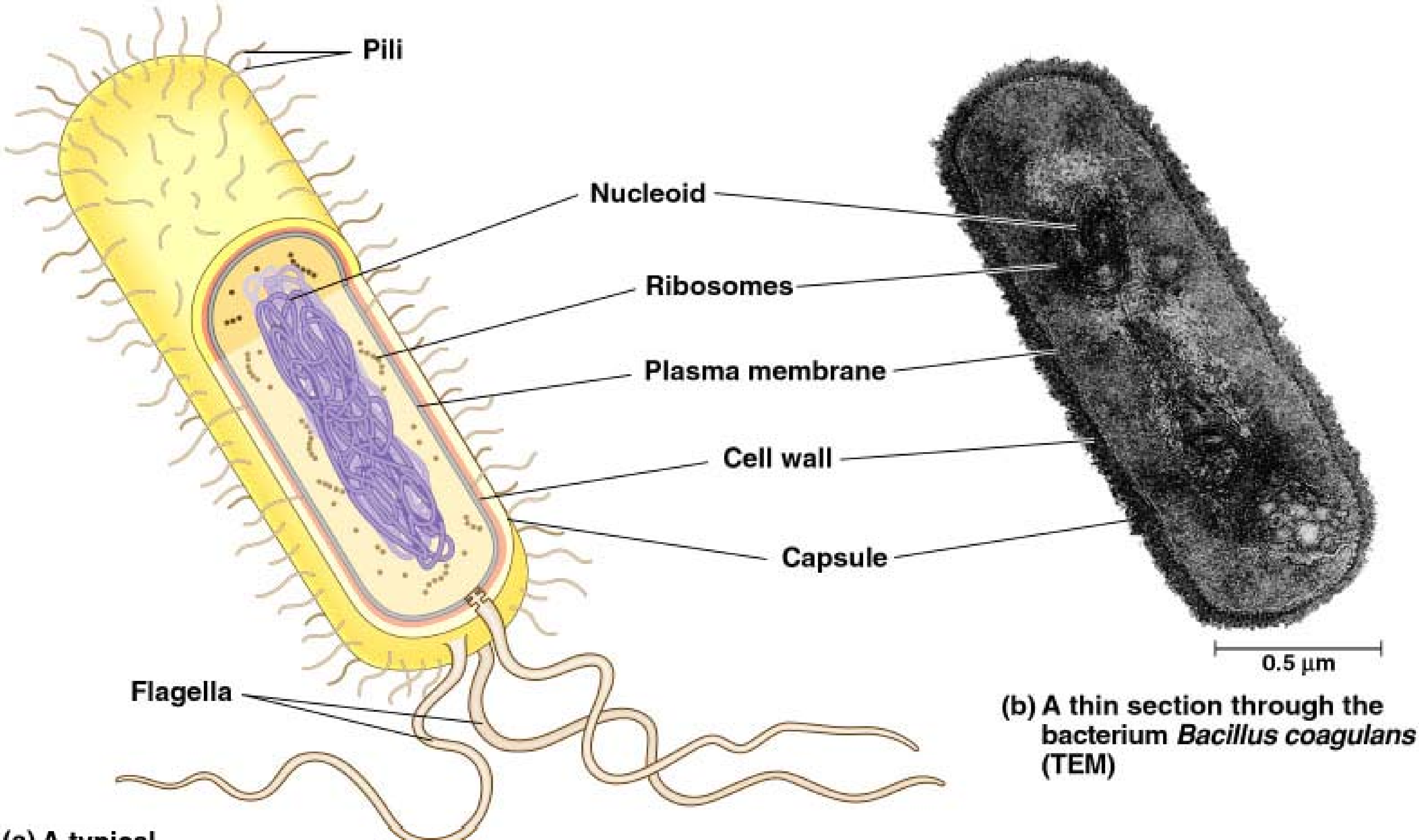
# Comparing Bacteria, Archaea and Eucarya

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

**"Features" found in all cells:**

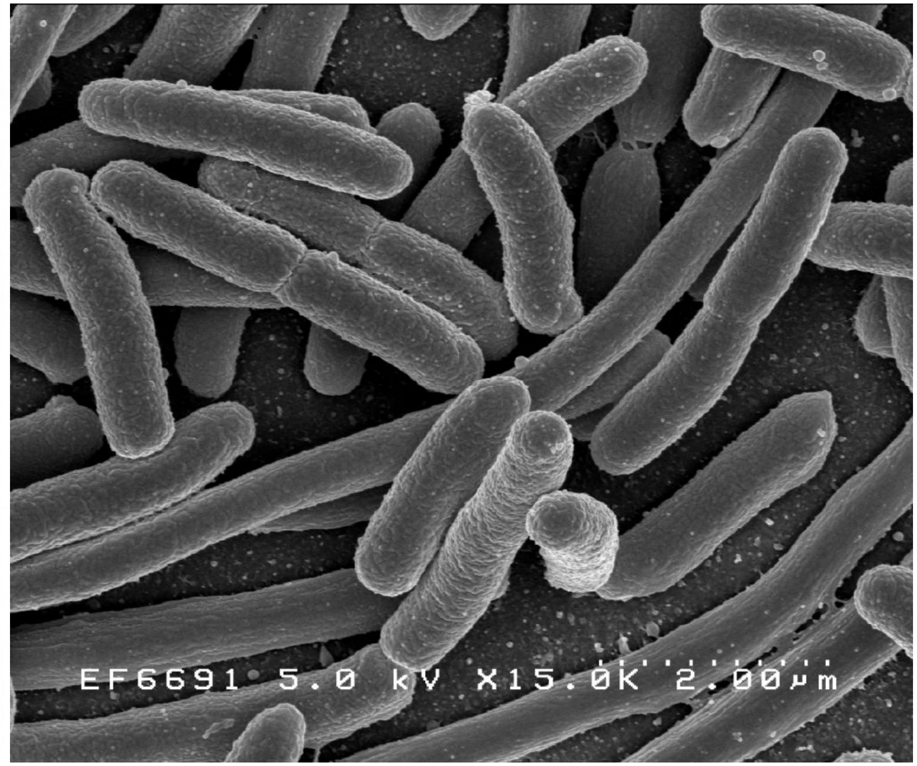
- **Ribosomes**
- **Cell Membrane**
- **Genetic Material**
- **Cytoplasm**
- **ATP Energy**
- **External Stimuli**
- **Regulate Flow**
- **Reproduce**

