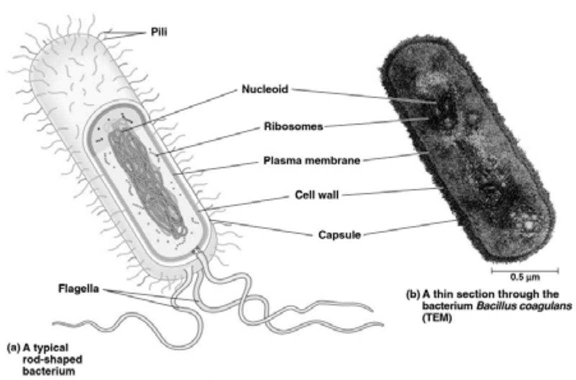
Comparing Bacteria, Archaea and Eucarya

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

“Features” found in all cells:

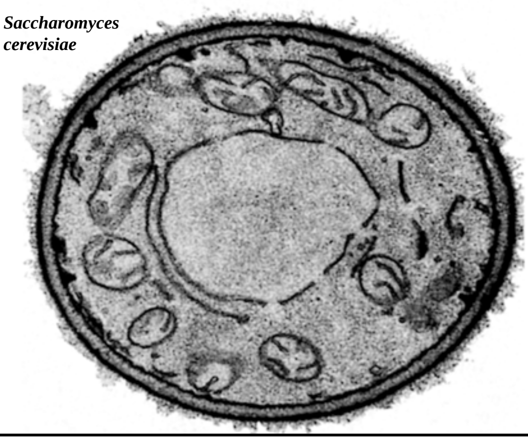
- **Ribosomes**
- **Cell Membrane**
- **Genetic Material**
- **Cytoplasm**
- **ATP Energy**
- **External Stimuli**
- **Regulate Flow**
- **Reproduce**

