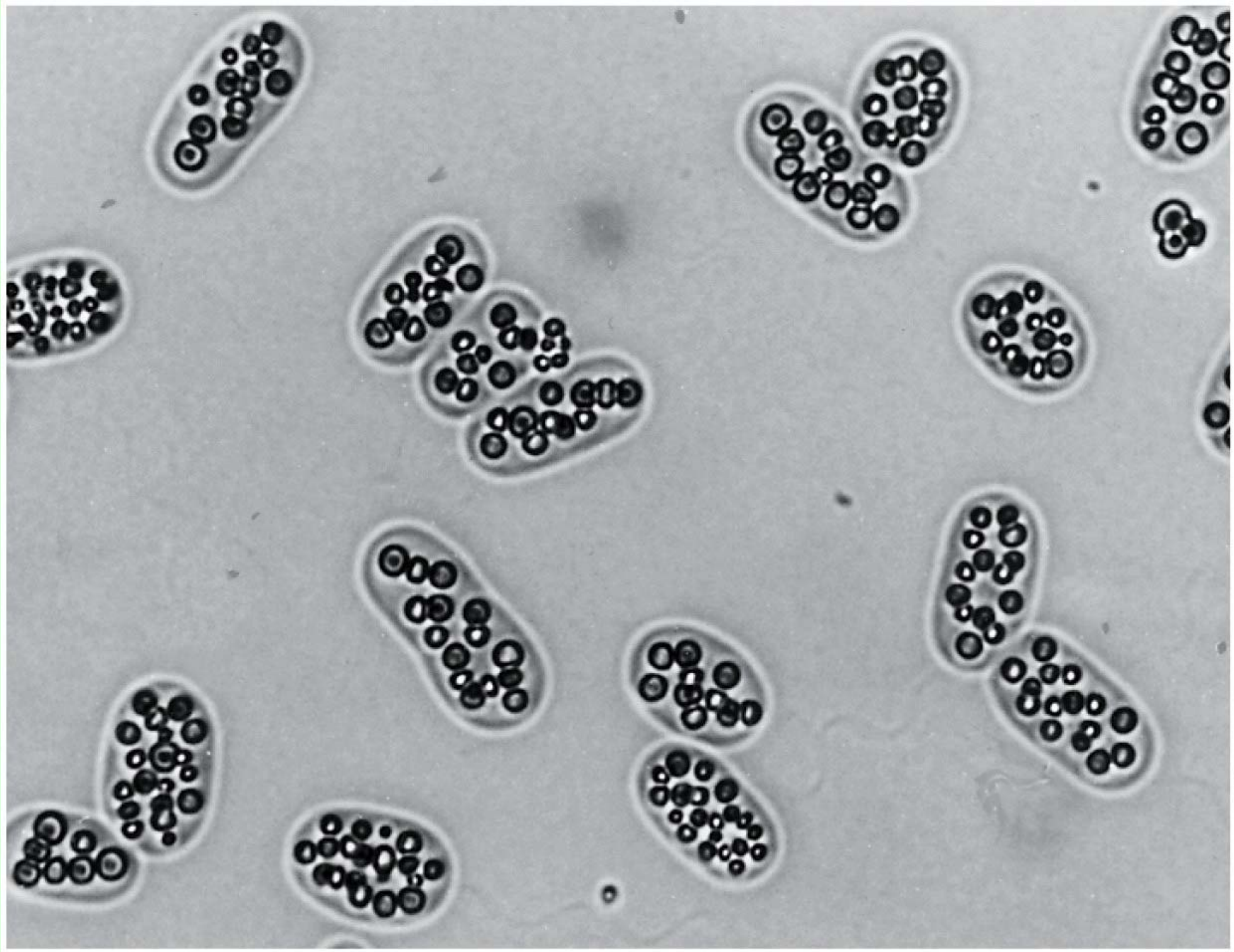


negative stain

Storage of PHB

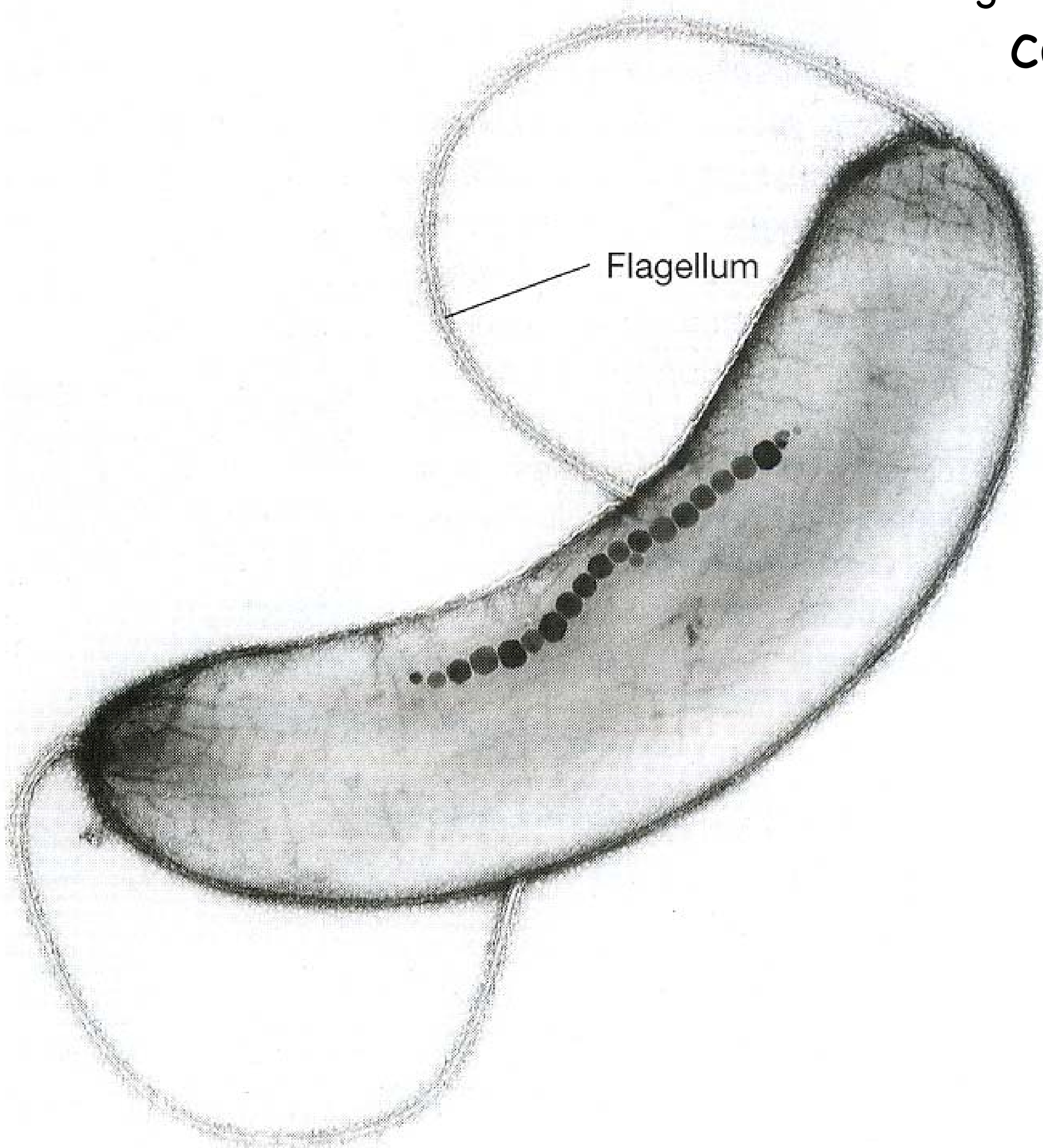