# A Bacterial Cell



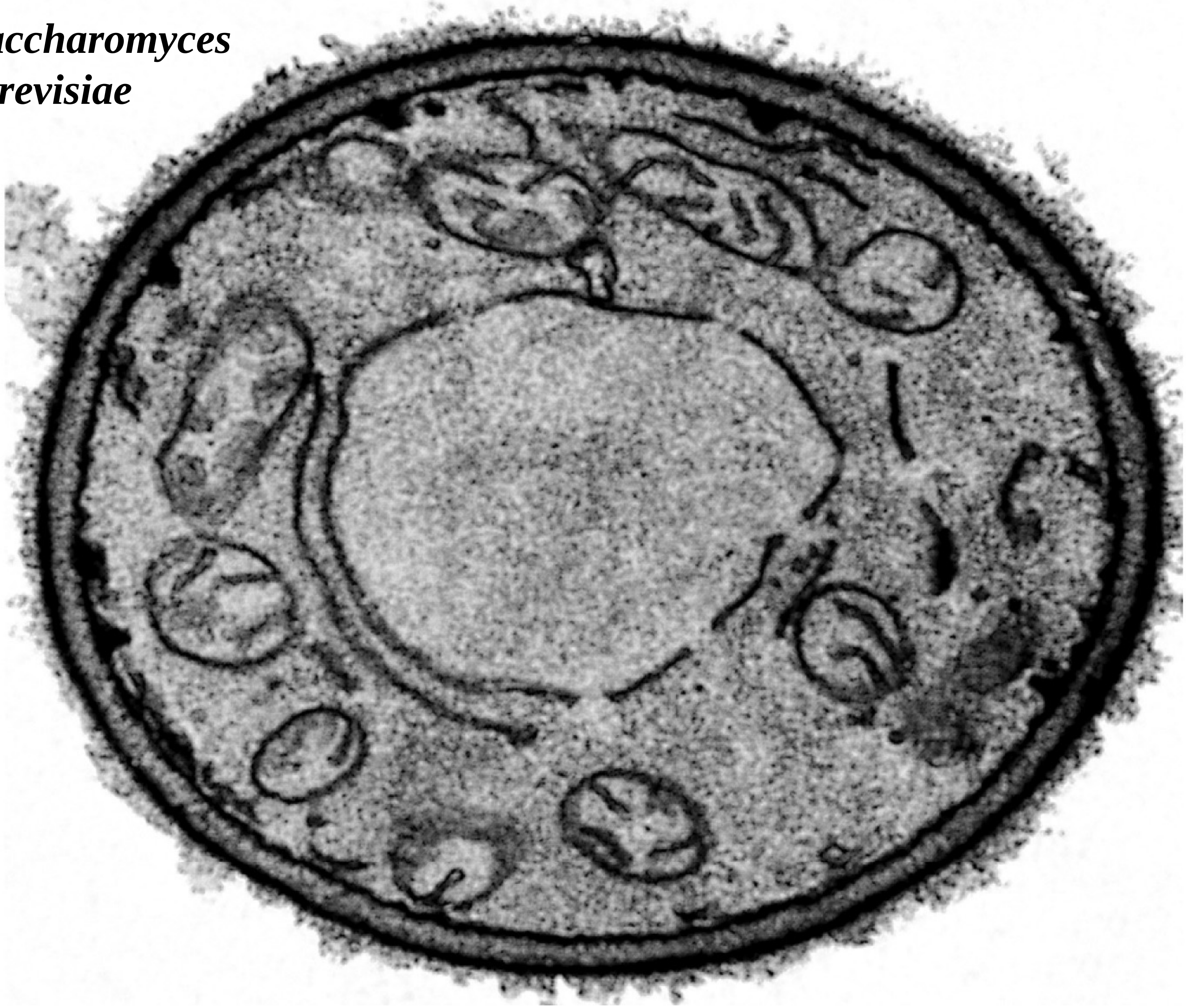

(a) A typical rod-shaped bacterium

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

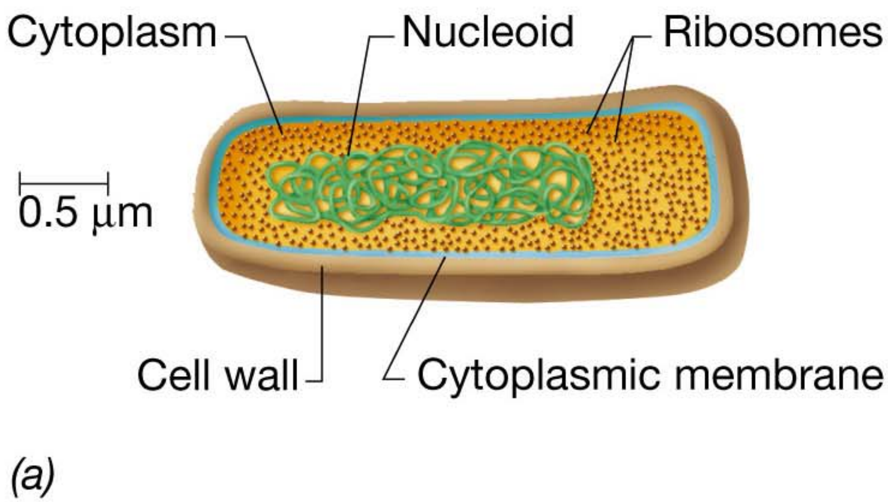


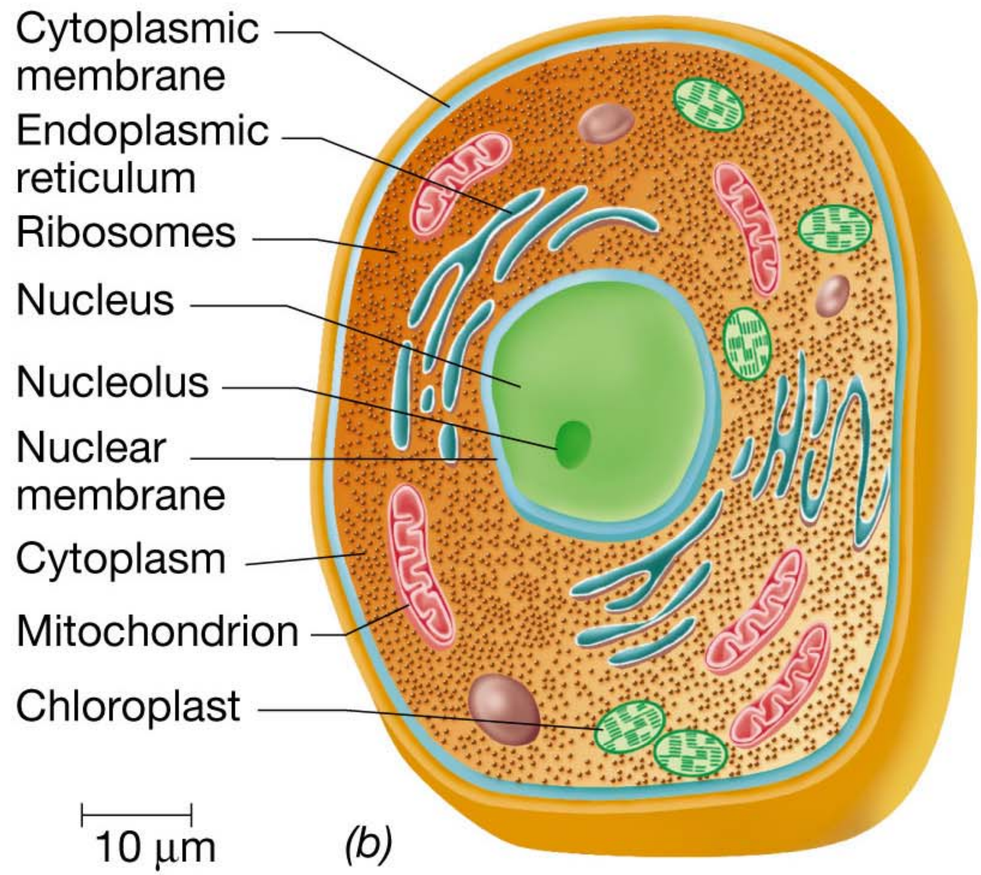

***Escherichia coli***

***Saccharomyces cerevisiae***

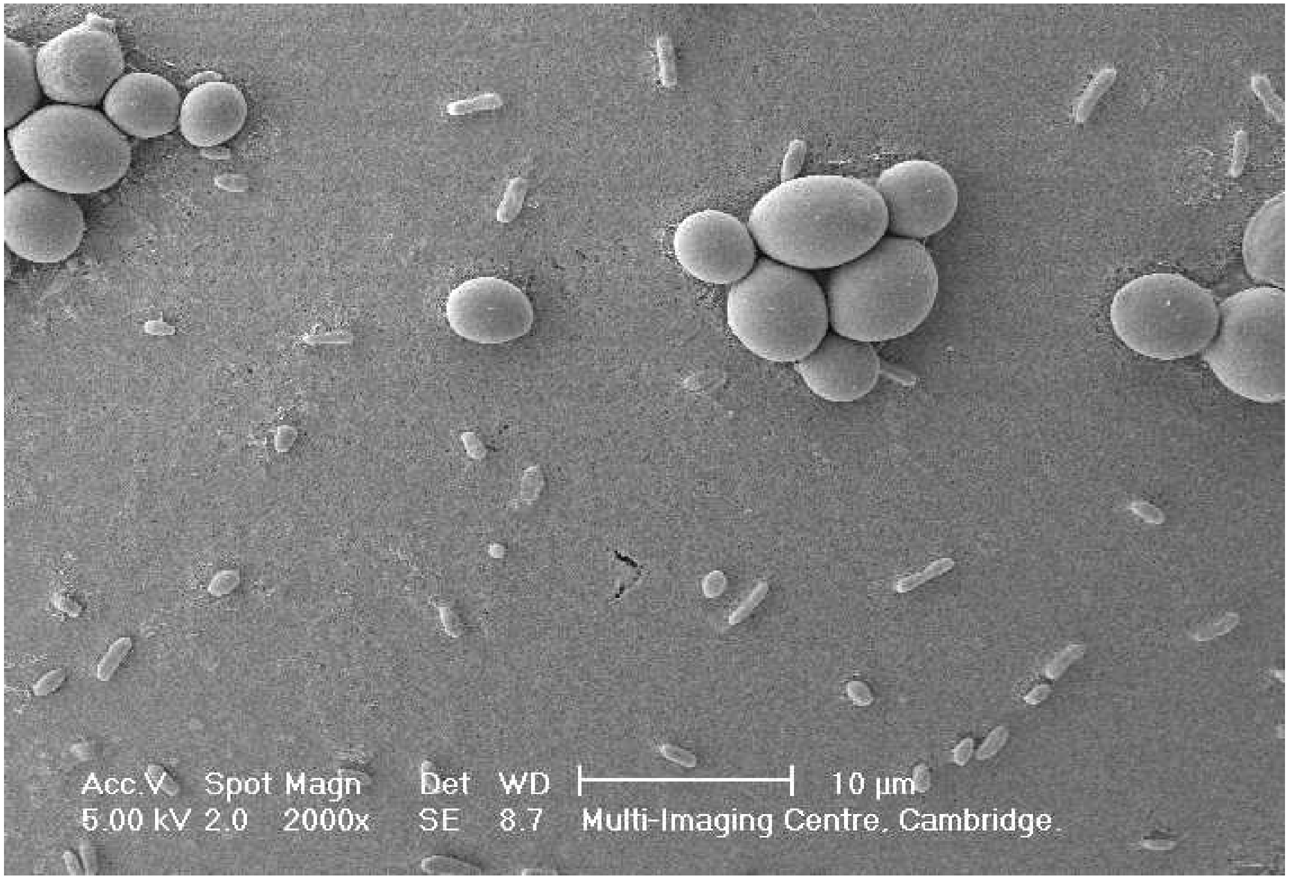


# Elements of cellular structure

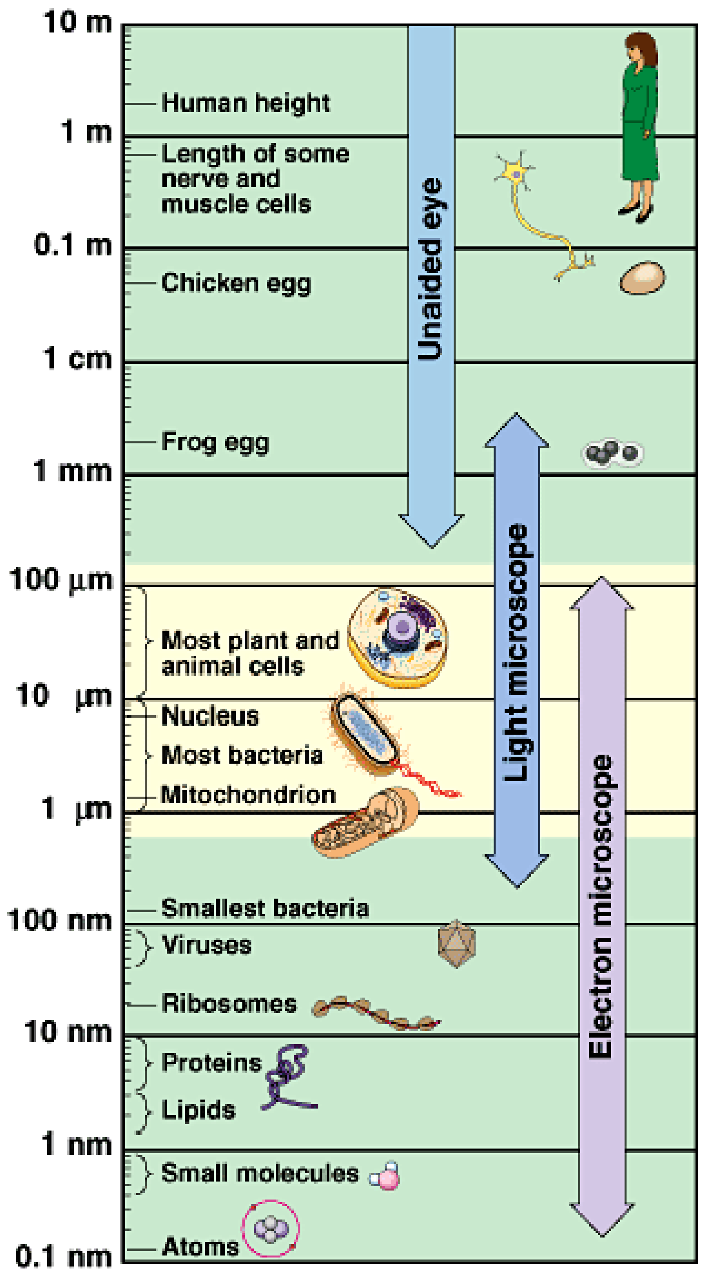


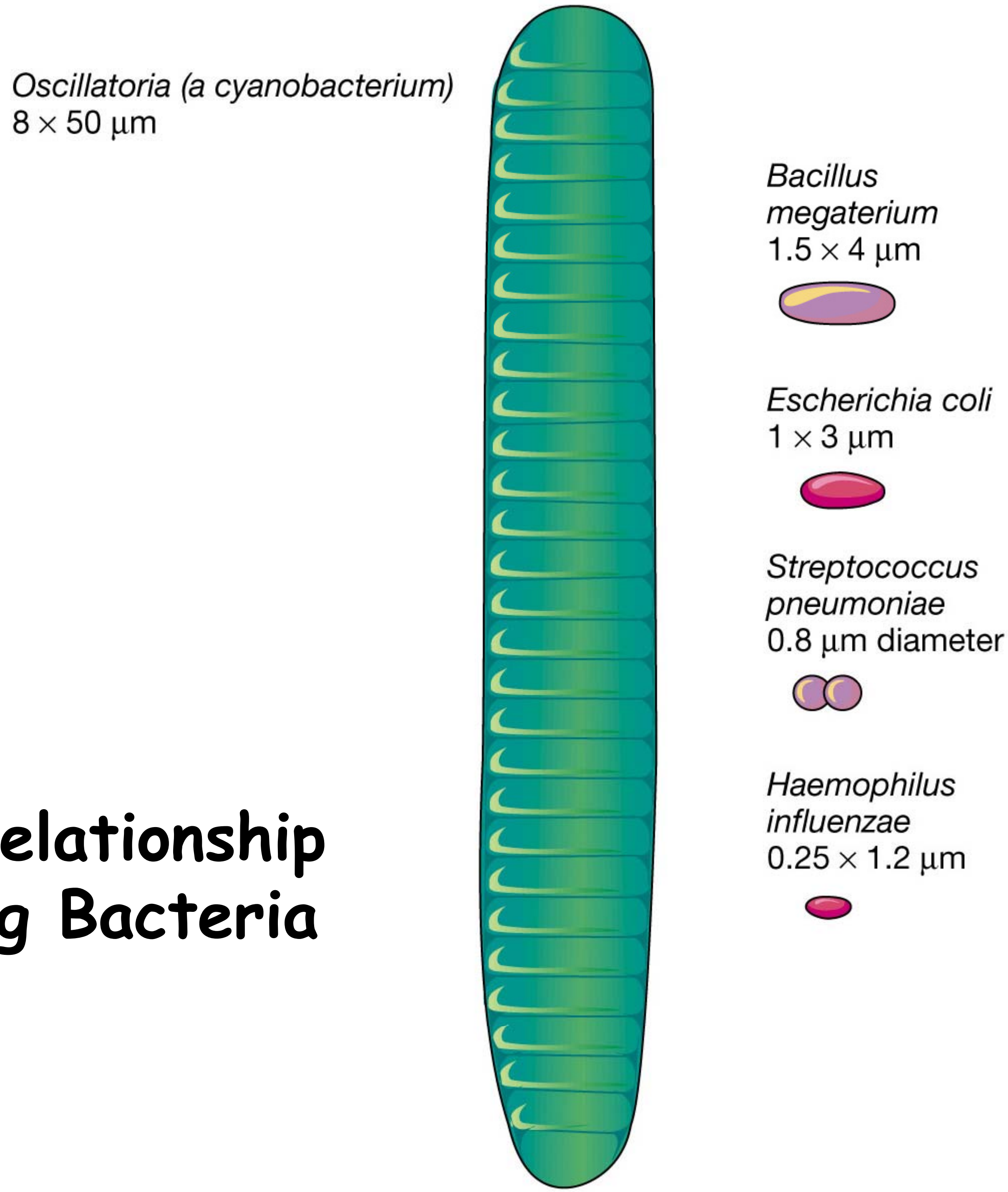
# *E. coli and S. cerevisiae*

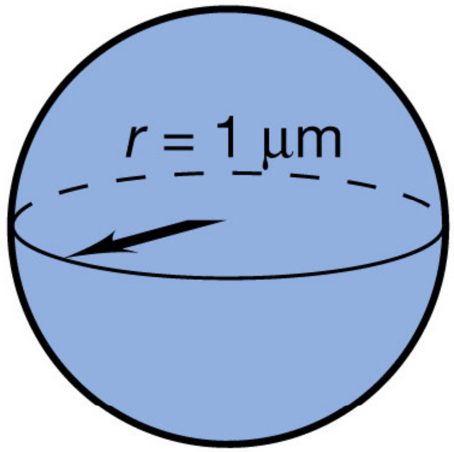


# The size range of cells



# Size relationship among Bacteria

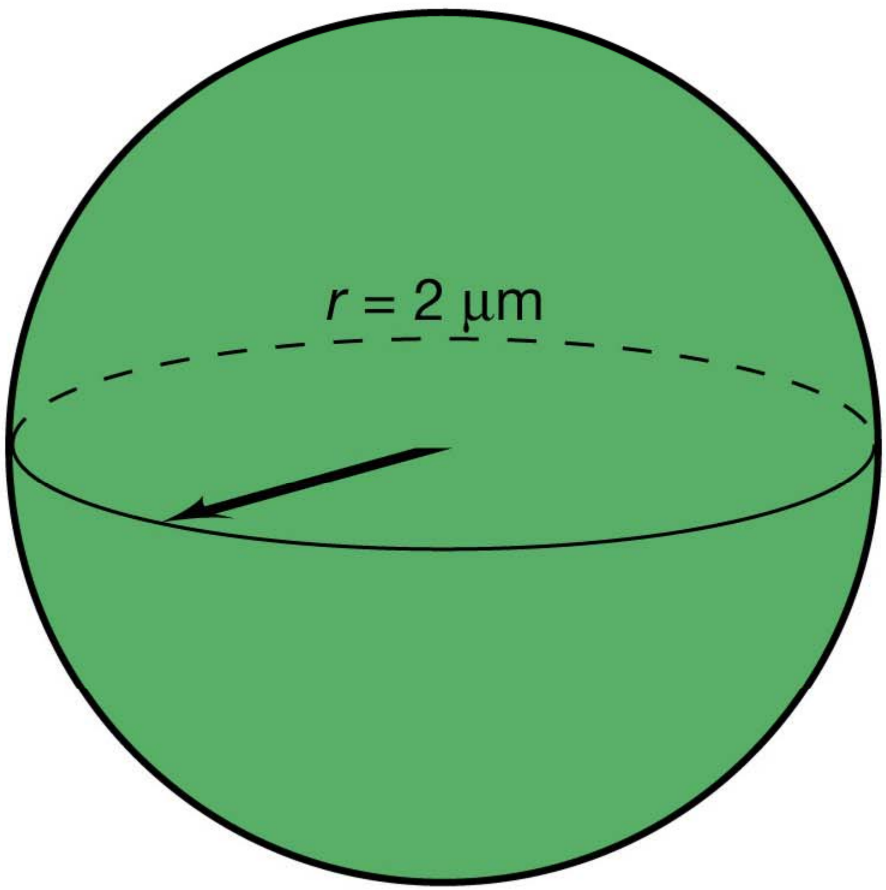





Surface area ($4\pi r^2$) = 12.6 $\mu m^2$

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

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

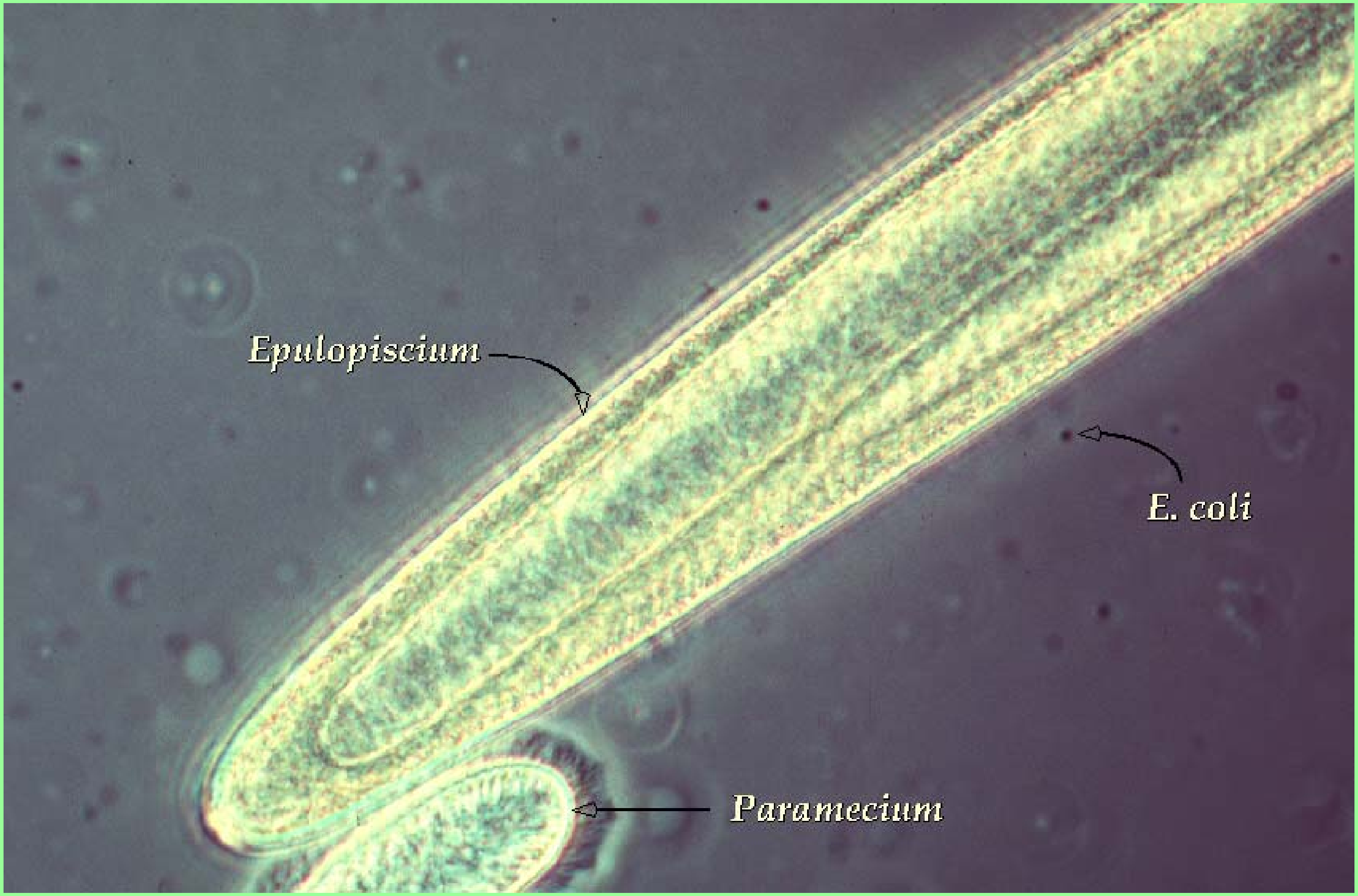



Surface area = 50.3 $\mu m^2$

Volume = 33.5 $\mu m^3$

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

# A Million times bigger than E. coli!



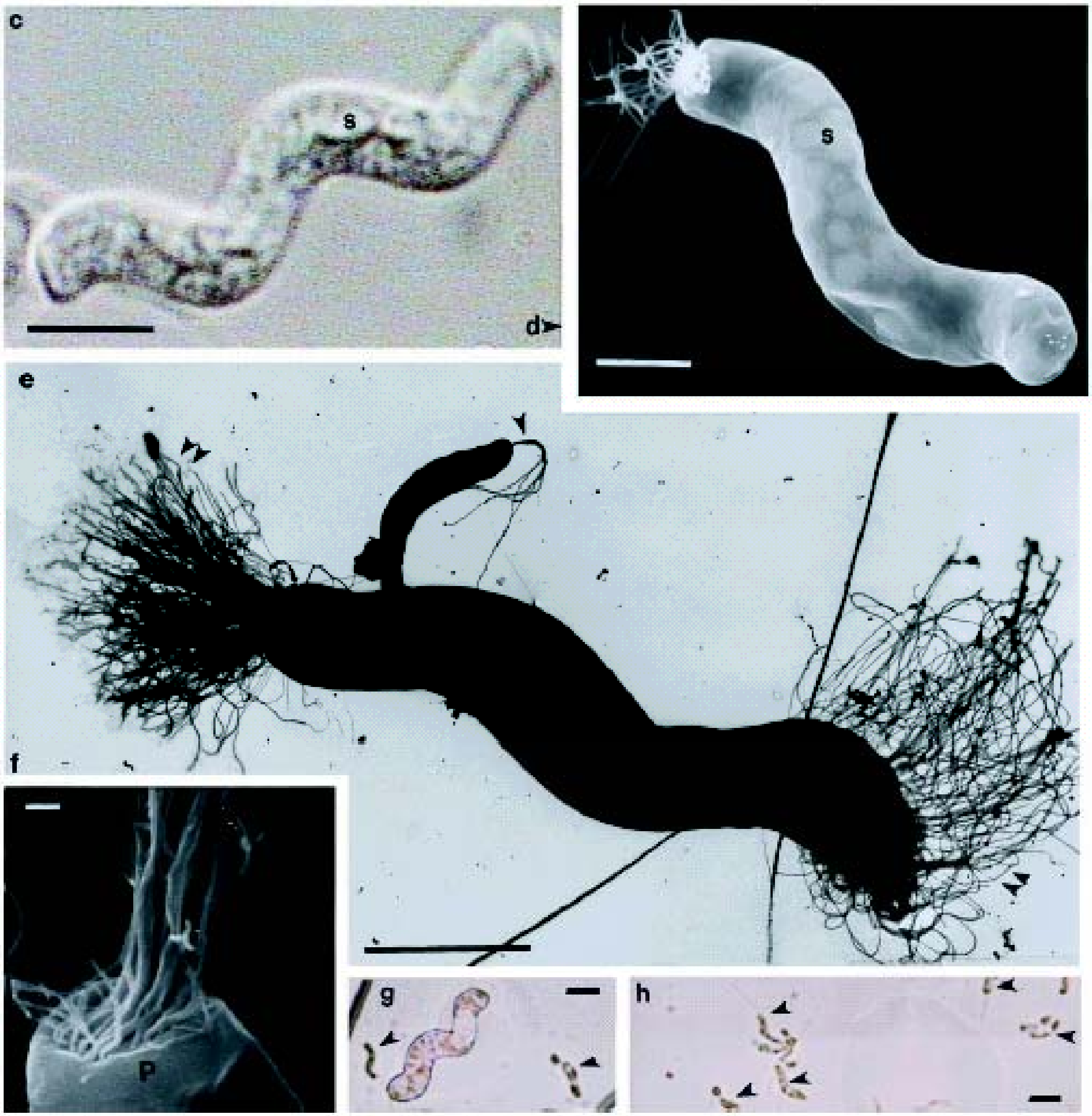



FIG. 1. (*a*) Mat surface at the Ebro Delta field site (3) showing lack of standing water. (Bar = 10 cm.) (*b*) Two spirilla cells (S, sulfur globule) shown by differential interference contrast (Nomarski). (Bar = 5 μm.) (*c*) Phase contrast microscopy of live spirillum cells. (Bar = 5 μm.) (*d*) Bipolar 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**