A Bacterial Cell

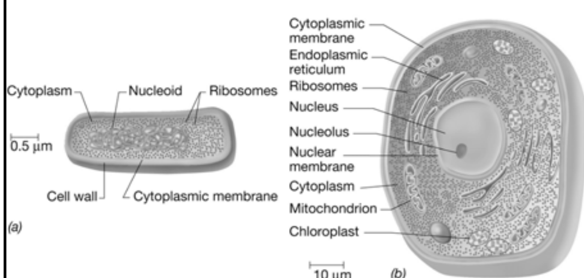


Escherichia coli

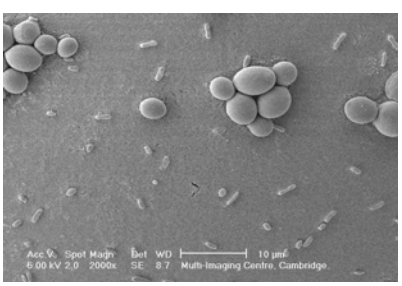
Saccharomyces cerevisiae



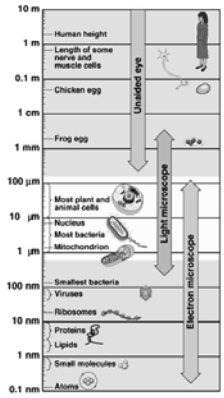
Elements of cellular structure

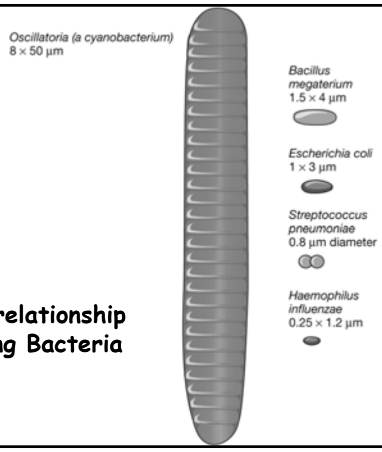


E. coli and S. cerevisiae

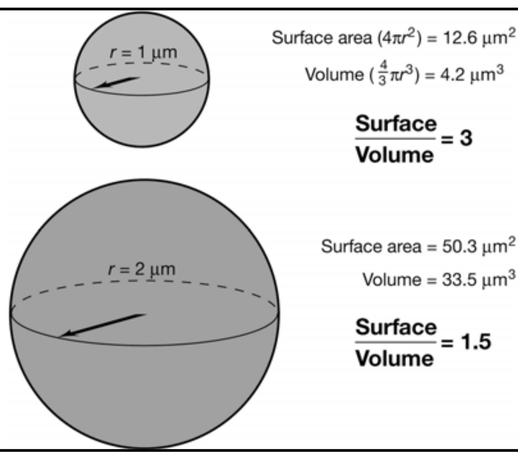


The size range of cells

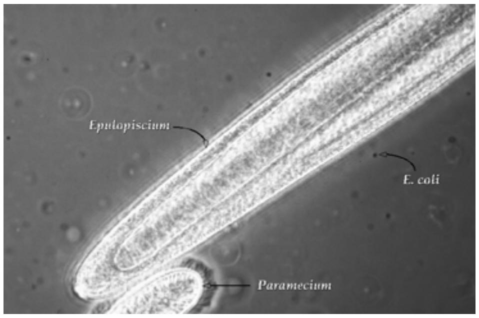




Size relationship among Bacteria



A Million times bigger than E. coli!



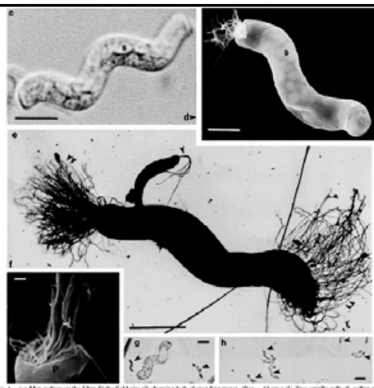


FIG. 1. (a) Mat surface at the Ebro Delta field site (3) showing lack of standing water. (Bar = 10 cm.) (b) Two spirilla cells (S, sulfur globule) shown by differential interference contrast (Nomarski). (Bar = 5 μm.) (c) Phase contrast microscopy of live spirillum cells. (Bar = 5 μm.) (d) Bipolar lophotrichous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

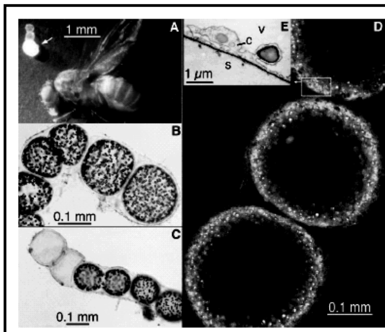
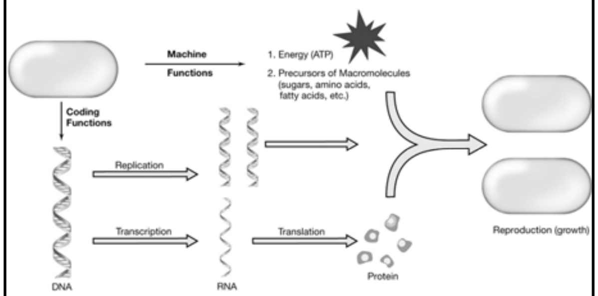


Fig. 1. *Thiomargarita namibiensis*. (A) The white arrow points to a single cell of *Thiomargarita*, 0.5 mm wide, which shines white because of internal sulfur inclusions. Above there is an empty part of the sheath, where the two neighboring cells have died. The cell was photographed next to a fruit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

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.

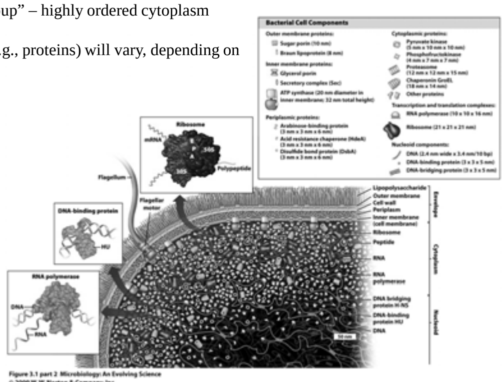
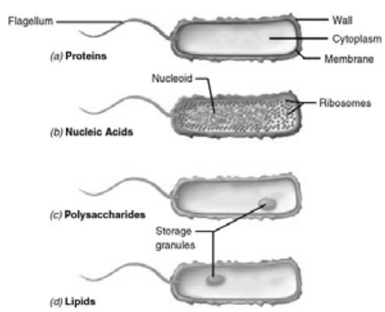


