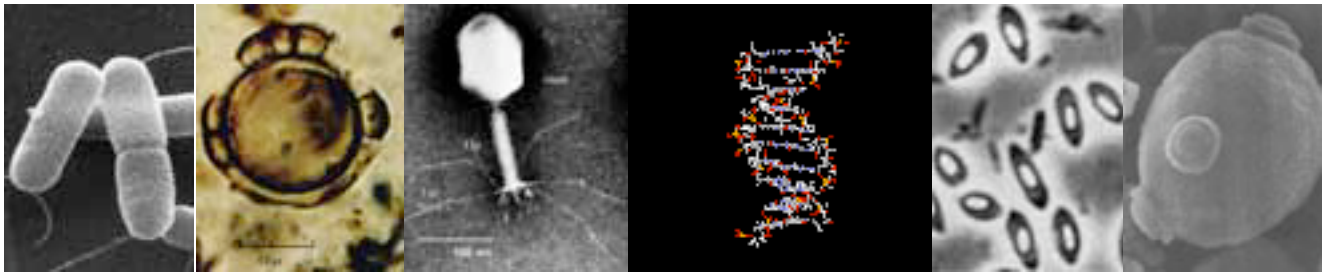


Microbial cell structure

General Microbiology - Lectures 3-4

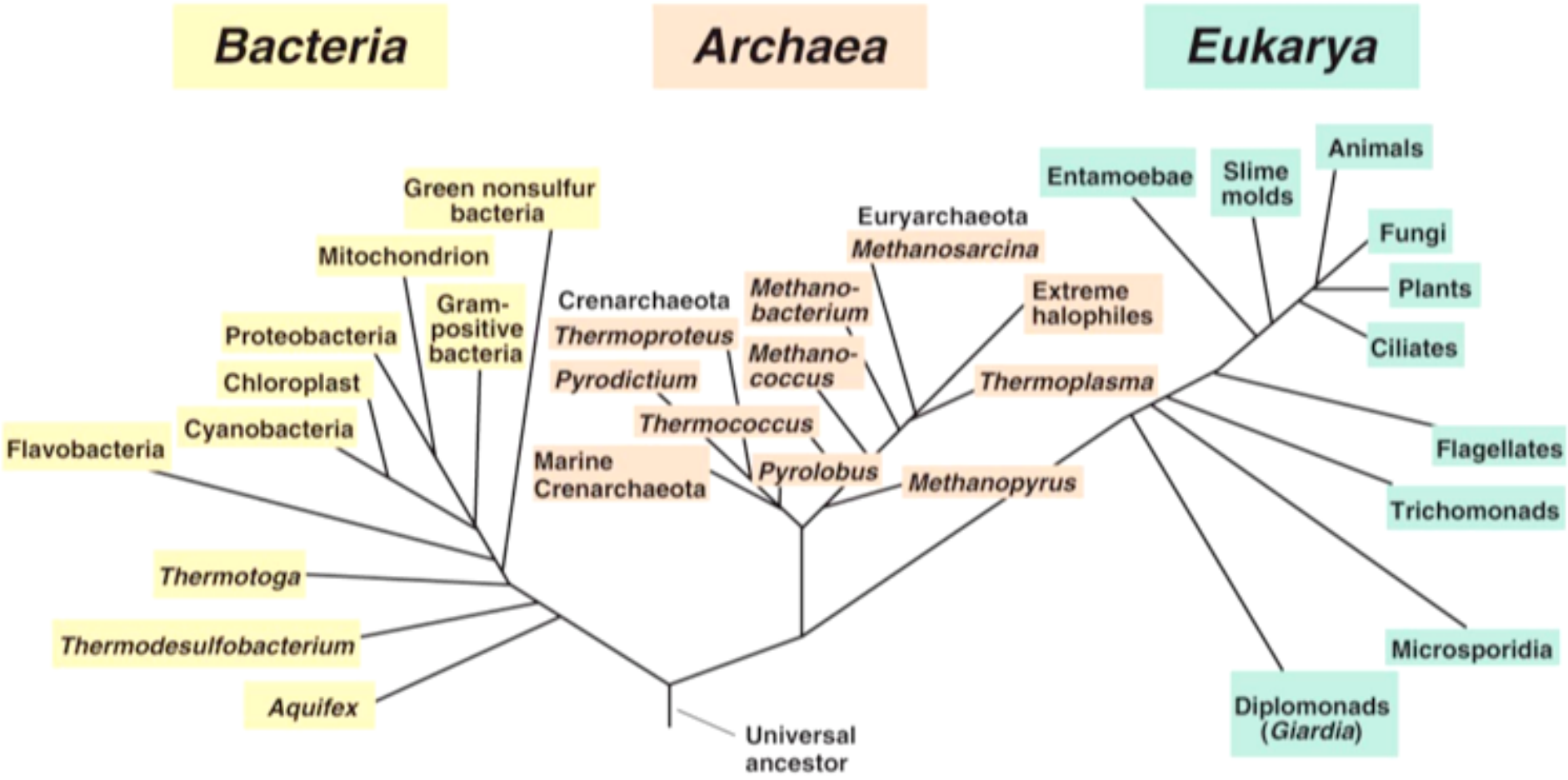
Cañada College - Fall 2008

Instructor: Tamas Torok, Ph.D.

Two days' topics

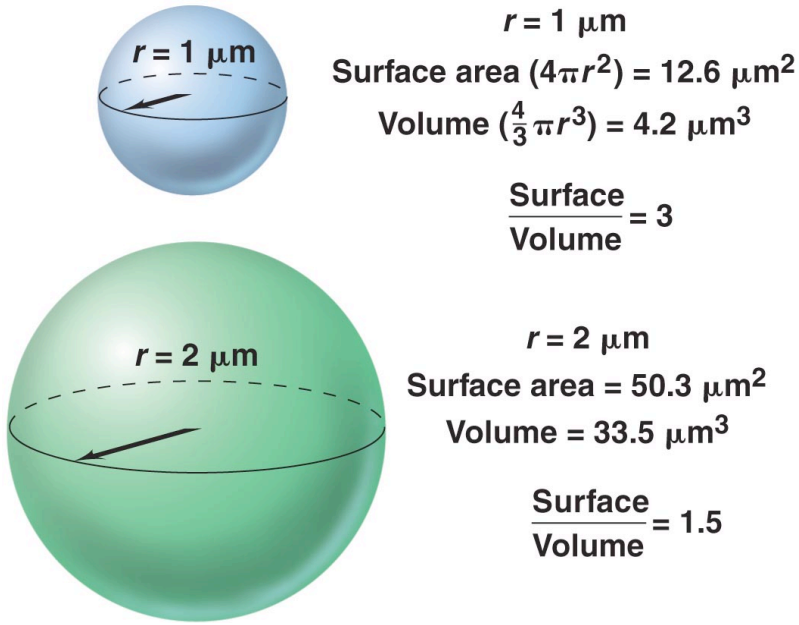
- **Microbial cell**
  - cell envelope
  - cell membrane
  - cytoplasm
  - genome
  - inclusions
  - cell organelles

Universal tree of life



Significance of smallness

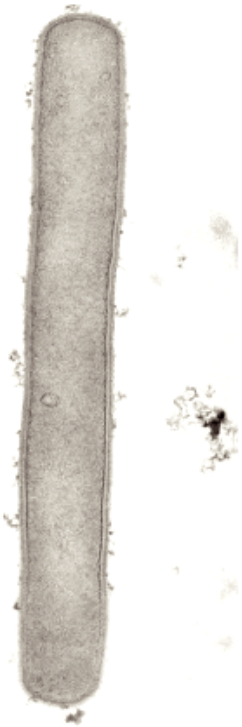
- **Small cells contain more surface area relative to cell volume than large cells (*i.e.*, higher S/V)**
  - **support greater nutrient exchange per unit cell volume**
  - **tend to grow faster than larger cells**



Cell types side-by-side

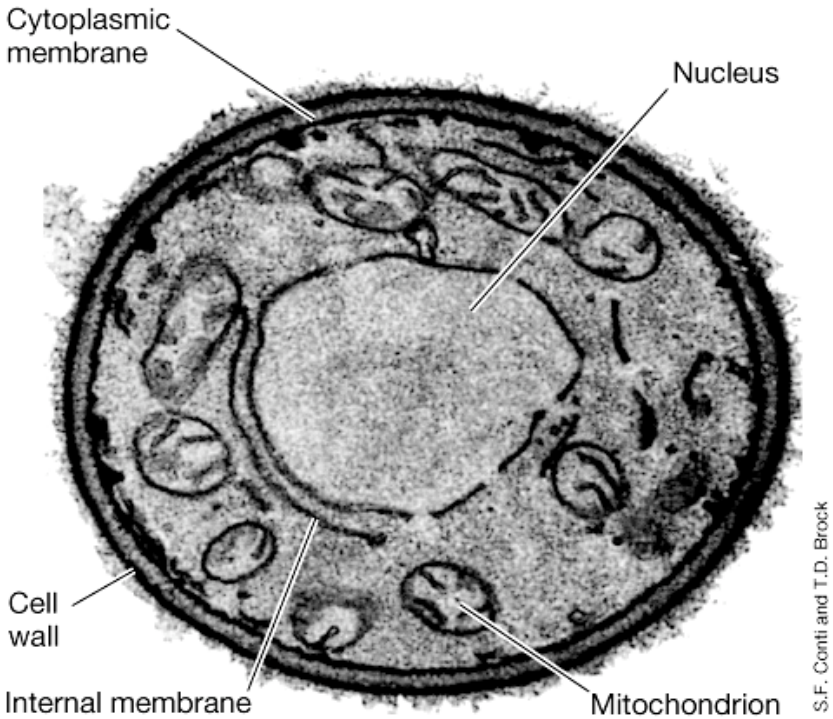
John Bozzola and M.T. Madigan

(a)



R. Rachel and K.O. Stetter

(b)

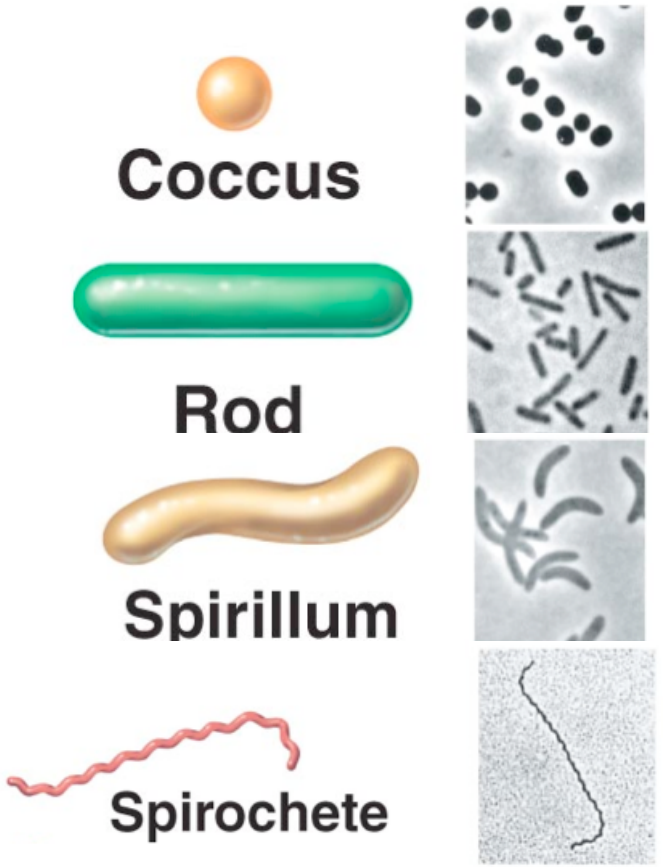


S.F. Conti and T.D. Brock

(c)