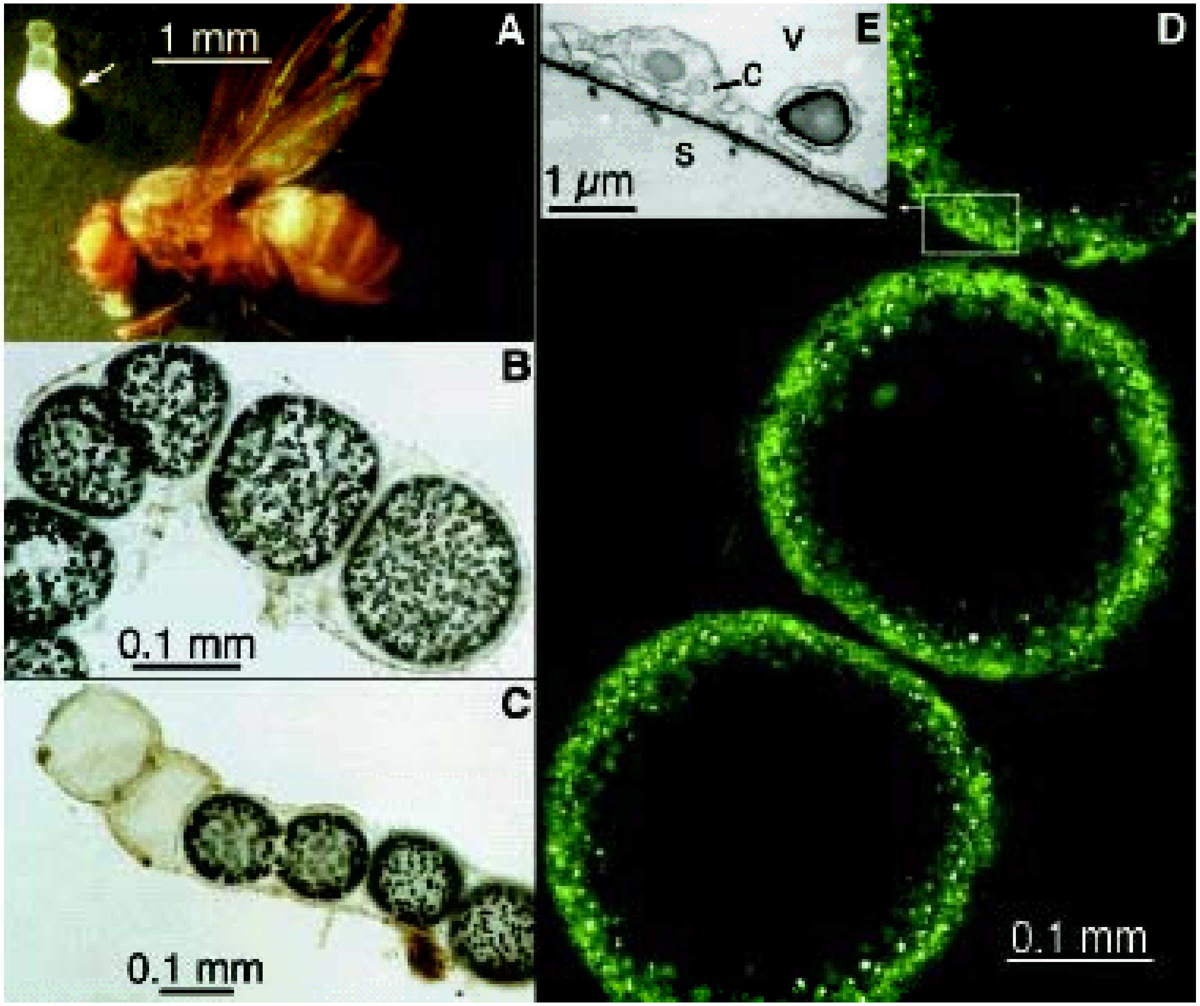
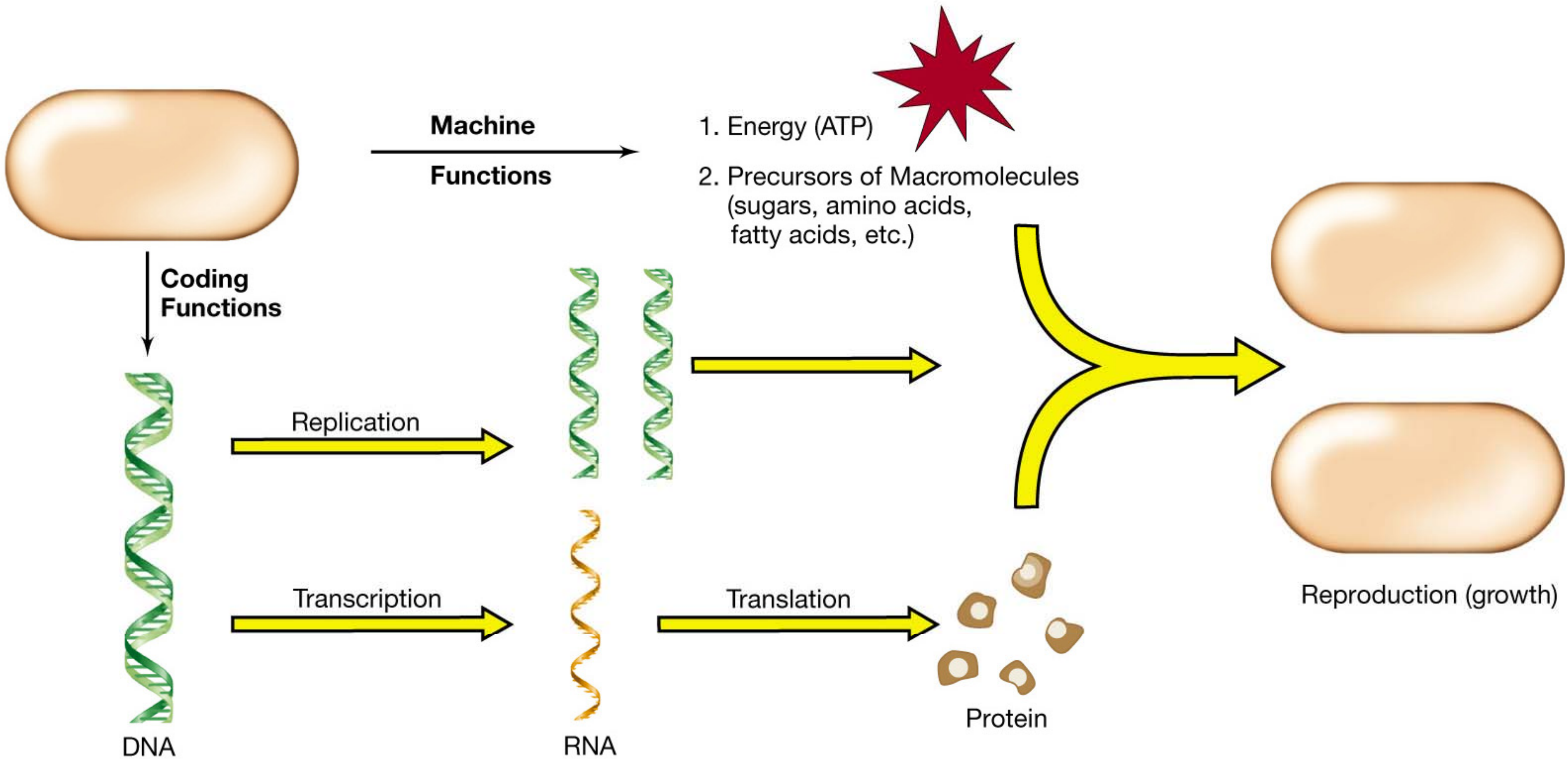



Fig. 1. *Thiomargarita namibiensis*. (A) The white arrow points to a single cell of *Thiomargarita*, 0.5 mm wide, which shines white because of internal sulfur inclusions. Above there is an empty part of the sheath, where the two neighboring cells have died. The cell was photographed next to a fruit fly (*Drosophila wiriles*) 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**

# Chemical features of a “typical” bacterial cell (*E. coli*)

**Table 3.1 Molecular composition of a bacterial cell, *Escherichia coli*, during balanced exponential growth.**[a]

| Component | Percentage of total weight[b] | Approximate number of molecules/cell | Number of different kinds |
|---|---|---|---|
| Water | 70% | 20,000,000,000 | 1 |
| Proteins | 16% | 2,400,000 | 2,000[c] |
| RNA: rRNA, tRNA, and other small regulatory RNA (sRNA), | 6% | 250,000 | 200 |
| mRNA | 0.7% | 4,000 | 2,000[c] |
| Lipids: phospholipids (membrane) | 3% | 25,000,000 | 50 |
| lipopolysaccharide (outer membrane) | 1% | 1,400,000 | 1 |
| DNA | 1% | 2[d] | 1 |
| Metabolites and biosynthetic precursors | 1.3% | 50,000,000 | 1,000 |
| Peptidoglycan (murein sacculus) | 0.8% | 1 | 1 |
| Inorganic ions | 0.1% | 250,000,000 | 20 |
| Polyamines (mainly putrescine and spermine) | 0.1% | 6,700,000 | 2 |

Mostly rRNA

[a]Values shown are for a hypothetical “average” cell cultured with aeration in glucose medium with minimal salts at 37°C.

[b]The total weight of the cell (including water) is about $10^{-12}$ gram (g), or 1 picogram (pg).

[c]The number of kinds of mRNA and of proteins is difficult to estimate because some genes are transcribed at extremely low levels and because RNA and proteins include kinds that are rapidly degraded.

[d]In rapidly growing cells, cell fission typically lags approximately one generation behind DNA replication; hence, two identical DNA copies per cell.

*Source:* Modified from Neidhardt, F., and H. E. Umbarger. 1996. Chemical composition of *Escherichia coli*, p. 14. In *Escherichia coli* and *Salmonella*: Cellular and Molecular Biology, 2nd ed. ASM Press, Washington, DC.

Table 3-1 Microbiology: An Evolving Science

Take Home Message:

Proteins are #1 by weight

Lipids are #1 by number

Peptidoglycan is 1 jumbo molecule

RNA is mostly ribosomes

DNA is also a huge polymer

Macromolecules in a typical bacterial cell:

Not just “soup” – highly ordered cytoplasm

Contents (e.g., proteins) will vary, depending on conditions.

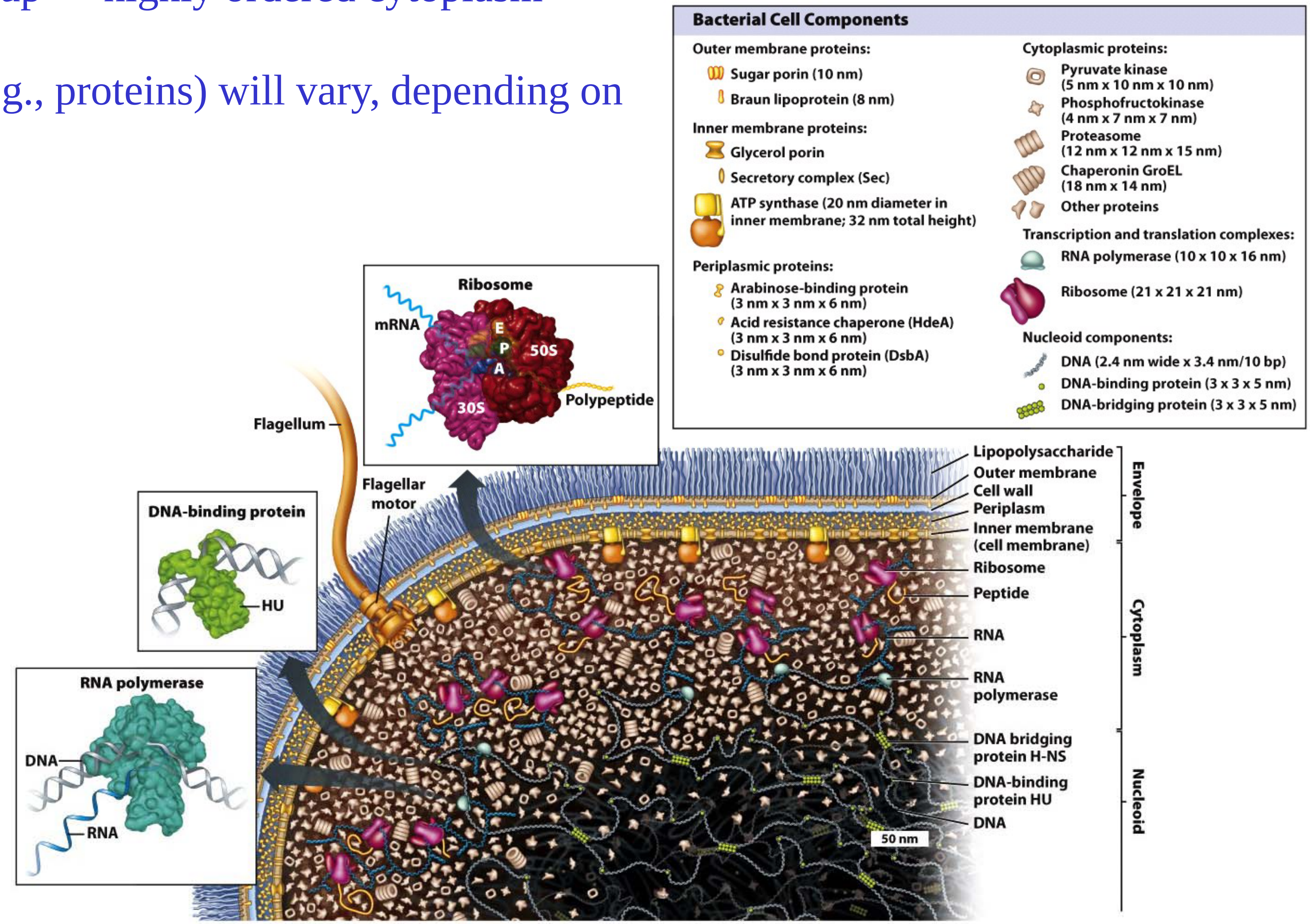
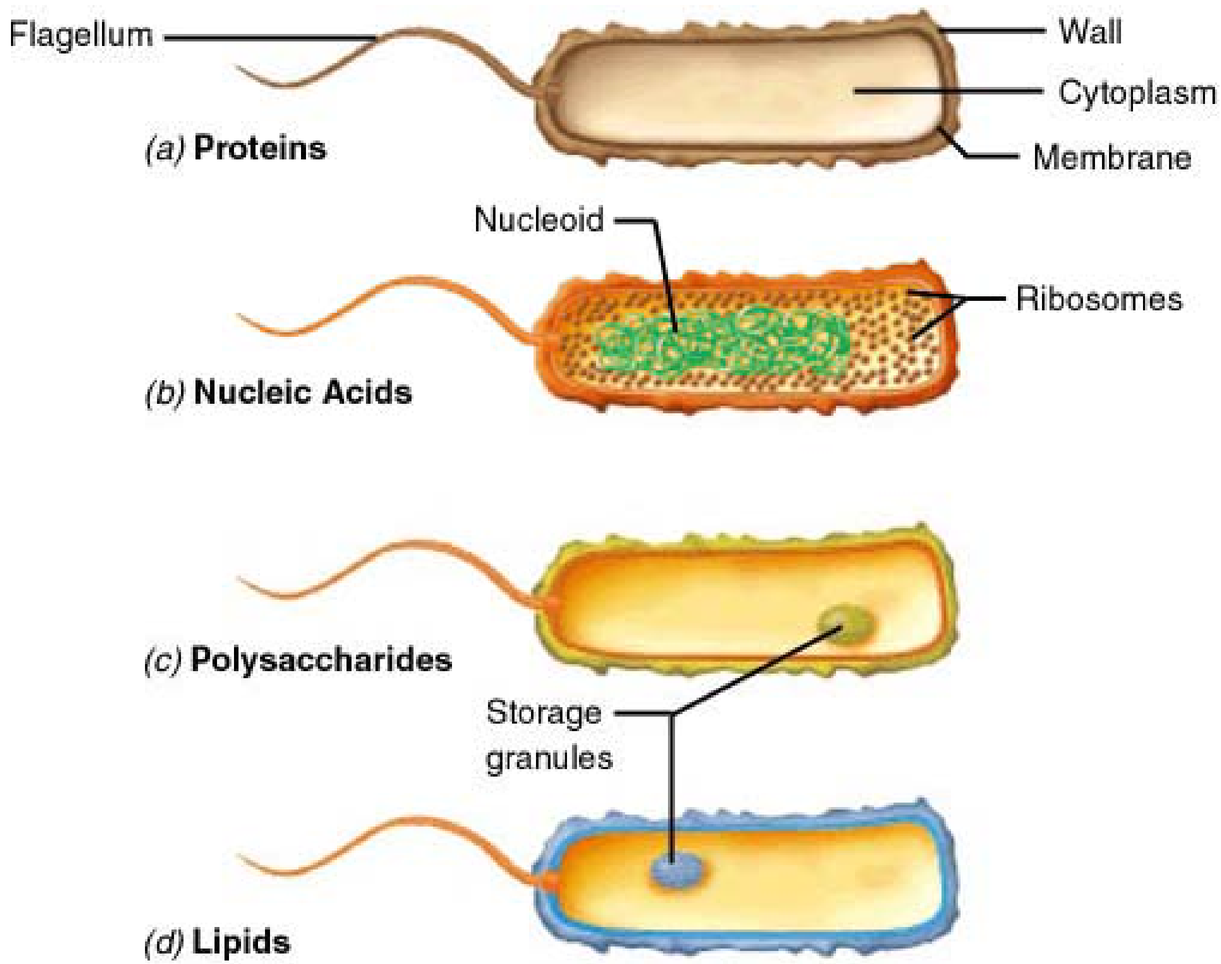



Figure 3.1 part 2 Microbiology: An Evolving Science

# Locations of macromolecules in the cell




All over

2 types mostly

Cell Wall mostly

Cell Wall
Cell Mem

# Comparing Bacteria, Archaea and Eucarya

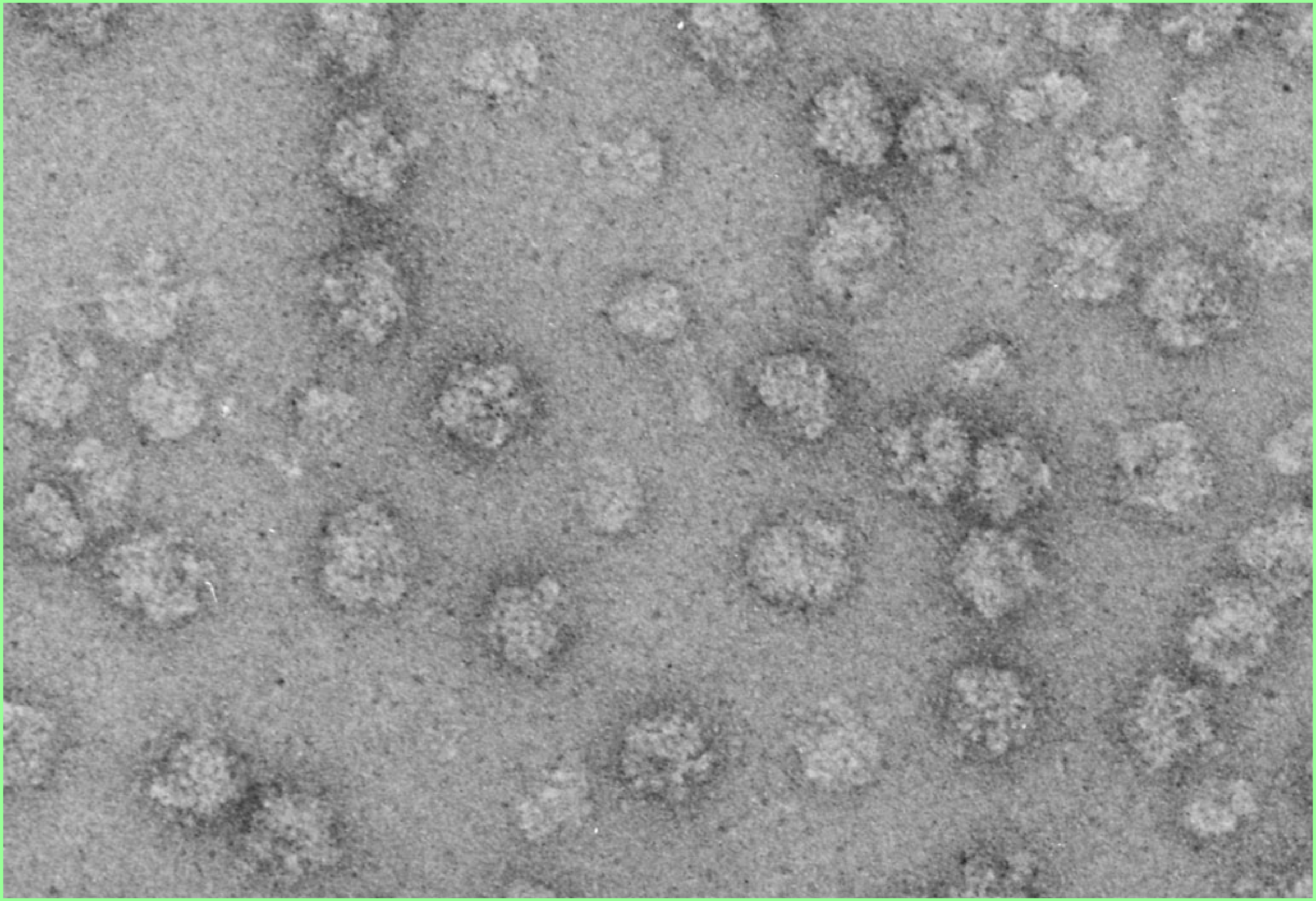
**Classification of microbial cellular features:**
**Invariant (or common to all)**