Figure 3.1 part 2 Microbiology: An Evolving Science

Locations of macromolecules in the cell



All over

2 types mostly

Cell Wall mostly

Cell Wall
Cell Mem

Comparing Bacteria, Archaea and Eucarya

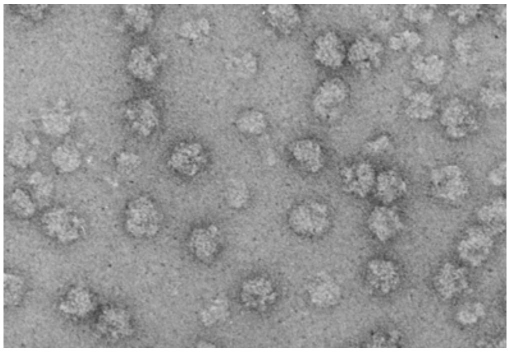
Classification of microbial cellular features:
Invariant (or common to all)

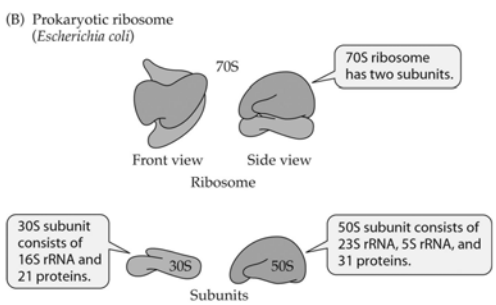
➡ **Ribosomes: Sites for protein synthesis – aka the grand translators.**

Cell Membranes: The barrier between order and chaos.

Nucleoid Region: Curator of the Information.

Ribosome structure





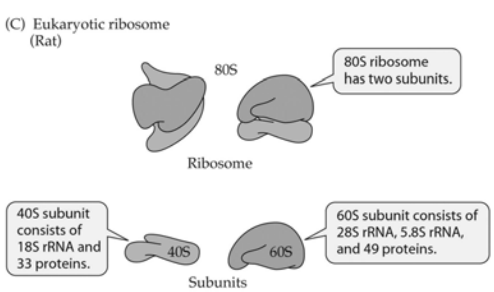


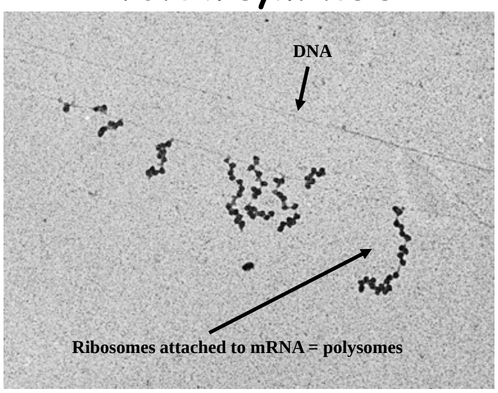
Table 7.6 Ribosome structure[a]

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) 5S (120)	28S (4200) 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

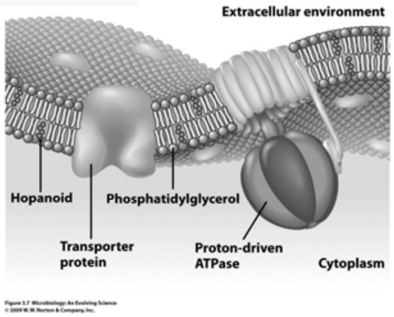
Classification of microbial cellular features:
Invariant (or common to all)

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

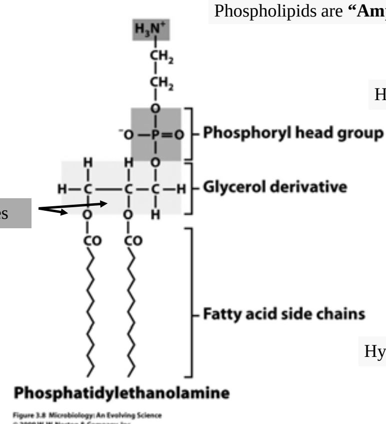


8 nm thick

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"**

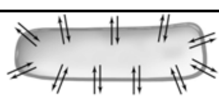


Hydrophilic

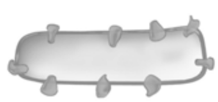
Ester linkages

Hydrophobic

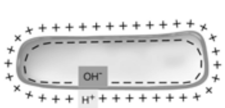
Functions of the cytoplasmic membrane



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

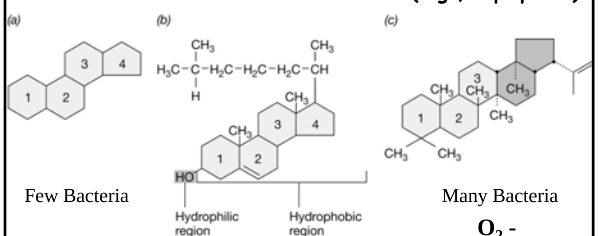
Energy Conservation — Site of generation and use of the proton motive force

