Functional Anatomy of Prokaryotic and Eukaryotic Cells
(Chapter 4)

Lecture Materials

for

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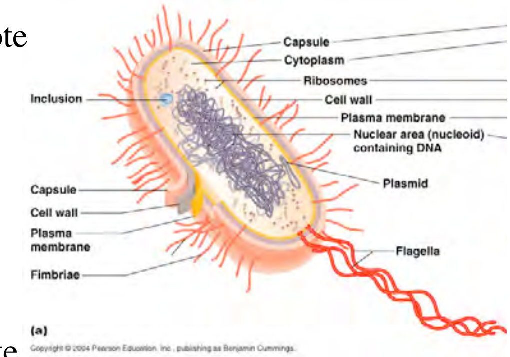
Primary Source for figures and content:

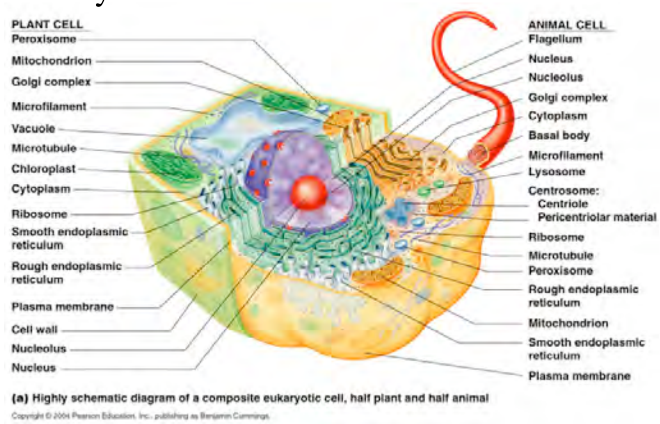
Tortora, G.J. Microbiology An Introduction 8th, 9th, 10th ed. San Francisco: Pearson Benjamin Cummings, 2004, 2007, 2010.

General Comparisons
(on handout)

Prokaryote



Eukaryote

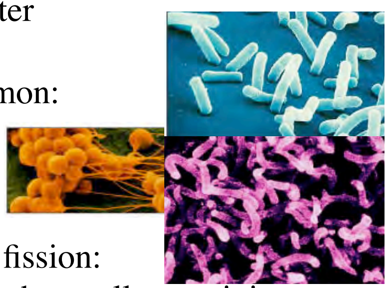


(a) Highly schematic diagram of a composite eukaryotic cell, half plant and half animal

The Prokaryotic Cell

-“pre-nucleus”
-bacteria and archaea

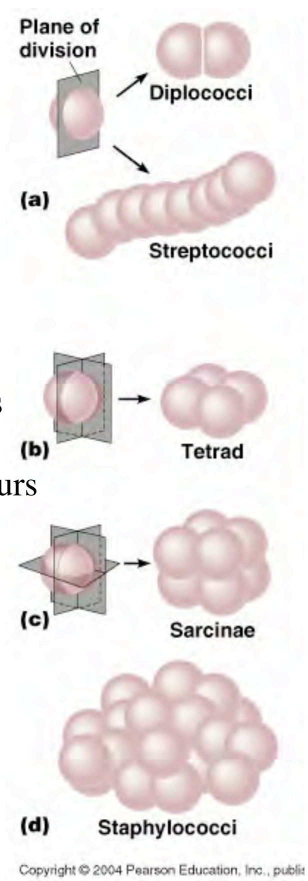
Size, shape & arrangement:
- 0.2-2.0μm diameter
- 2-8 μm length
- three shapes common:
  - coccus = sphere
  - bacillus = rod
  - spiral = twisted



-division by binary fission:
can result in daughter cells remaining loosely adhered along the division plane resulting in characteristic arrangements
(arrangements on handout)

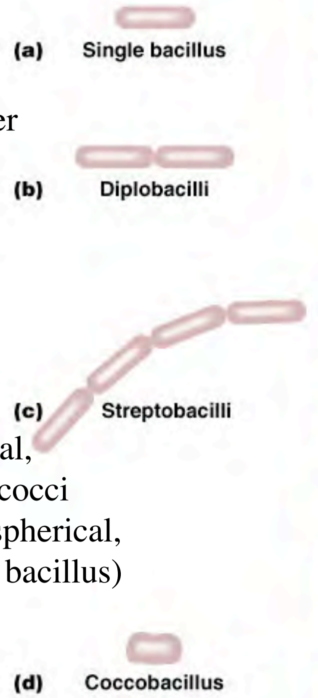
Cocci

-single coccus: daughter cells separate
-diplococcus: 2, flat on adjacent sides
-streptococci: chain, all cells divide in same plane
-tetrad: 4, division occurs in two planes
-sarcinae: 8, division occurs in three planes
-staphylococci: group, cluster, cells divide in random planes



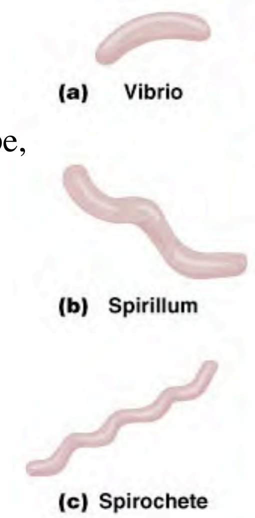
Bacilli
-rods of various length:
oval to "hot dog"
-rods divide only along
the short axis

-single bacillus: daughter
cells separate
-diplobacilli: 2
-streptobacilli: chain



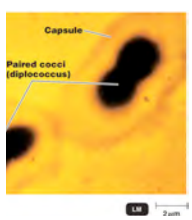
-coccobacillus: short oval,
often confused with cocci
(cocci are perfectly spherical,
any ovalish shape = bacillus)

Spiral
-one or more twists
-vibrio: curved rod
-spirillum: rigid helical shape,
move via flagella
-spirochete: flexible helical
shape, move via
axial filaments

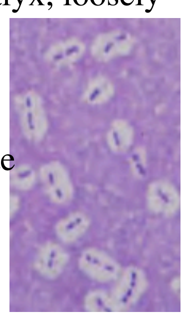


Most bacteria are monomorphic:
always one shape
Some are genetically pleomorphic: have
varied shapes within the population of a
single species

<u>Structure of the Prokaryotic Cell</u>
(general cell on handout)
*Not all cells have all structures!
1). Glycocalyx

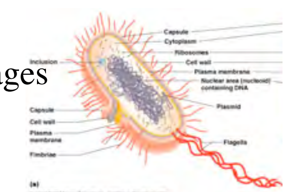


glycocalyx = external, outermost
surface layer of secreted carbohydrate-rich
gelatinous material, usually sticky or slimy
capsule = organized glycocalyx, firmly
attached to cell wall
slime layer = unorganized glycocalyx, loosely
attached to cell wall

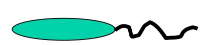


glycocalyx functions:
-promote biofilm formation
-allow cell adhesion to substrate
or host tissues
-protect cell from dehydration
-protect cell from nutrient loss
-protect cell from phagocytosis
(capsules are required for some
pathogenic bacterial to be virulent)
(virulence = ability to cause disease)

2). Flagella
-long, filamentous appendages
-used for motility
-arrangements:

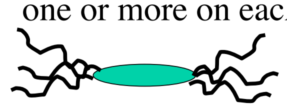


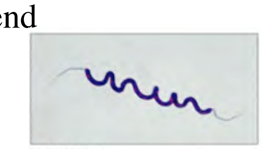
1. monotrichous:
one on one end



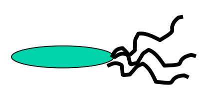

(a) Monotrichous

2. amphitrichous:
one or more on each end



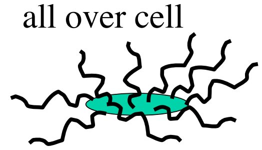

(b) Amphitrichous

3. lophotrichous:
two or more on one end



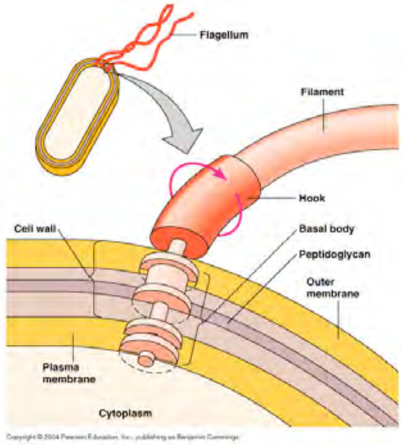

(c) Lophotrichous

4. peritrichous:
all over cell




(d) Peritrichous

-structure:
(handout)



a. filament:
- -made up of intertwined chains of flagellin protein
- -hollow core
- -sticks out beyond plasma membrane and cell wall

b. hook:
- -provides rotational movement of flagella
- -solid, composed of hook protein

c. basal body:
- -rod and disc structure
- -anchors flagellum to cell wall

flagellum rotates to cause taxis of bacteria

taxis = movement, usually toward or away from a stimulus (chemotaxis, phototaxis)

Salmonella monotrichous flagella

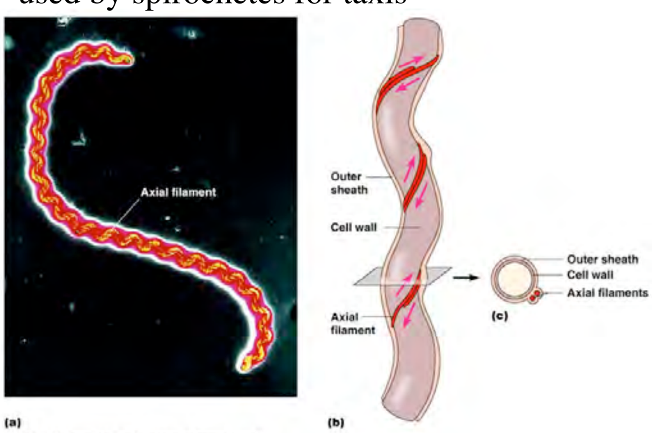
Play SalmonellaFlagella.mov

Flagella Movements   Play flagella_movement.swf

3). Axial Filaments

-a.k.a. endoflagella

-used by spirochetes for taxis

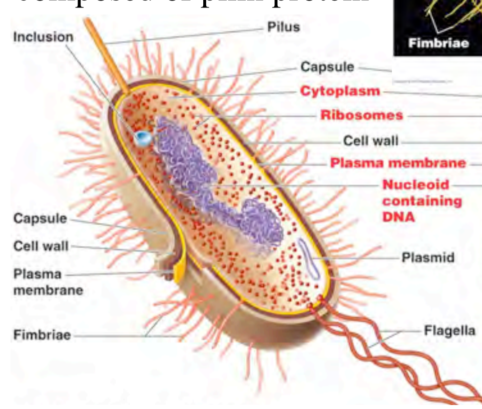


- -consist of flagella-like structures wound around spirochete under the outer sheath
- -rotation of filaments produces cork-screw rotation of sheath and thus whole spirochete
- -rotation allows penetration of secretions and tissues

4). Fimbriae and Pili

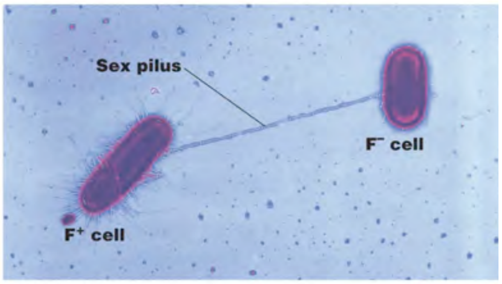
-short, hair-like appendages

-composed of pilin protein



Fimbriae:
- -at poles or all over surface
- -up to few hundred per cell
- -"fuzzy" coat used for adherence

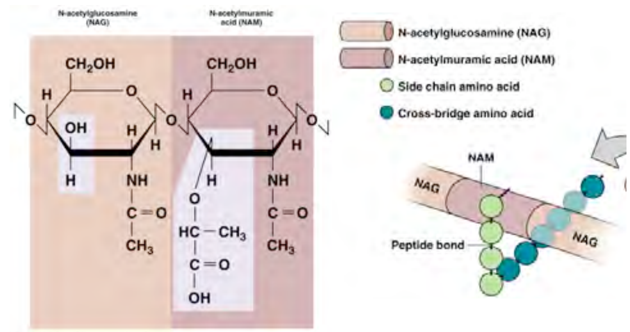
Pili/Pilus:
-usually one, if present
-used to transfer DNA to neighboring cell
("conjugation/sex pilus")



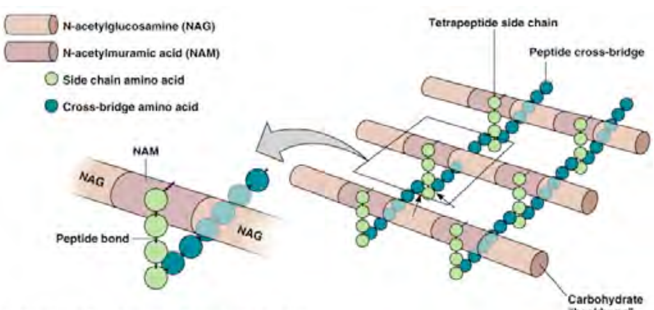
(a) Sex pilus

-more rarely, some types used for movement
via pilus retraction
*twitching motility
short, jerky
*gliding motility
through biofilms

5). Cell Wall
-located outside the cell/plasma membrane
-gives cell its shape
-provides protection
-resists osmotic lysis
-provides anchorage point for flagella
composition:
-in bacteria = peptidoglycan (aka murein):
-lattice of disaccharides and polypeptides
-repeating disaccharide chains formed by
two monosaccharides linked end to end:
NAG (N-acetylglucosmine)
NAM (N-acetylmuramic acid)

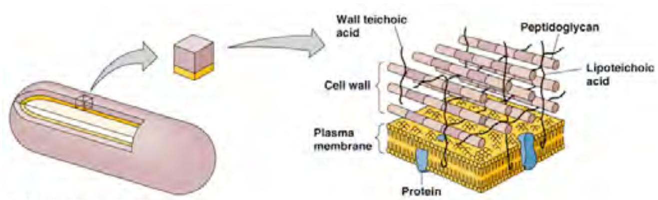


-disaccharide chains are held together by
polypeptides to form a tight wall
(handout)