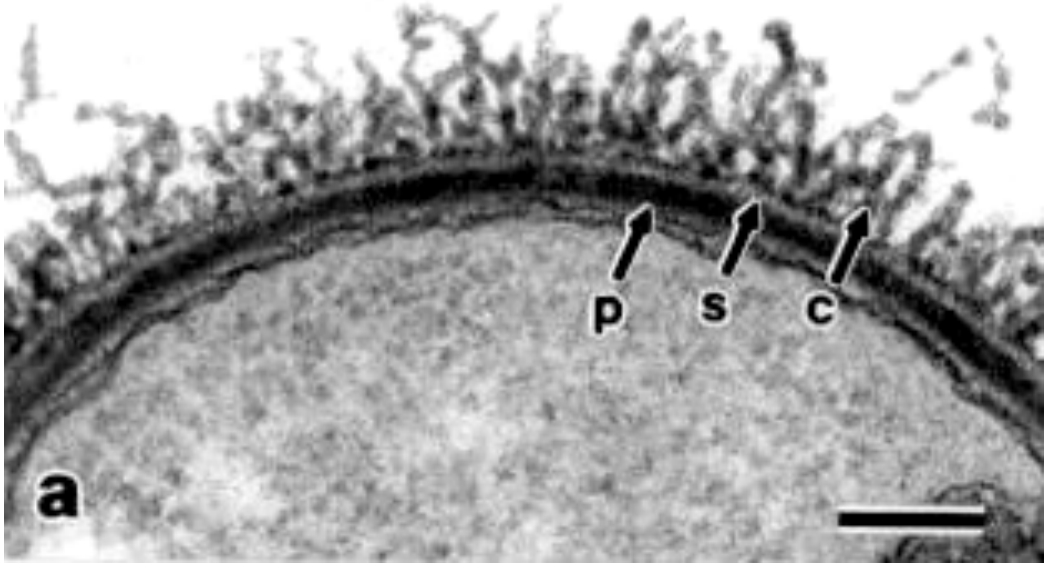
Bacterial and archaeal cell morphology

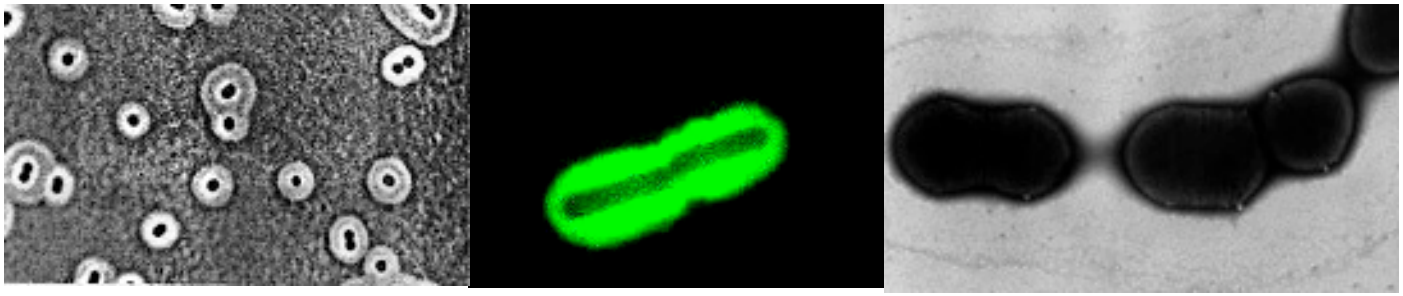
- Cell shape and size are genetically determined
  - monomorphic *vs.* pleomorphic
- Size range
  - bacteria and archaea from 0.2 µm to >700 µm
  - eukaryotes - 10 µm-200 µm
- Cellular organisms
  - < 0.15 µm in diameter unlikely
  - open oceans tend to contain small cells (0.2–0.4 µm in diameter)
- Phenotype depends on the environment
  - single planctonic cells ↔ microcolonies ↔ biofilm

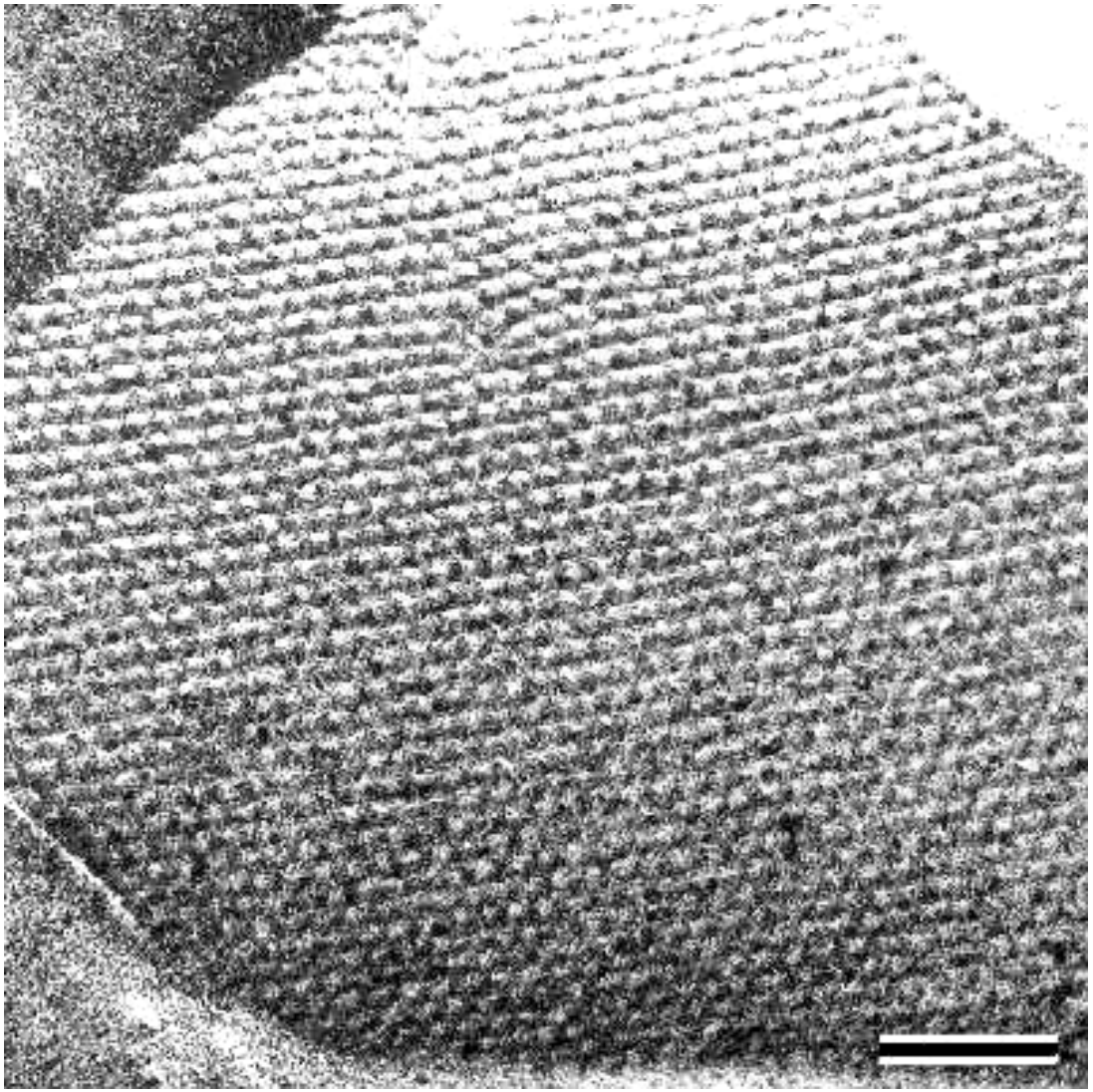


Cell envelope in *Bacteria* and *Archaea*

- Capsule
- EPS, slime
- S-layer
- Outer membrane
- Cell wall





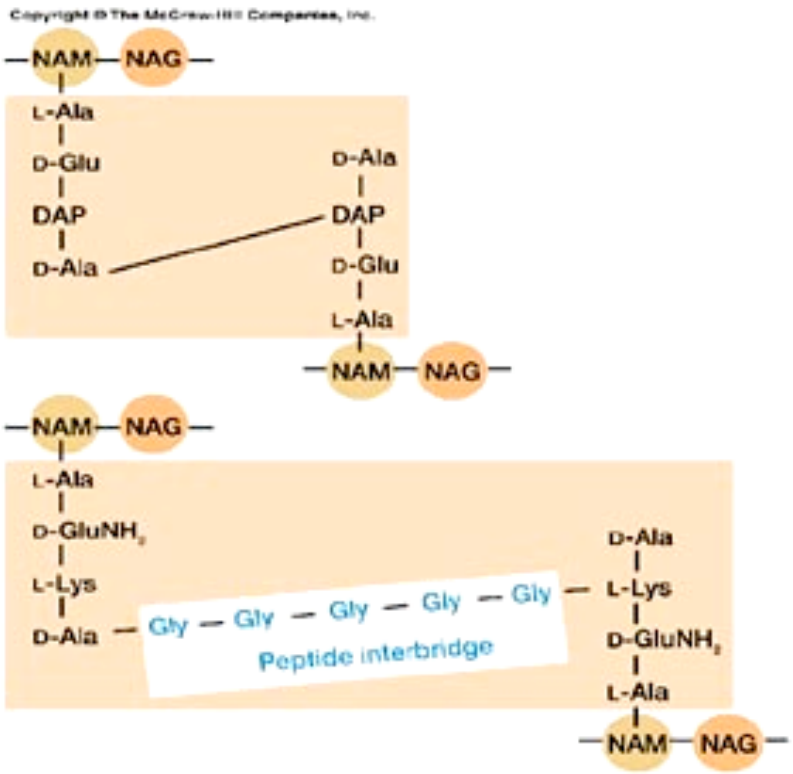


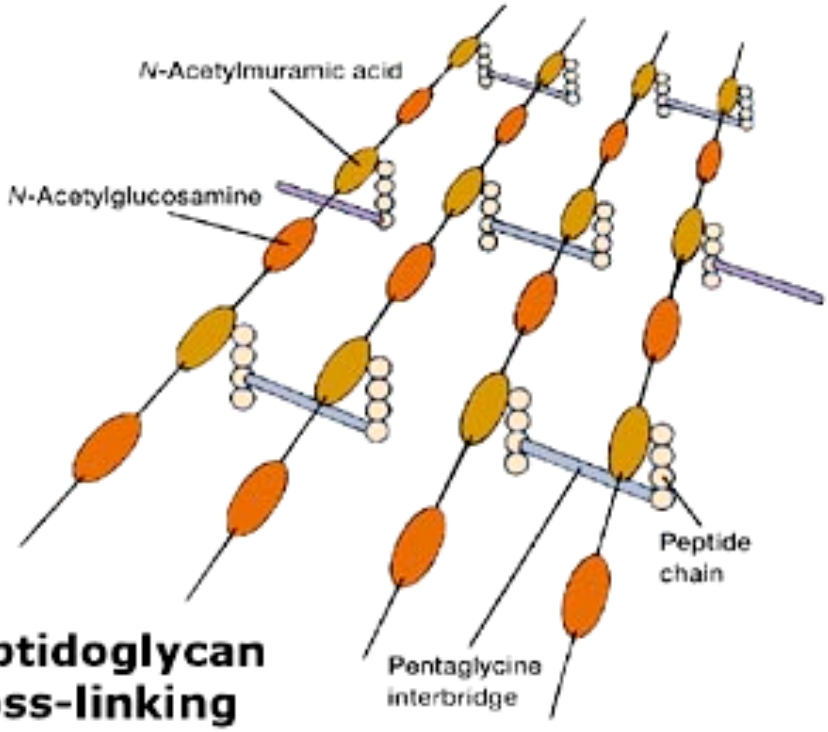
S-layer

- Crystalline protein or glycoprotein lattice

Bacterial cell wall

- Semi-rigid/rigid, maintains cell shape and protects its content
- Provides anchorage for means of movement, attachment, and “sex”
- Peptidoglycan (murein)
  - repeating units of *N*-acetylglucosamine (NAG) and *N*-acetylmuramic acid (NAM)
  - cross-bridged
    - tetrapeptide chain (L-alanine, D-glutamic acid, lysine or diaminopimelic acid, and D-alanine)
    - pentapeptide interbridge (glycine)
  - teichoic acids in Gram (+) bacterial cell wall
- Thickness of peptidoglycan layer may vary

