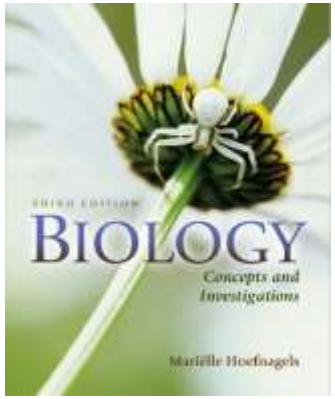

Chapter 3

Cells

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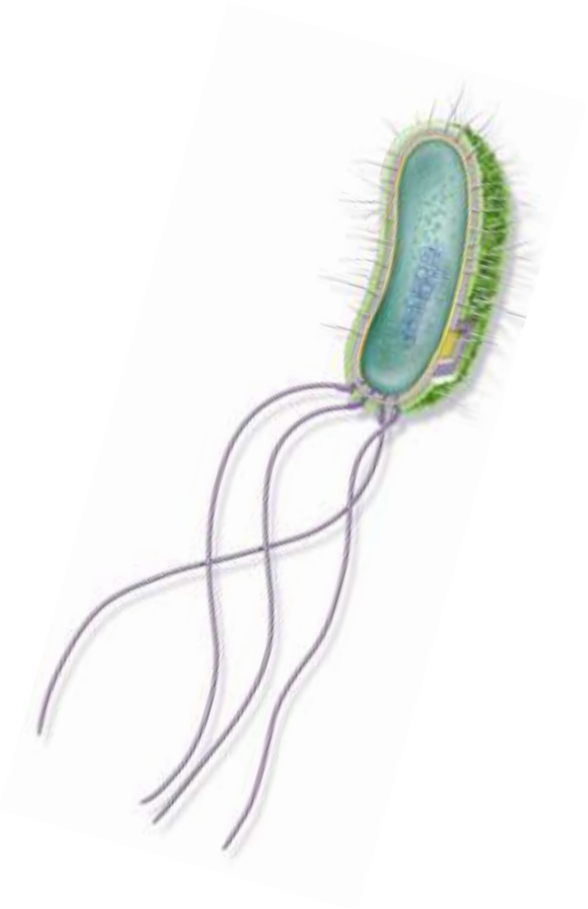
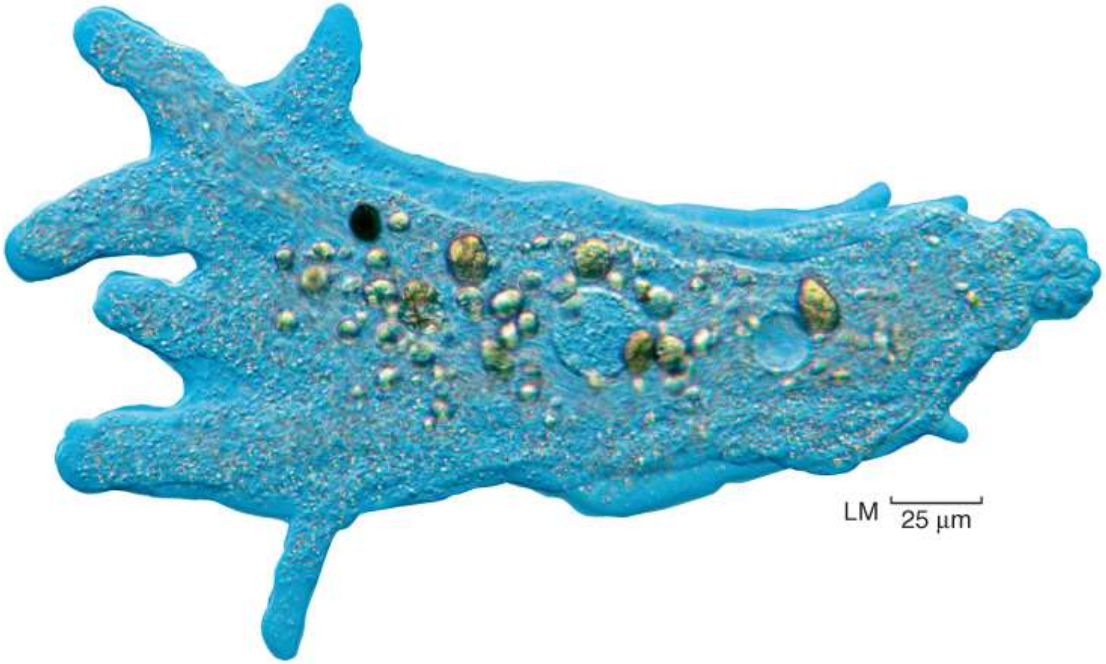
All Organisms Are Composed of Cells



A **cell** is the smallest unit of life that can function independently.

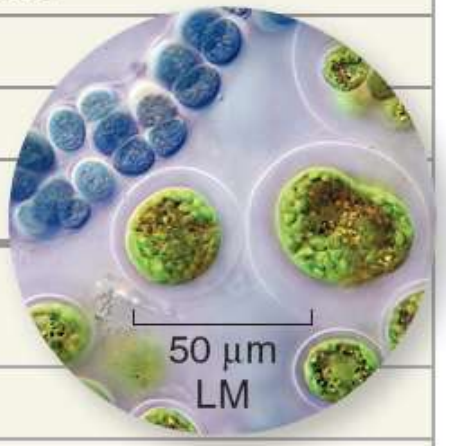


All Organisms Are Composed of Cells

Cell theory explains the prevalence and commonalities of cells.

TABLE **3.1** **The Cell Theory: A Summary**

Early cell theory
All organisms are made of one or more cells.
The cell is the fundamental unit of life.
All cells come from preexisting cells.
Additional ideas in modern cell theory
All cells have the same basic chemical composition.
All cells use energy.
All cells contain DNA that is duplicated and passed on as each cell divides.



All Organisms Are Composed of Cells

Most cells are too small to see without a microscope.