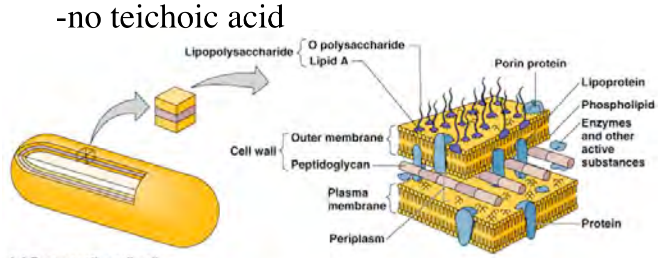
(a) Structure of peptidoglycan in gram-positive bacteria

-Two common cell wall types in bacteria:
can be distinguished by a staining
procedure (Gram's Stain)
(handout)
1. Gram Positive Cell Walls
-thick, many layers of peptidoglycan,
strong, rigid
-also contain teichoic acids (neg. charge,
may regulate cation movement)



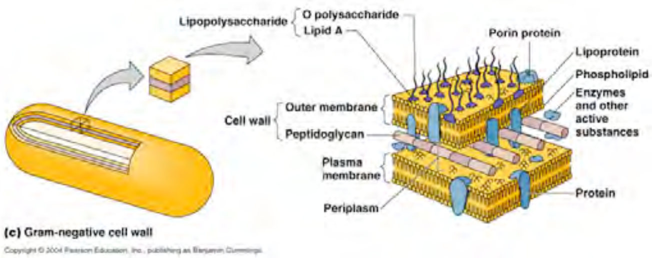
(b) Gram-positive cell wall

*G+wall = thick peptidogycan + teichoic acid
2. Gram Negative Cell Wall
-has an outer membrane
-periplasmic space between outer
membrane and cell membrane houses
the peptidoglycan in periplasm
-few layers of peptidoglycan, thinner,
weaker
-no teichoic acid



(c) Gram-negative cell wall

*G-wall = outer membrane + thin peptidogycan in periplasm

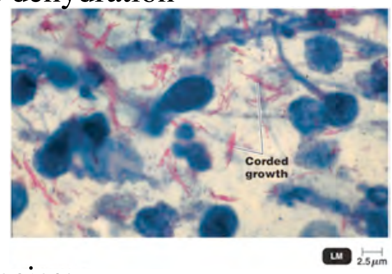


(c) Gram-negative cell wall

-outer membrane:
- -composed of phospholipids, lipoproteins, and lipopolysaccharide (LPS)
- -has porins to allow exchange with environment
- -functions of outer membrane:
  - -evade phagocytosis
  - -avoid action of complement
  - -chemical barrier: resist antibiotics, digestive enzymes, detergents, heavy metals, dyes, etc.
- -LPS is toxic to animals (Lipid A portion) causes endotoxic shock

Unusual wall structures

1. *Mycobacterium* species:
   - -Gram+ structure with mycolic acids
   - - (waxy) resists dehydration



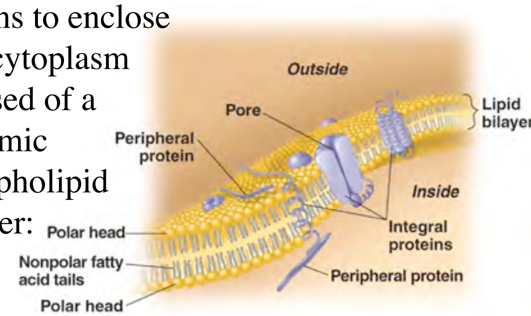
2. *Mycoplasma* species:
   - -smallest bacteria
   - -no cell wall
   - -have sterols in membrane (resist osmotic lysis)
3. Archaea
   - -either no walls or
   - -walls consisting of pseudomurein (different carbohydrate)

-Many antimicrobial drugs target bacterial cell walls:
- -safe target, chemical structure not found in animals
- e.g. Penicillin: prevents peptide crosslinking, prevents formation of functional wall in growing cells
- e.g. Lysozyme:
  - -enzyme produced by some eukaryotes
  - -found in human secretions
  - -digests the NAG-NAM linkages
  - -weak wall = osmotic cell lysis
  - -most effective against Gram+ (outer membrane protects Gram-)

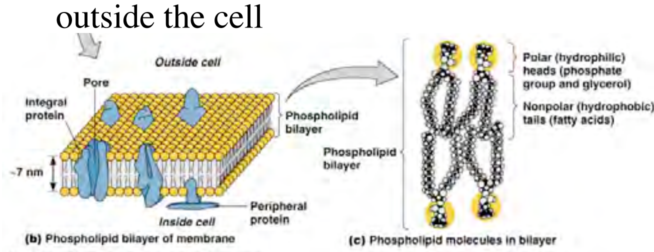
Penicillin effects on growing *Bacillus*

Play CellLysis.mpg

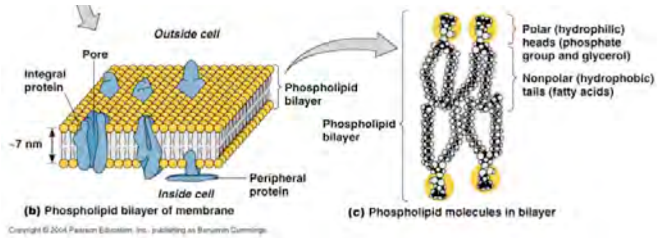
6). Plasma Membrane / Cell Membrane / Cytoplasmic Membrane
- -located inside the cell wall
- -functions to enclose the cytoplasm
- -composed of a dynamic phospholipid bilayer:



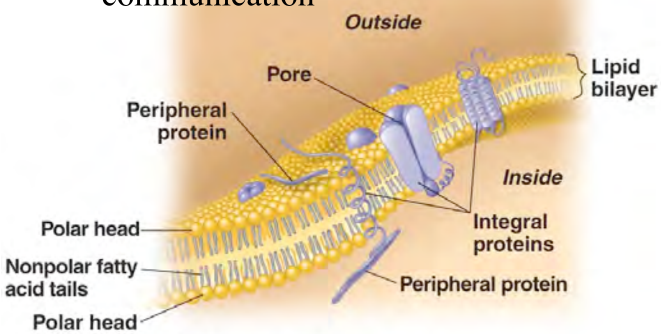
  - -phosphate + glycerol = hydrophilic end
  - -fatty acid tails = hydrophobic end
- -membrane self forms into bilayer to protect hydrophobic regions from water inside and outside the cell



(b) Phospholipid bilayer of membrane
(c) Phospholipid molecules in bilayer



-membrane has associated proteins
  peripheral proteins: at surface
    -enzymes for metabolic reactions
    -support, communication
  integral proteins / transmembrane proteins: span width of bilayer
    -channels for transport
    -communication



Membrane functions as a semi-permeable barrier: allows passage of some materials, prevents passage of others

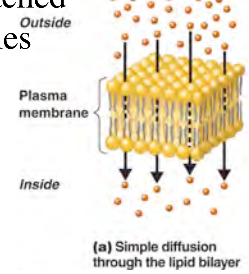
Movement of materials across the membrane is regulated

Transport can be passive (no ATP) or active (requires ATP energy)