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

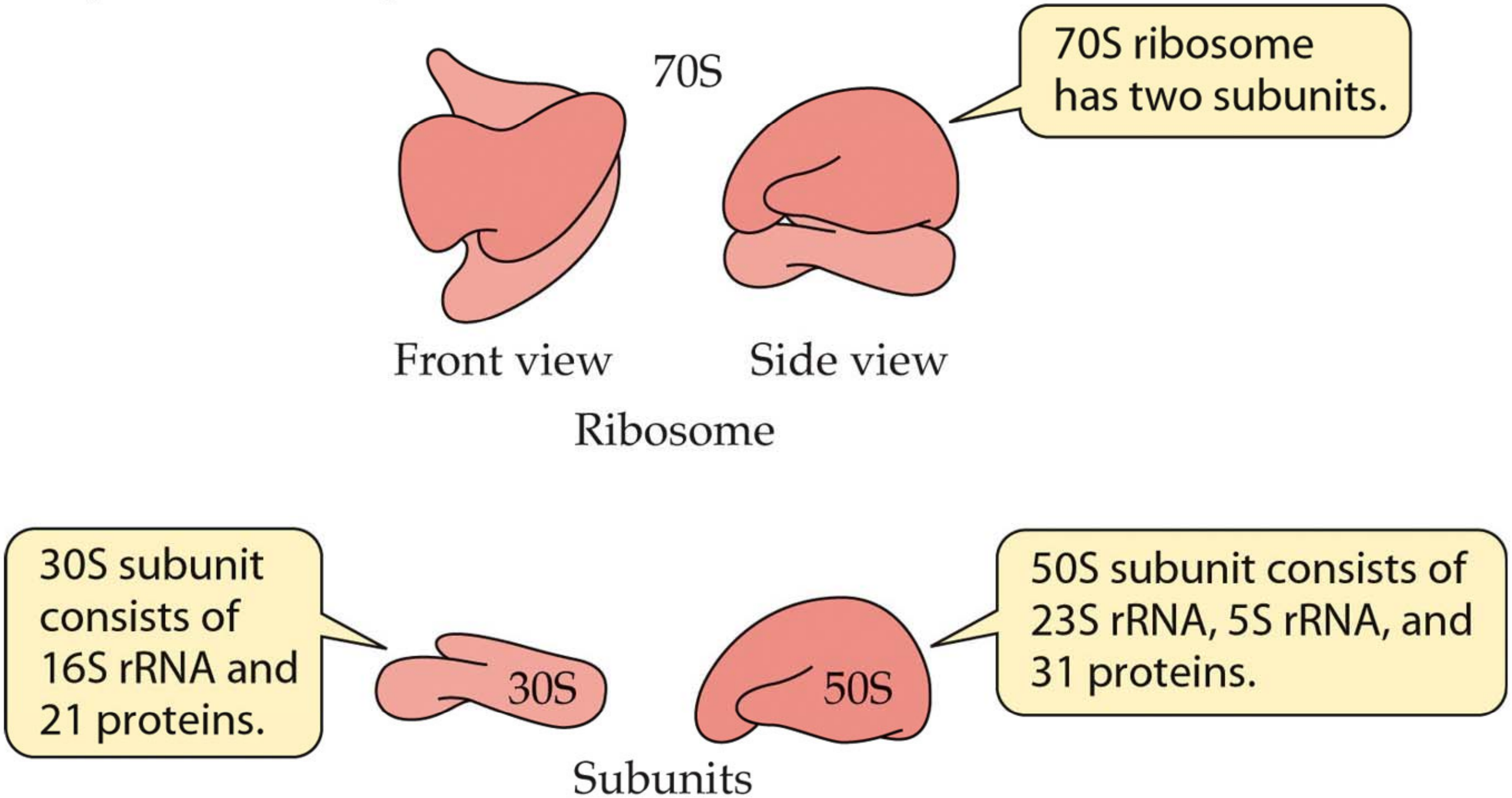
**Cell Membranes: The barrier between order and chaos.**

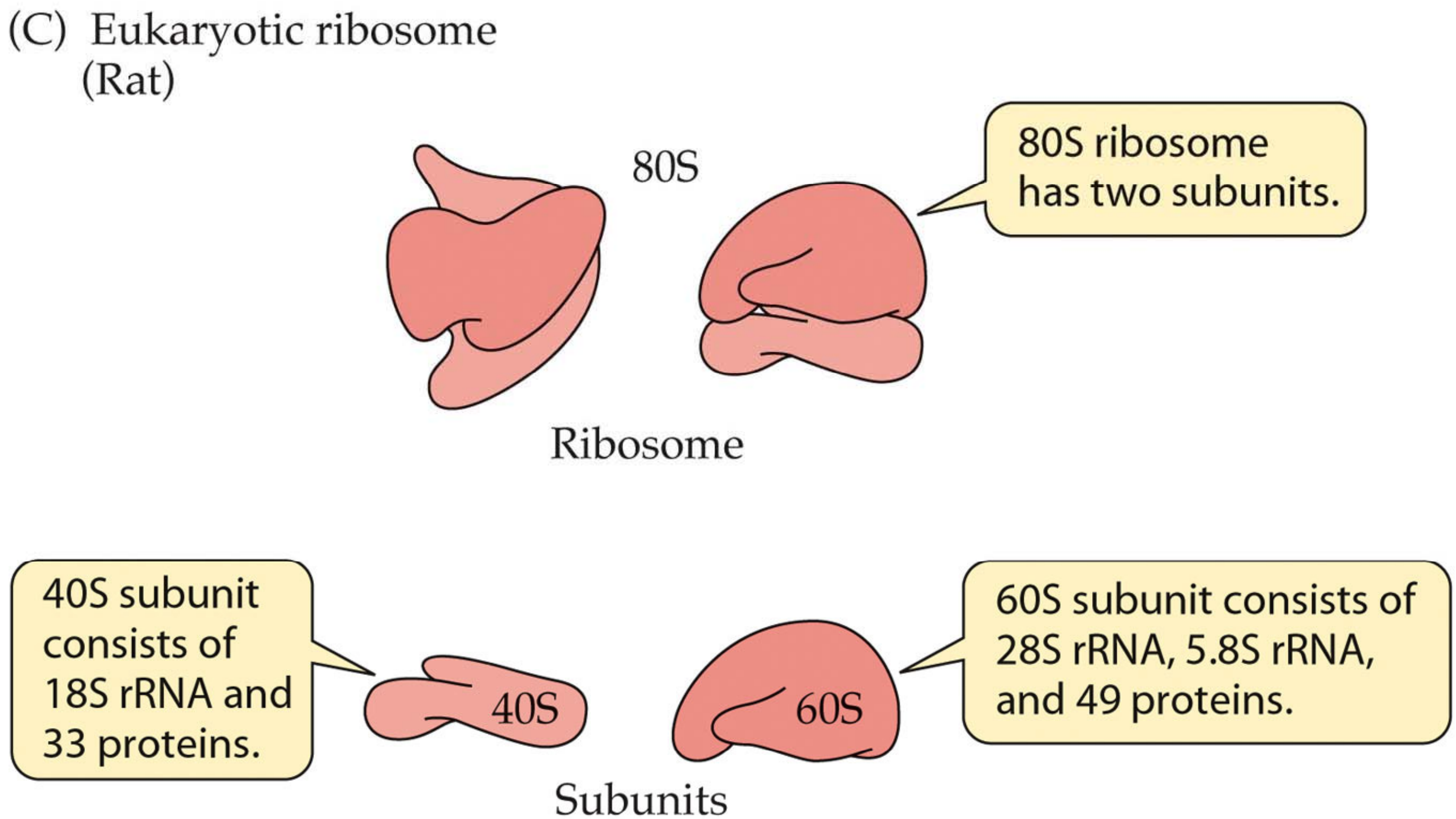
**Nucleoid Region: Curator of the Information.**

# 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

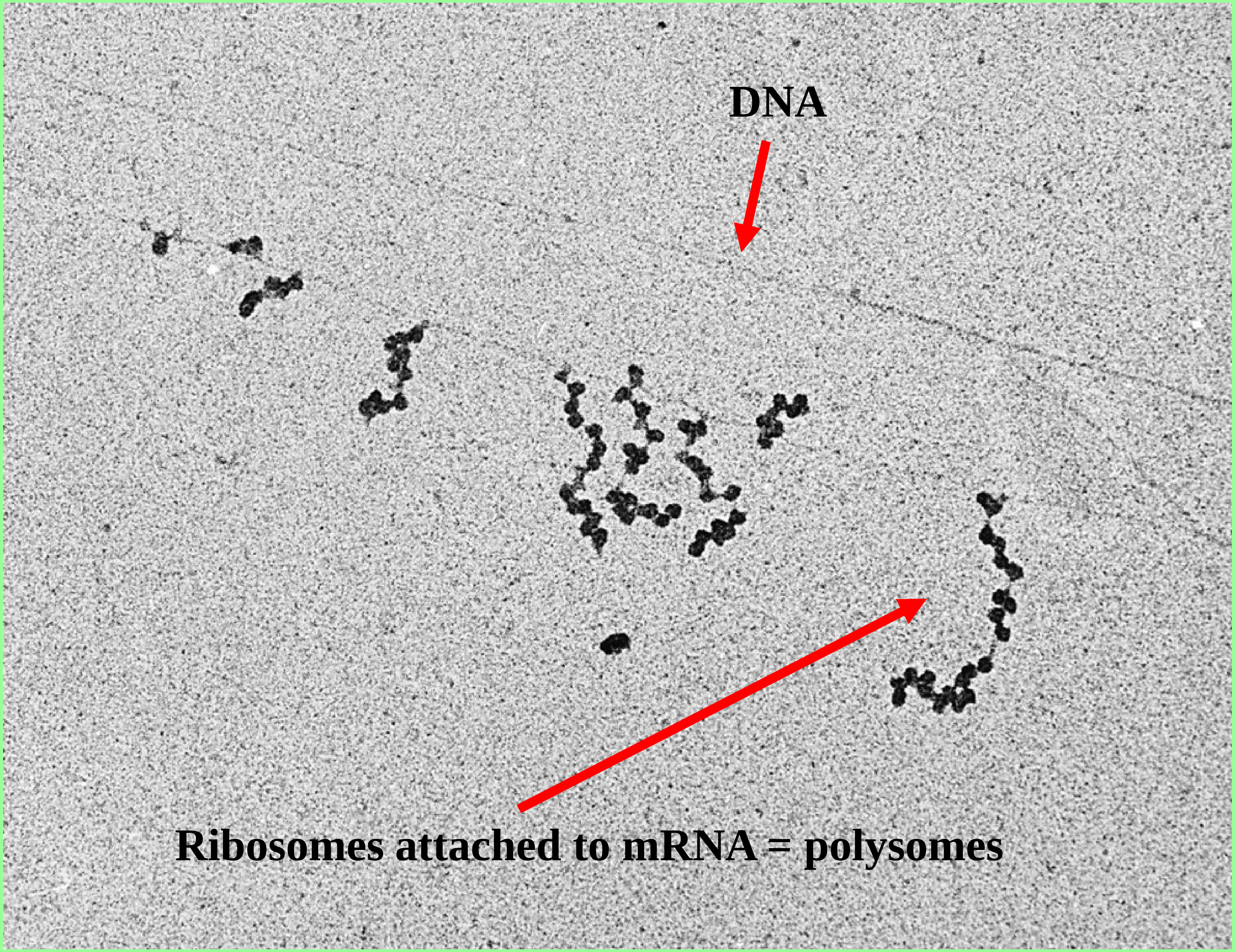
## Table 7.6 Ribosome structure[a]

| Property | Prokaryote | Eukaryote |
|---|---|---|
| Overall size | 70S | 80S **Most Complex** |
| 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



# Comparing Bacteria, Archaea and Eucarya

**Classification of microbial 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.**

# The Cytoplasmic Membrane

8 nm thick

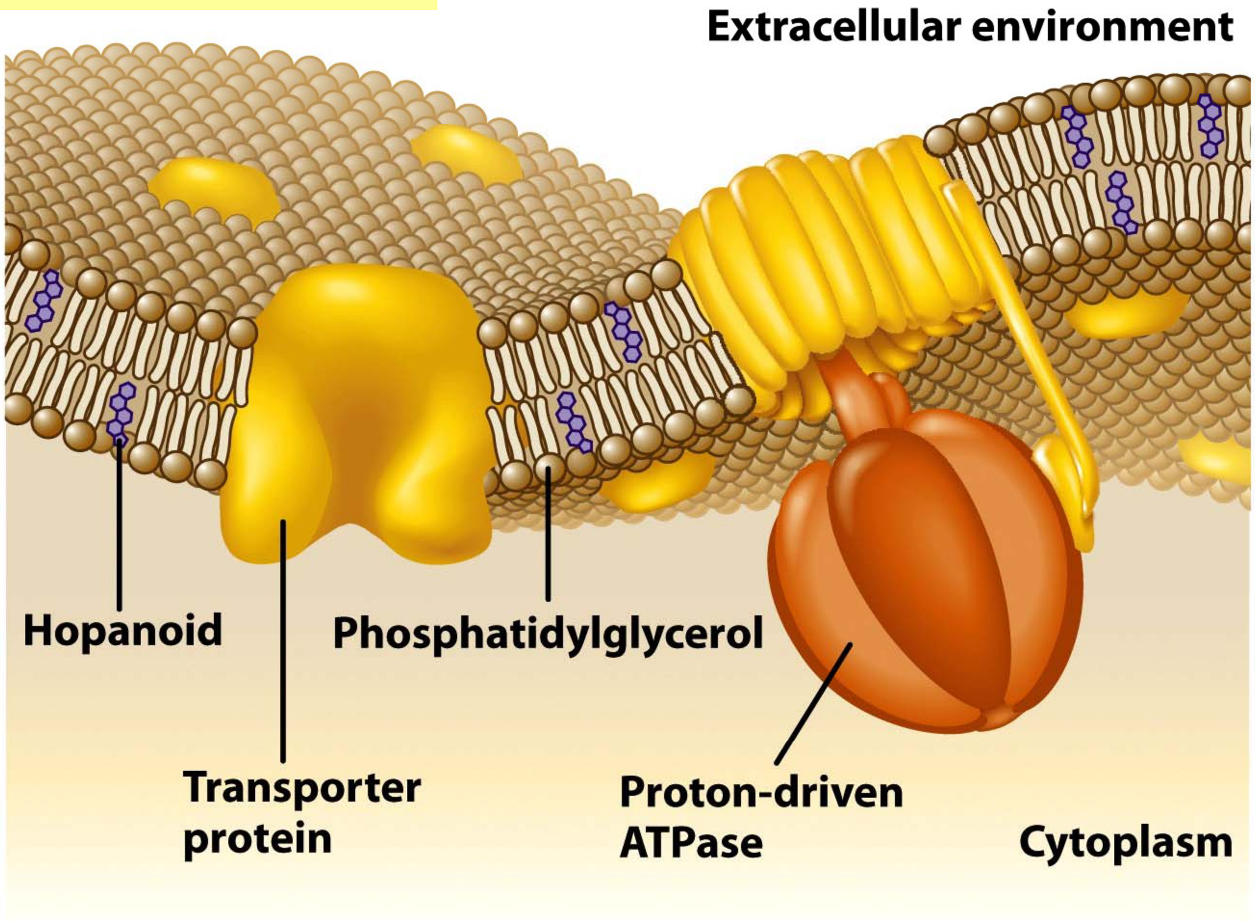



Figure 3.7 Microbiology: An Evolving Science

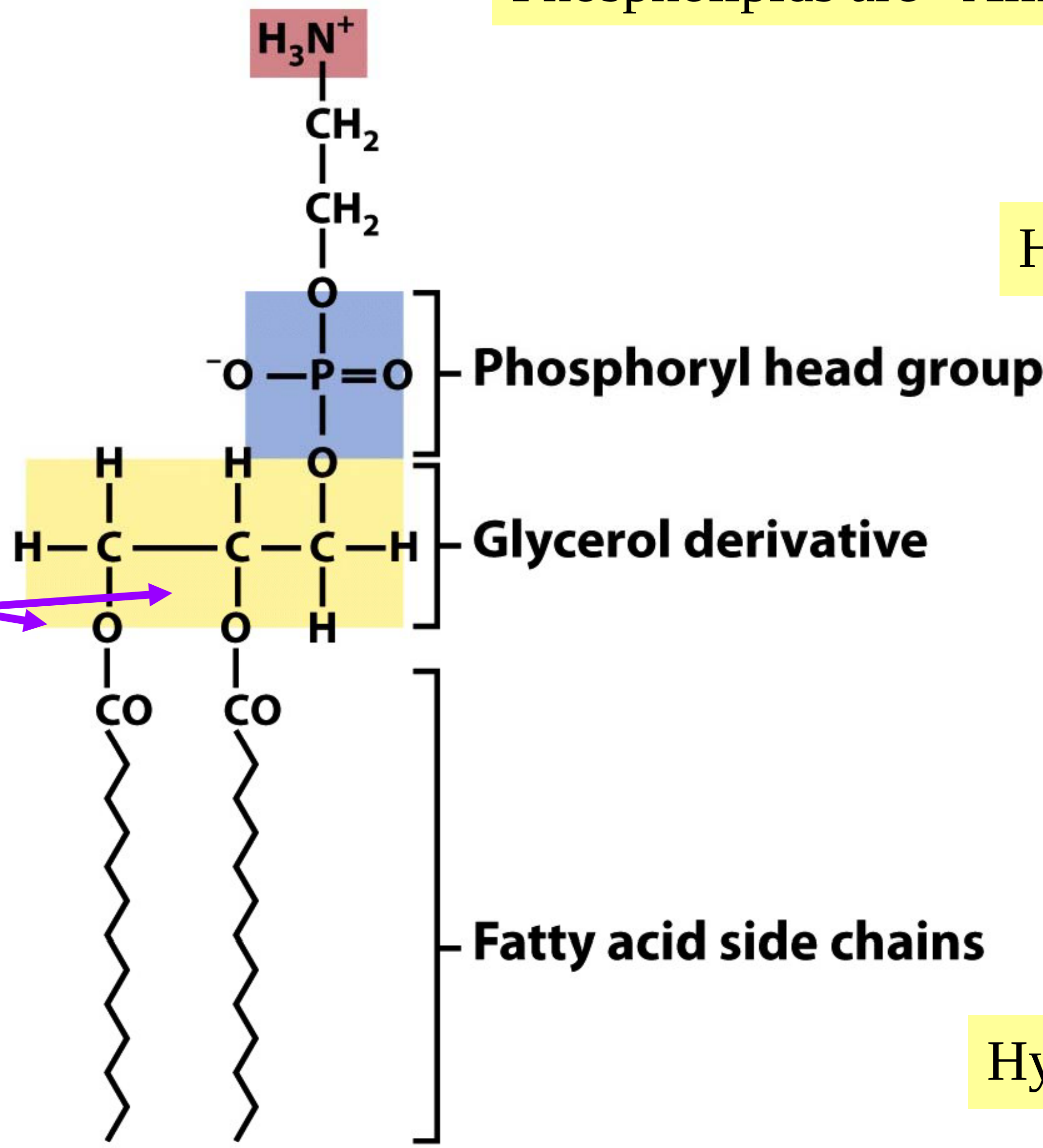

Membrane has similar viscosity as oil: **Fluid Mosaic Model**

Stabilized by H bonds, hydrophobic interactions, and by $Mg^{++}$ and $Ca^{++}$ binding to phosphate heads

Phospholipids are **"Amphipathic"**

Hydrophilic

Ester linkages

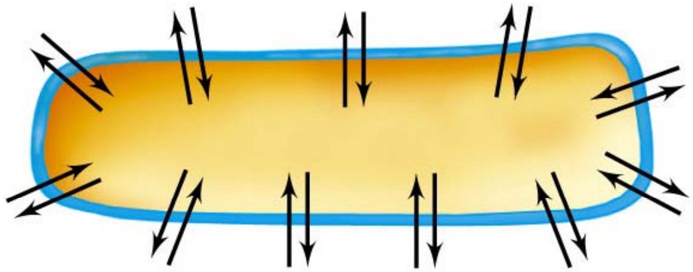



Hydrophobic

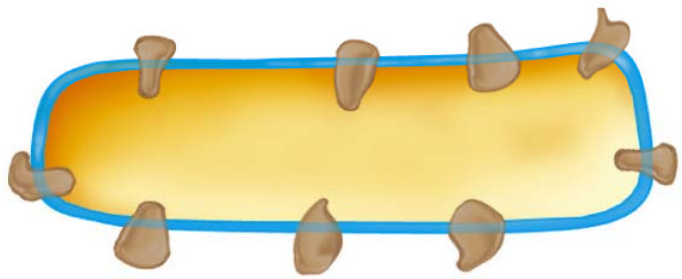
**Phosphatidylethanolamine**

Figure 3.8 Microbiology: An Evolving Science

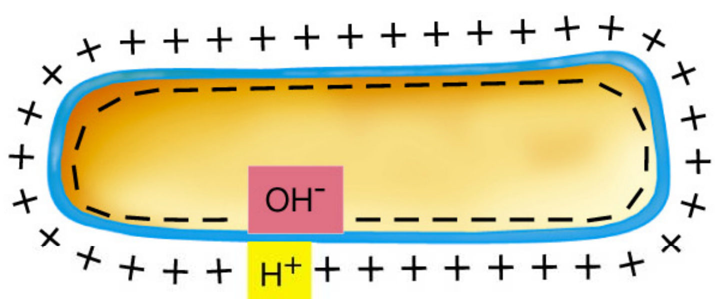
# Functions of the cytoplasmic membrane



**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




Charge separation:
Potential energy
Analogous to a battery

**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 |

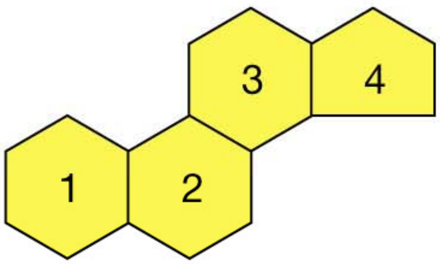
Free diffusion of water (passive transport) assisted by aquaporins