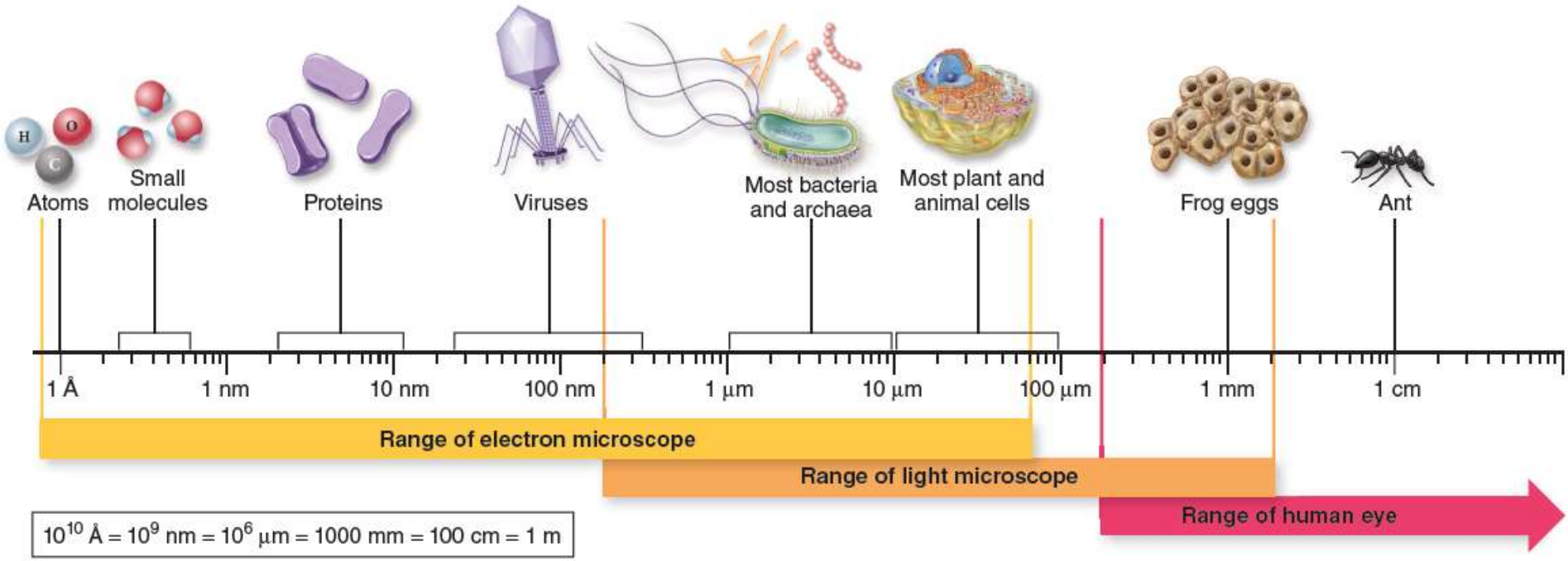
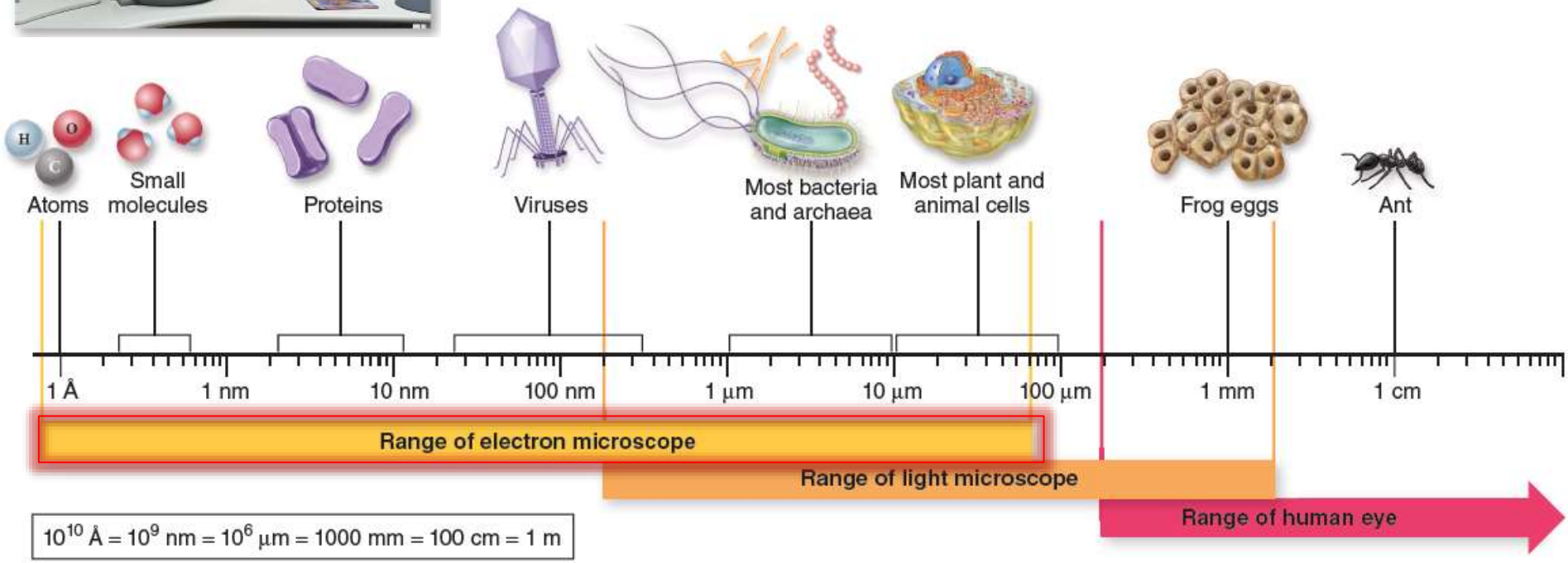


Figure 3.2

All Organisms Are Composed of Cells

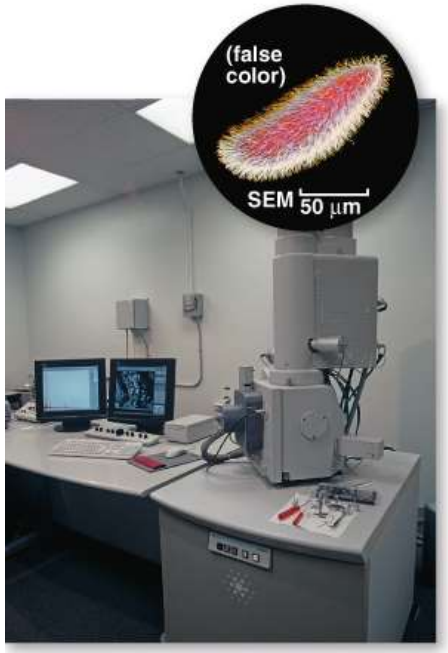
A transmission electron microscope is a very powerful tool for seeing internal cell structures.



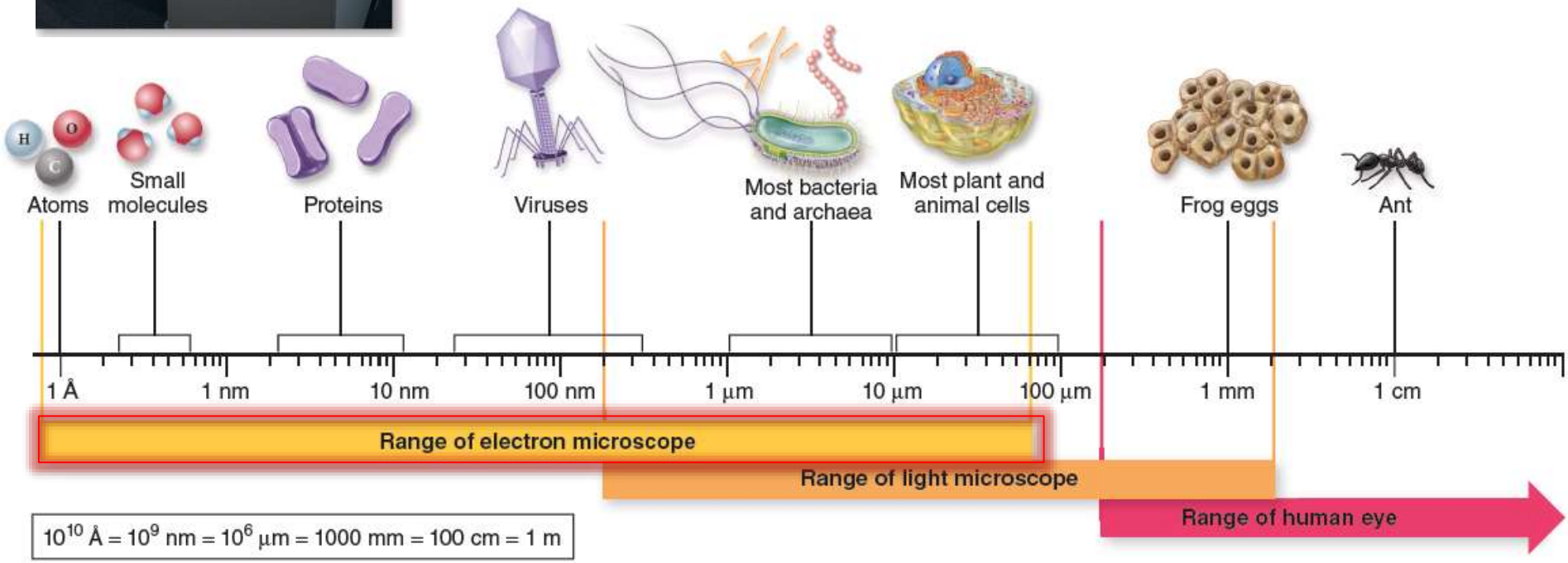
Section 3.1

Figures 3.2, 3.3

All Organisms Are Composed of Cells



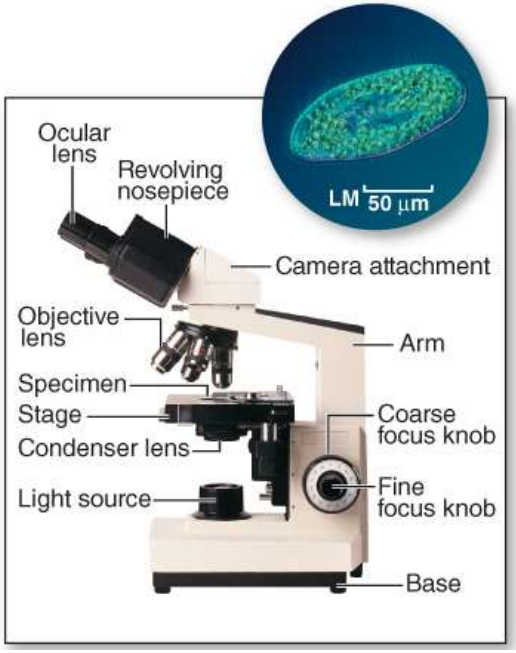
A scanning electron microscope is also very powerful and reveals details on cell surfaces.