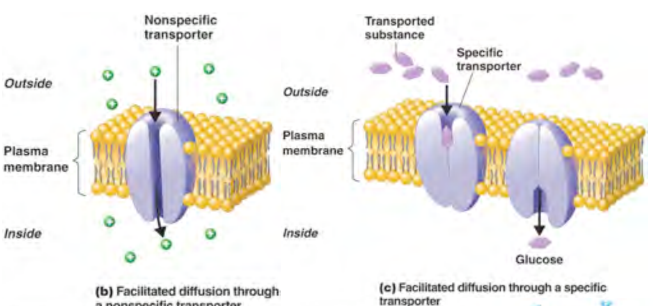
Passive Transport Processes

-substances move from area of high concentration to area of low concentration with no energy from the cell

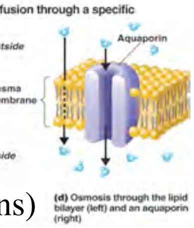
1. Simple diffusion
  -molecules or ions move from high to low concentration across the lipid membrane until equilibrium is reached
  -gasses, nonpolar molecules



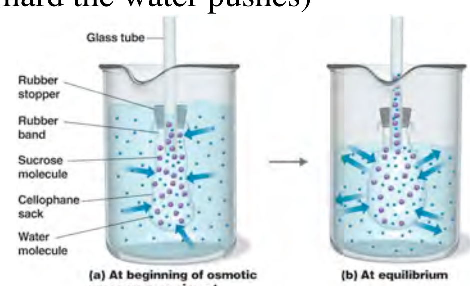
2. Facilitated diffusion
  -diffusion that requires a transport protein: a channel, transporter or permease
  -necessary for large or polar molecules that cannot pass through the lipid membrane



3. Osmosis
  -diffusion of water across a semi-permeable membrane (through lipids or aquaporins)
  -water moves to areas of high solute concentration when solutes cannot diffuse (water moves from the water high to the water low)



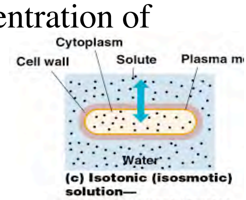
-diffusing water creates osmotic pressure = the amount of pressure required to prevent the movement of pure water into a solution containing solutes (how hard the water pushes)



A cell cannot control osmosis, it can only tolerate or counteract water movement

All cells must deal with tonicity conditions in the environment:

-isotonic solution: has a concentration of solutes equal to that inside the cell, no net movement of water

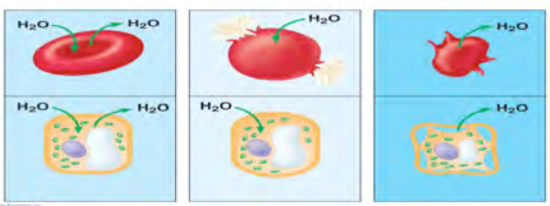


-hypotonic solution: has a concentration of solutes that is lower than inside the cell, net movement of water into the cell (can cause osmotic lysis, especially in cells without a wall or with weakened wall)

(d) Hypotonic (hypoosmotic) solution—water moves into the cell and may cause the cell to burst if the wall is weak or damaged (osmotic lysis)

(e) Hypertonic (hyperosmotic) solution—water moves out of the cell, causing its cytoplasm to shrink (plasmolysis)

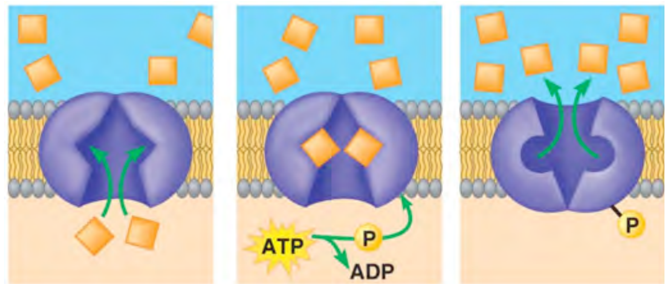
-hypertonic solution: has a concentration of solutes that is greater than inside the cell, net movement of water out of the cell (can cause plasmolysis of cells with walls and crenation of wall-less cells)



Active Transport Processes

-cell uses energy (ATP) to move substances from areas of low concentration to high (against the diffusion gradient)

1. Active transport:
   - -uses transport proteins that require ATP energy to "pump" substances against the concentration gradient



2. Group translocation:
   - -active transport where the substance is chemically altered during transport to make it membrane impermeable so it cannot diffuse back

-The plasma membrane of prokaryotes contains many metabolic enzymes (no membrane bound organelles):

- -enzymes involved in ATP synthesis along inside surface
- -infoldings called chromatophores contain enzymes for photosynthesis

-any disruption of the membrane structure will allow leakage of the cellular contents e.g. alcohols and detergents

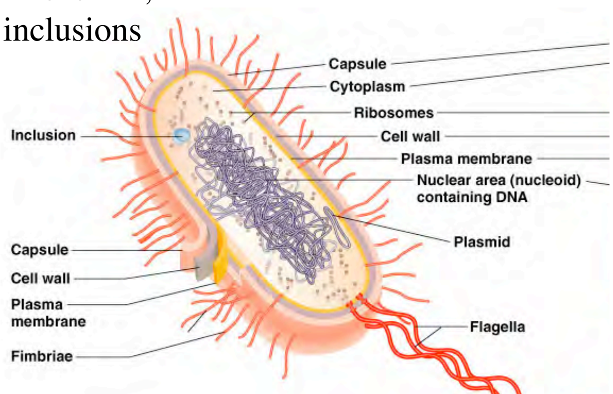
-damage to the membrane can cause cell lysis which results in cell death

7). Cytoplasm

-the substance contained by the plasma membrane

-~80% water with proteins (enzymes), carbohydrates, lipids, ions

-includes some solid structures:
- nucleoid,
- ribosomes,
- inclusions

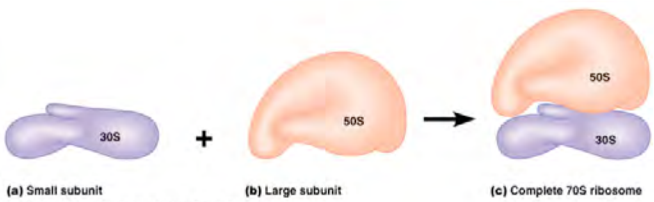


8). Nuclear Area / Nucleoid

-location of the bacterial chromosome:
- -long loop of DNA, attached to the plasma membrane, genetic info of cell

Some bacteria also contain plasmids
Plasmid = small circular DNA element
- -separate from the genome
- -does not contain any essential genes
- -has 5-100 “bonus” genes (e.g. drug resistance, capsules, toxins, enzymes...)
- -plasmids replicate independent of the host genome, can be passed to other cells
- -plasmids can be found throughout the cytoplasm

9). Ribosomes
-site of protein synthesis
-composed of rRNA and protein
-consist of 2 subunits:
30s + 50s = 70s prokaryotic ribosome



(ribosomes are another common antimicrobial drug target because the prokaryotic 70s ribosome is very different from the eukaryotic 80s ribosome)

10). Inclusions
-all tend to be storage deposits
a. Metachromatic granules:
- -inorganic phosphate (for ATP)

b. Polysaccharide granules:
- -glycogen and starch (energy)