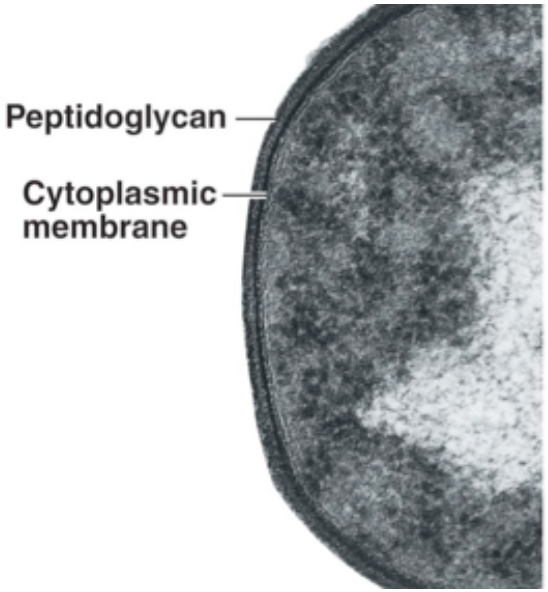


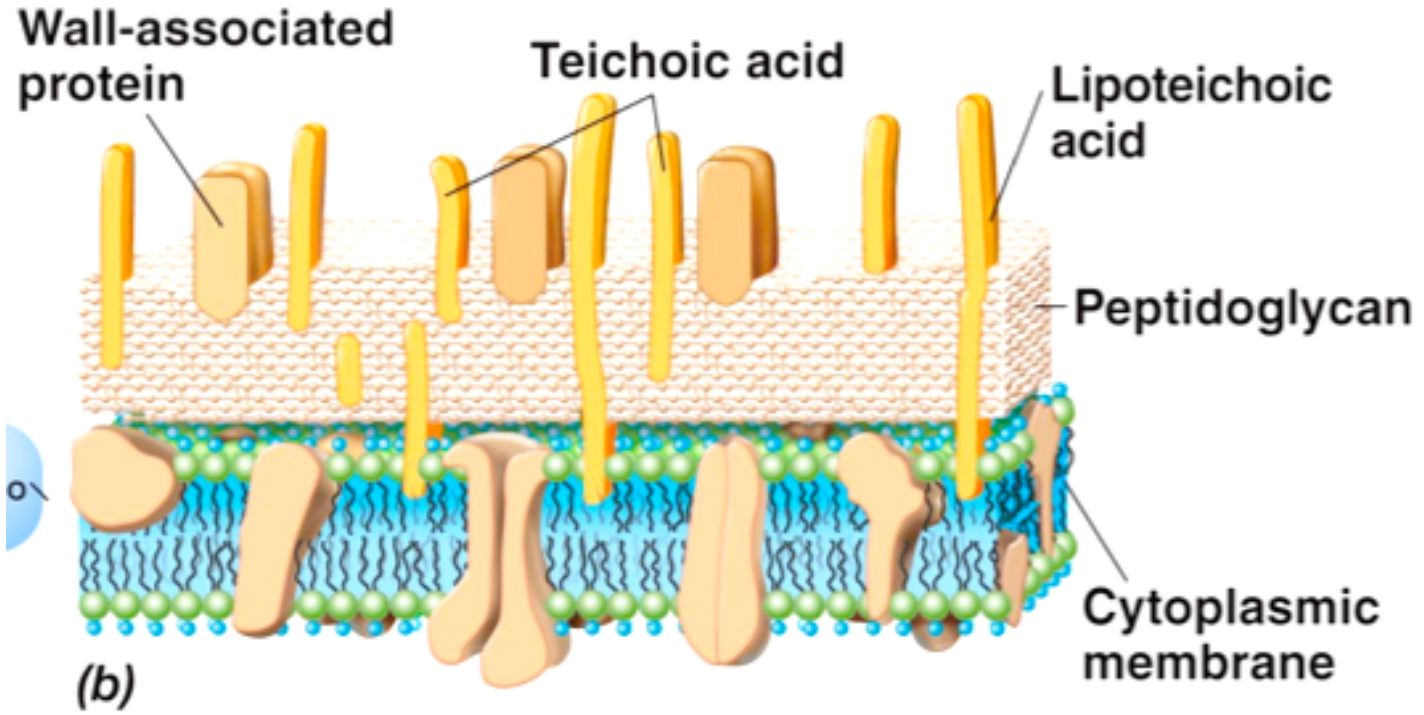


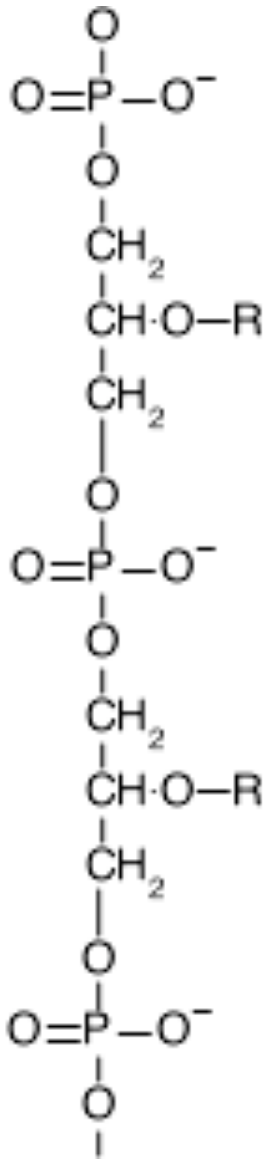
Peptidoglycan cross-linking

Bacterial cell wall

(cells stain Gram +)

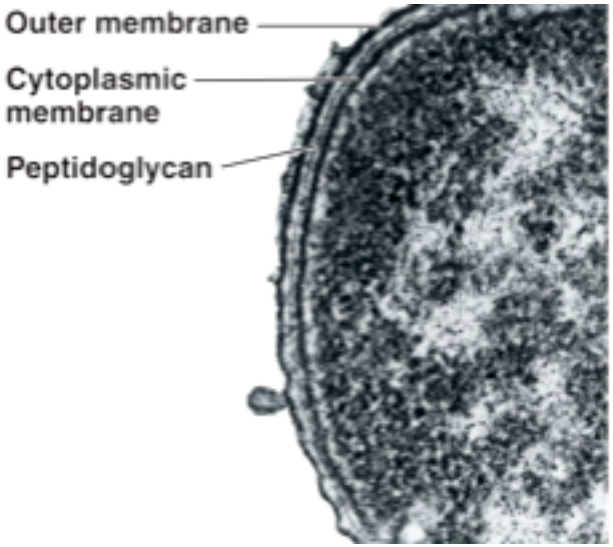






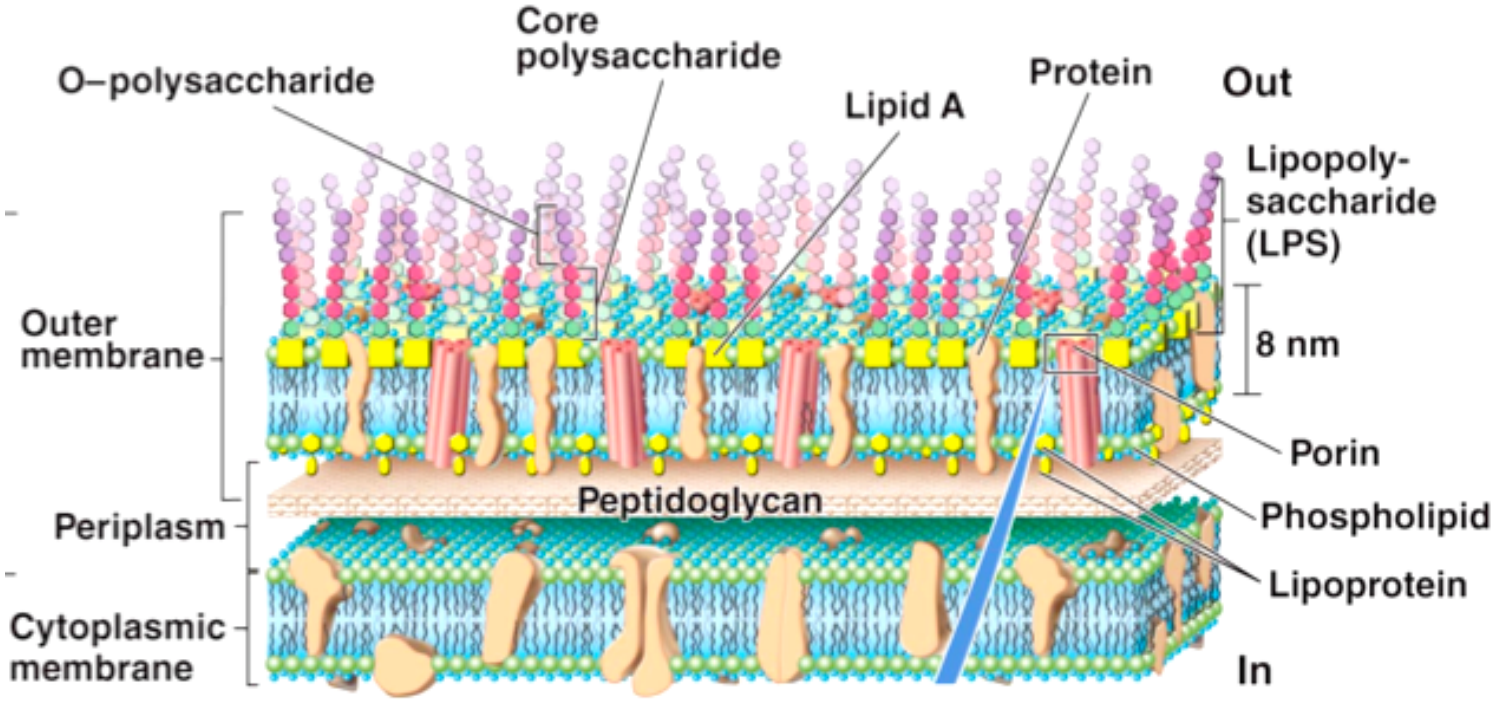
Teichoic acids

- Polymer of glycerol or ribitol joined by phosphate groups
- Amino acids attached
- Covalently bound to muramic acid and links several layers of peptidoglycan mesh together



Bacterial cell wall

(cells stain Gram -)



Comparison of cell wall types

Property	Gram (+)	Gram (-)
Thickness of wall	20-80 nm	10 nm
Peptidoglycan content	>50%	10-20%
Teichoic acid	+	-
Lipid and lipoprotein content	0-3%	58%
Protein content	0%	9%
Lipopolysaccharide	0%	13%
Sensitive to penicillin	+	not as much
Digested by lysozyme	+	not as much

Cell envelope of *Archaea*

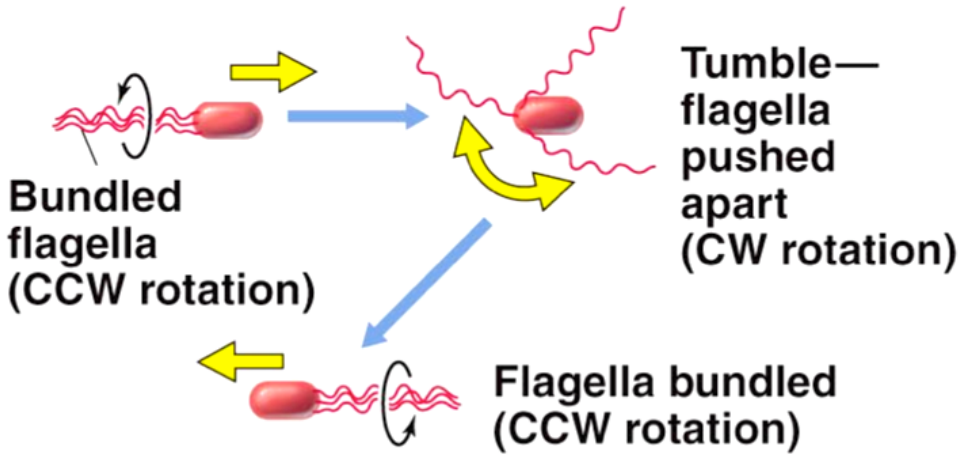
- If cell wall is present, different chemistry
  - no peptidoglycan
  - various types of cell wall, including pseudopeptidoglycan
- Typically no outer membrane
- S-layer most common cell envelope type among *Archaea*

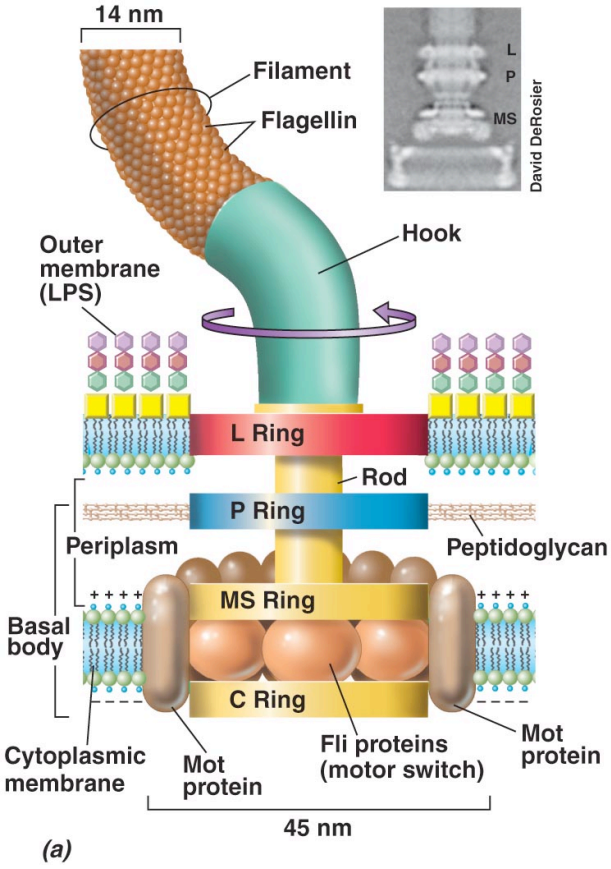
Microbial locomotion

- **Flagella and movement**
  - rotational speed increases or decreases in relation to strength of the proton motive force
  - peritrichously flagellated cells move slowly in a straight line
  - polarly flagellated cells move more rapidly and typically spin around
- **Gliding motility**
- **Microbial taxes**
  - directed movement in response to chemical or physical gradients (*e.g.*, chemotaxis, phototaxis, hydrotaxis, etc.)