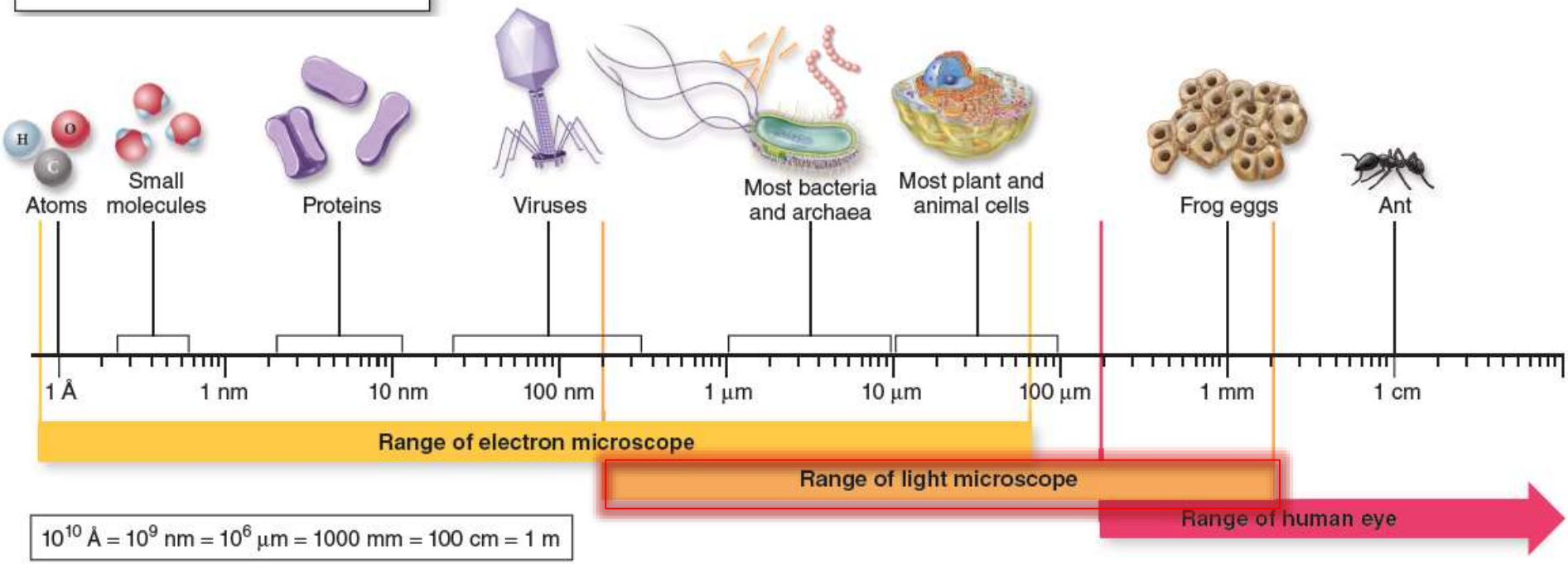
Section 3.1

Figures 3.2, 3.3

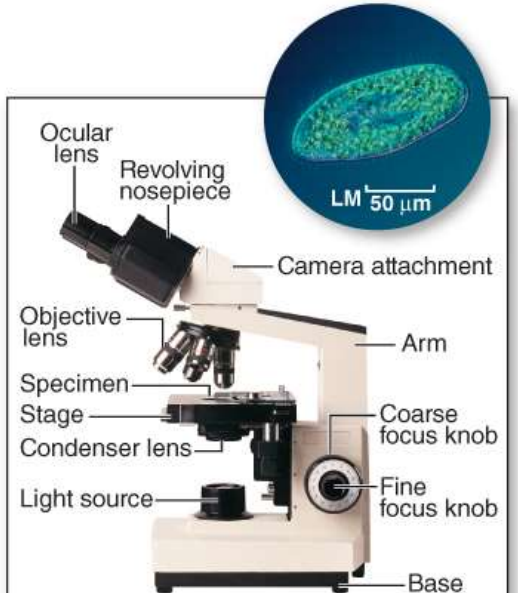
All Organisms Are Composed of Cells



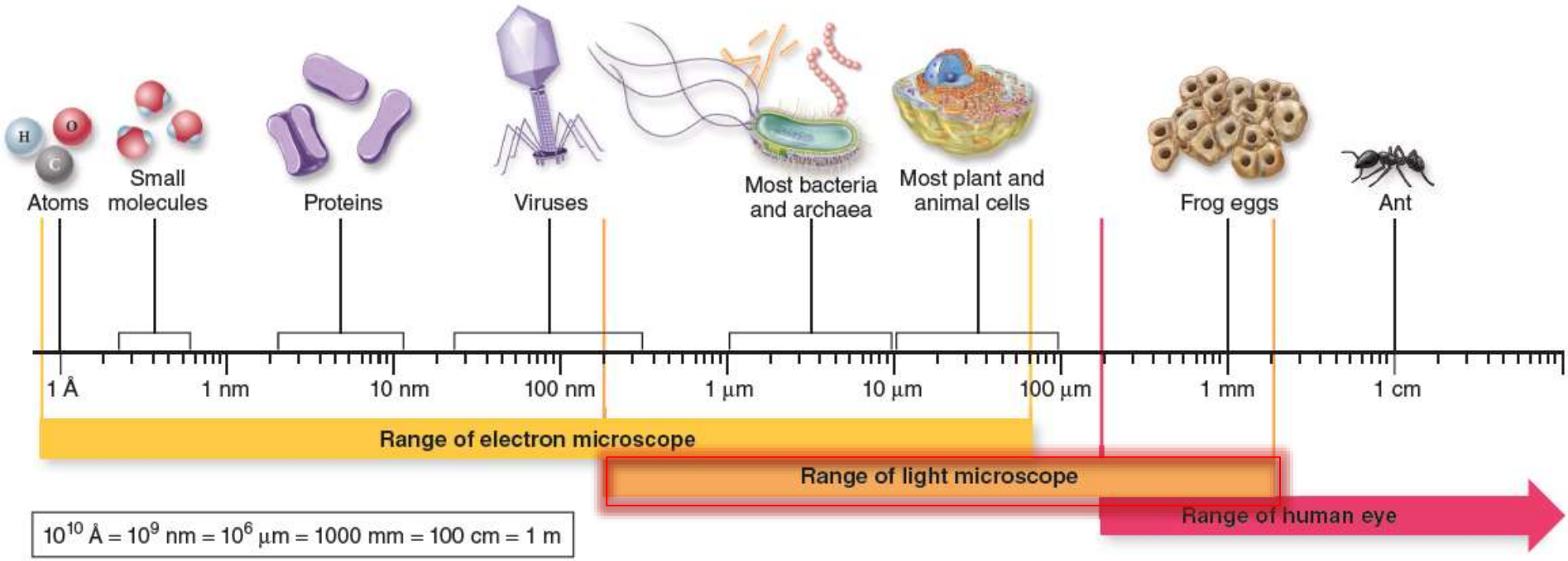
Light microscopes are less powerful than electron microscopes. They generate color images of living cells.



All Organisms Are Composed of Cells



Notice that bacteria and archaea cells are smaller than plant and animal cells.



All Organisms Are Composed of Cells

Here's a closer look at the size comparison between different cell types.