Active or passive transport (depends on conditions), but proteins aid movement

[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

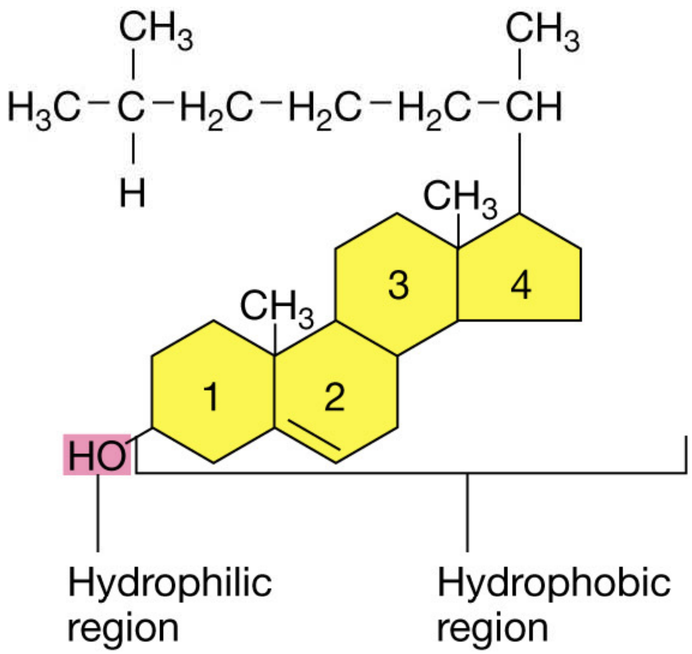
(a)




Few Bacteria

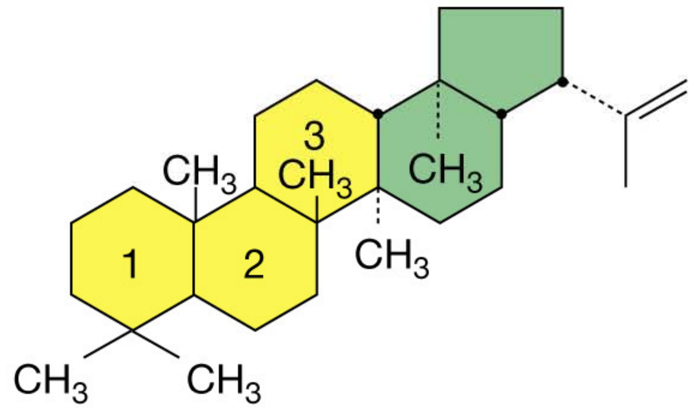
## Cholesterol

(b)




## Hopanoid (e.g., Diploptene)

(c)

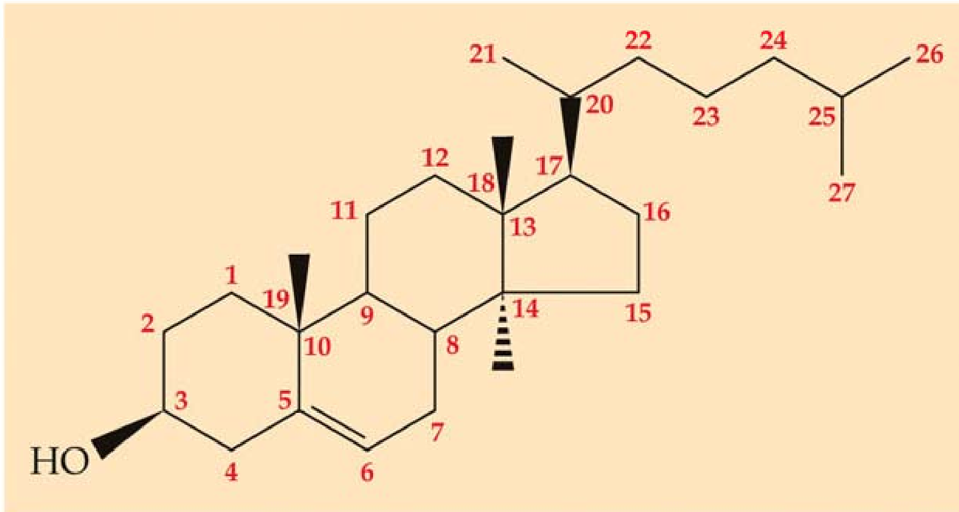



Many Bacteria

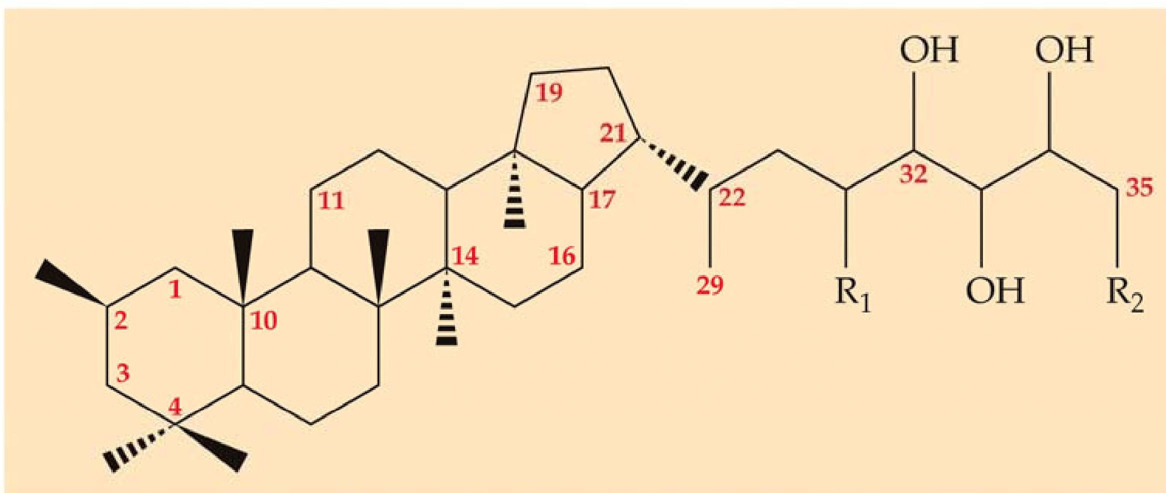
$O_2$ -

# All rigid planar molecules

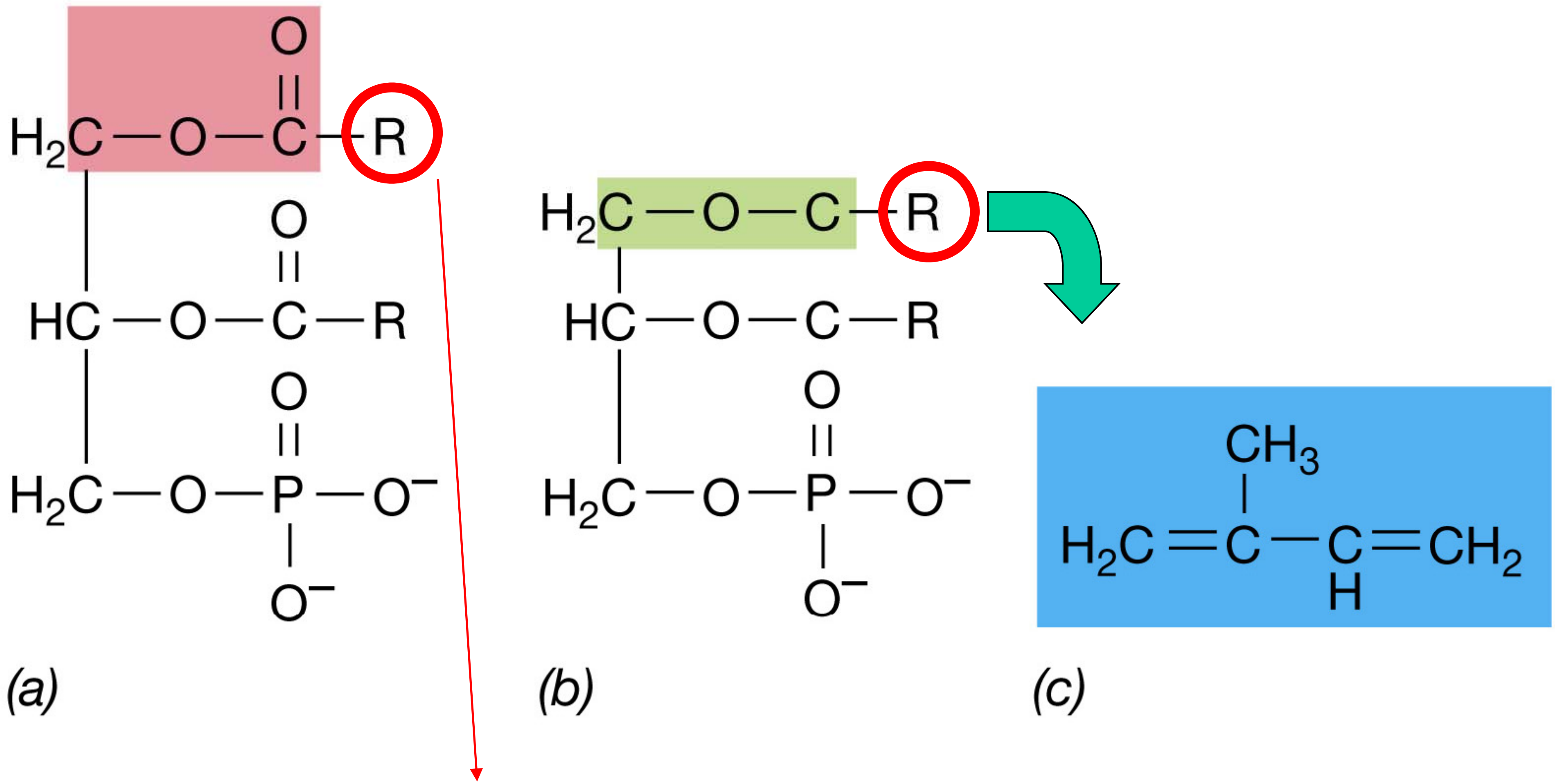
(A) Cholesterol




(B) A hopanoid from a cyanobacterium

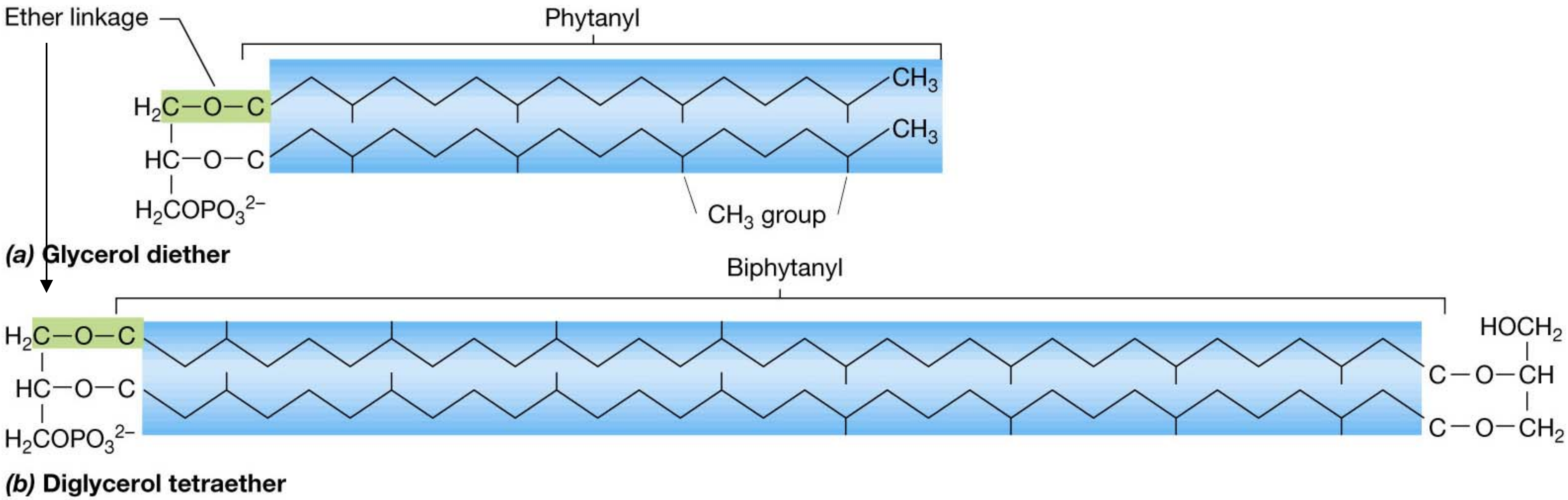


**Ester Linkage** **Ether Linkage** **Isoprene Unit**



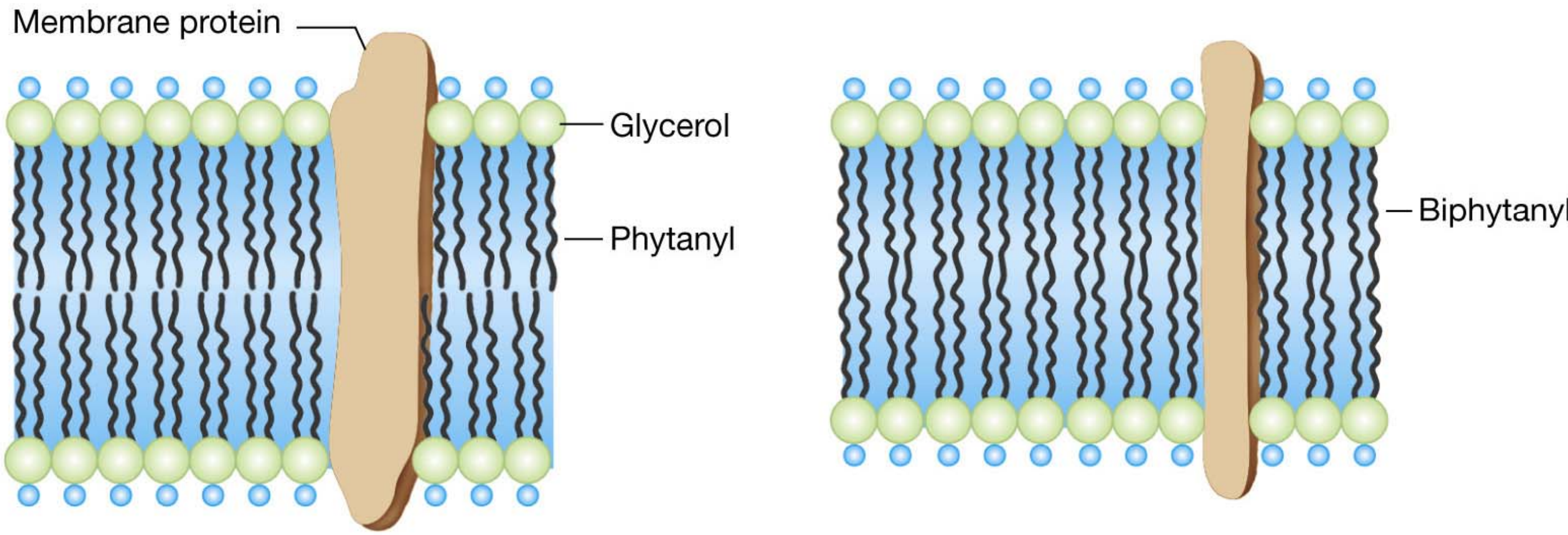

Fatty Acid

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




Lipid monolayer, not a bilayer: mostly found in extremophiles

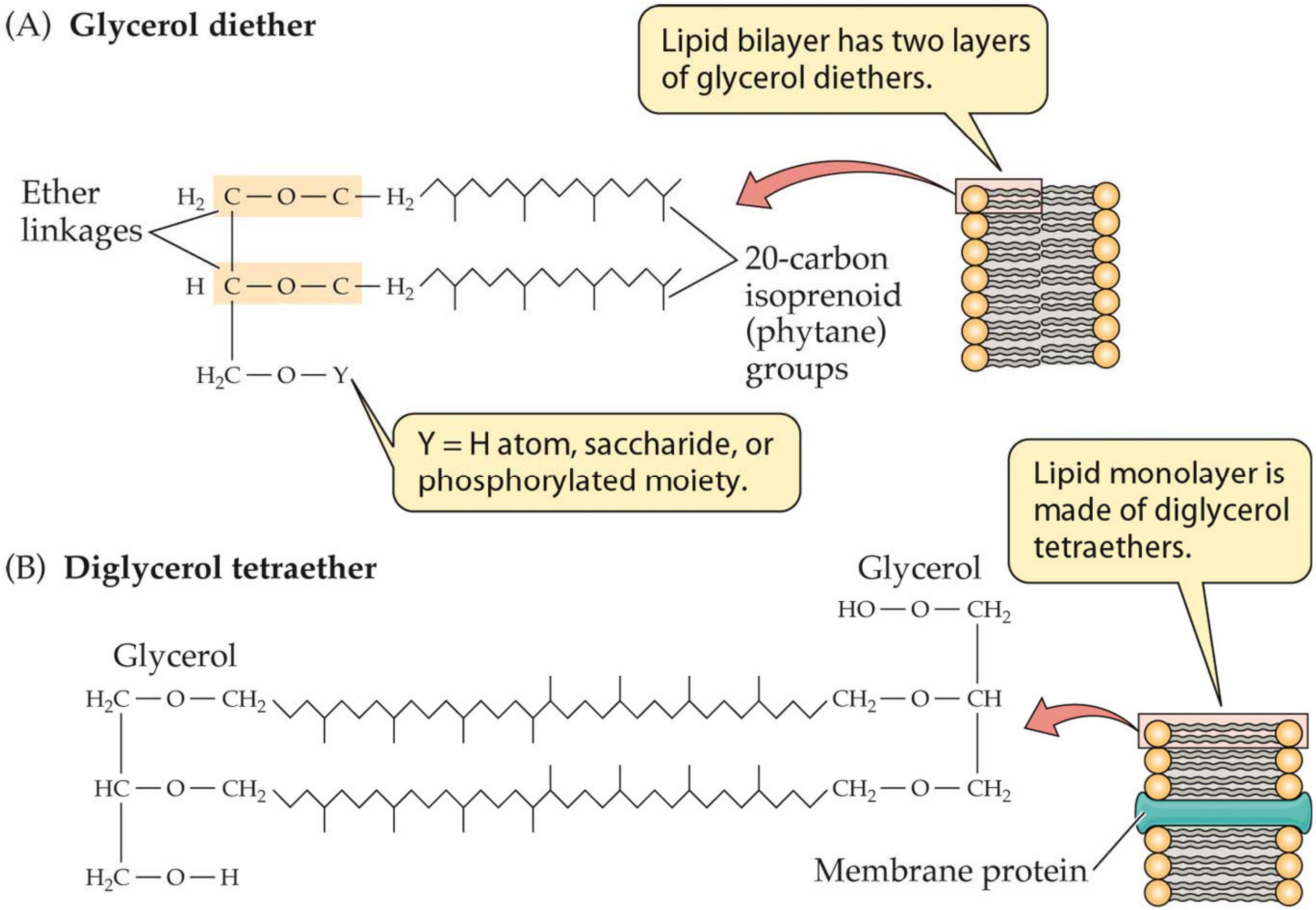
# Major lipids of *Archaea* and the structure of archaeal membranes