Flagella

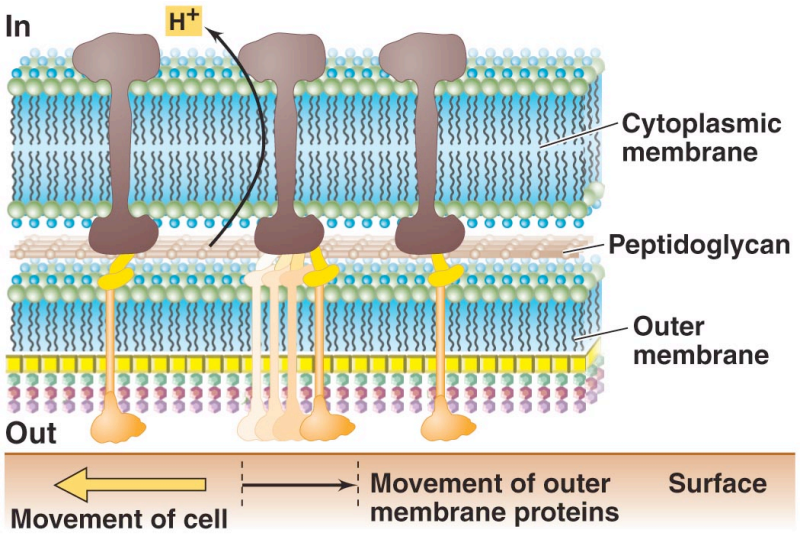
- Assists in swimming
- Helical in shape
- Filament composed of flagellin
- Move by rotation





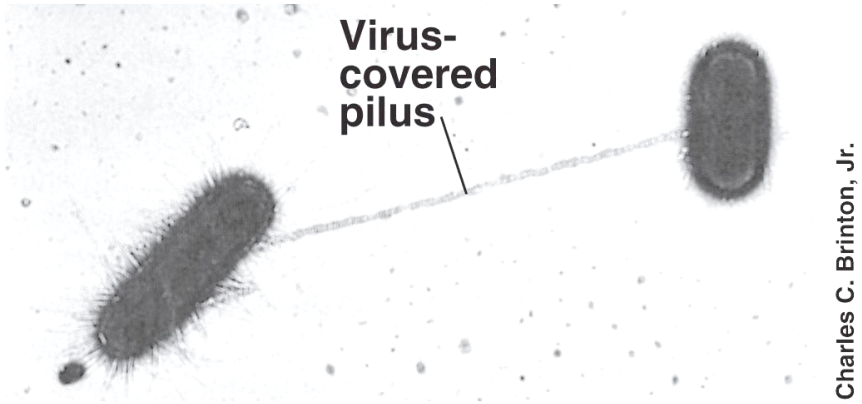
Gliding motility

- Flagella-independent motility
- Slower and smoother form of movement than swimming
- Movement typically occurs along long axis of cell
- Requires surface contact
- Mechanisms
  - excretion of polysaccharide slime
  - Type IV pili
  - gliding-specific proteins

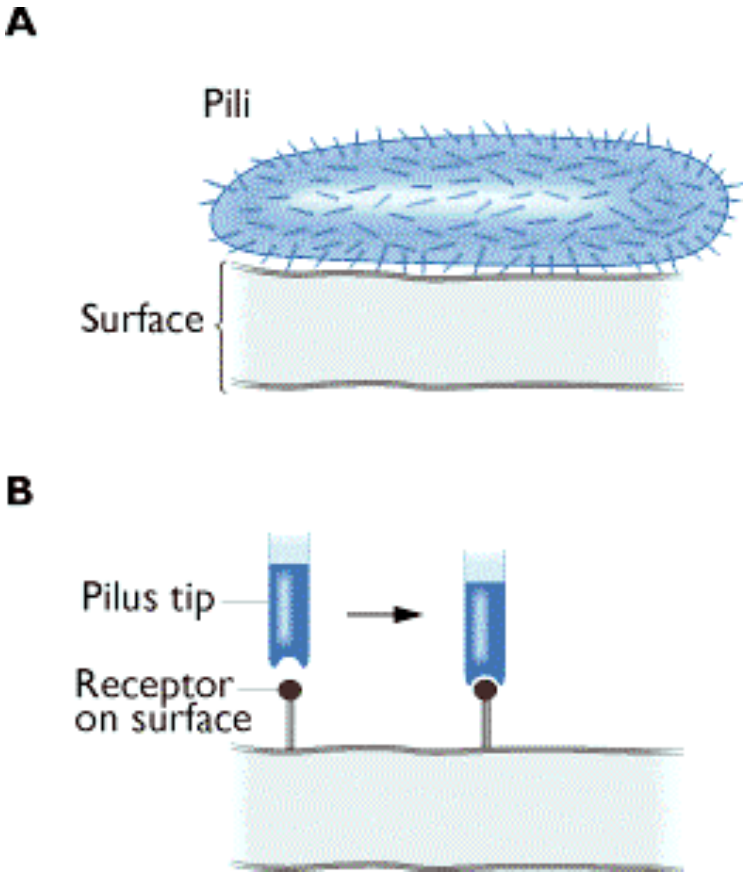


Bacterial attachment

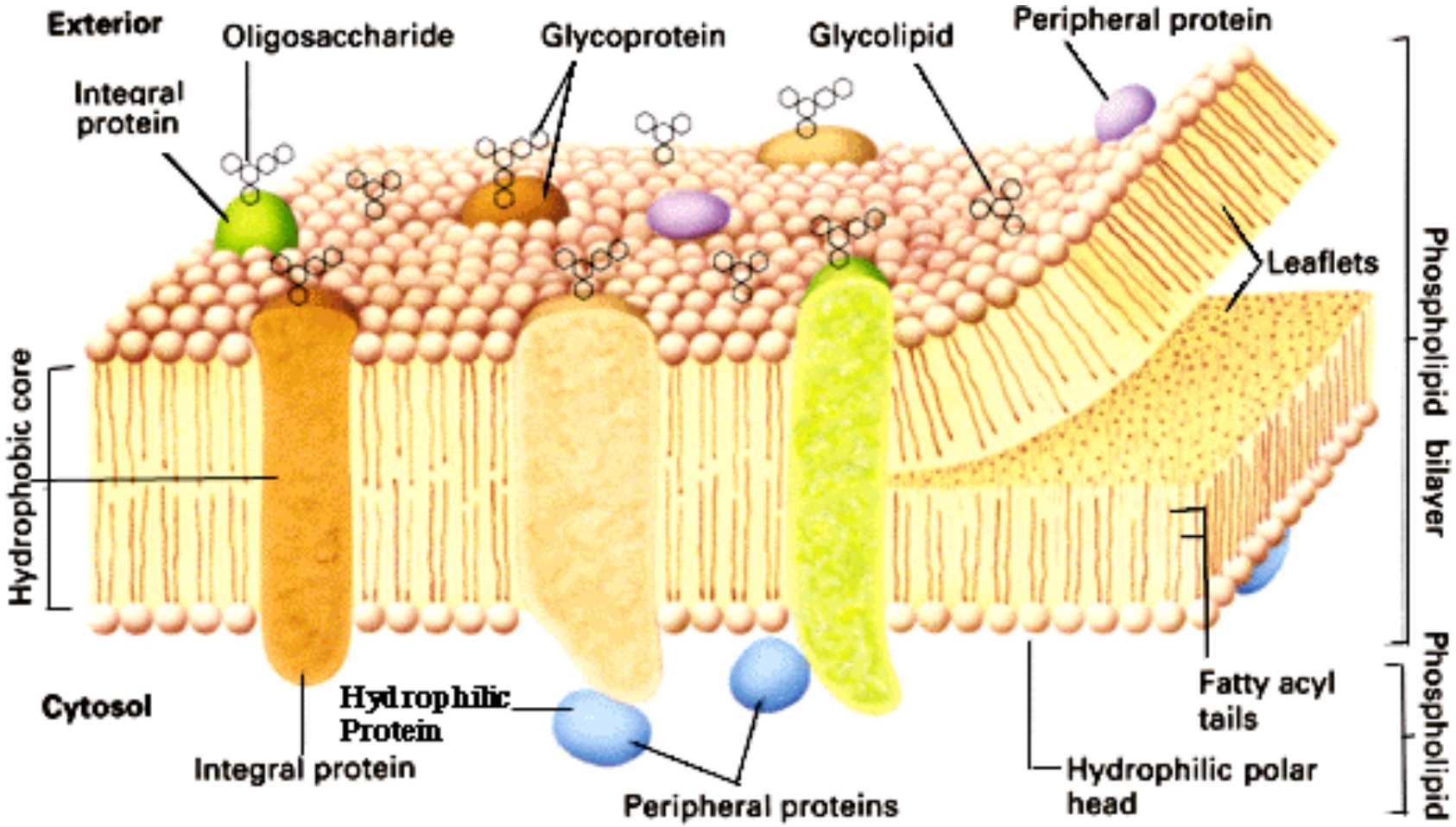
- **Fimbriae and pili**
  - **filamentous protein structure**
  - **assist in surface attachment**
  - **pili facilitate genetic exchange between cells**



Charles C. Brinton, Jr.