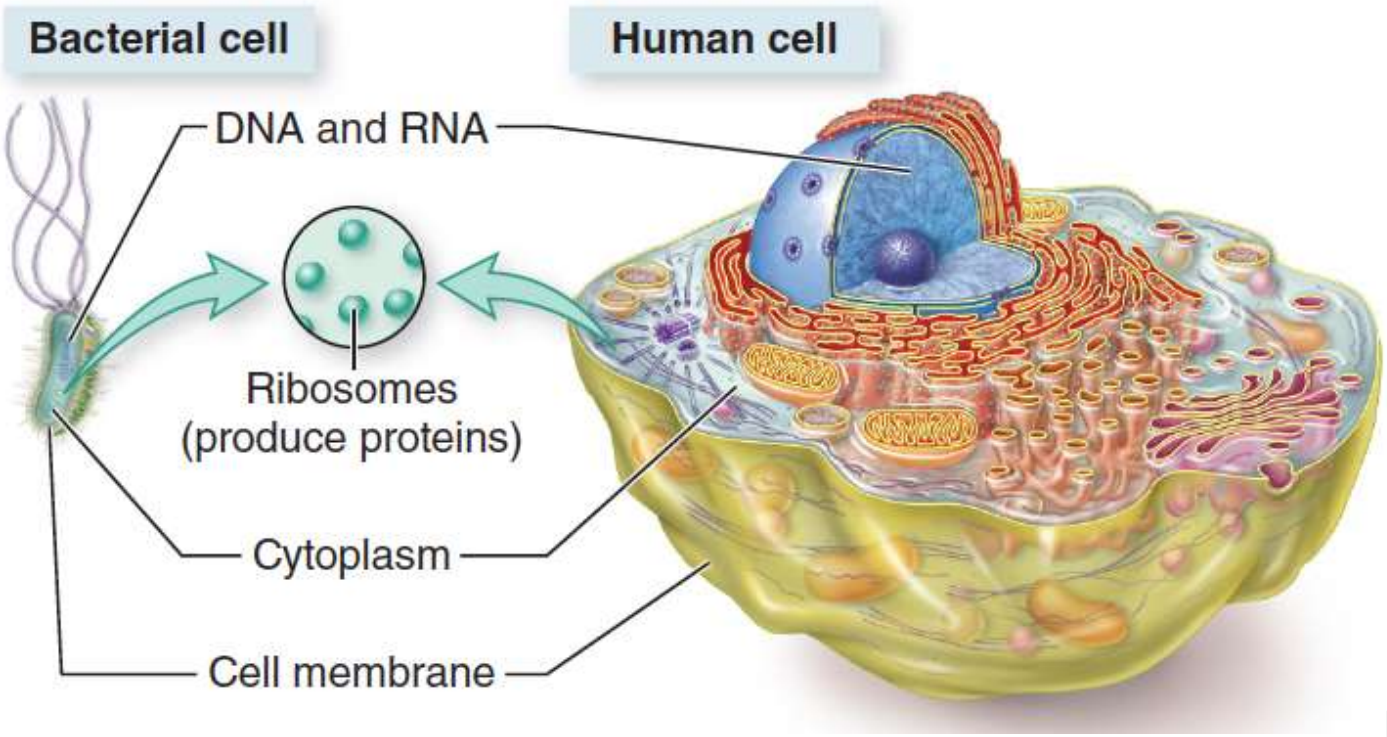


Figure 3.31

All Organisms Are Composed of Cells

Regardless of size, all cells have genetic material, ribosomes, cytoplasm, and a cell membrane.

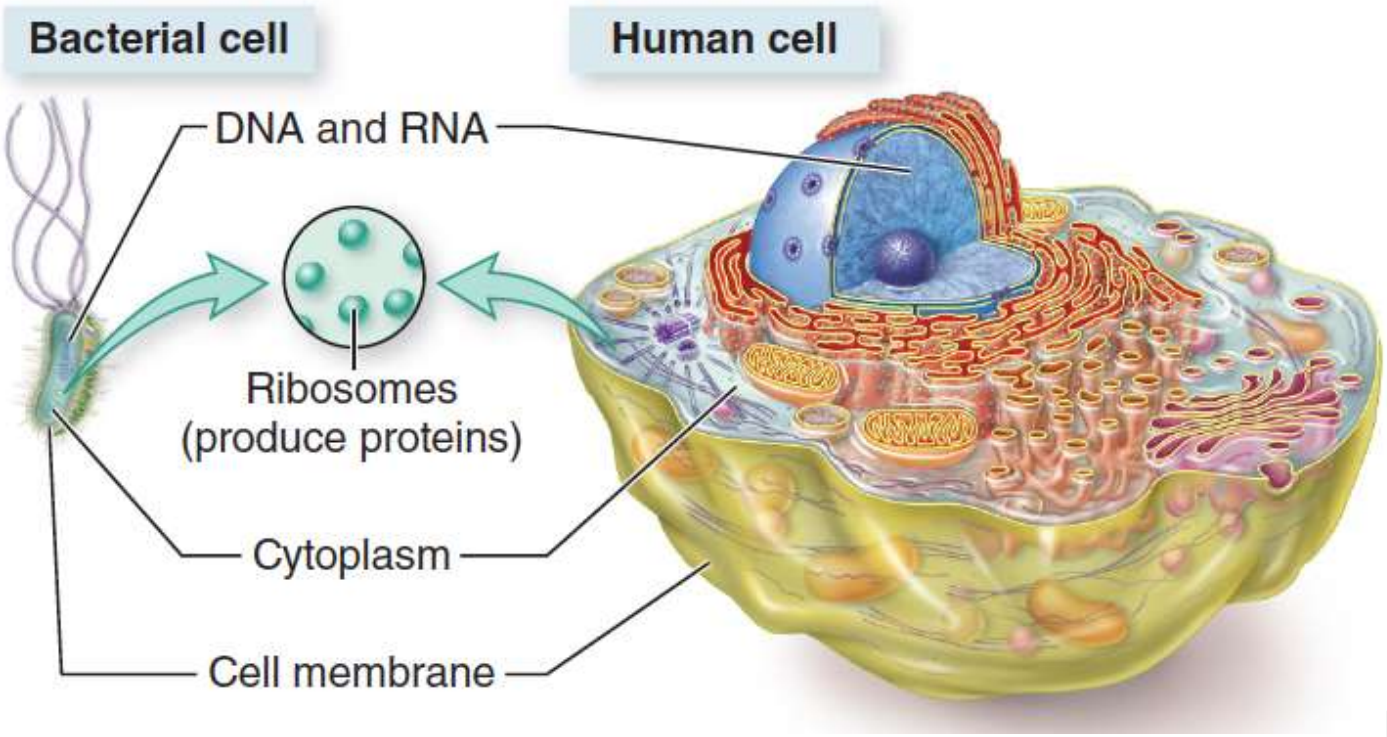
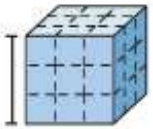


Figure 3.31

Why Are Cells So Small?

Size of cube		
1 cm 	2 cm 	3 cm 
Surface area = height x width x number of sides		
1 cm x 1 cm x 6 = 6 cm^2	2 cm x 2 cm x 6 = 24 cm^2	3 cm x 3 cm x 6 = 54 cm^2
Volume = height x width x length		
1 cm x 1 cm x 1 cm = 1 cm^3	2 cm x 2 cm x 2 cm = 8 cm^3	3 cm x 3 cm x 3 cm = 27 cm^3
Ratio of surface area to volume		
6/1 = 6.0	24/8 = 3.0	54/27 = 2.0

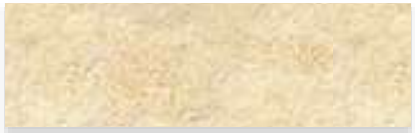
Smaller cells have more surface area relative to their volume. High surface area allows the cell to quickly exchange materials with its surroundings.

Figure 3.4

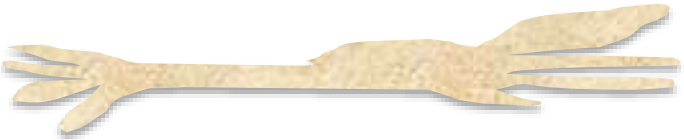
Question #1

Which cell shape has the highest ratio of surface area to volume?

A. 

B. 

C. 