***(c)* Lipid bilayer**

***(d)* Lipid monolayer**

# Archaeal cell membrane structure



# Passive Diffusion:

-small, uncharged molecules ($O_2$, $CO_2$, $H_2O$)

-weak acids and bases in protonated form (more hydrophobic)

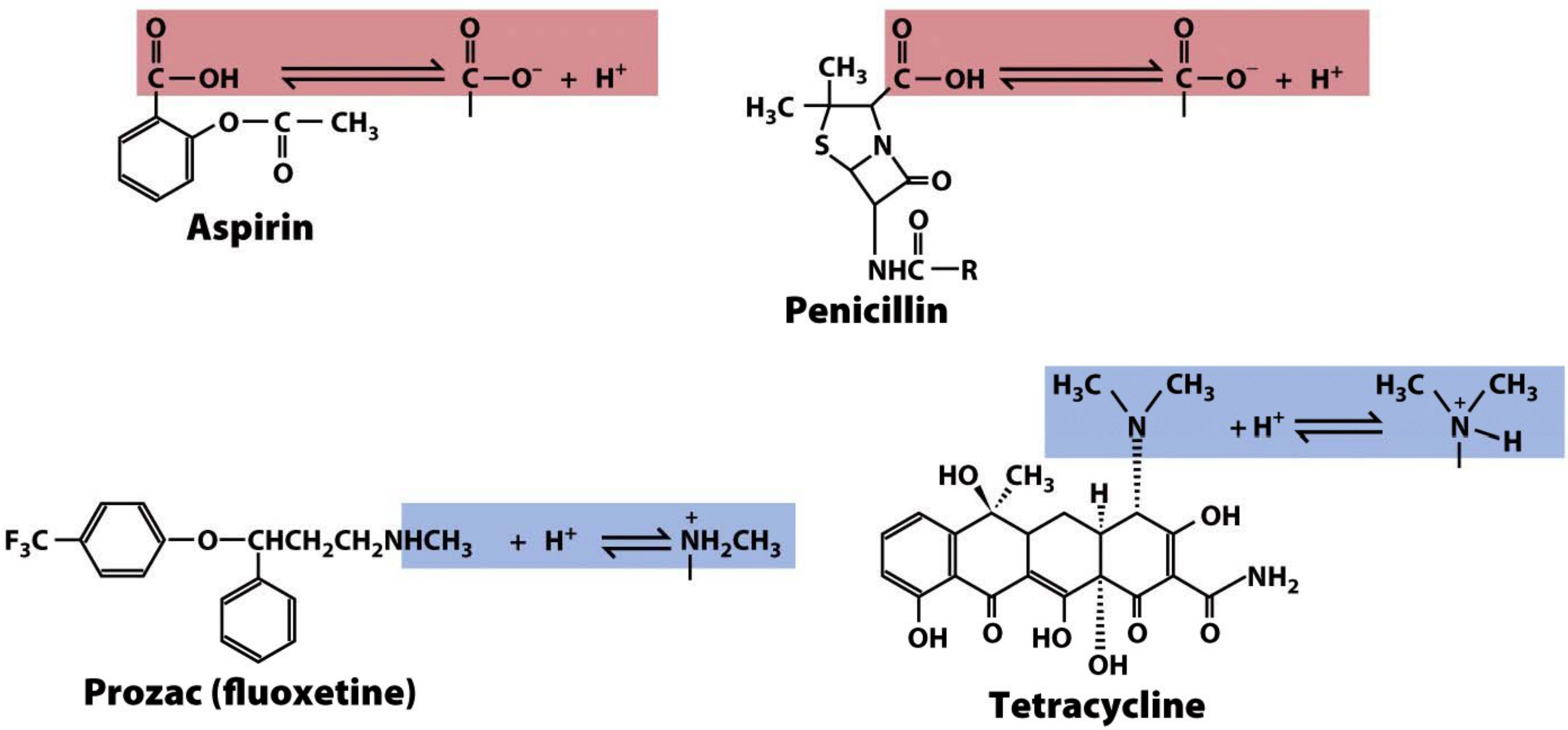



Figure 3.9 Microbiology: An Evolving Science

# **Facilitated Diffusion** (a type of passive tranport):

Powered by solute's own concentration gradient

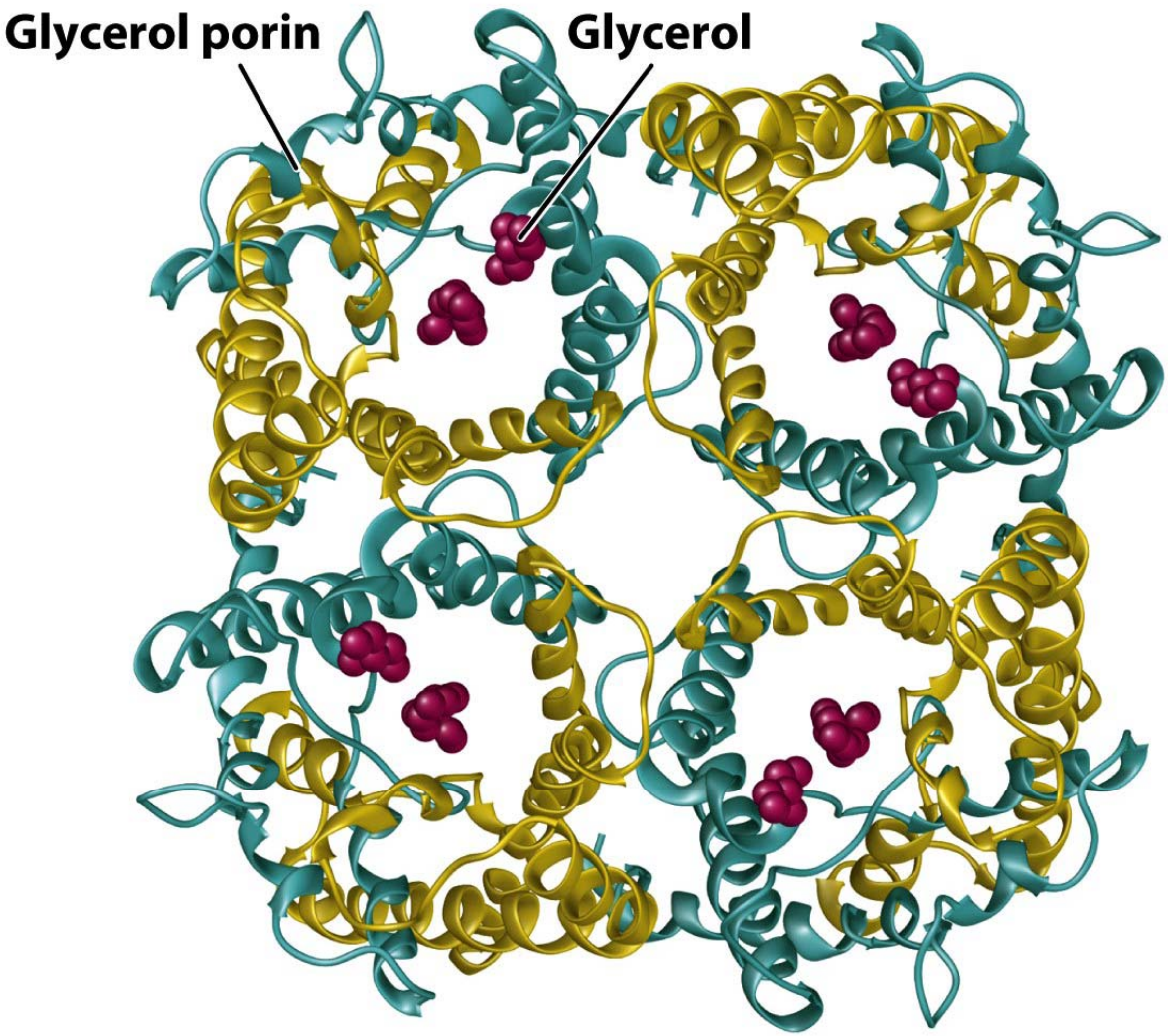



Figure 4.5a Microbiology: An Evolving Science

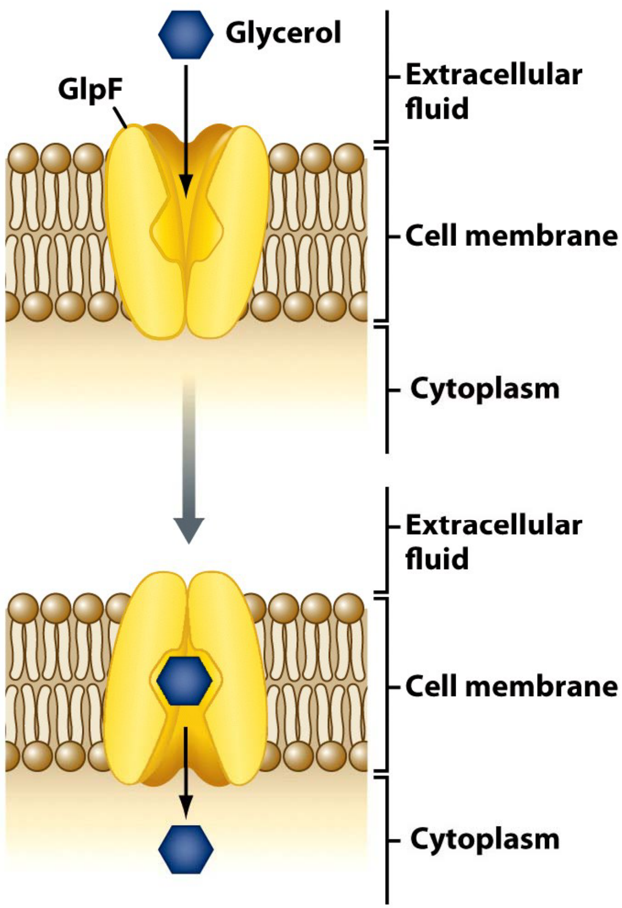




Figure 4.5b Microbiology: An Evolving Science


**Aquaporins, glycerol transporters**

But how do you get glucose into the cell?
The overall strategy for feeding in Bacteria and Archaea:

Suppose you wished to use bacteria in a landfill to break down paper. Paper consists of a polymer, cellulose. It is a readily metabolizable macromolecule - it is a good *carbon and energy source* for bacteria

Problem: Microbes do not ingest – no phagocytosis, no pinocytosis – everything must be solubilized before transport into the cell. How do you get the cellulose into the cell?

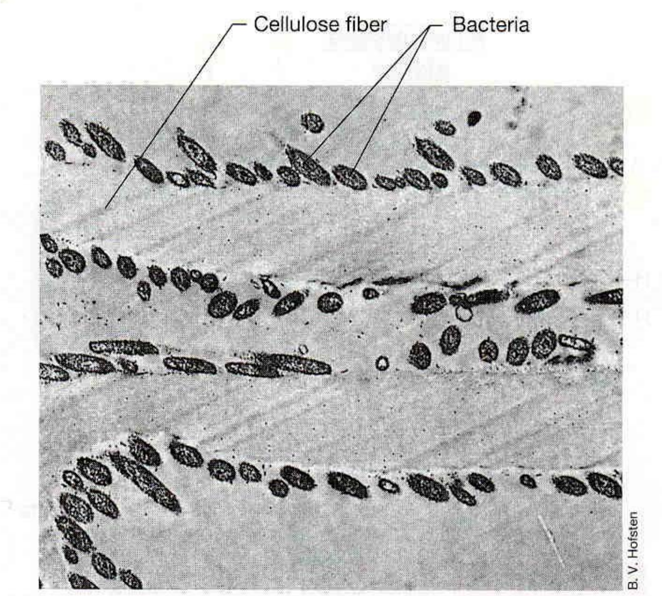
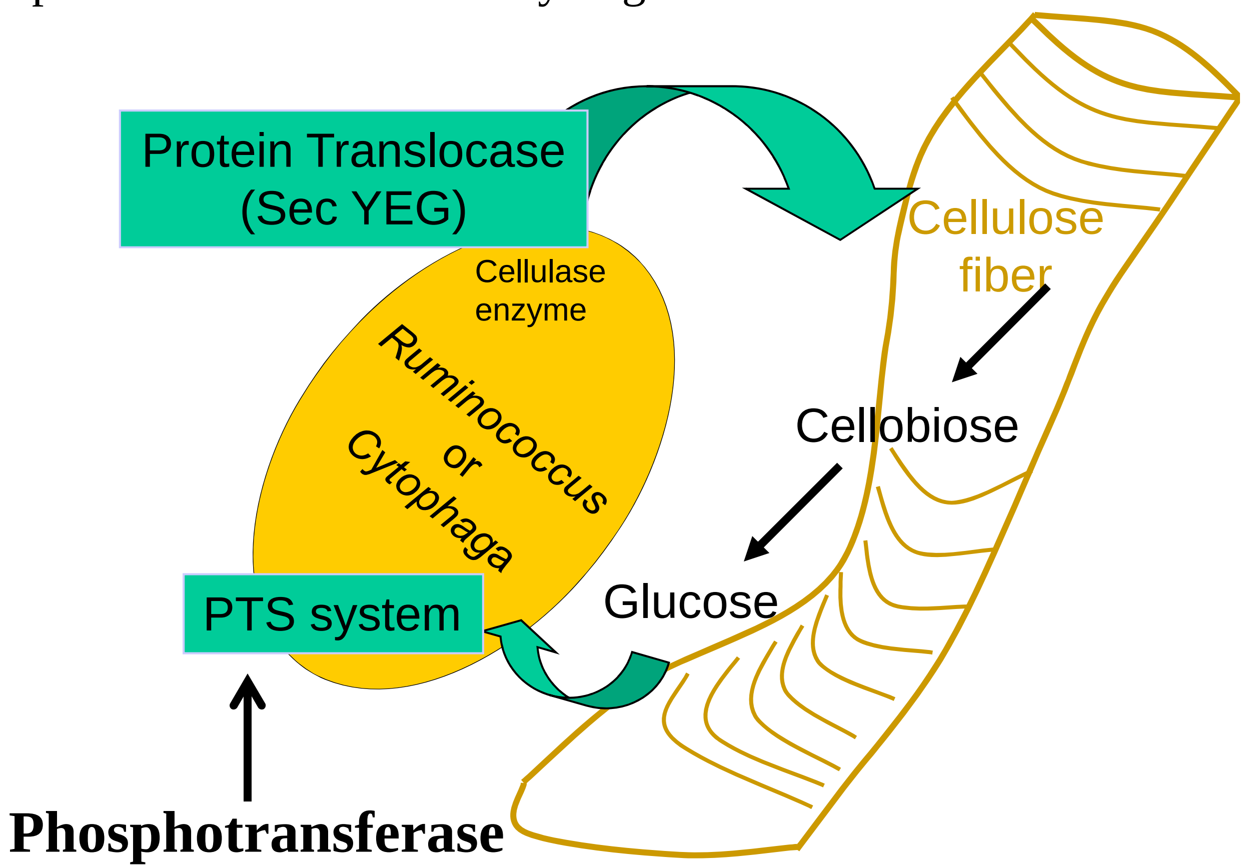



**Figure 17.61** Transmission electron micrograph showing attachment of cellulose-digesting bacteria, *Sporocytophaga myxococcoides*, to cellulose fibers. Cells are about 0.5 μm in diameter.

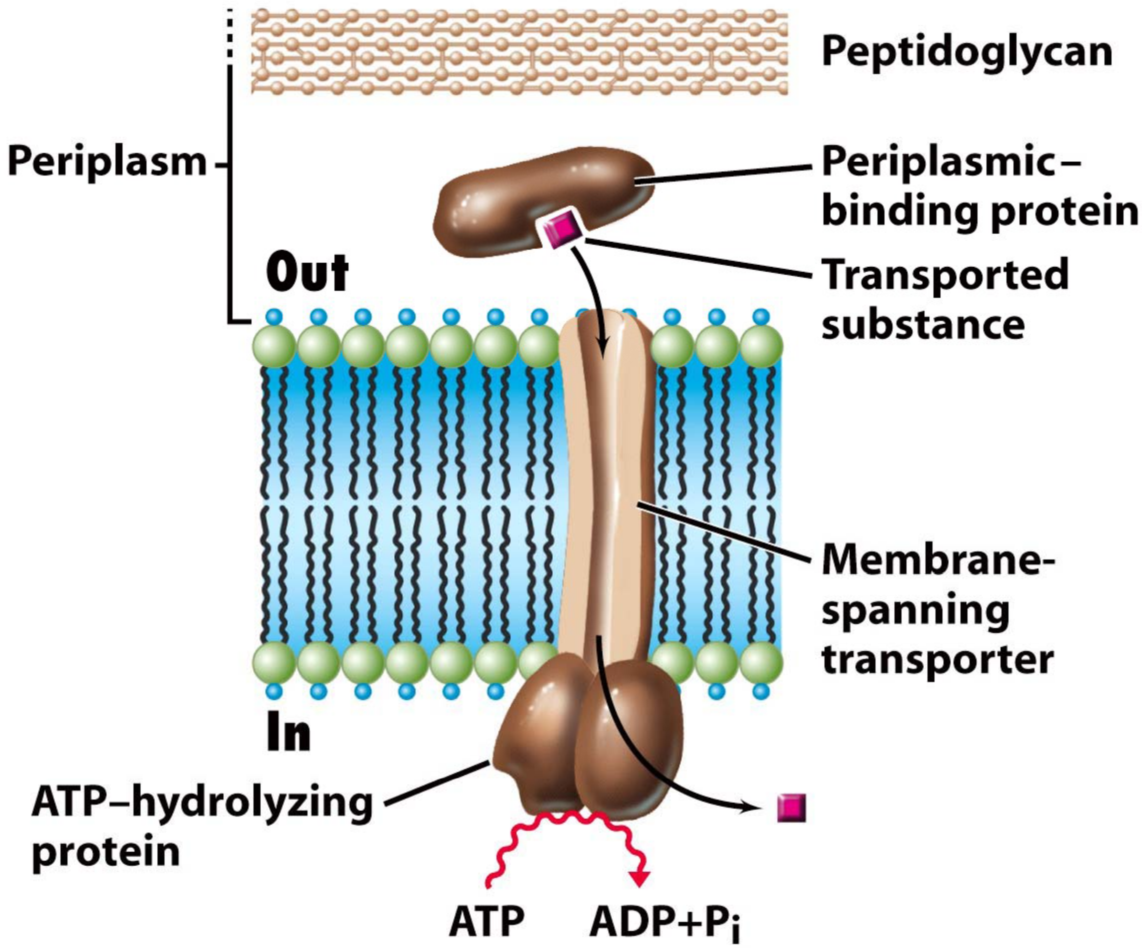


**Primary Transport** (a type of **Active Transport**):

→ ATP hydrolysis provides energy for transfer

→ ABC transporters = ATP-Binding Cassette

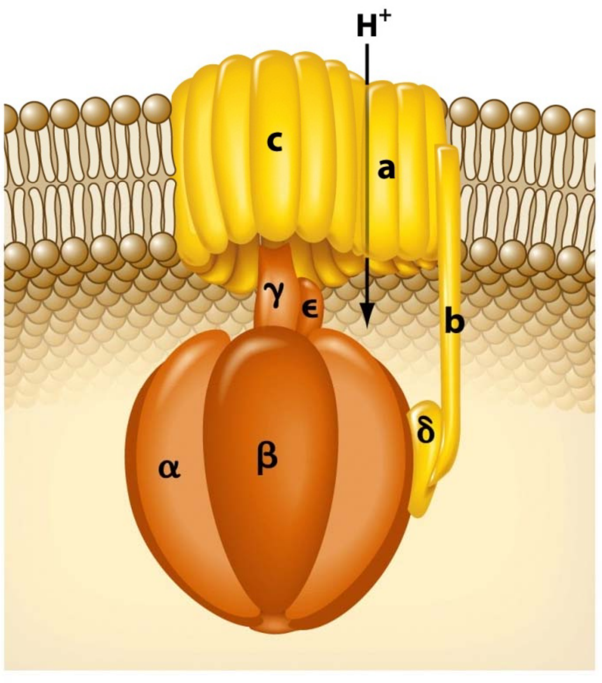
1. Periplasmic binding proteins “find” low-concentration solutes ($\geq 10^{-6}$ M)
2. Binding protein docks on membrane-spanning domain
3. Conformational change and ATP hydrolysis drive transport



Proton pumps (e.g. cytochrome oxidase) push protons out of cell; the electron transport chain is **anchored in membrane**.