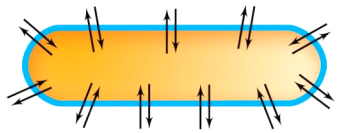


Cytoplasmic membrane

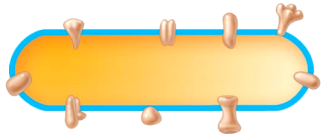


Cell membrane

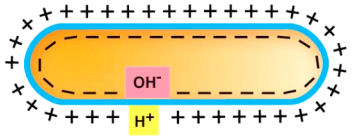
- Plasma membranes are 6-8 nm thick conserved structures throughout all living organisms
- Highly organized barrier with asymmetric topology and functions
- Capable of dynamically changing with the environment
- Major functions
  - retains the cytoplasm
  - selective barrier (molecule size and polarity)
  - transport
  - energy generation
  - synthesis



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



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



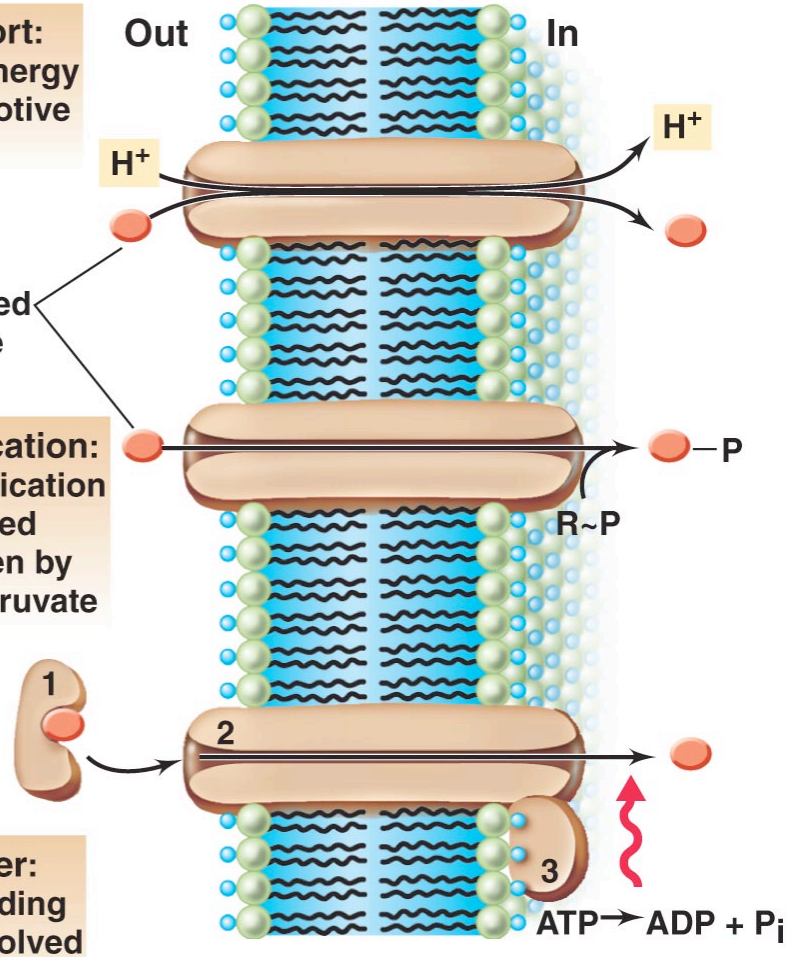
3. Energy Conservation — Site of generation and use of the proton motive force

Membrane transport systems

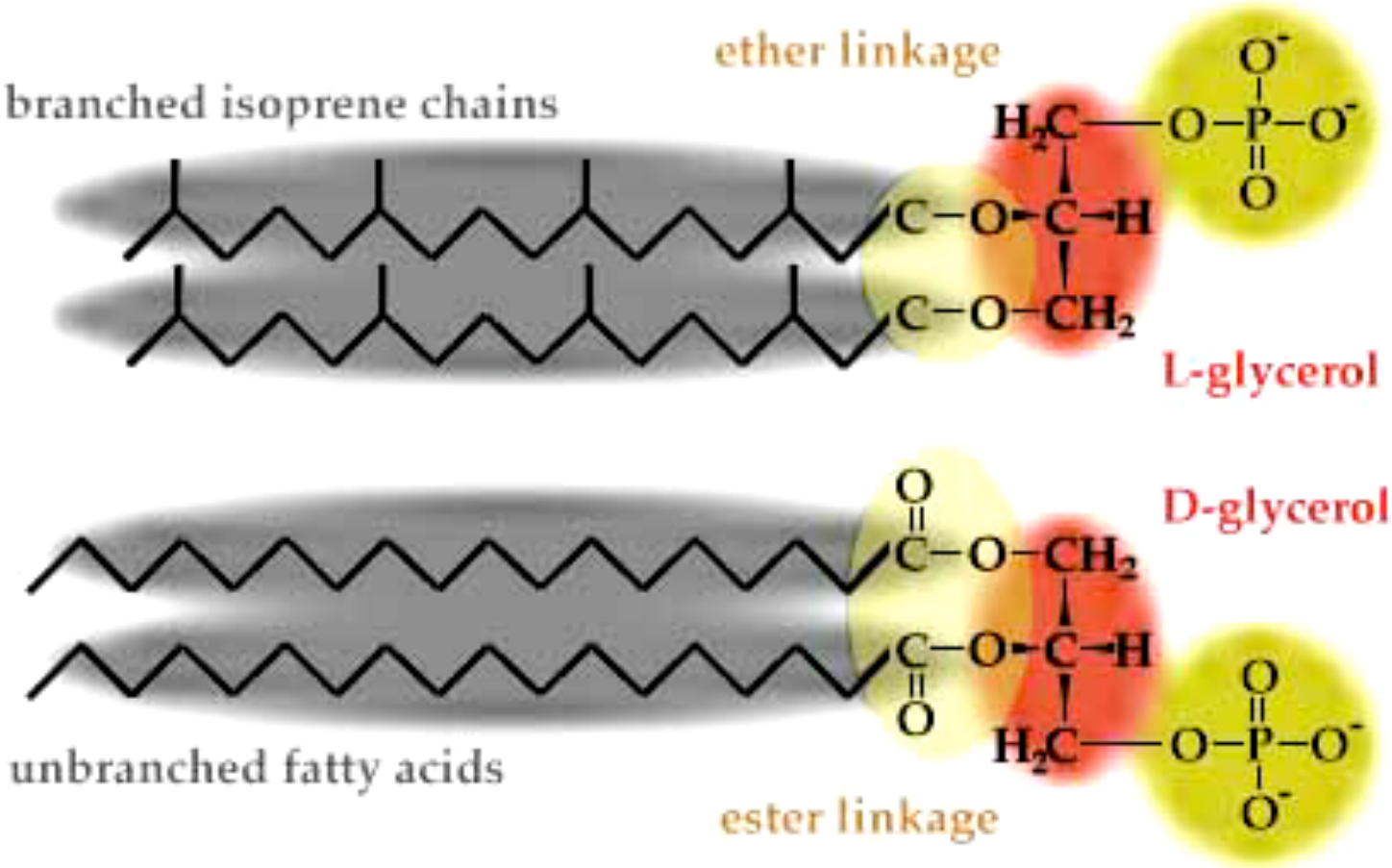
Simple transport: Driven by the energy in the proton motive force

Group translocation: Chemical modification of the transported substance driven by phosphoenolpyruvate

ABC transporter: Periplasmic binding proteins are involved and energy comes from ATP

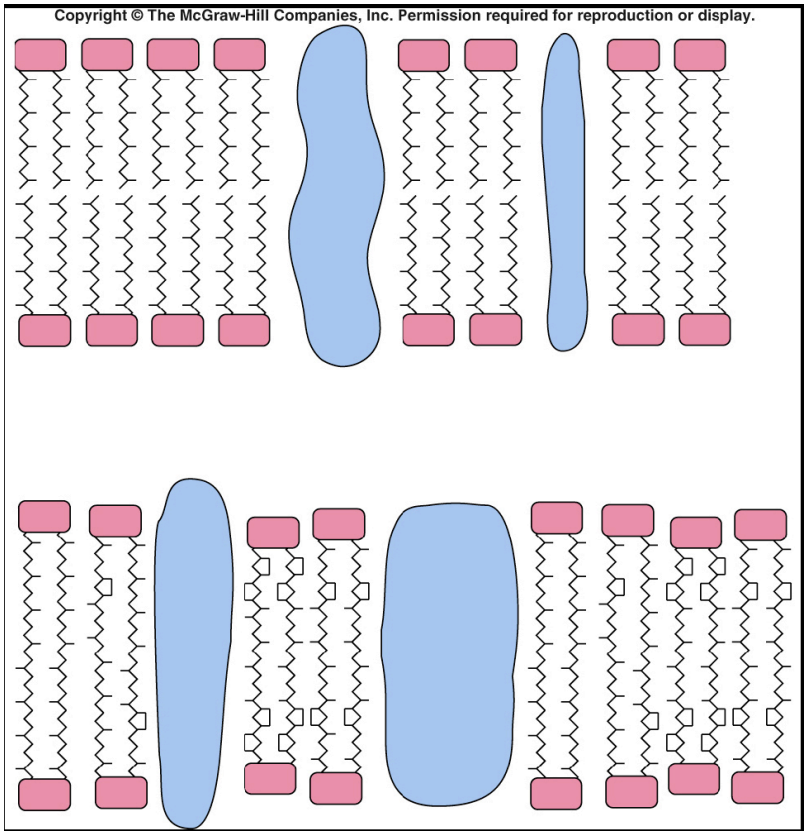


Bacterial and eukaryotic *vs.* archaeal plasma membranes



Cell membranes

- **Lipid bilayer as seen in most *Archaea* and all *Eucarya* and *Bacteria***
- **Lipid monolayer as found only in some archaeal organisms, especially in extreme thermophiles**



Cytoplasm

- Gel-like matrix within the cytoplasmic membrane
- Compartmentalization by special function in bacteria and archaea
  - examples
    - glycolysis
    - DNA synthesis enzymes around the replication fork
    - protein synthesis machinery
- Constituents
    - proteins, including enzymes
    - vitamins
    - ions
    - nucleic acids and their precursors
    - amino acids and their precursors
    - sugars, carbohydrates, and their derivatives
    - fatty acids and their derivatives

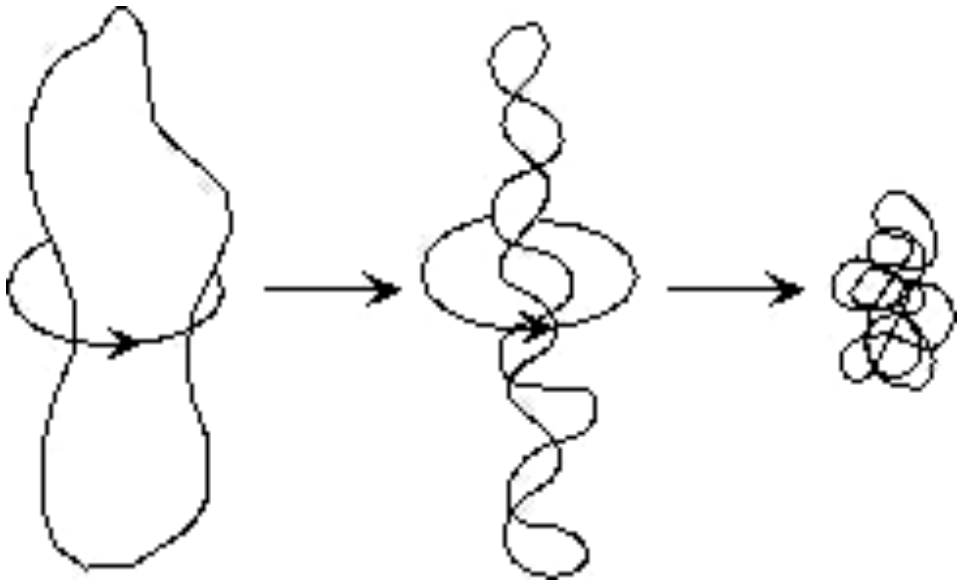
Bacterial and archaeal genome

- Cells lack a membrane defined nucleus
  - discrete region contains the genetic material and this nucleoid region can be distinguished on EMs of cells
  - bacterial and archaeal chromosome consists of a single, circle of deoxyribonucleic acid
  - histone-like proteins in *Archaea*
- Genome = DNA_{chrom} + $DNA_{extrachrom}$
- Circular and linear plasmids autonomously replicating

E. coli chromosome

- **Genome size**
  - **4.6 Mb = 1,400 µm**
- **Relaxed coil**
  - **430 µm**
- **Full complement with DNA-binding proteins**
  - **17 µm**
- **Cell size**
  - **2-3 µm**

?