D. 

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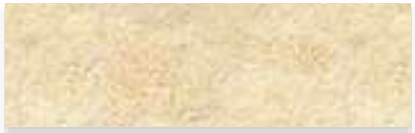
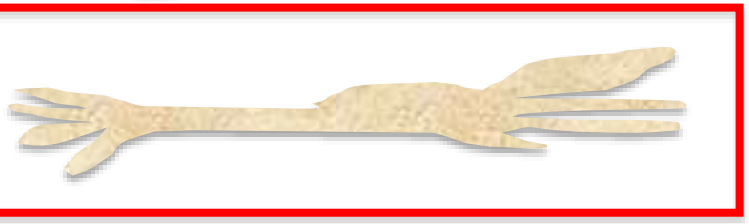
B. 

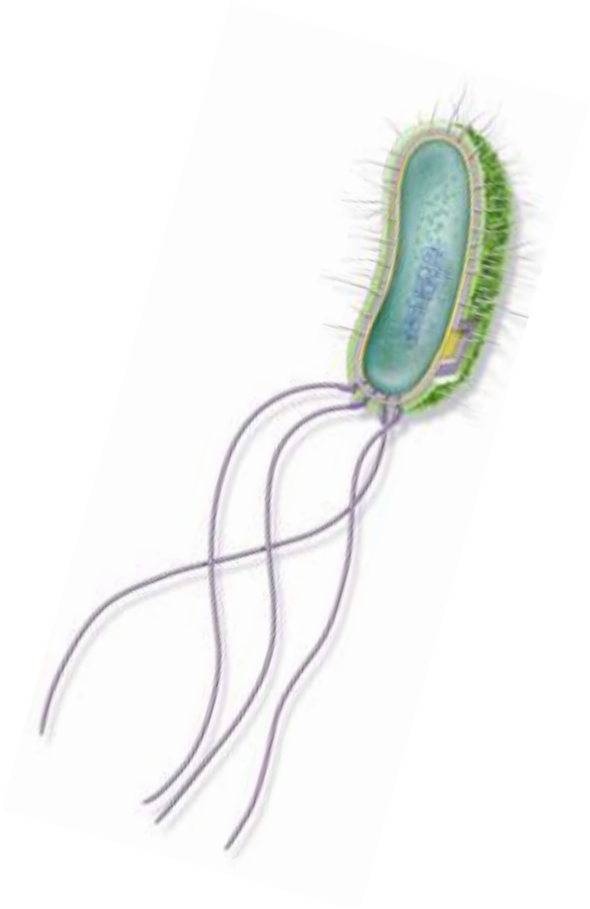
C. 

D. 

3.1 Mastering Concepts

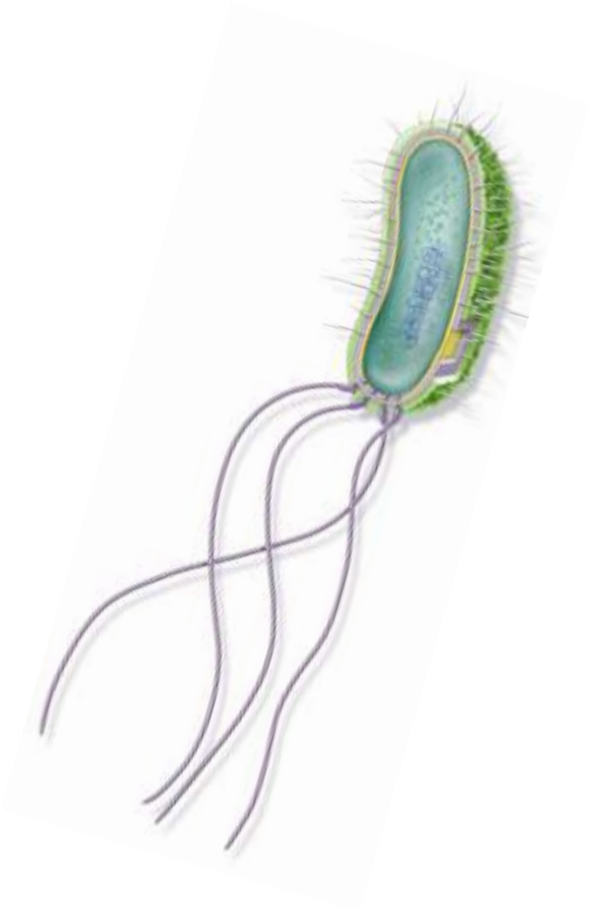
Describe adaptations that increase the ratio of surface area to volume in cells.

Different Cell Types Characterize Life's Three Domains



Prokaryotes are the most ancient forms of life. They lack a nucleus.

Different Cell Types Characterize Life's Three Domains



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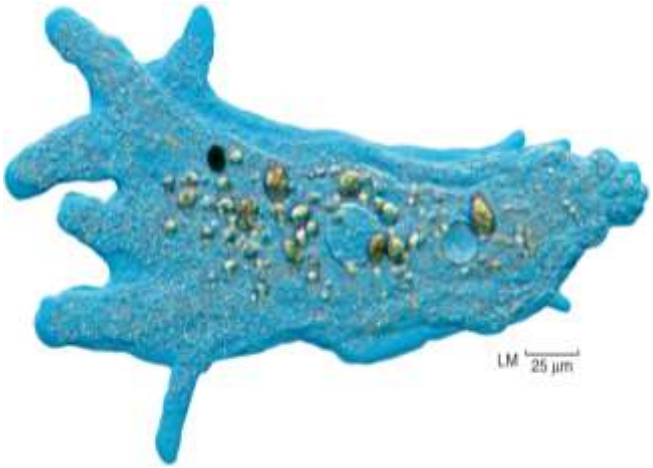
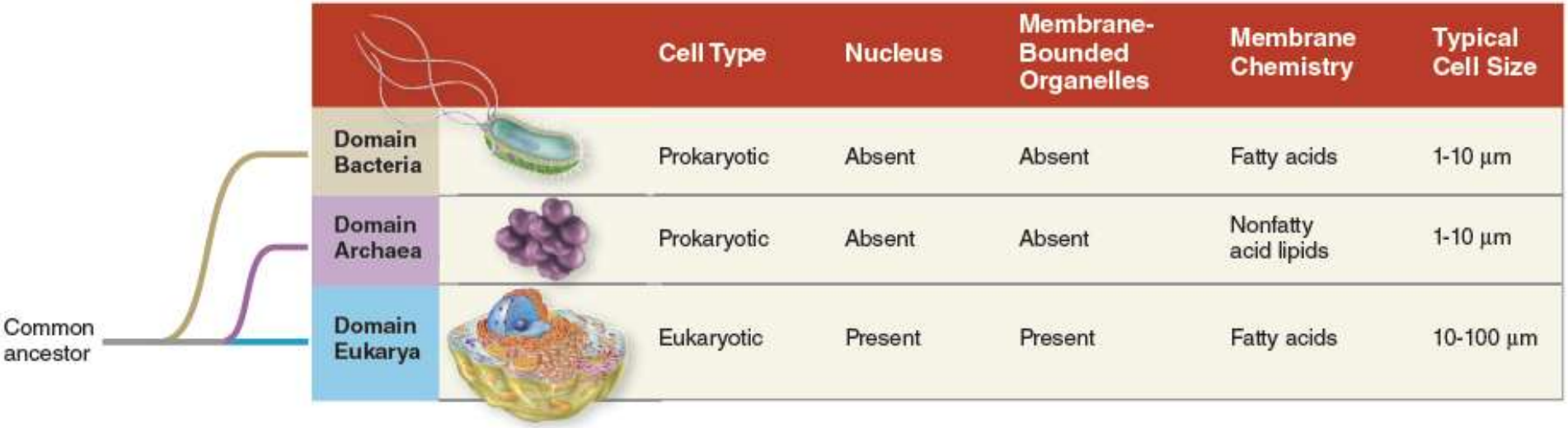


Eukaryotes have cells with a nucleus and other membranous organelles.