Table 4.2 Comparative permeability of membranes to various molecules	
Substance	**Rate of permeability** [a]
Water	100 ← Free diffusion of water (passive transport) assisted by aquaporins
Glycerol	0.1
Tryptophan	0.001
Glucose	0.001
Chloride ion (Cl^-)	0.000001
Potassium ion (K^+)	0.0000001
Sodium ion (Na^+)	0.00000001

} Glycerol through Sodium ion: 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 | **Cholesterol** | **Hopanoid (e.g., Diploptene)**



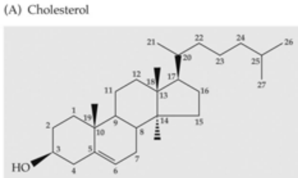
Few Bacteria

Many Bacteria

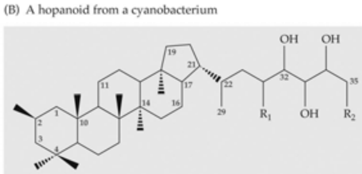
O_2 -

All rigid planar molecules

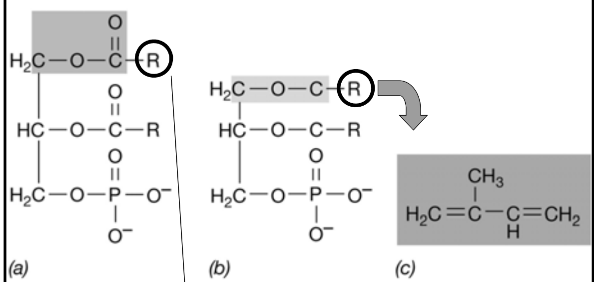
(A) Cholesterol



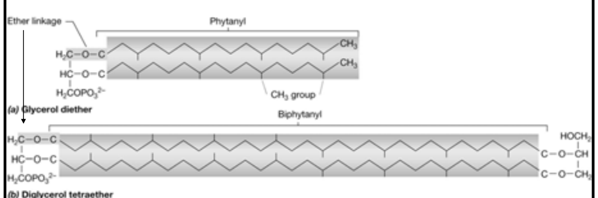
(B) A hopanoid from a cyanobacterium



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

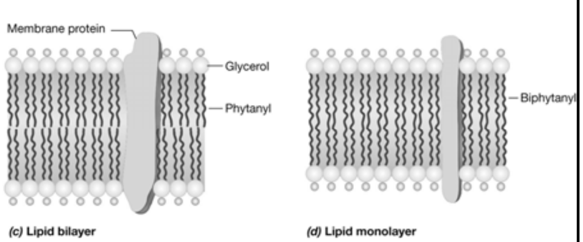


Major lipids of *Archaea* and the structure of archaeal membranes

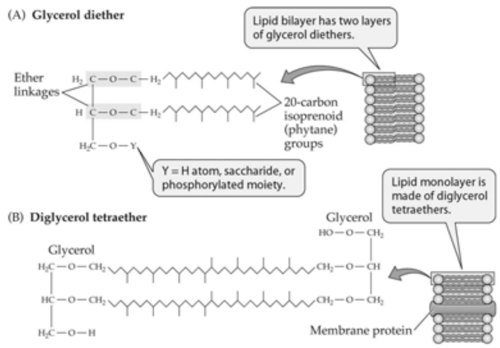


Lipid monolayer, not a bilayer: mostly found in extremophiles

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



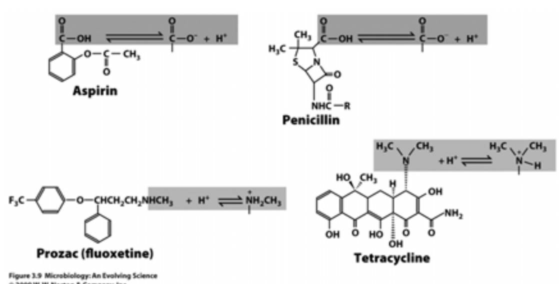
Archaeal cell membrane structure



Passive Diffusion:

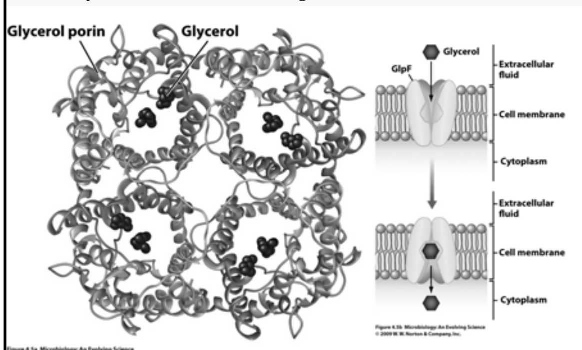
-small, uncharged molecules (O_2, CO_2, H_2O)

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



Facilitated Diffusion (a type of passive tranport):

Powered by solute's own concentration gradient



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?

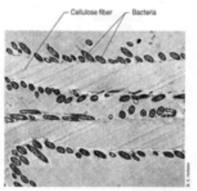
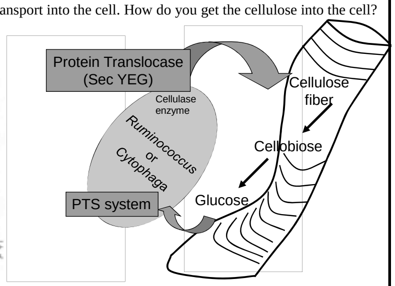


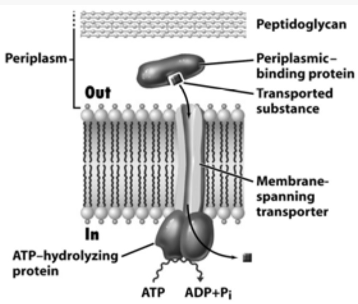
Figure 17.61 Transmission electron micrograph showing attachment of cellulose-digesting bacteria, Sporocytophaga myxococcoides, to cellulose fibers. Cells are about 0.5 µm in diameter.



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

→ ATP hydrolysis provides energy for transfer
→ ABC transporters = ATP-Binding Cassette

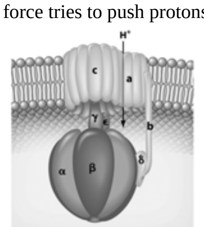
1. Periplasmic binding proteins "find" low-concentration solutes ($\geq 10^{-6}$ M)
2. Binding protein docks on membrane-spanning domain
3. Conformational change and ATP hydrolysis drive transport



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

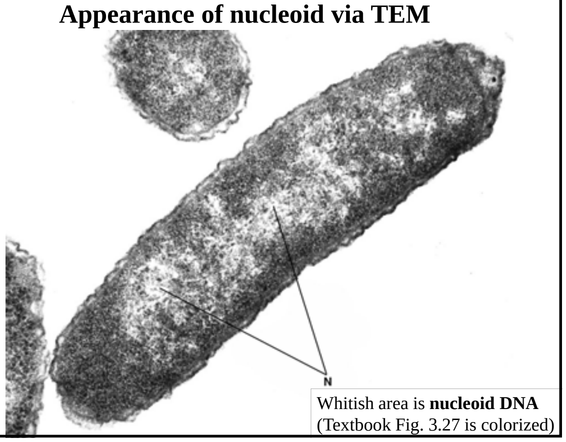
Classification of microbial cellular features:
Invariant (or common to all)

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



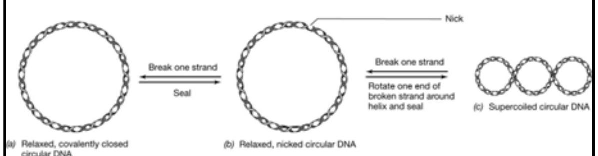
Whitish area is **nucleoid DNA**
(Textbook Fig. 3.27 is colorized)

DNA strands released from cell

Bacterial & Archaeal DNA

Statistics:
Chromosomes: ~1; bears essential genes
Plasmids: 0 to hundreds; helpful genes
Circumference: ~ 1 mm