**Energy conservation**: proton-motive force (PMF) is generated from protons.

- Osmotic force tries to push protons back into cell
- Electrical force tries to push protons back into cell




PMF is used to create ATP via the enzyme ATP synthase

# Comparing Bacteria, Archaea and Eucarya

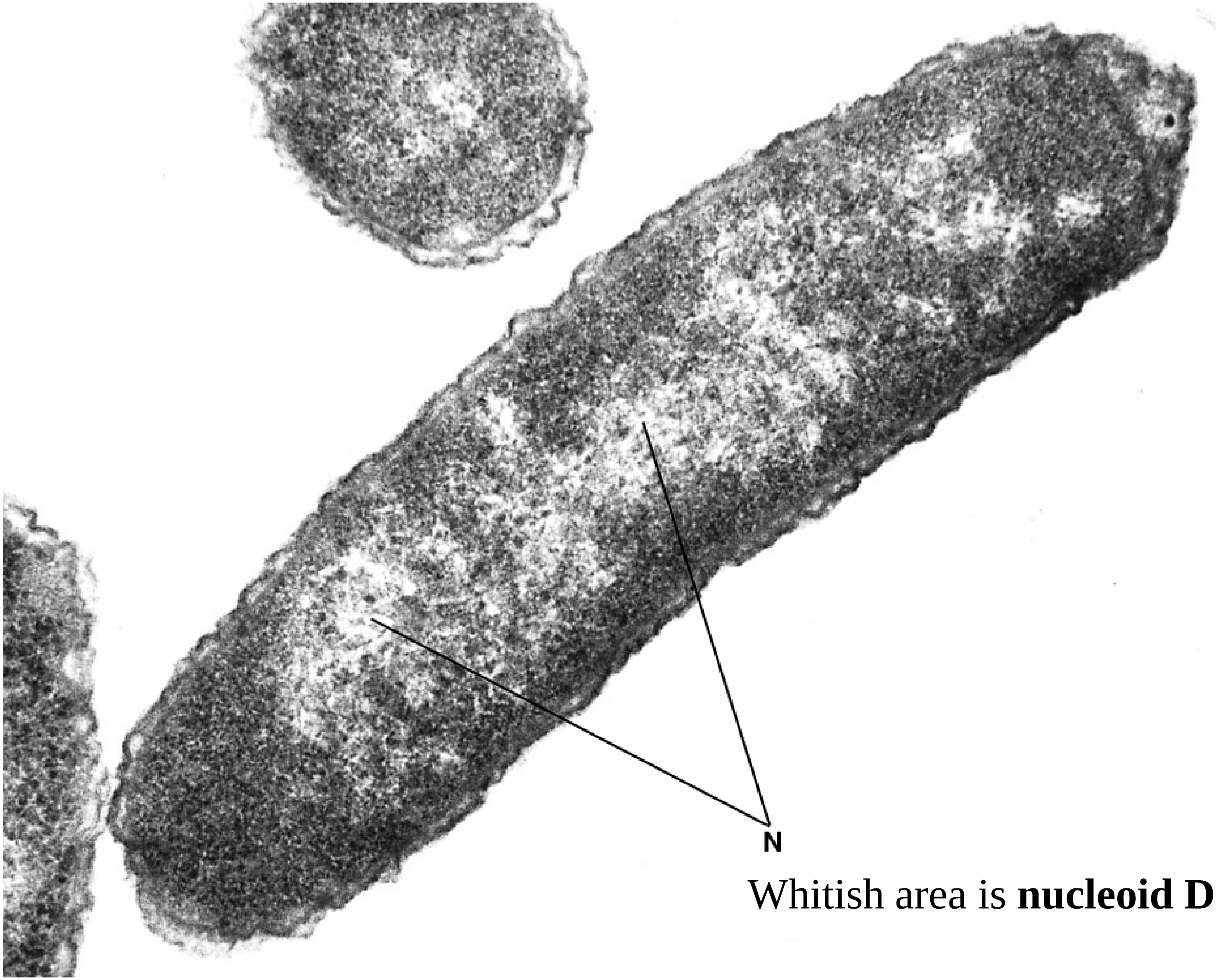
**Classification of microbial cellular features:**
**Invariant (or common to all)**

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

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

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

# Appearance of nucleoid via TEM




Whitish area is **nucleoid DNA**

# DNA strands released from cell

# Bacterial & Archaeal DNA

Statistics:

Chromosomes: ~1; bears essential genes

Plasmids: 0 to hundreds; helpful genes

Actual Length: ~ 1 mm

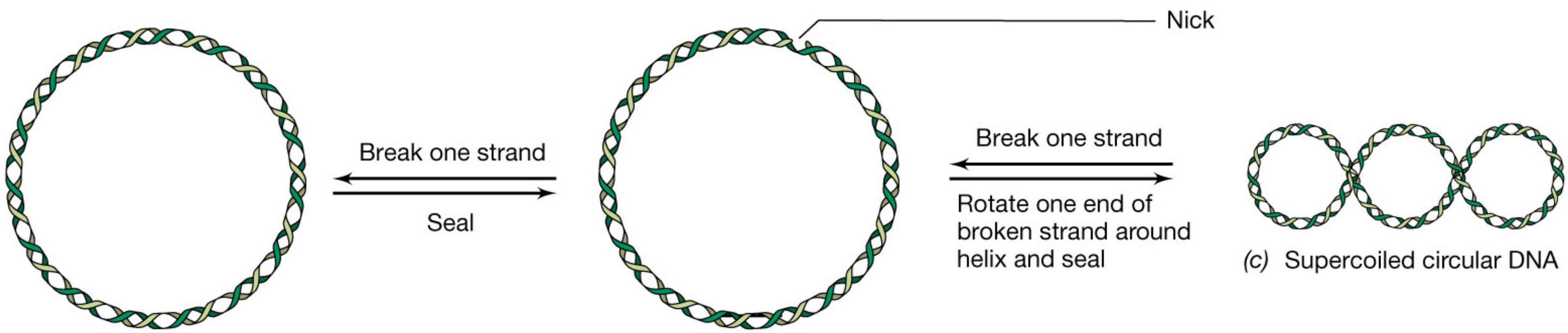
Enigma:

How to fit 1 mm long chromosome into a 1 μm wide cell?

Condensation: 30 to 50 loops of DNA emerging from a denser core

Supercoiling: tight twisting

Organization: wrapped around histone-like proteins (in Bacteria) or histones (in Archaea)



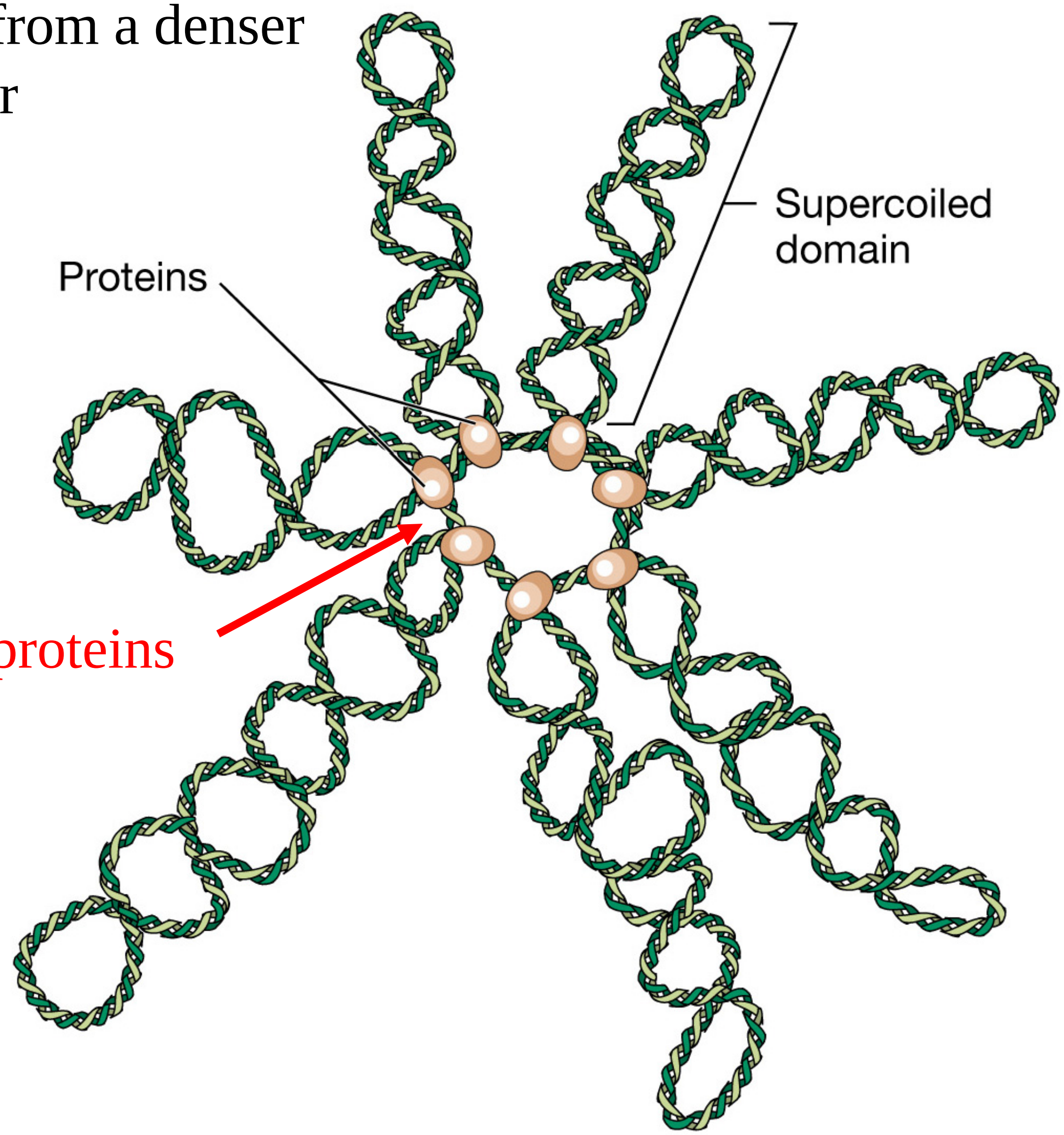

*(a)* Relaxed, covalently closed circular DNA

*(b)* Relaxed, nicked circular DNA

*(c)* Supercoiled circular DNA

Condensation:

30 to 50 loops of DNA emerging from a denser core centered on *ori* at cell equator