Different Cell Types Characterize Life's Three Domains

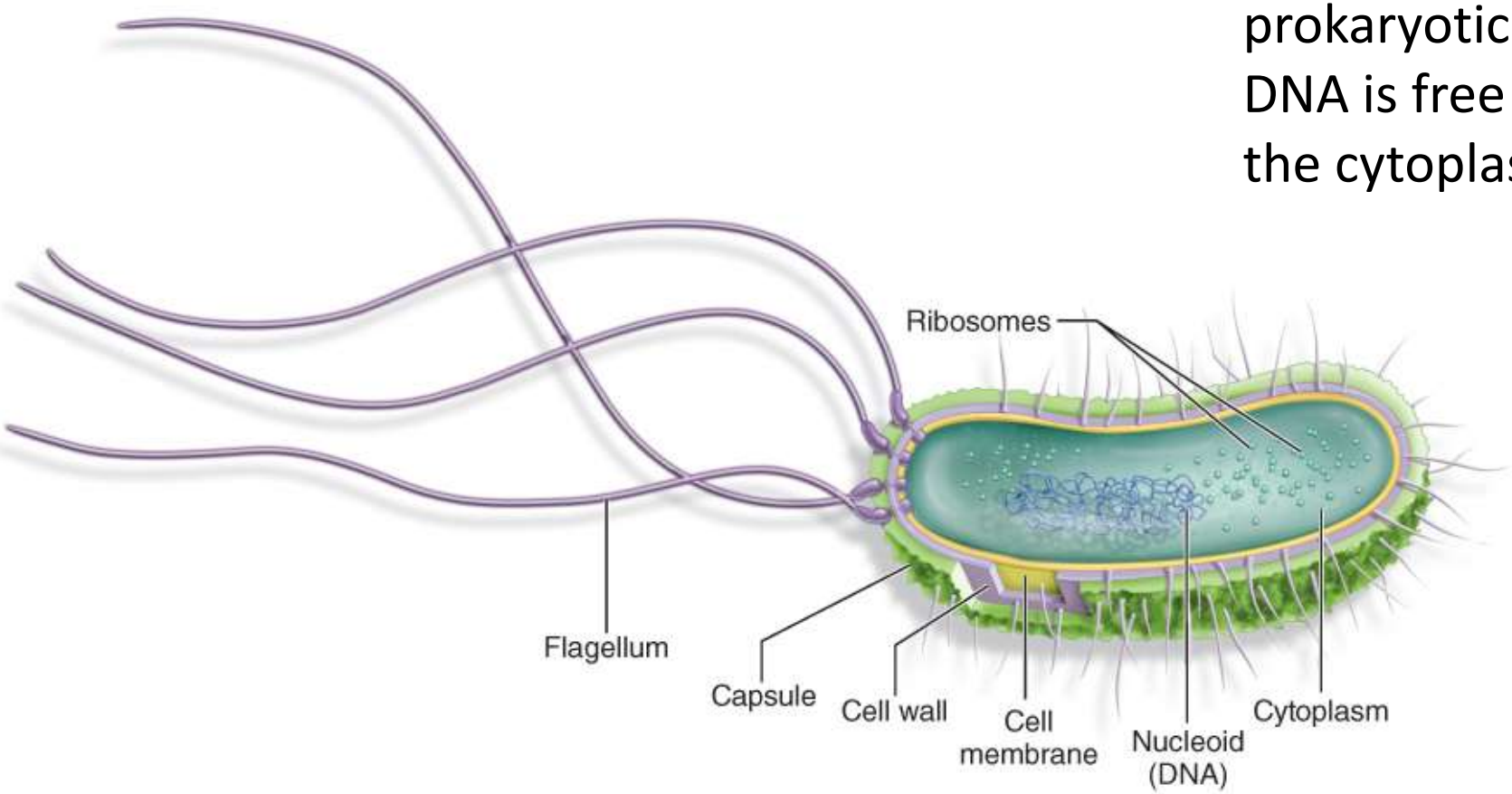


	Cell Type	Nucleus	Membrane-Bounded Organelles	Membrane Chemistry	Typical Cell Size
Domain Bacteria	Prokaryotic	Absent	Absent	Fatty acids	1-10 µm
Domain Archaea	Prokaryotic	Absent	Absent	Nonfatty acid lipids	1-10 µm
Domain Eukarya	Eukaryotic	Present	Present	Fatty acids	10-100 µm

Unique features distinguish the Bacteria, Archaea, and Eukarya.

The Anatomy of a Bacterium

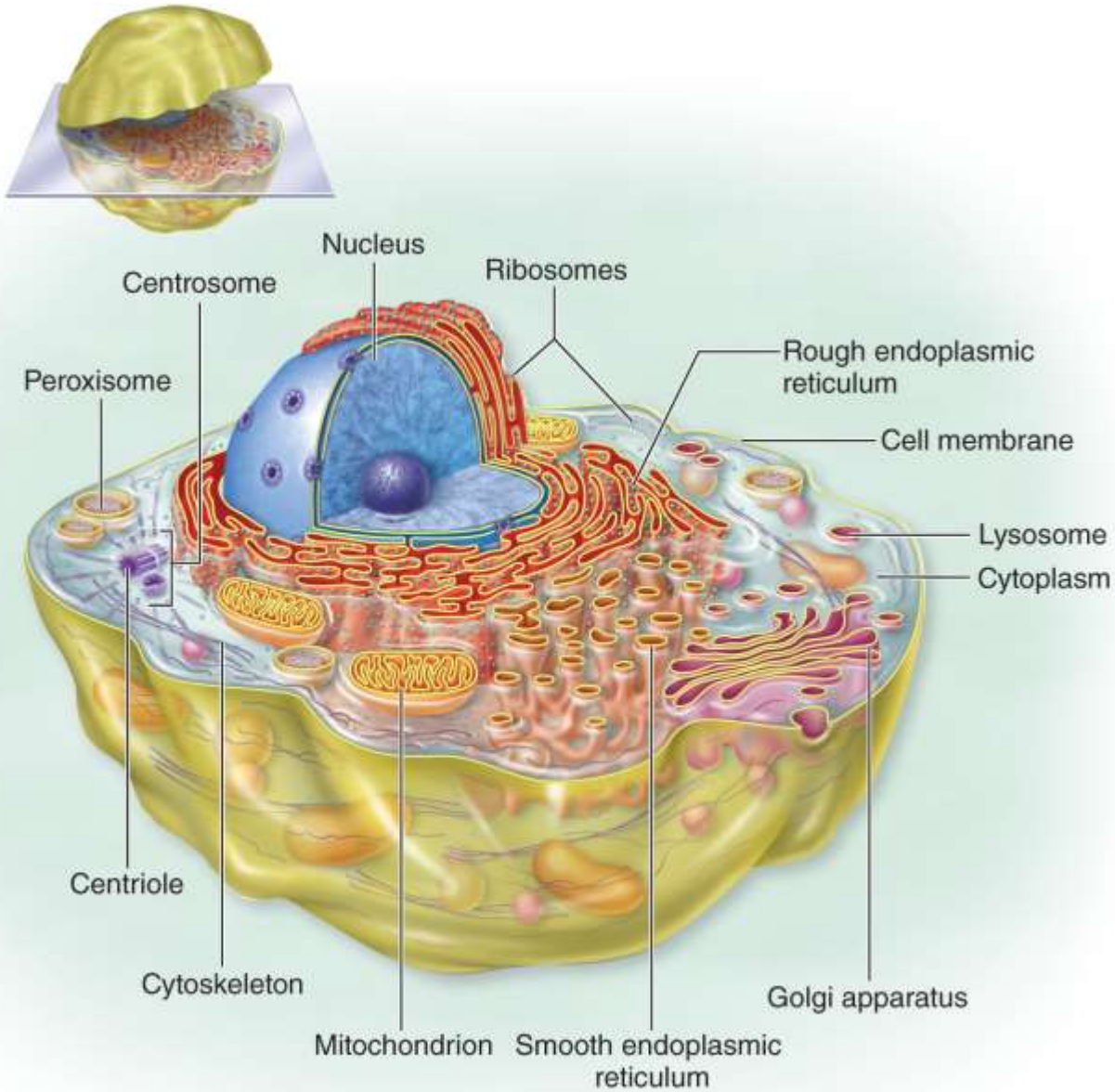
Bacteria are prokaryotic. DNA is free in the cytoplasm.