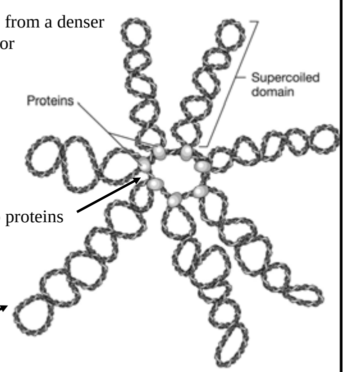
Enigma:
How to fit 1 mm long chromosome into a 1 μm wide cell?
Condensation: 30 to 50 loops of DNA emerging from a denser core
Supercoiling: tight twisting
Organization: wrapped around histone-like proteins (in Bacteria) or histones (in Archaea)



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

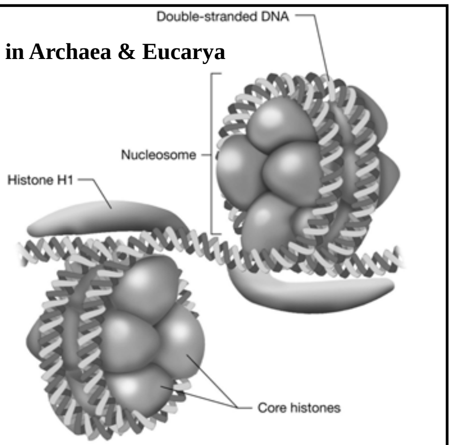
Stabilization by binding to proteins

Supercoiling

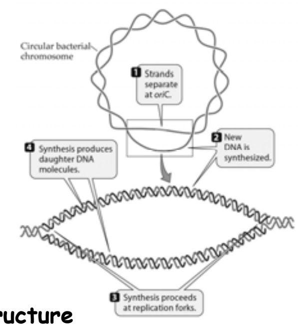


(d) Chromosomal DNA with supercoiled domains

Nucleosomes in Archaea & Eucarya



Overview of DNA replication



Theta Structure

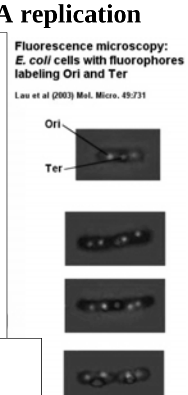
See Chapter 7.3, 7.5 - 7.7

Overview of DNA replication

40 minutes to replicate *E. coli* chromosome.

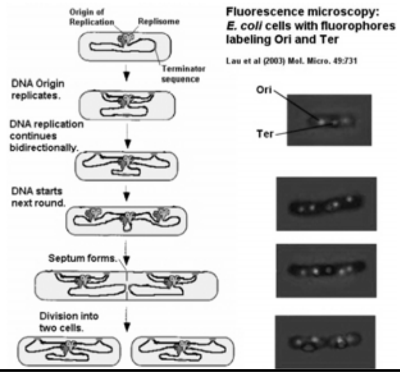
20 minutes for cell division.

How???

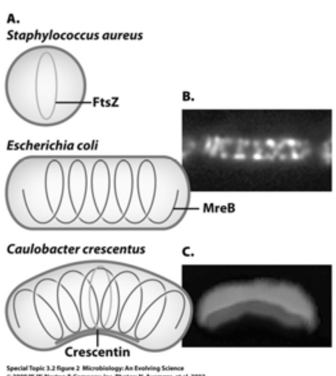


http://www.wwnorton.com/college/biology/mbio/content/ch03/animation.asp

Overview of DNA replication

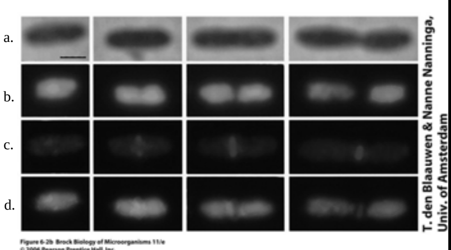


Bacteria have cytoskeletons!



Bacteria divide by binary fission. FtsZ marks the spot.

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

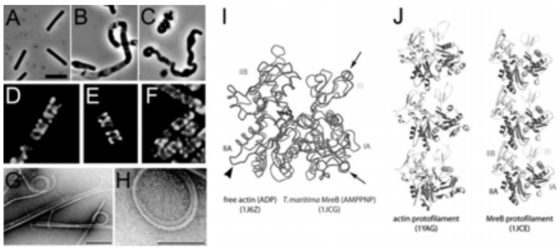


FtsZ is a structural analog (ancestor?) of eukaryotic tubulin

→ 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