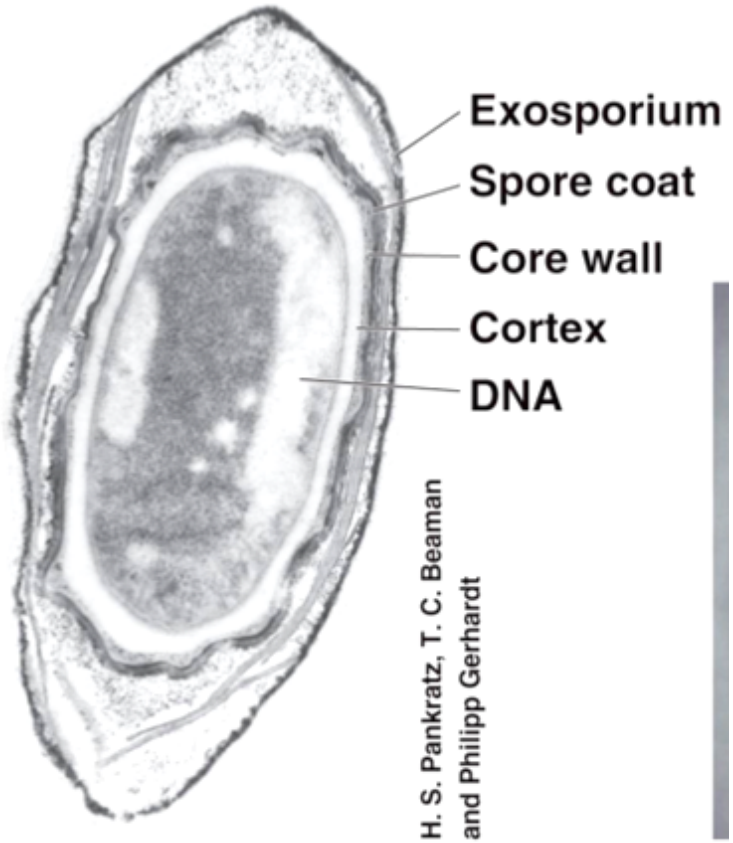


Bacterial and archaeal cell inclusions

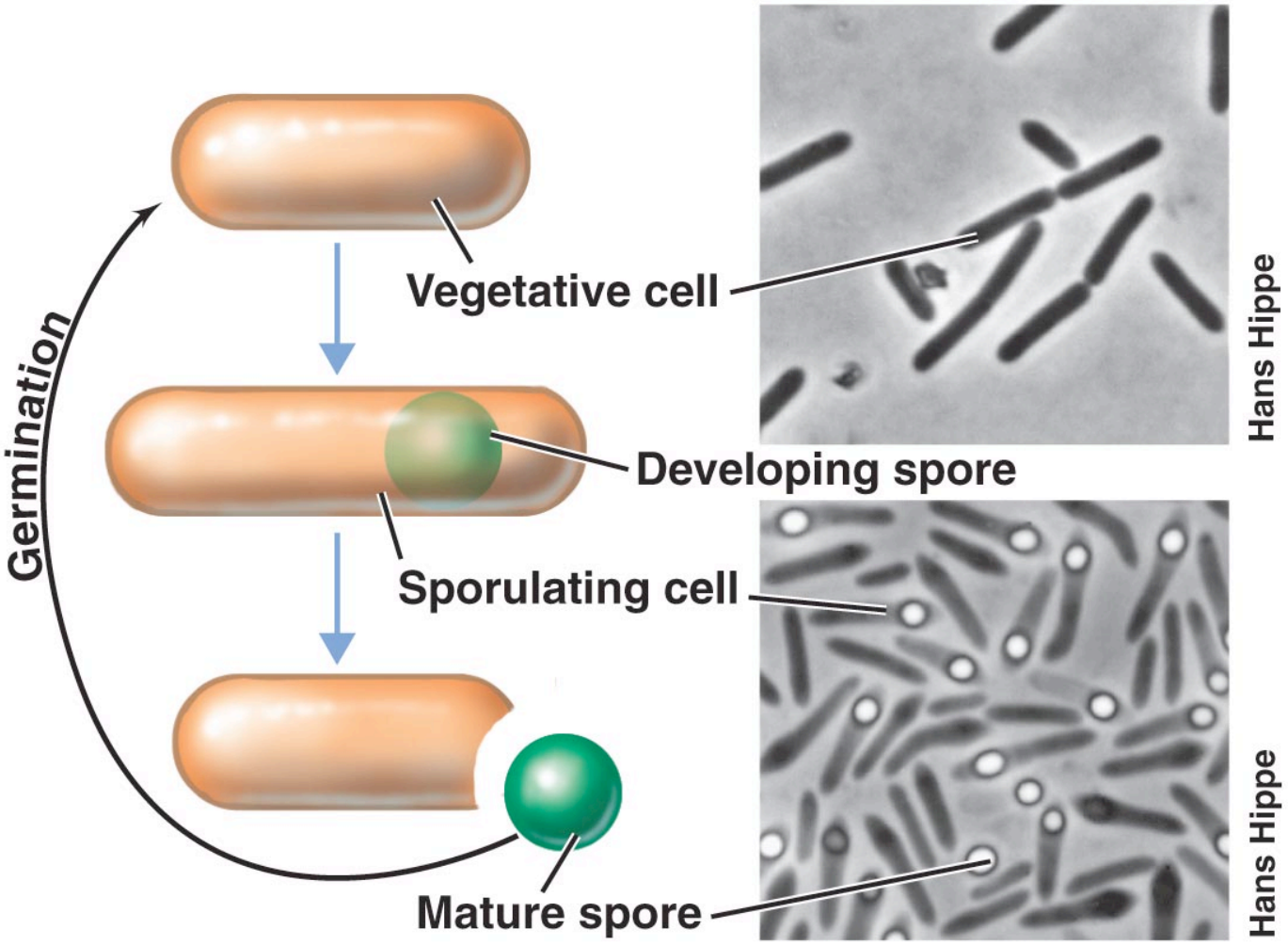
- **Carbon storage polymers**
  - poly-β-hydroxybutyric acid (PHB): lipid
  - glycogen: glucose polymer
- **Polyphosphates**
  - accumulations of inorganic phosphate
- **Sulfur globules**
  - composed of elemental sulfur
- **Magnetosomes**
  - magnetic storage inclusions
- **Gas vesicles**
  - confer buoyancy in planktonic cells
  - spindle-shaped gas-filled structures made of protein
  - gas vesicle membrane impermeable to water
  - function by decreasing cell density

Bacterial endospore

- Cellular differentiation process results in resting cells under unfavorable conditions
- Endospores are highly resistant to chemical and physical impact
- Dipicolinic acid and calcium ions may be responsible for the resistance
- Remains dormant for decades - even thousands of years
- Germinates to reform a vegetative cell when conditions improve



Bacterial endospore

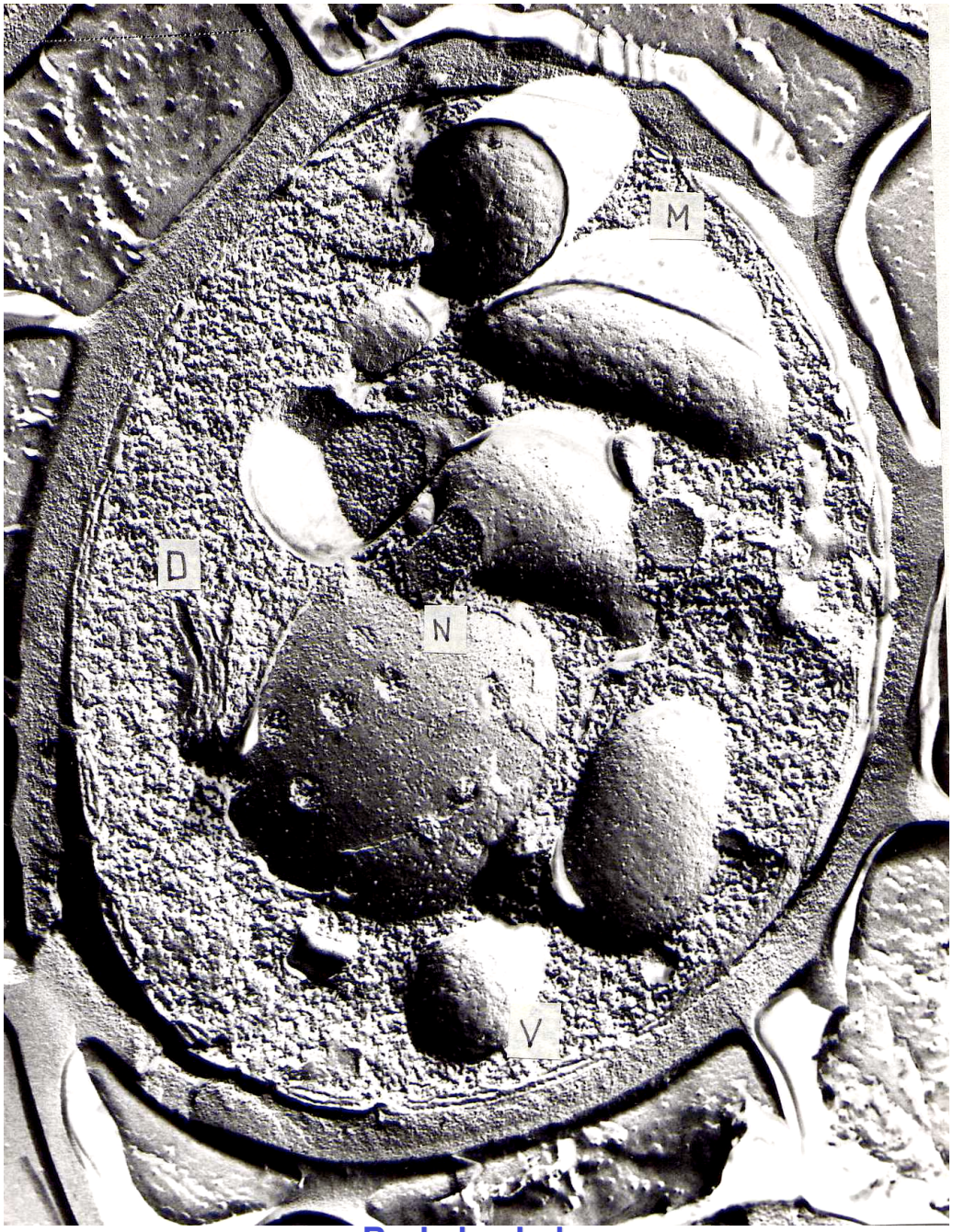


Archaeal cell

- **More differences in cell function**
  - **like *Bacteria*, *Archaea* have 70S ribsomes, but they have a different shape**
  - ***Archaea* have more complex RNA polymerases than *Bacteria*, similar to *Eucarya***
  - **archaeal tRNAs contain unique modifications not found in the other two domains**
  - **DNA stability - histones and DNA-binding proteins**
  - **protein stability due to different folding patterns**
- ***Archaea* are phylogenetically more similar to *Eucarya* than *Bacteria* is to either of them**
  - **indicates that the common progenitor of these groups existed very early in evolution**