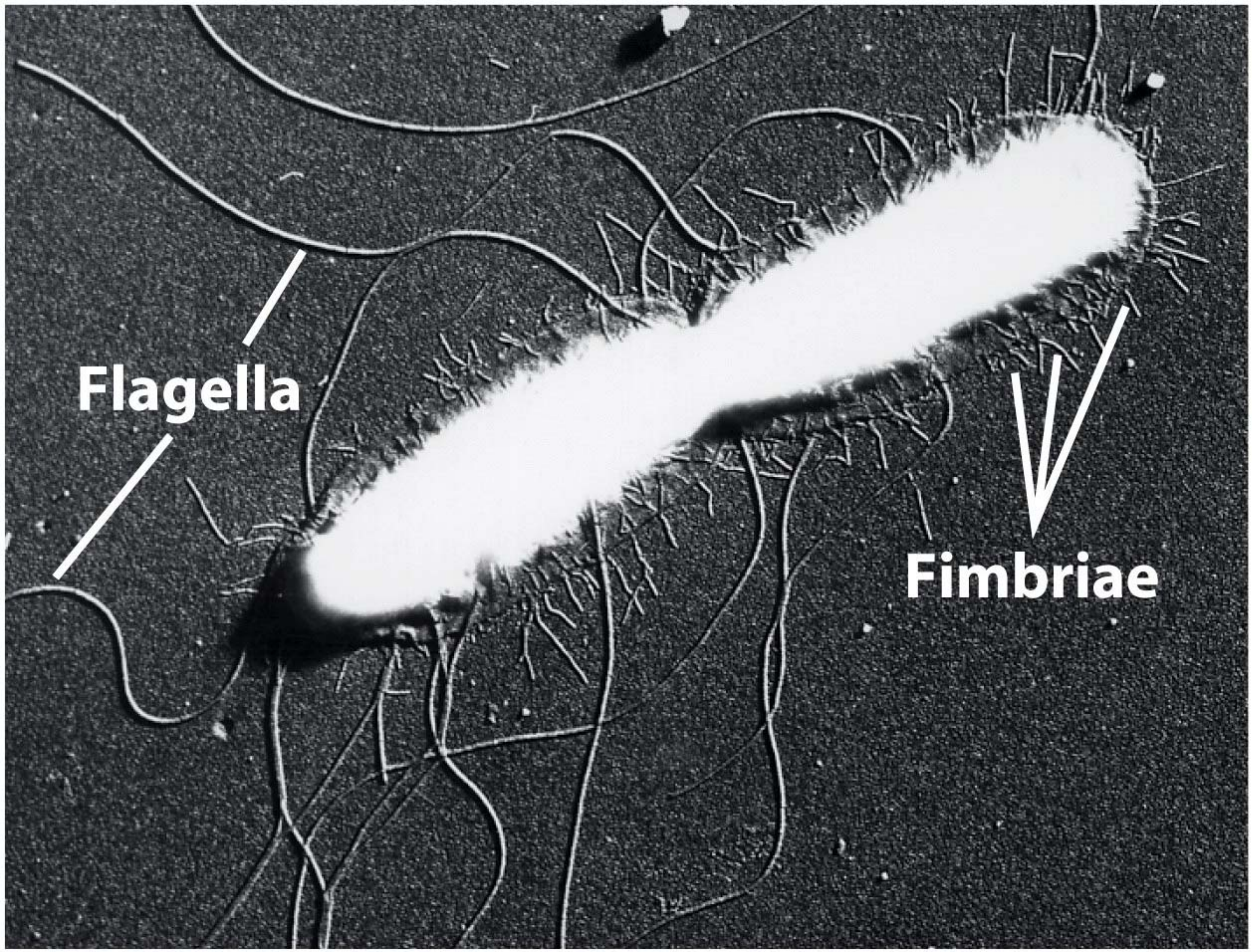




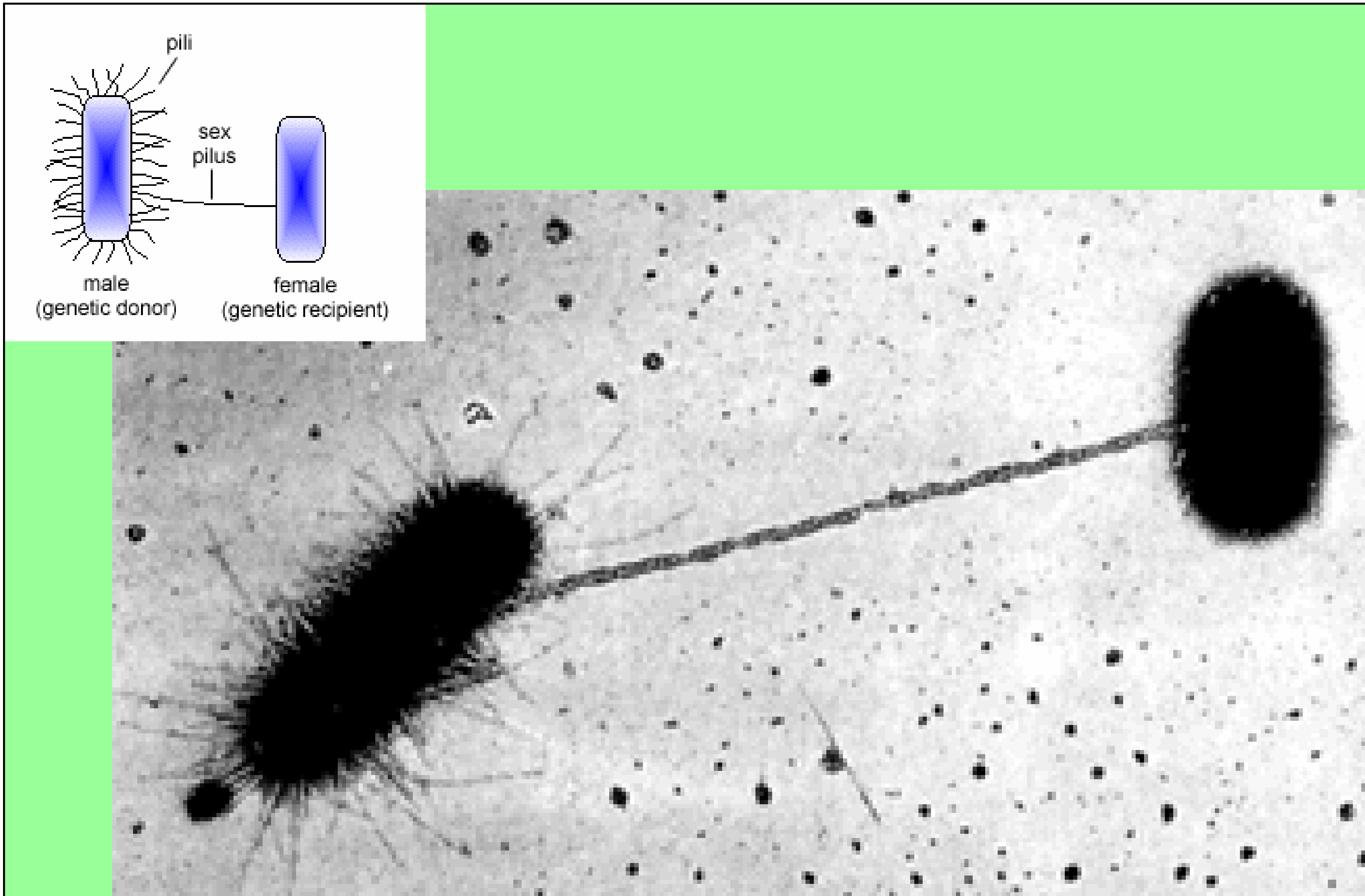
Sulfur globules inside the purple sulfur bacterium *Isochromatium buderi*

Magnetotactic bacteria with Fe_3O_4 (magnetite) particles called magnetosomes





EM of *Salmonella typhi*



"Sex" Pili used in bacterial conjugation of *E. coli* cells