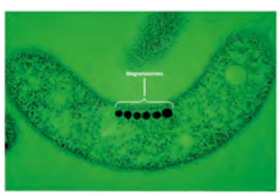
c. Lipid droplets
- -fats (energy)

d. Sulfur granules
- -in sulfur bacteria only
- -use sulfur in ATP production

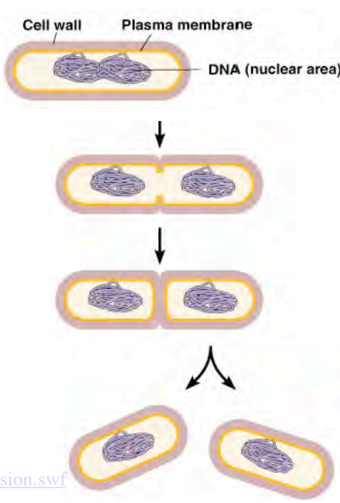
e. Carboxysomes
- -contain the enzyme to fix CO_2 during photosynthesis

f. Gas vaculoles
- -air bags, provide buoyancy in water

g. Magnetosomes
- -iron oxide deposits
- -allow detection of earth’s magnetic field (orientation)
- -break down hydrogen peroxide

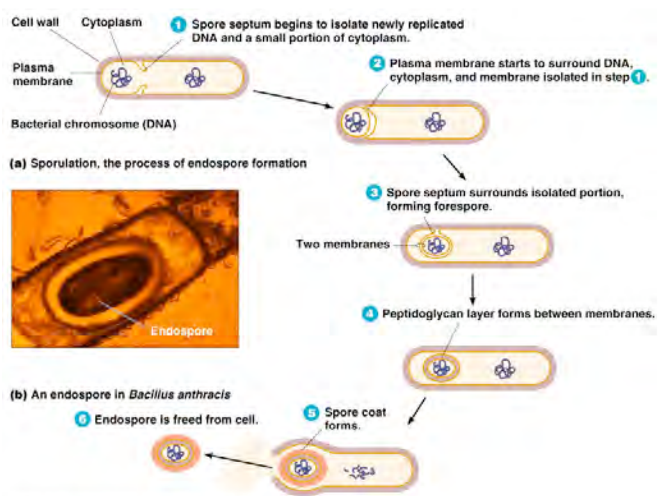


Prokaryotic Cell Reproduction:
Binary fission = cell division
1. cell elongates and DNA is replicated
2. cell wall and plasma membrane begin to divide
3. cross walls form between the divided DNA
4. daughter cells separate

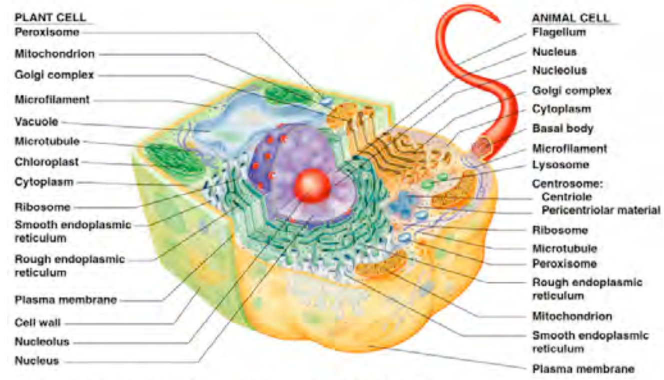


Play binary_fission.swf

Bacterial Endospores
-formed by some Gram + bacilli
(e.g *Clostridium* & *Bacillus* species)
endospore = dehydrated, thick wall structure for survival: resistant to heat, toxins, radiation, etc
Formation occurs when the environment becomes unfavorable: process called sporulation (on handout)

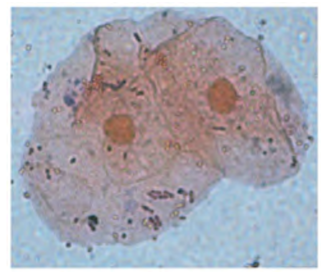


-sporulation is NOT reproduction:
 1 parent cell → 1 endospore
 (reproduction = ↑#s)
-endospores can remain dormant for thousands of years
-upon return of favorable conditions, endospores germinate into vegetative cells

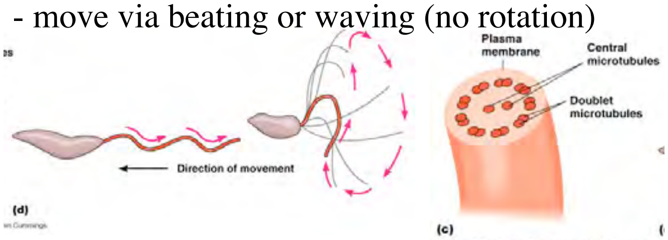


(a) Highly schematic diagram of a composite eukaryotic cell, half plant and half animal

The Eukaryotic Cell “true nucleus”
- algae, protozoa, fungi, plants and animals
- up to 100μm
- variable sizes and shapes

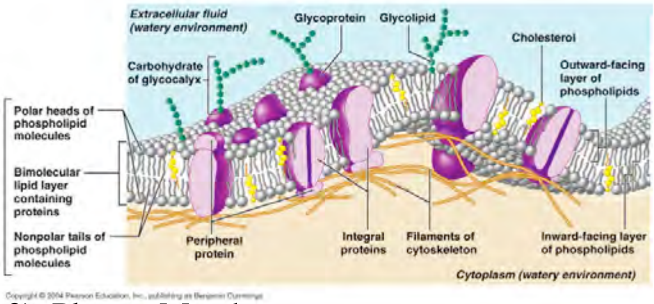


1). Flagella and Cilia
- projections used for cellular locomotion
- contain cytoplasm, surrounded by plasma membrane (not outside the cell)
- move via beating or waving (no rotation)



- internal structure: 9+2 array of microtubules (straw-like tubes composed of tubulin)
- anchored in the cytoplasm by basal bodies composed of microtubules (no rod/disk)
Flagella- long, wave like motion, few on cell
Cilia- short, beating motion, numerous

2). Cell Wall
- algae: wall composed of cellulose (simple polysaccharide)
- fungi: wall composed of chitin (simple polysaccharide)
- protozoa: no wall: either flexible pellicle or no covering
- eukaryotes that lack a wall usually have glycocalyx instead: sticky carbohydrate layer exterior to the plasma membrane for strength, attachment, and cell recognition
No eukaryotes have peptidoglycan or pseudomurein (prokaryote polymers only)

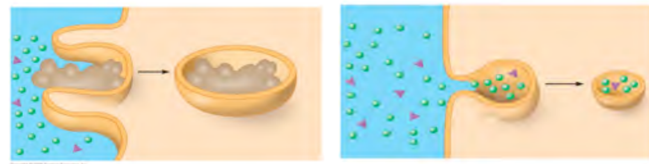


3). Plasma Membrane
- phospholipid bilayer: basic structure
- sterols: resist osmotic lysis
- carbohydrates on surface: receptors
- integral and peripheral proteins: transport and metabolism (enzymes)

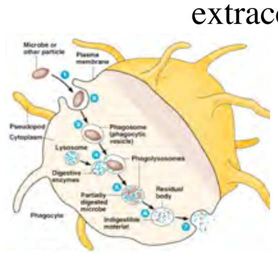
Membrane is semipermeable: exhibits passive and active transport