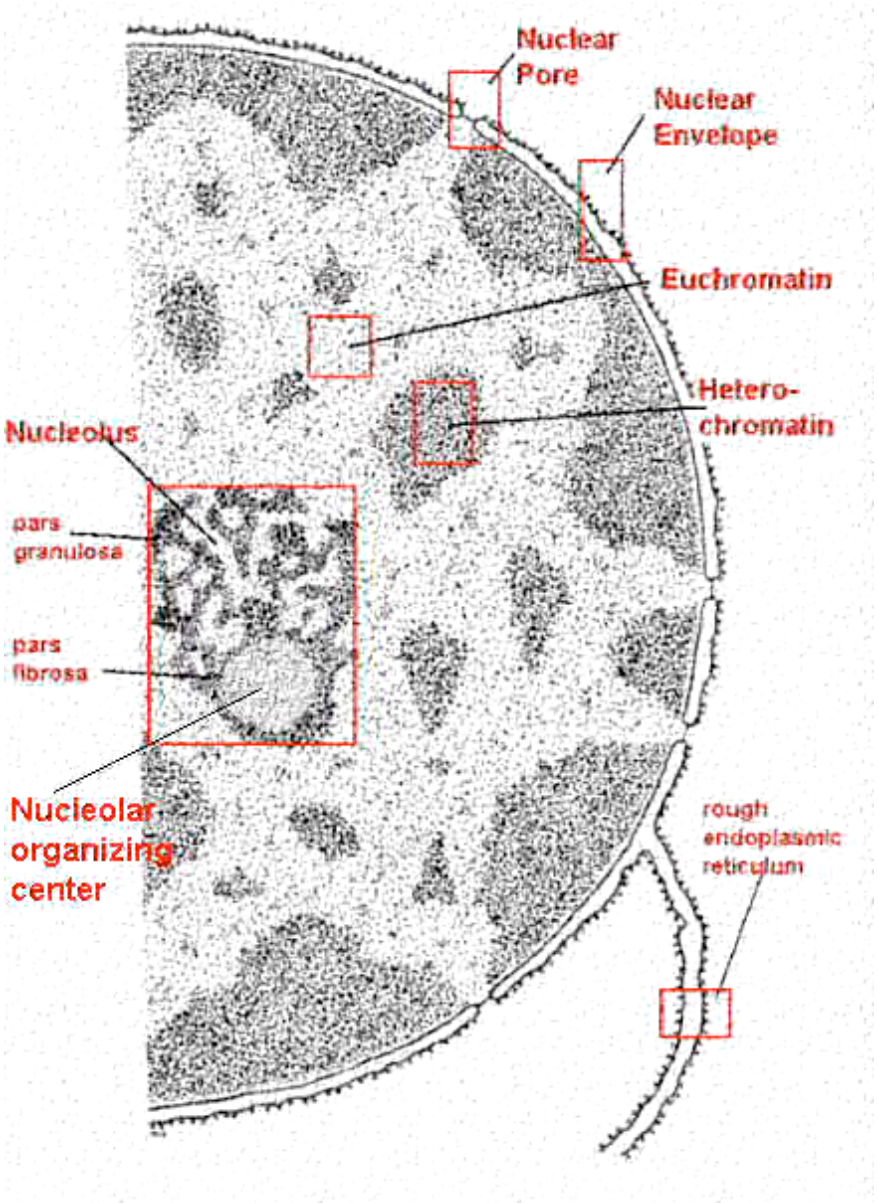
Eukaryotic cell

- **Cell envelop**
  - usually simpler than in *Bacteria* or *Archaea*
  - pellicle - protozoan cell envelop
  - glycocalyx - layers of sticky carbohydrates
  - cell wall - most often polysaccharide
- **Plasma membrane**
  - similar in function and basic structure as in *Bacteria* and *Archaea*
  - differences in membrane proteins and receptors
- **Cytoplasm**
  - highly organized
  - cytoskeleton provides support and shape to the cytosol
- **Cell organelles**


M
D
N
V

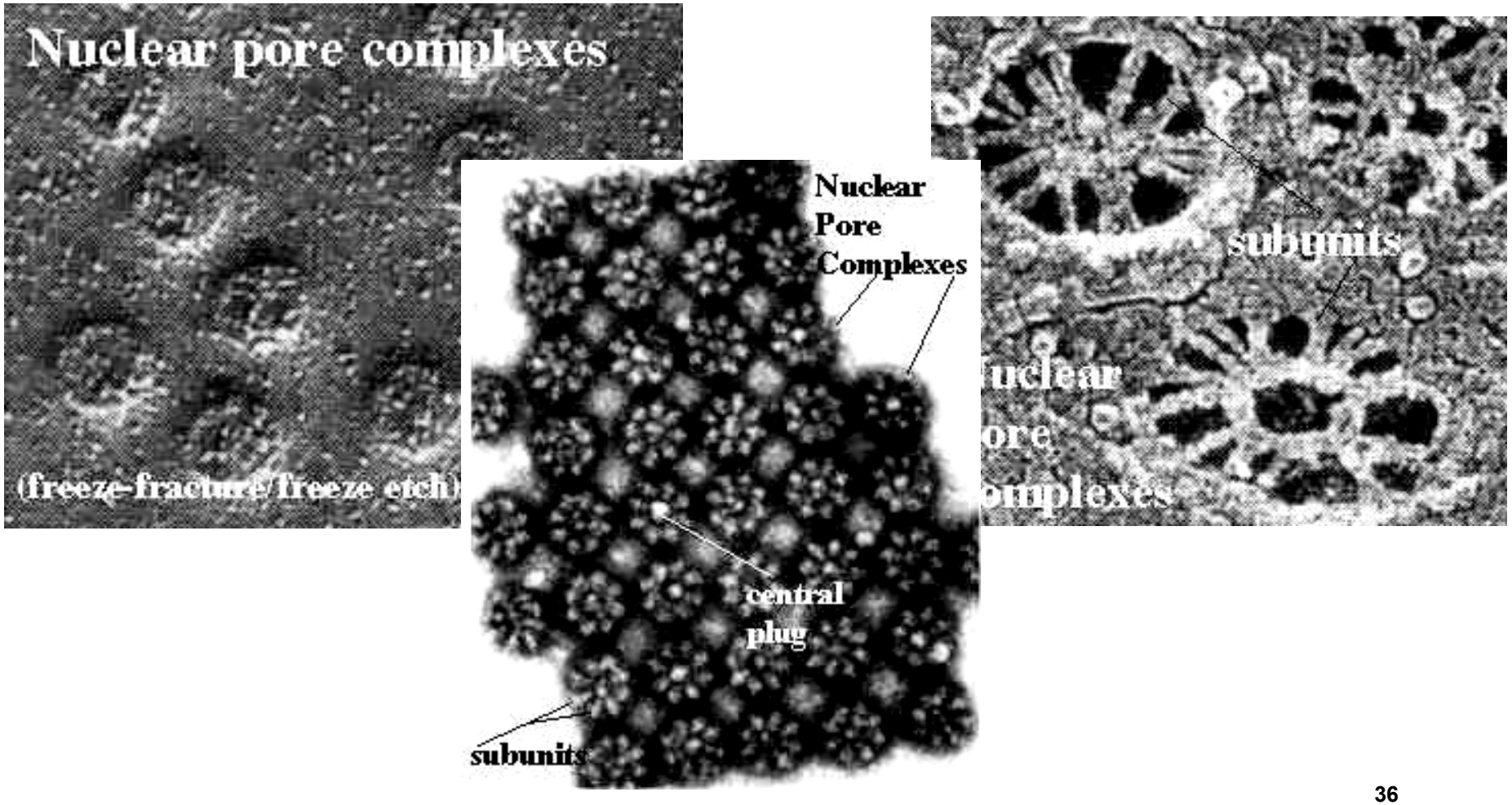
Cytoskeleton image

Nucleus

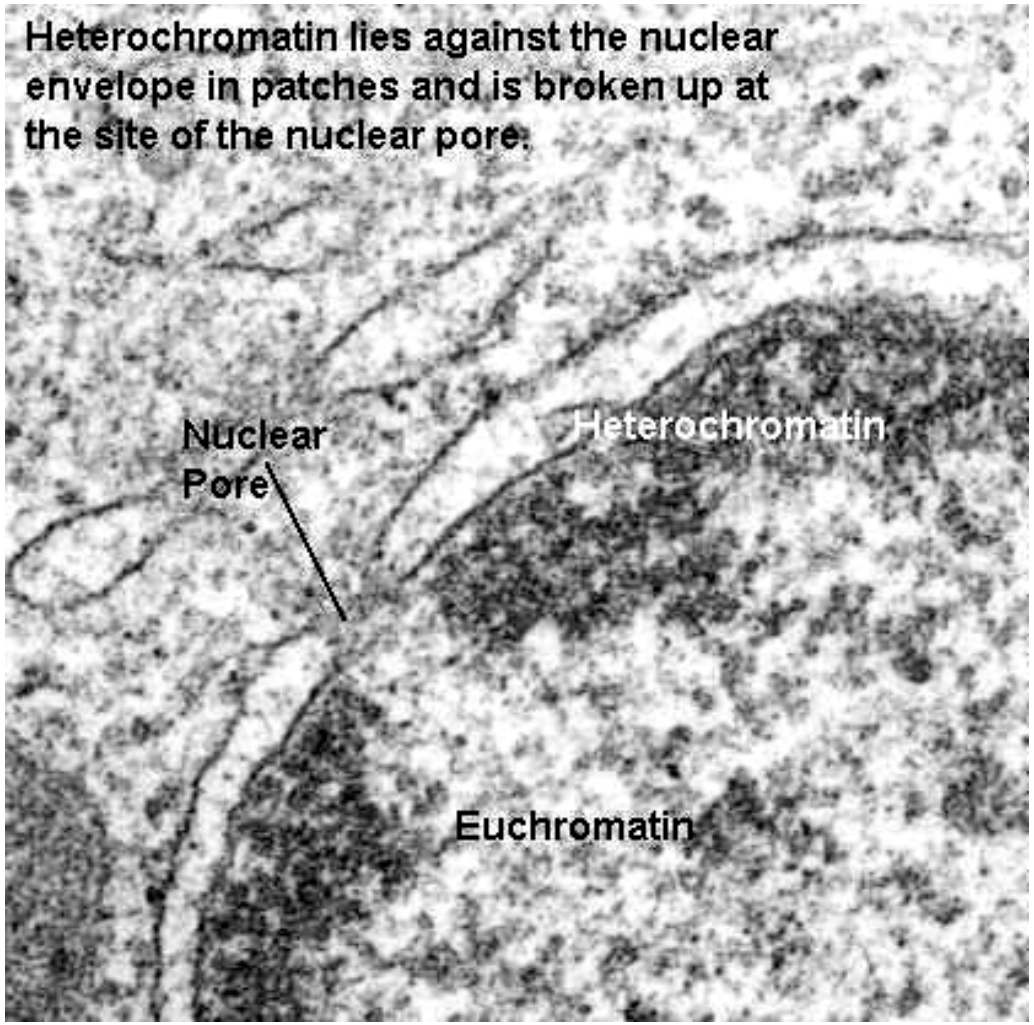


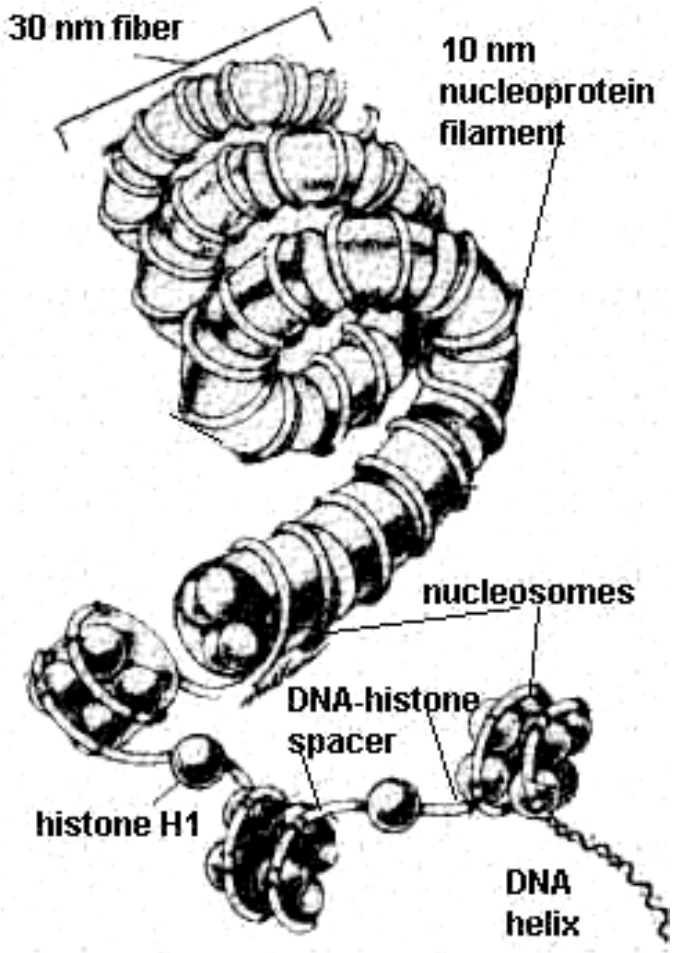
- Genetic material is enclosed by a nuclear membrane
- Nuclear pores
- Nucleolus is a dark spot on EM images