Section 3.2

Figure 3.6

The Anatomy of an Animal Cell

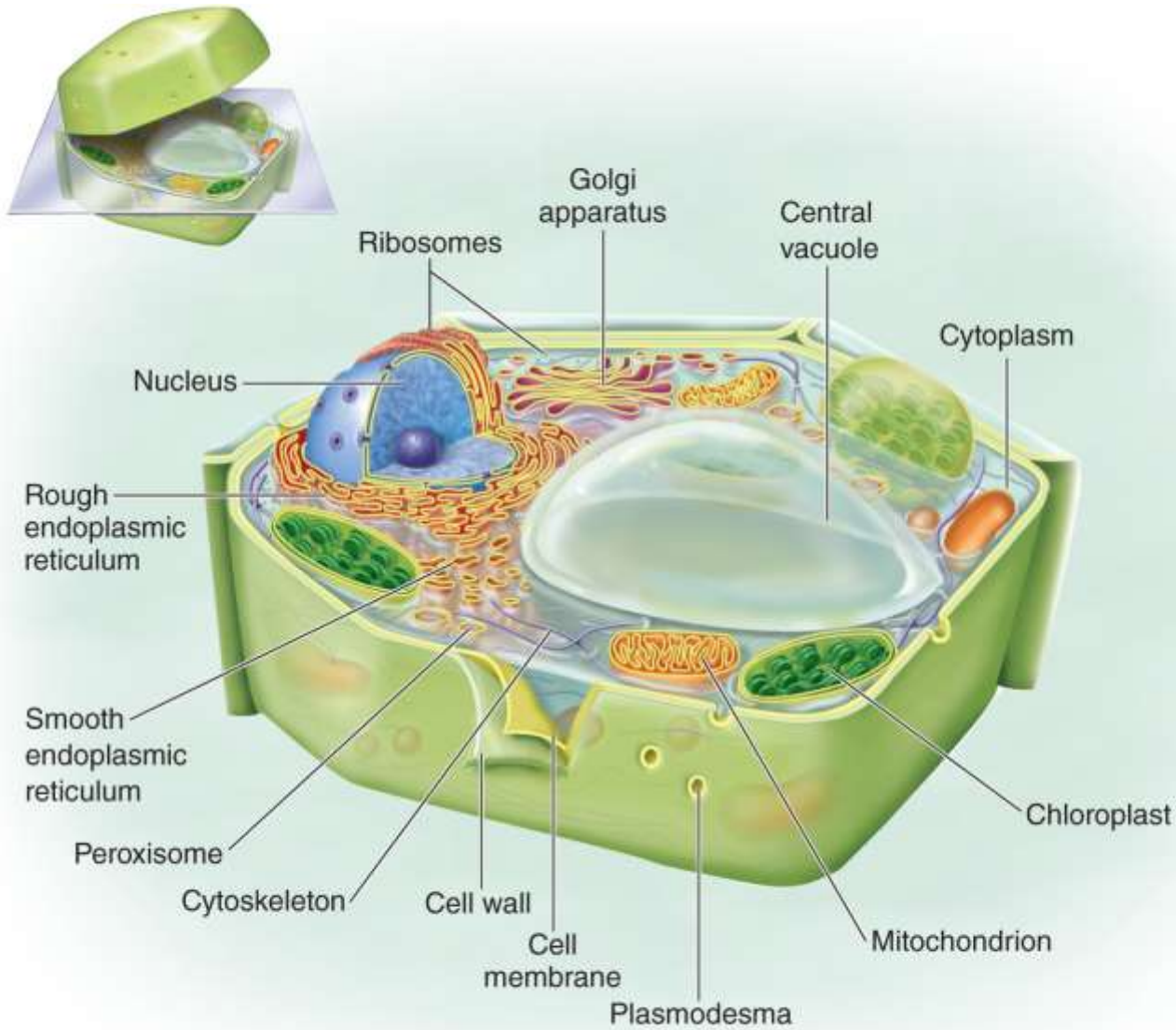


Animal cells are eukaryotic. They have membrane bounded organelles.

Section 3.2

Figure 3.8

The Anatomy of a Plant Cell



Plant cells are also eukaryotic, but notice the cell wall and chloroplasts.

Figure 3.9

Question #2

How many of these features does a typical bacterial cell have?

DNA, cell wall, nucleus, ribosomes, cell membrane

A. five
B. four
C. three
D. two
E. one

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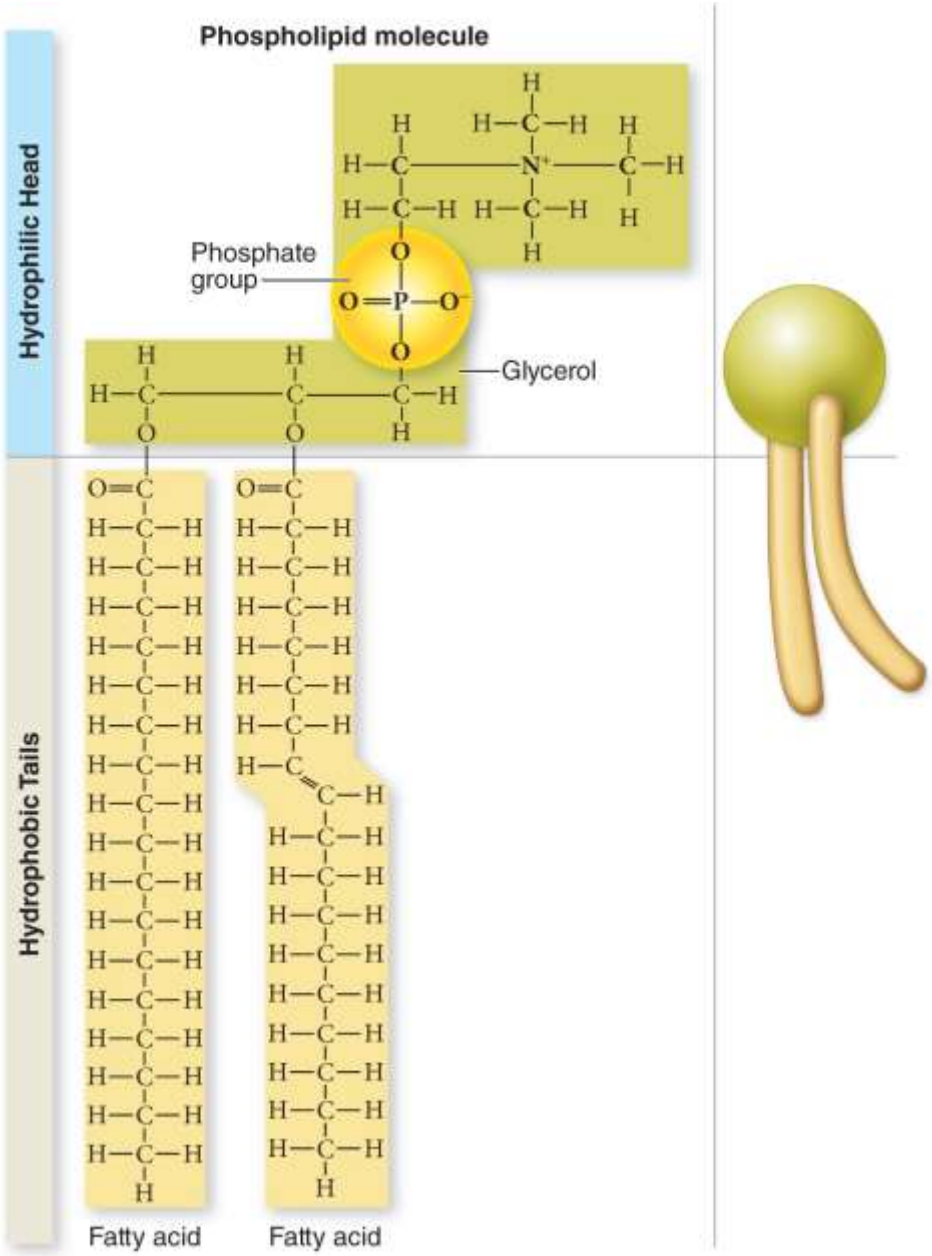
DNA, cell wall, nucleus, ribosomes, cell membrane

A. five
B. four
C. three
D. two
E. one

3.2 Mastering Concepts

How do prokaryotic cells differ from eukaryotic cells?