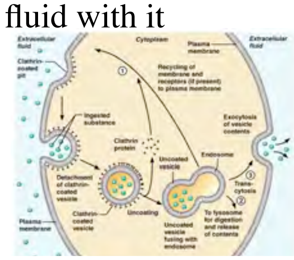
1. Passive (no energy):
   A. simple diffusion
   B. facilitated diffusion
   C. osmosis

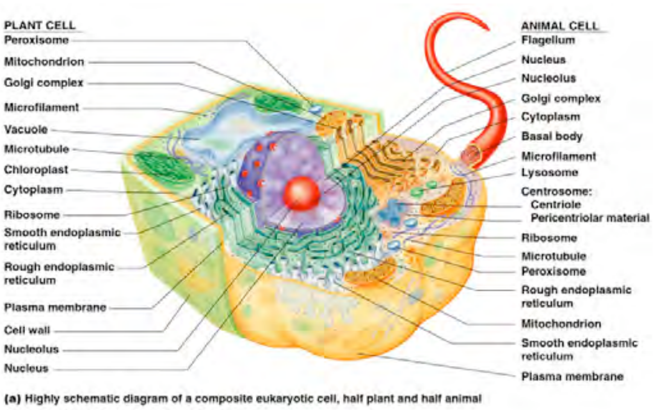
2. Active (requires ATP):
   A. active transport
      (no group translocation)
   B. endocytosis (wall-less cells only):
      use plasma membrane to surround substances and fold them into the cell in a membrane vesicle



1. phagocytosis: "cell eating"
   pseudopods engulf large particles
2. pinocytosis: "cell drinking"
   membrane folds inward taking extracellular fluid with it



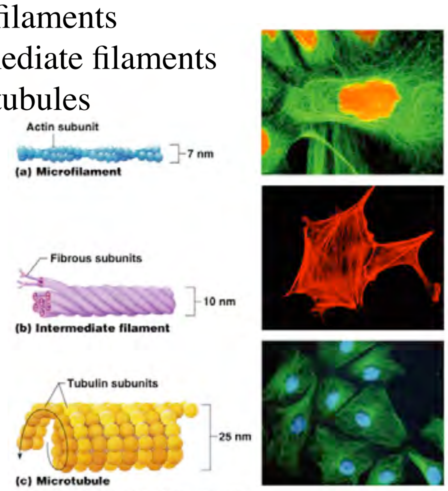




(a) Highly schematic diagram of a composite eukaryotic cell, half plant and half animal

4). Cytoplasm
-substance between the plasma membrane and the nucleus
-contains:
   -cellular components (organelles)
   -cytosol = fluid portion of cytoplasm
   -cytoskeleton

Cytoskeleton
-composed of three types of filaments that form a scaffold:
   1. microfilaments
   2. intermediate filaments
   3. microtubules



-functions:
   -provide support and shape of cell
   -assist in transporting substances inside cell
   -assist in cell motility

cytoplasmic streaming = movement of cytoplasm inside the cell along the cytoskeleton

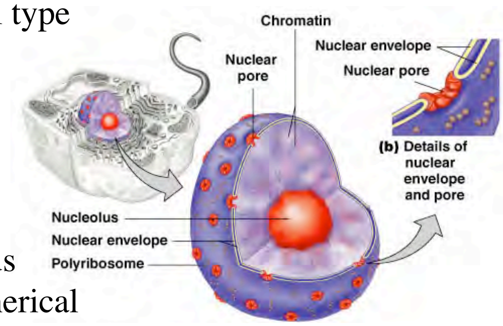
Movie: cytoplasmic streaming in algae

Play CytoplasmicStreaming.mpg

-few enzymes present in eukaryotic cytoplasm
(reactions tend to occur within organelles)

Organelles = small, usually membrane-bound, located in the cytoplasm, function to carry out specialized functions

-type and quantity of organelles depends on the cell type



5). Nucleus

-large, spherical

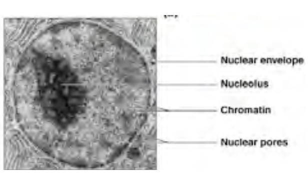
-houses the cell's hereditary information

-double-membrane bound:

membrane = nuclear envelope

-two layers of phospholipid bilayer

-has nuclear pores that control the movement of materials between the nucleus and the cytoplasm

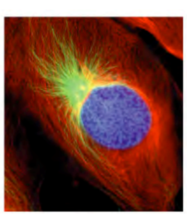


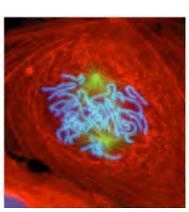
-nucleoli/nucleolus = visible dense region(s) inside nucleus, location where rRNA is being synthesized

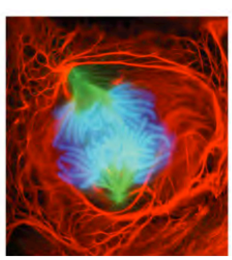
-in non-dividing cells DNA appears as a loose mass called chromatin

-in dividing cells, DNA is tightly packaged as separated DNA elements called chromosomes

-eukaryote chromosome numbers differ but all have more than one, all are linear



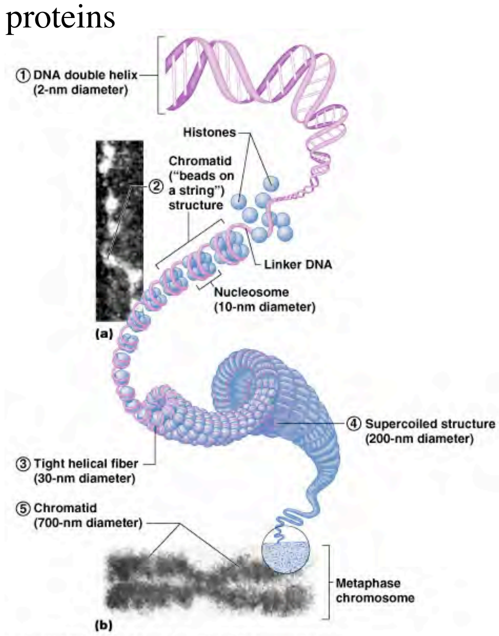




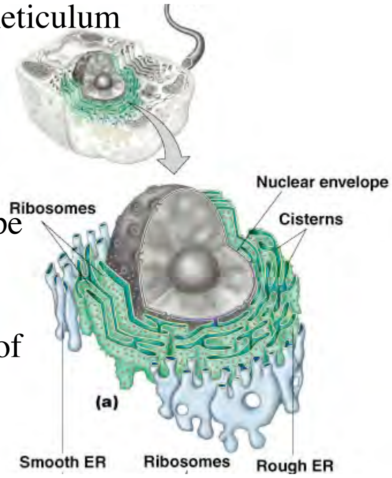
-DNA is always organized

-when not being used for RNA synthesis, DNA is wound around histone proteins forming repeating nucleosomes

nucleosome = 165 bp DNA wound around 8 histone proteins



6). Endoplasmic Reticulum



-network of
membrane sacs
called cisterns

-continuous with
nuclear envelope

Two forms:

A. Rough ER
- -flattened sacs of membrane
- -studded with ribosomes
- -proteins manufactured on RER ribosomes are fed into the cisterns to be modified
- -the proteins are ultimately for use outside the cytoplasm (in membrane or secreted)