Imaging nuclear pores

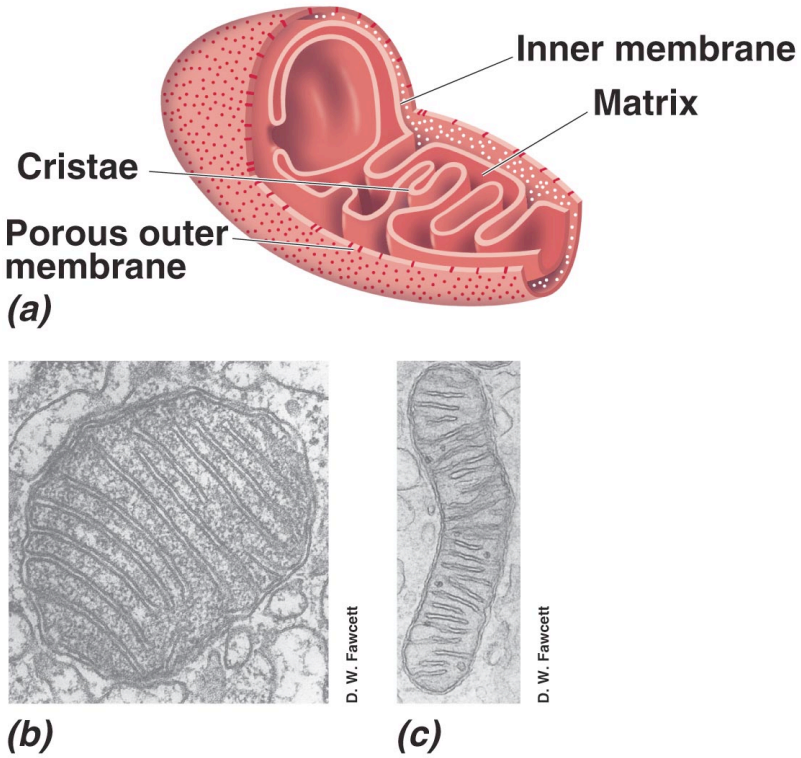


Chromosome organization





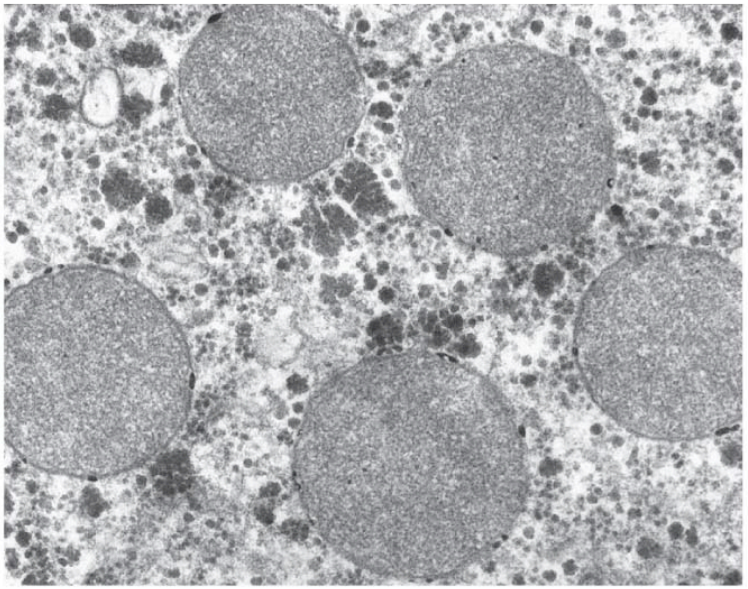
Mitochondrion



- Major energy production center
- Inner and outer membranes
- Evolution of mitochondria
  - mitochondria (and chloroplasts) contain DNA
  - eukaryotic nuclei contain genes derived from bacteria
  - mitochondria and chloroplasts contain their own ribosomes
  - antibiotic specificity
  - molecular phylogeny

Hydrogenosome

- Similar size to mitochondria
- Lack TCA cycle enzymes and cristae
- Oxidation of pyruvate to H_2, CO_2, and acetate
- Various ciliated protists have hydrogenosomes

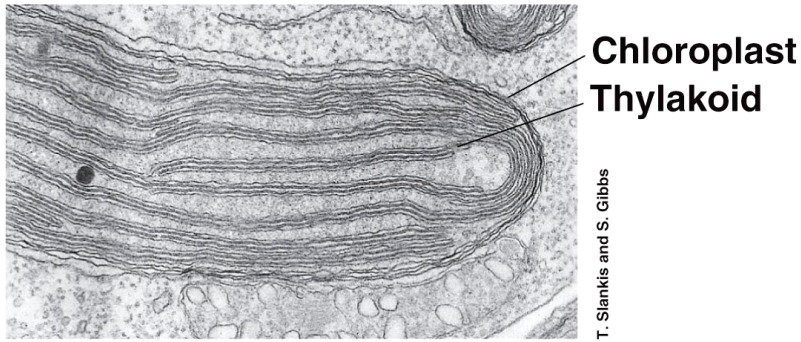


Helen Shio and Miklós Müller

(a)

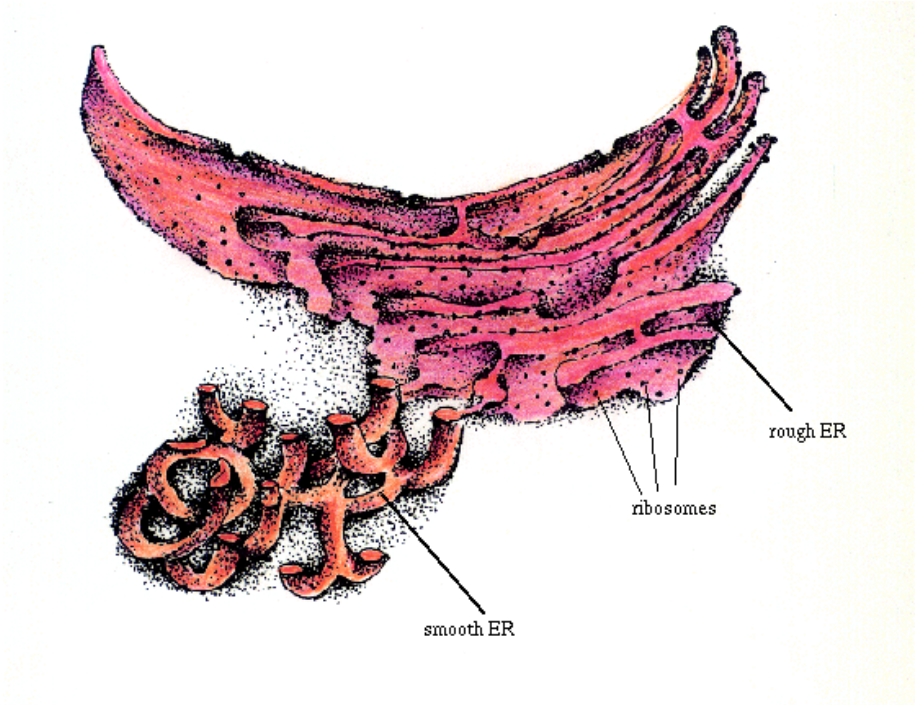
Chloroplast

- Chlorophyll-containing organelle found in phototrophic eukaryotes
- Size, shape, and number of chloroplasts varies
- Flattened membrane discs are thylakoids
- Lumen of the chloroplast is called the stroma, site of Calvin cycle

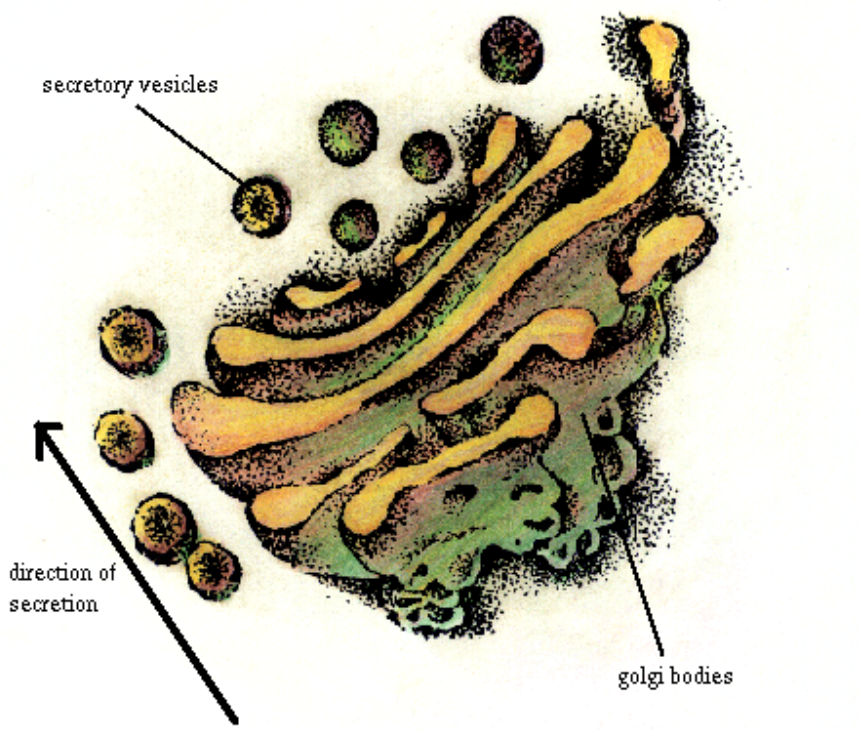


Endoplasmic reticulum

- **ER is the transport network for molecules targeted for certain modifications and specific final destinations, as opposed to molecules that are destined to float freely in the cytoplasm**



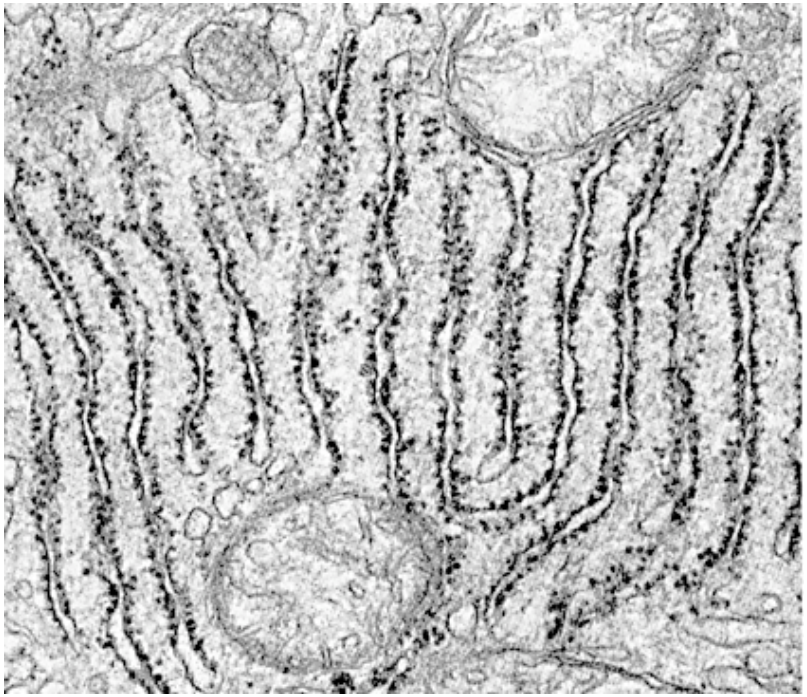
Golgi apparatus

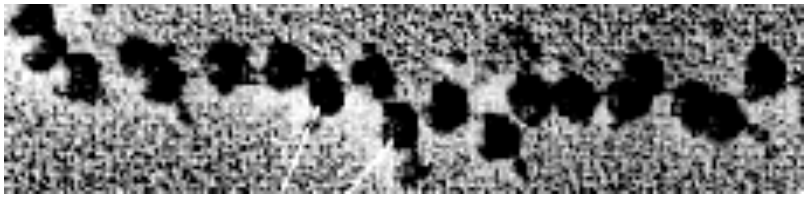


- Modifies molecules and packages them into small membrane bound sacs called vesicles
- Sacs can be targeted to various locations in the cell and even to its exterior

Ribosome

- Site of protein synthesis, where RNA is translated into protein
- Made up of 50 proteins and several long RNAs
- 80 S *vs*. 70 S in *Bacteria* and *Archaea*
- Disassembles into two sub-units when not actively synthesizing protein





Other organelles and eukaryotic cell structures

- **Lysosomes**
  - membrane-enclosed compartments
  - contain various digestive enzymes used for hydrolysis
  - allow for lytic activity to occur within the cell without damaging other cellular components
- **Peroxisomes**
  - oxidize various compounds

Other organelles and eukaryotic cell structures

- **Microtubules**
  - 25-nm diameter structures of α- and β-tubulin
  - maintain cell shape, in motility, in chromosome movement, and in movement of organelles
- **Microfilaments**
  - 7-nm diameter structures, polymers of actin
  - maintain cell shape, motility by pseudopodia, and cell division
- **Intermediate filaments**
  - 8–12-nm keratin proteins
  - maintain cell shape and position organelles in cell