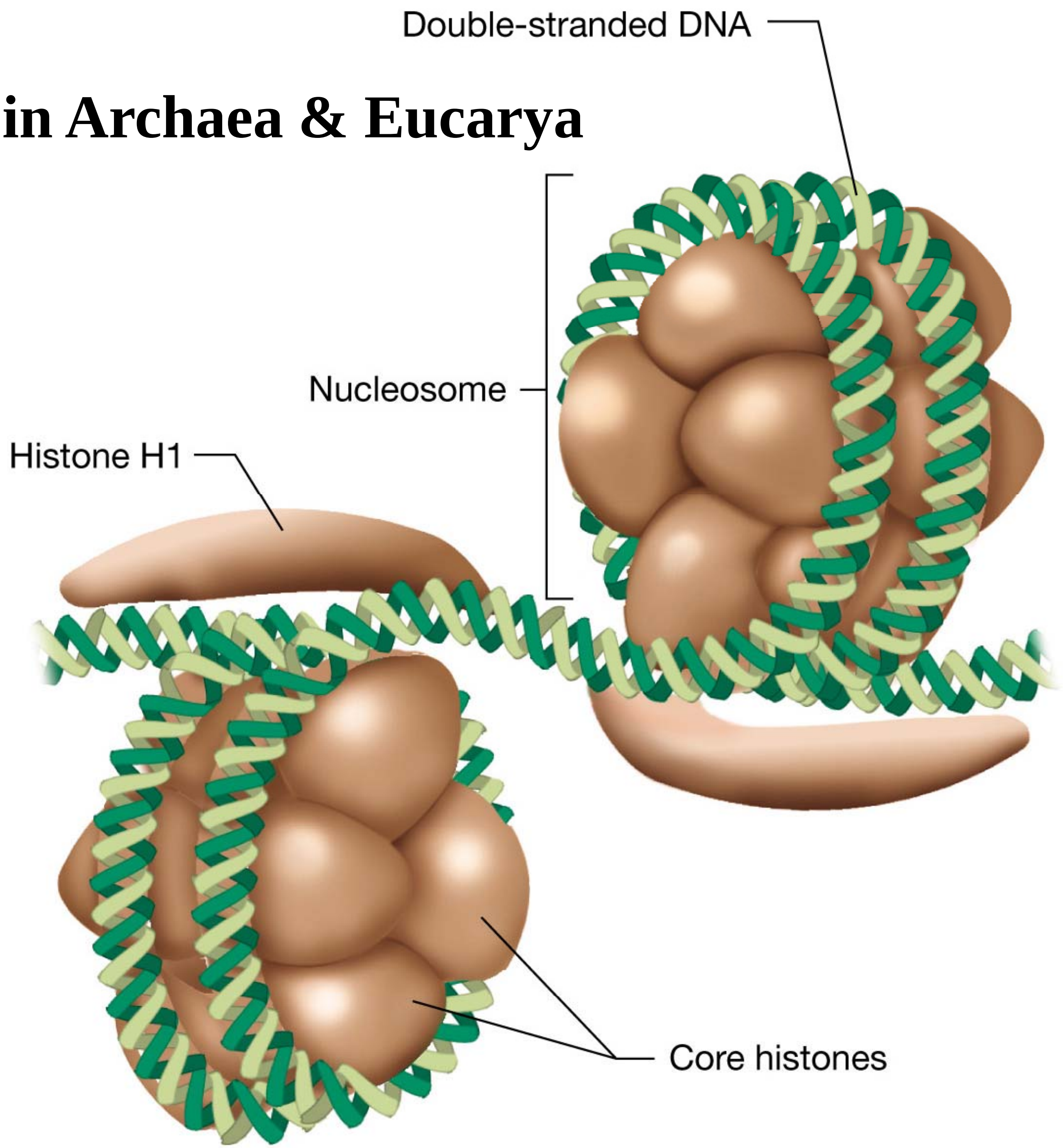



Stabilization by binding to proteins

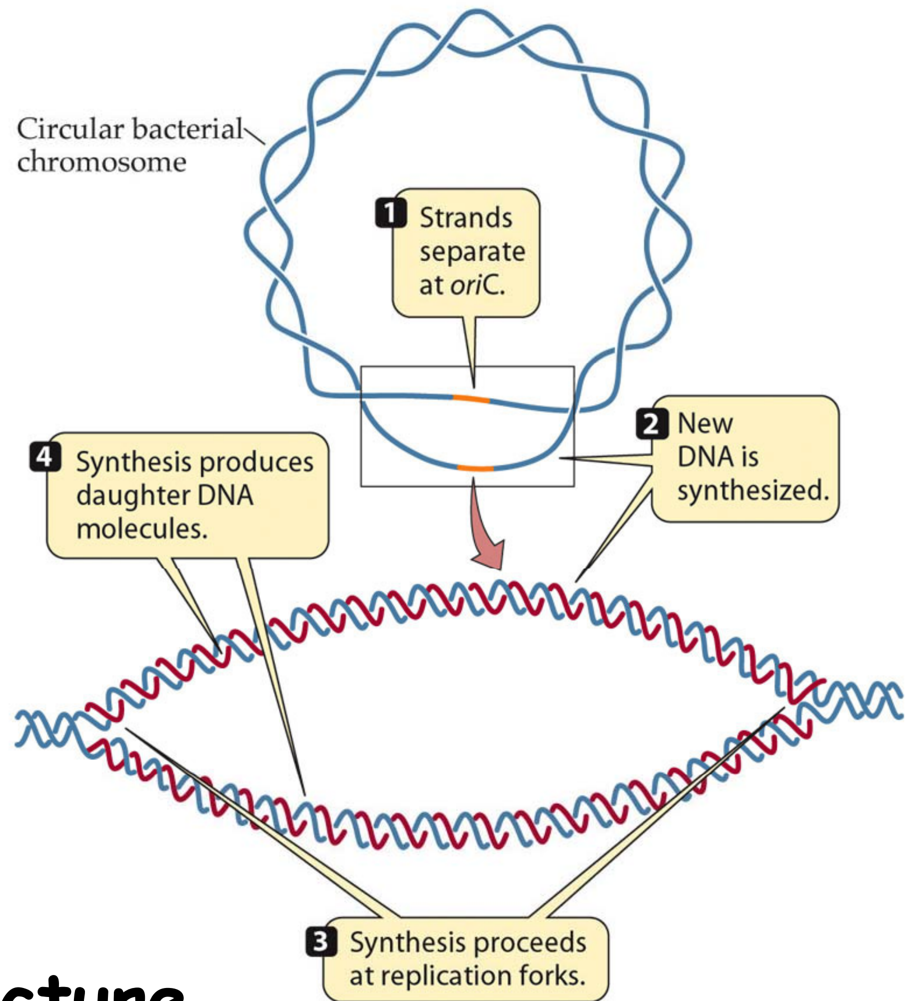
Supercoiling

*(d)* Chromosomal DNA with supercoiled domains

# Nucleosomes in Archaea & Eucarya



# Overview of DNA replication

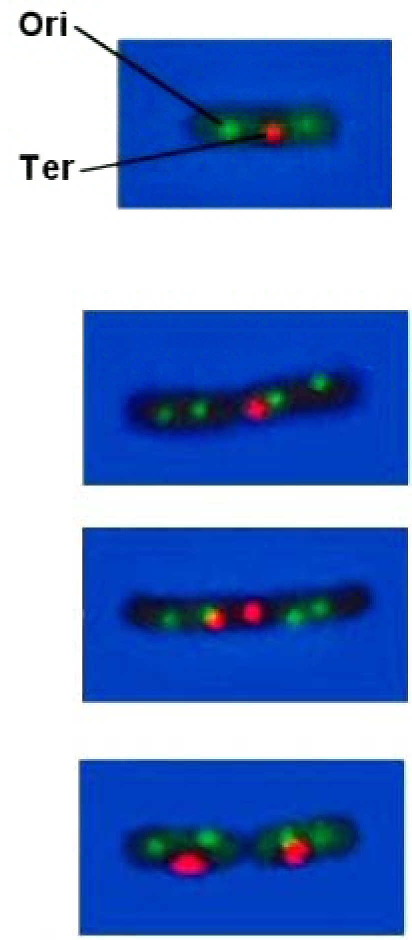



**Theta Structure**

# Overview of DNA replication

**Fluorescence microscopy:**
***E. coli*** **cells with fluorophores labeling Ori and Ter**

Lau et al (2003) Mol. Micro. 49:731

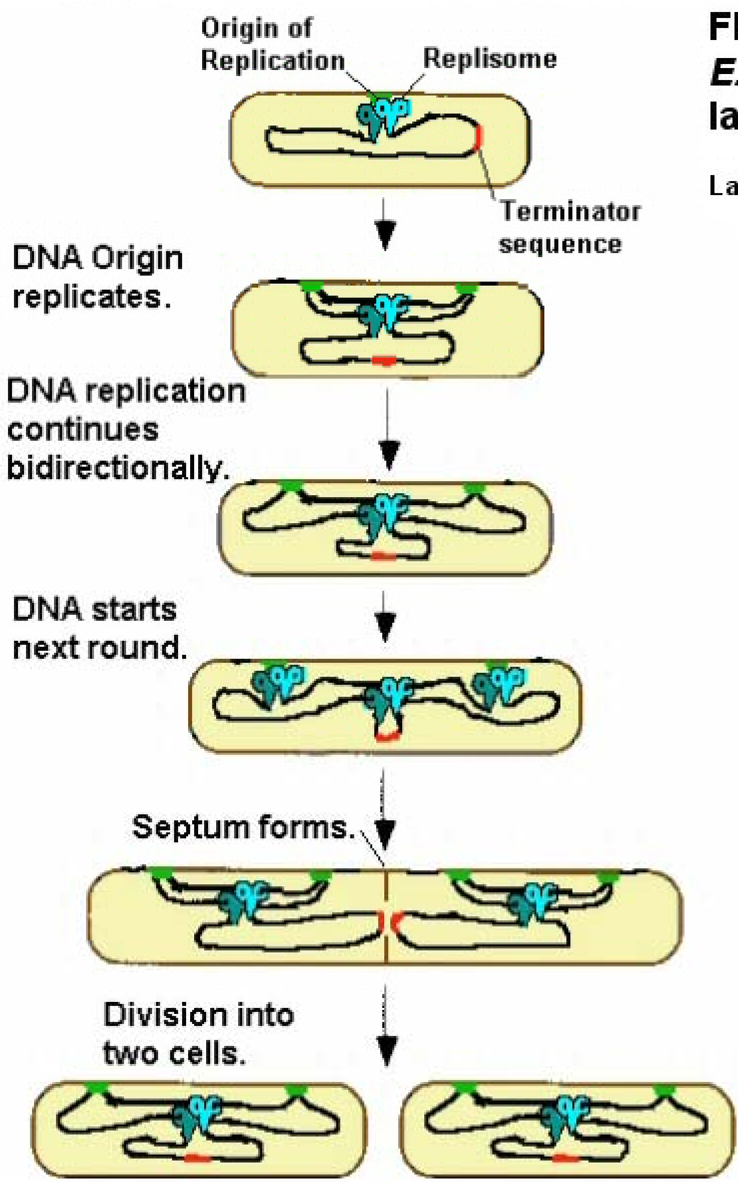



40 minutes to replicate *E. coli* chromosome.

20 minutes for cell division.

How???

# Overview of DNA replication




**Fluorescence microscopy:**
***E. coli*** **cells with fluorophores labeling Ori and Ter**

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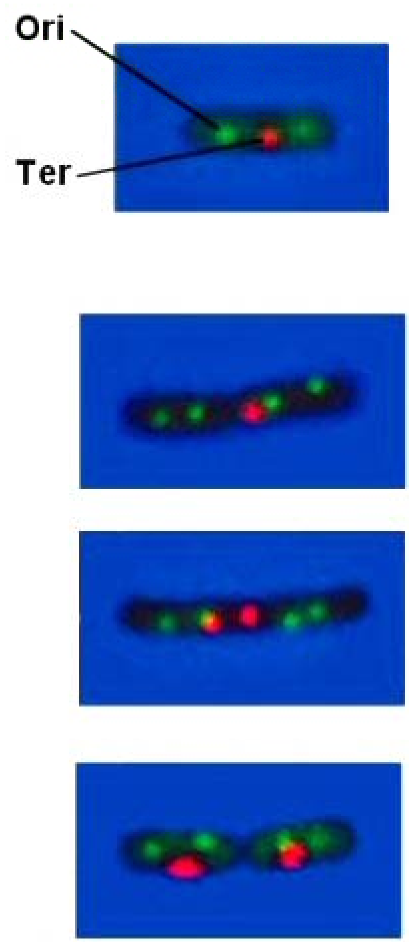
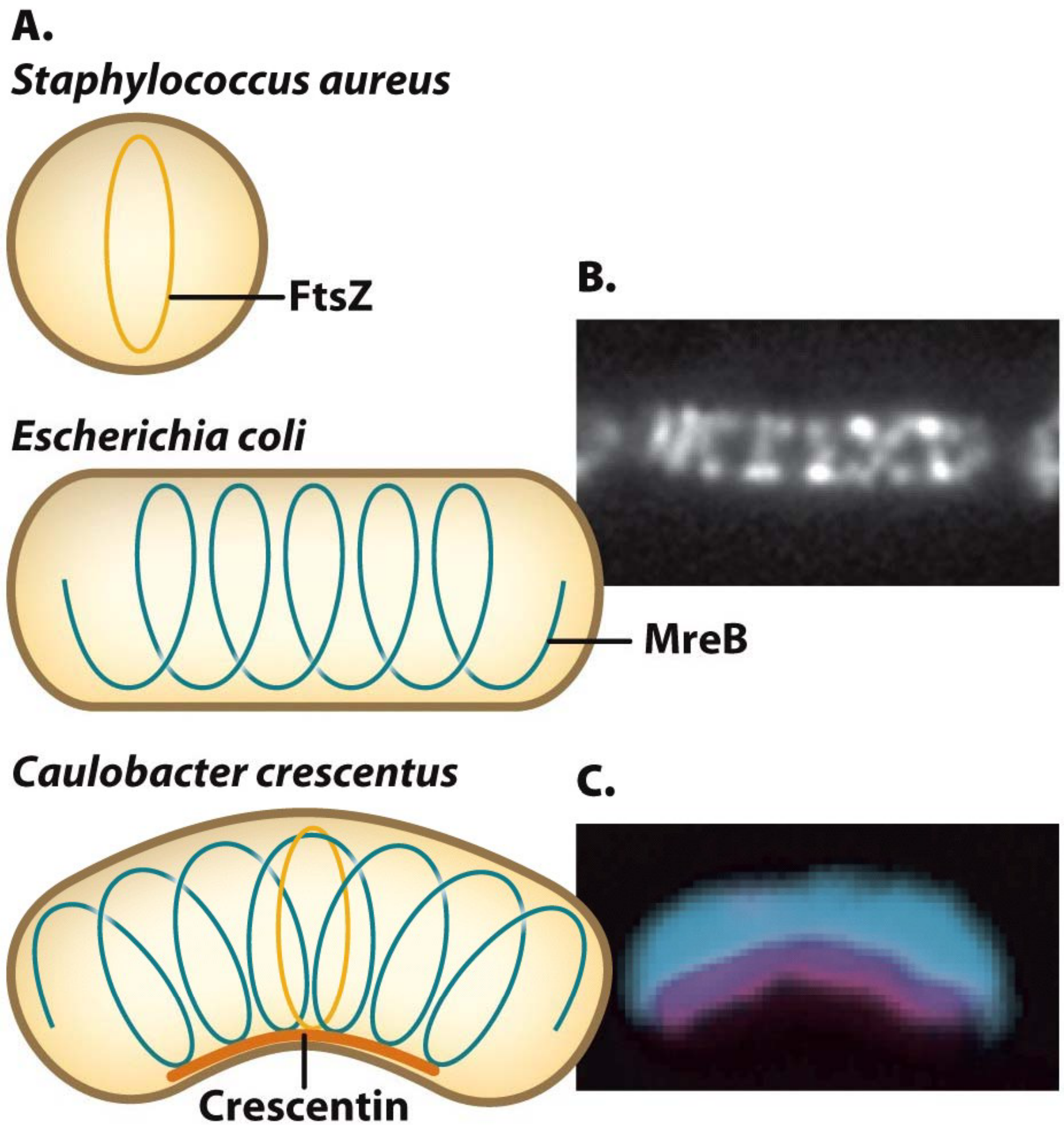


# Bacteria have cytoskeletons!




Special Topic 3.2 figure 2 Microbiology: An Evolving Science

# Bacteria divide by binary fission.    FtsZ marks the spot.

a. Phase contrast
b. Nucleoid stain
c. Antibody to FtsZ
d. Overlay of b & c

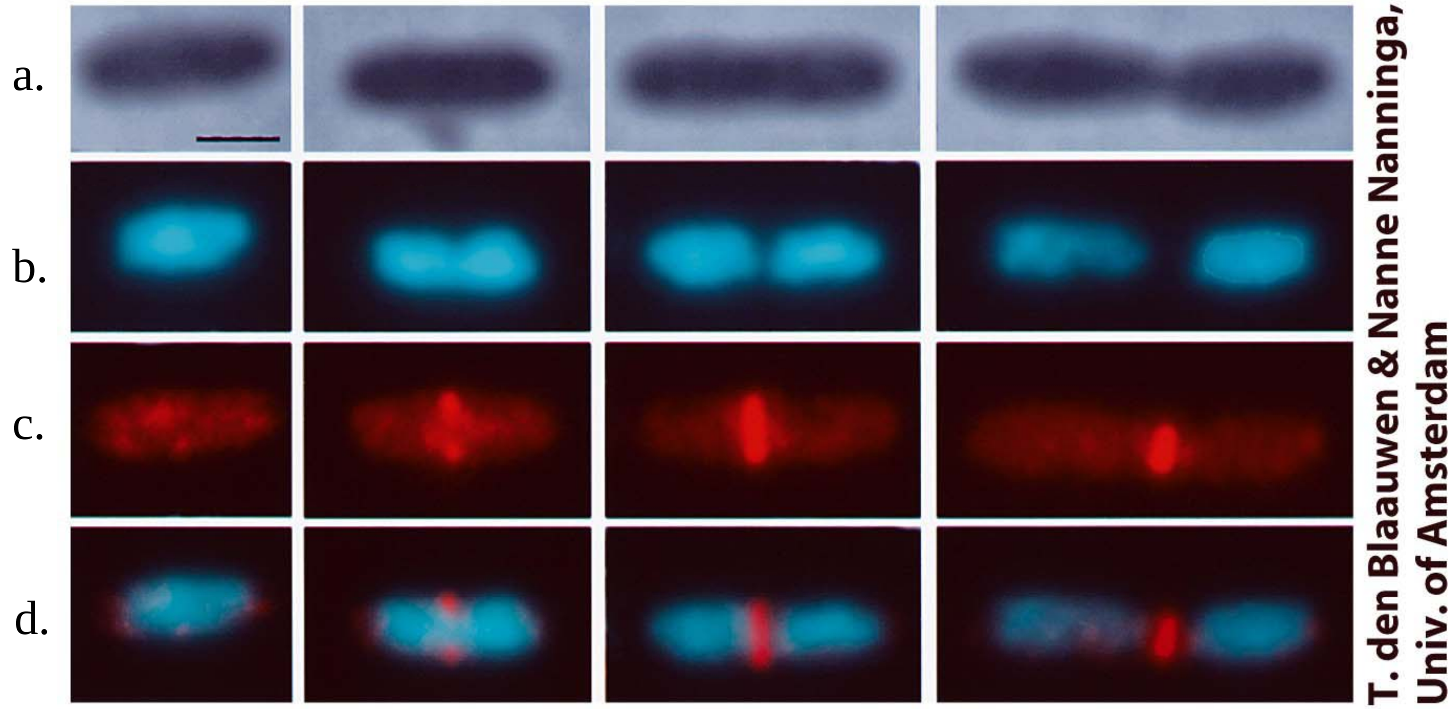


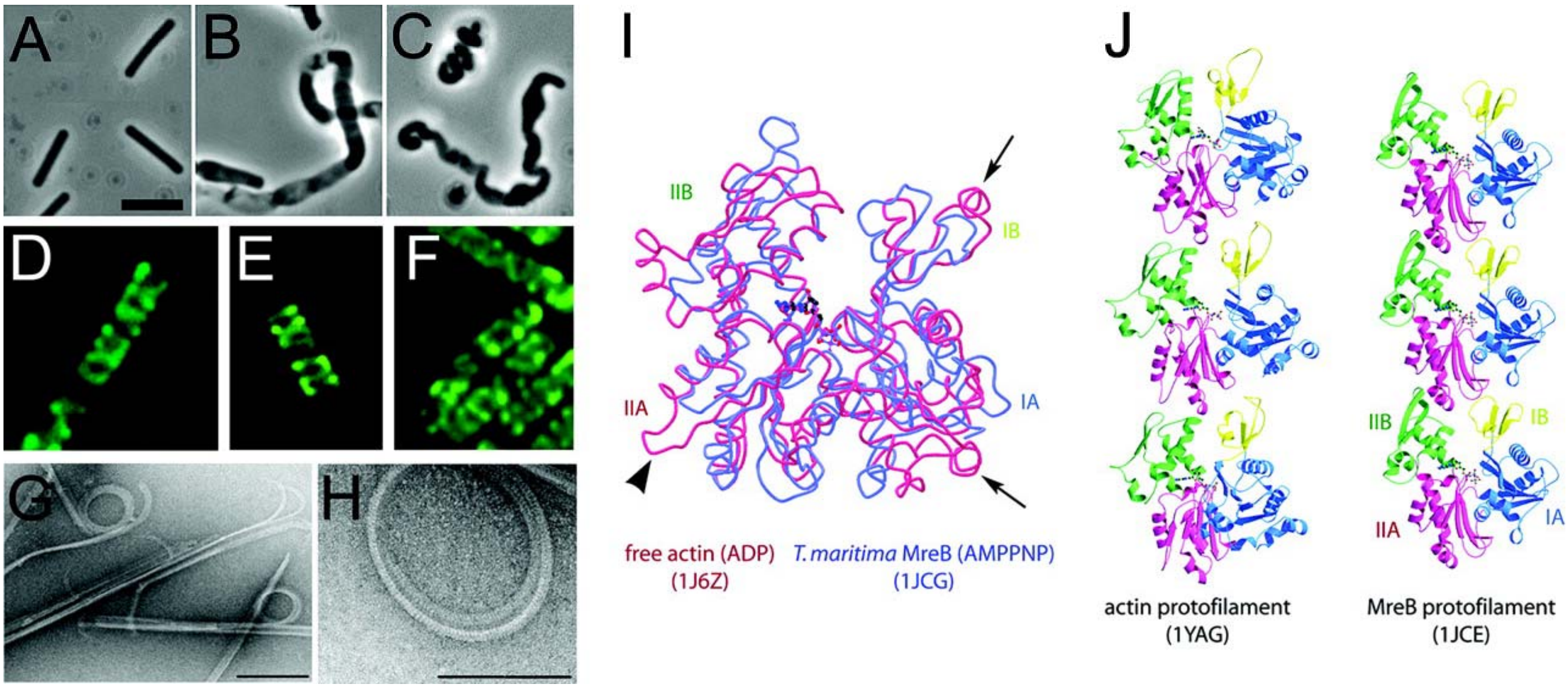

Figure 6-2b Brock Biology of Microorganisms 11/e


## FtsZ is a structural analog (ancestor?) of eukaryotic tubulin

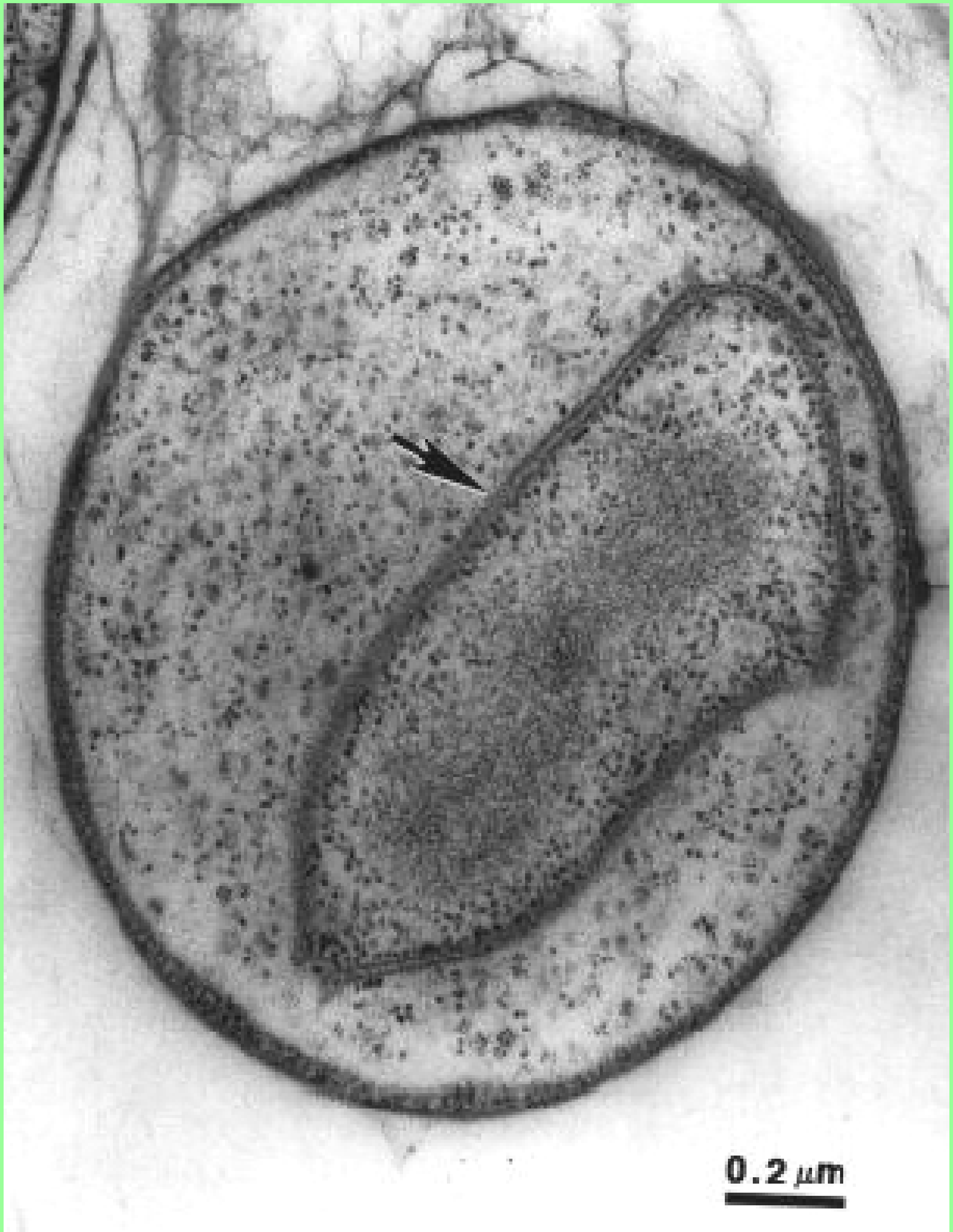
→ forms Z-ring at future site of cytokinesis
→ only 17% amino acid identity to tubulin but similar 3D structures and assembly properties

# MreB is a homolog (ancestor?) of actin

-cell shape determinant
-present in rod- and spiral-shaped cells but absent from cocci
-only 15% amino acid identity but similar 3D structure




A-C: WT and mreB mutants of *B. subtilis* (note cell shapes)
D-F: Helical filaments formed by MreB-like proteins in *B. subtilis*
G&H: MreB filaments
I &J: Actin and MreB structures overlaid. Only 15% amino acid identity but similar 3D structure.




***Gemmata obscuriglobus***

Membrane encompassed nucleoid