B. Smooth ER
- -more tubular, no ribosomes
- -synthesizes fats and sterols and detoxifies harmful substances

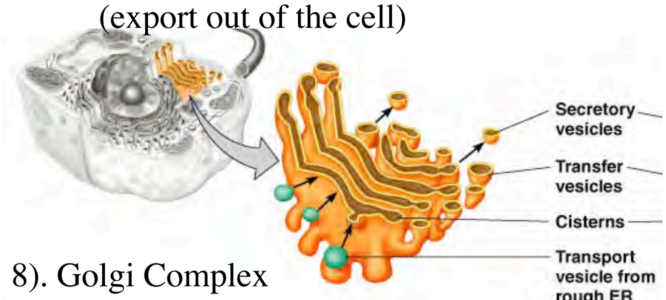
7). Ribosomes

-site of protein synthesis

-eukaryotic ribosome = 80s

-consists of two subunits: 60s and 40s

-attached to the RER or free in the cytoplasm:
- -free ribosomes: in the cytoplasm manufacture proteins to be used in the cytoplasm
- -fixed ribosomes: attached to the RER manufacture proteins to be used in the plasma membrane or for exocytosis (export out of the cell)

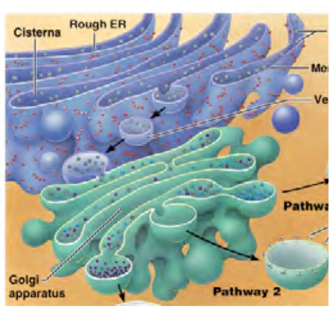


8). Golgi Complex

- 3-20 large cisterns, stacked, not connected

-not attached to the nuclear envelope or ER

-functions to modify and sort proteins



Proteins synthesized in the RER are packaged into transport vesicles which bud off the RER and fuse with the Golgi

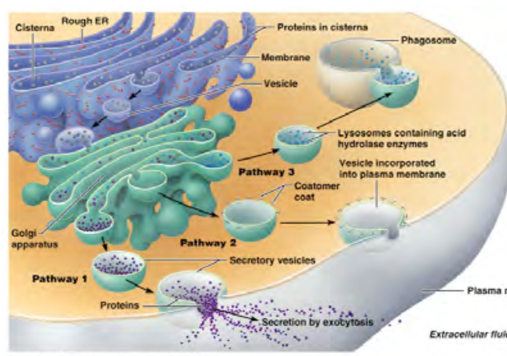
The proteins are modified by the Golgi and pass from one cistern to the next in transport vesicles

(modifications: addition of lipids or carbohydrates, protein refolding)

The proteins are sorted according to final destination and packed into vesicles

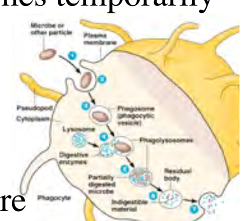
Three possible fates:

1. Secretory vesicles:
carry exocytosis proteins,
vesicle fuses with the plasma membrane dumping the protein contents outside of the cell



2. Membrane renewal vesicles: carry new integral or peripheral proteins to be added to the plasma membrane

3. Lysosomes: digestive enzymes temporarily housed in a storage vesicle



9). Lysosomes

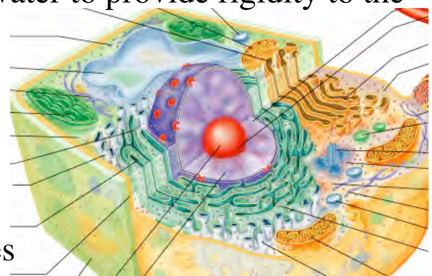
-formed by the Golgi

-single membrane bound sphere

-contain digestive enzymes to break down large molecules, organelles or bacteria

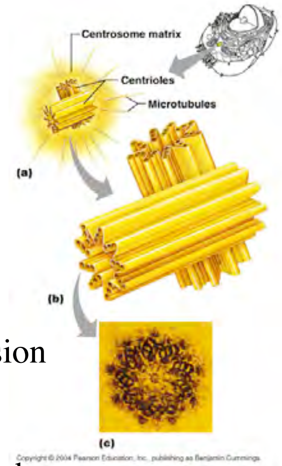
-upon completion of digestion, residual body (waste) is exocytosed

10). Vacuoles
-membrane enclosed space in the cytoplasm
-derived from the Golgi
-some serve as temporary storage compartments (for proteins, carbohydrates, toxins, etc.)
-some fill with water to provide rigidity to the cell

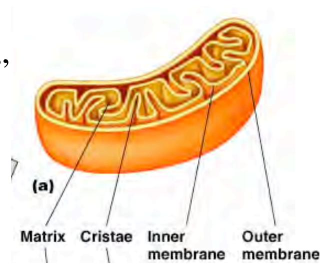


11). Peroxisomes
-membrane spheres smaller than lysosomes
-come from pre-existing peroxisomes, not Golgi or ER
-contain:
-enzymes for oxidation reactions
-catalase to break down toxic peroxide (oxidation of organics during metabolism generates peroxide and other free radicals)

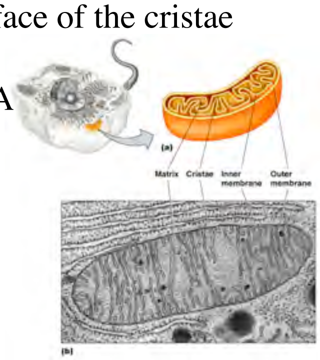
12). Centrosome
-located near the nucleus
-important for nuclear division during mitosis
-consists of two parts:
1. pericentriolar material
cytosol + protein fibers
organizes the mitotic spindle for cell division
2. pair of centrioles
2 cylinders
at right angles to each other
composed of 9+0 arrangement of microtubules
source of microtubules to form the mitotic spindle



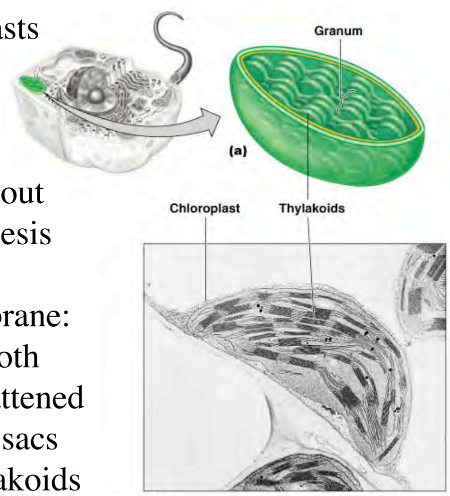
13). Mitochondria
"powerhouse of the cell"
-rod shaped
-enclosed in double membrane:
-outer membrane: smooth
-inner membrane: folded into cristae
-open middle = matrix, where cellular respiration occurs
-most of the ATP in a cell is generated in a reaction called electron transport which occurs along the surface of the cristae



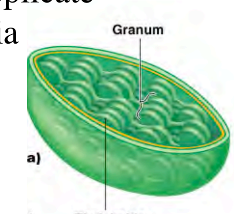
Mitochondria contain their own circle DNA and 70s ribosomes and can replicate by binary fission independent of the cell



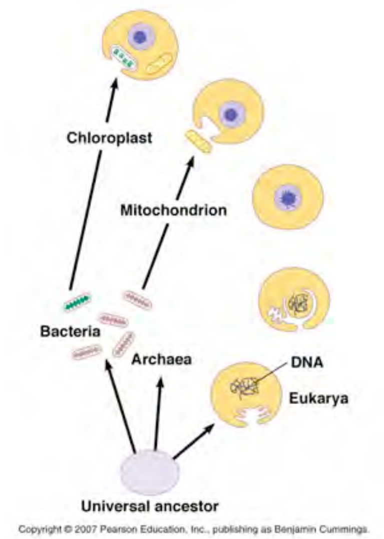
14). Chloroplasts
-found only in algae and plants
-used to carry out photosynthesis reactions
-double membrane:
-outer smooth
-inner = flattened membrane sacs called thylakoids
-thylakoids are arranged in stacks called grana



Chloroplasts contain their own circle DNA and 70s ribosomes and replicate independent of the cell via binary fission

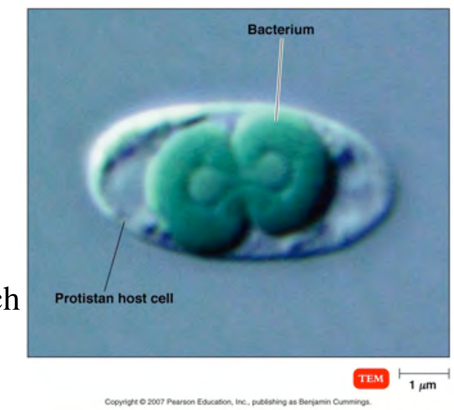


Cellular Evolution
prokaryotes: appear 3.5 billion years ago
eukaryotes: appear 2.5 billion years ago
Endosymbiotic Theory states that eukaryotic cells evolved from a cooperation of prokaryotic cells
- large prokaryotes lost their walls and engulfed smaller ones which specialized to become organelles



Evidence: both mitochondria and chloroplasts have features similar to bacteria:
- circular loop of DNA
- 70s ribosomes
- similar size and shape
- can replicate independent of host cell via binary fission
- double membrane: cell membrane plus endosome/phagosome from being internalized?

Cyanophora paradoxa: living example of a prokaryote inside a eukaryote (both require each other for survival)

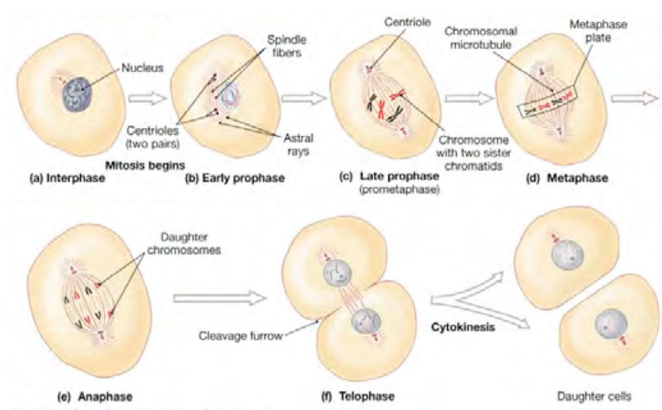


Eukaryotic Cell Division
Mitosis - asexual reproduction
Meiosis - produces sex cells for sexual reproduction

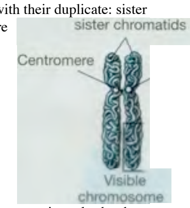
Mitosis
- one diploid/2n parent cell divides to produce two diploid/2n daughter cells
- all cells are identical (clones)

1. Cells in interphase (period when cells are not dividing) duplicate organelles and DNA in preparation for mitosis (nuclear division)
2. Mitosis (on handout)

Mitosis (on handout)



Prophase: chromatin condenses into chromosomes that pair with their duplicate: sister chromatids attached by a centromere
nuclear envelope breaks down
centrioles migrate to opposite poles
spindle fibers form and attach to centromeres



Metaphase: chromosomes align on the metaphase plate

Anaphase: centromeres split and sister chromatids are pulled to opposite poles by the spindle apparatus (once separate they are called chromosomes)

Telophase: nuclear membranes form
chromosomes decondense into chromatin
spindle disassembles
Cytokinesis occurs: cytoplasm constricts at the metaphase plate forming a cleavage furrow that pinches the cells apart

Czura Fall 2005

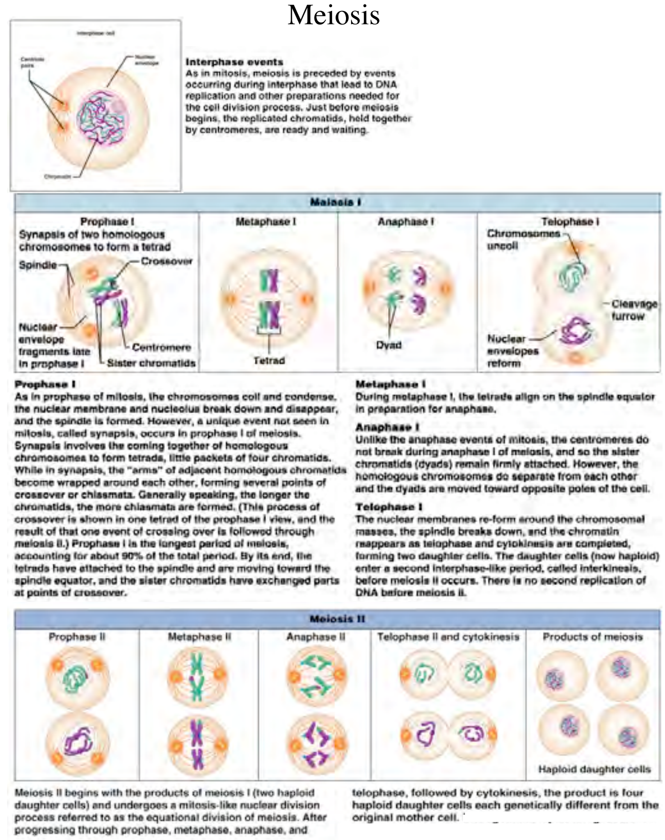
Meiosis

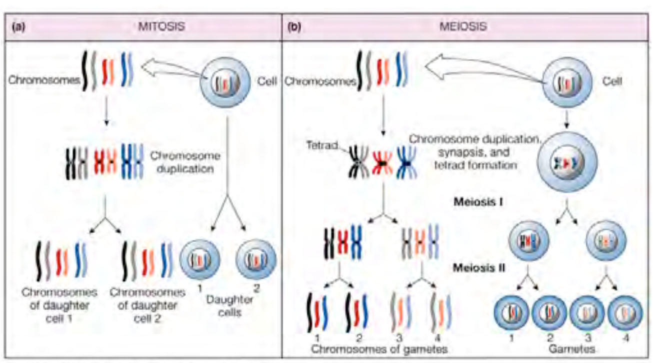
-one diploid/2n parent cell divides to produce four haploid/1n daughter cells

-all four cells are different from each other and different from the original cell

(stages shown on handout)

Meiosis





(on handout)

-Mitosis produces two daughter cells that are clones of the original parent cell.

-Meiosis produces four sex cells/spores that each only have half the number of chromosomes as the parent (parent is diploid, resulting cells are haploid). None of the four cell are identical to the parent, and they are usually not identical to each other.