A Membrane Surrounds Each Cell

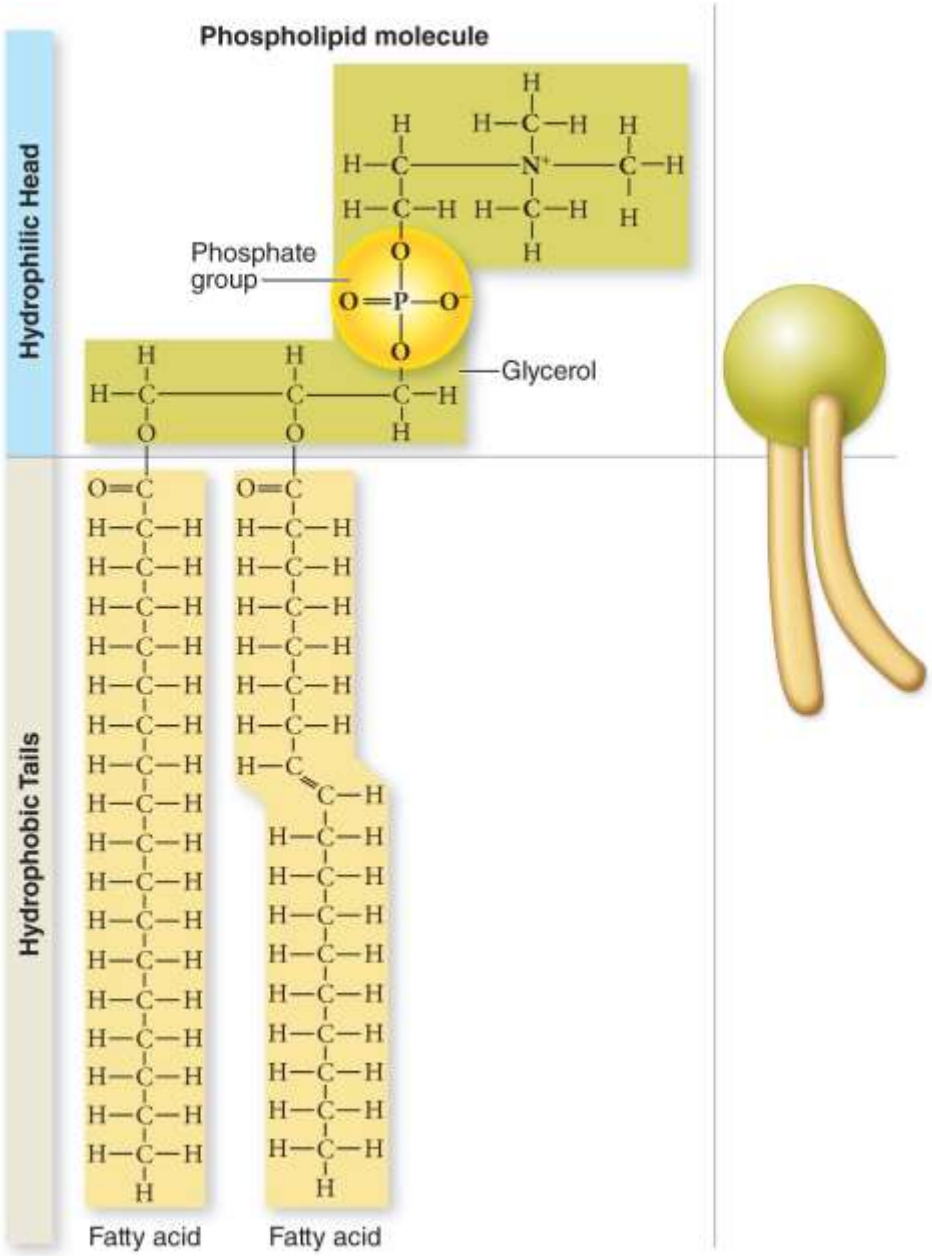


Cell membranes are composed of molecules called phospholipids.

Section 3.3

Figure 3.10

A Membrane Surrounds Each Cell



A phospholipid has two regions:

- Hydrophilic head: polar bonds, which are attracted to water
- Hydrophobic tails: nonpolar bonds, which repel water

Figure 3.10

A Membrane Surrounds Each Cell

Because of their chemical structure, phospholipids spontaneously form bilayers in water.

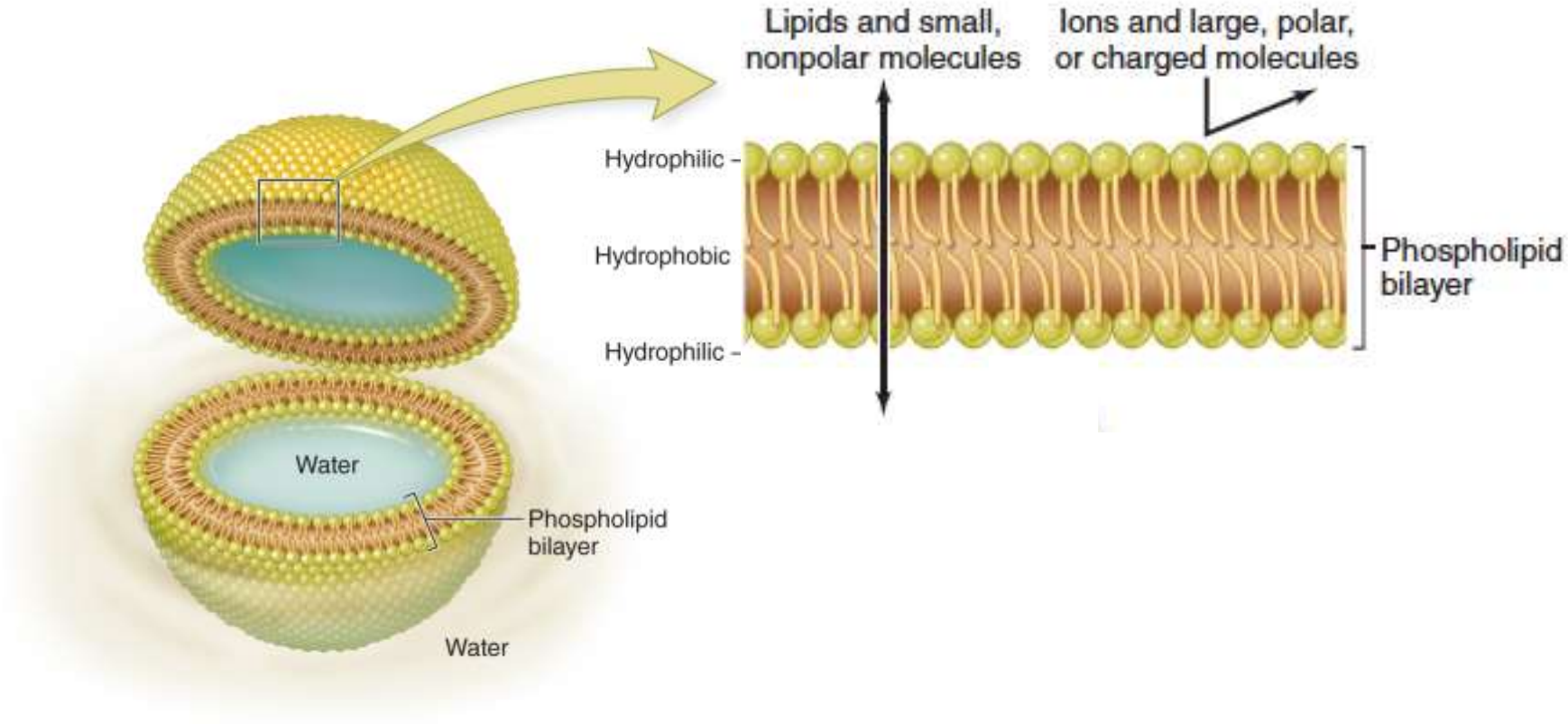
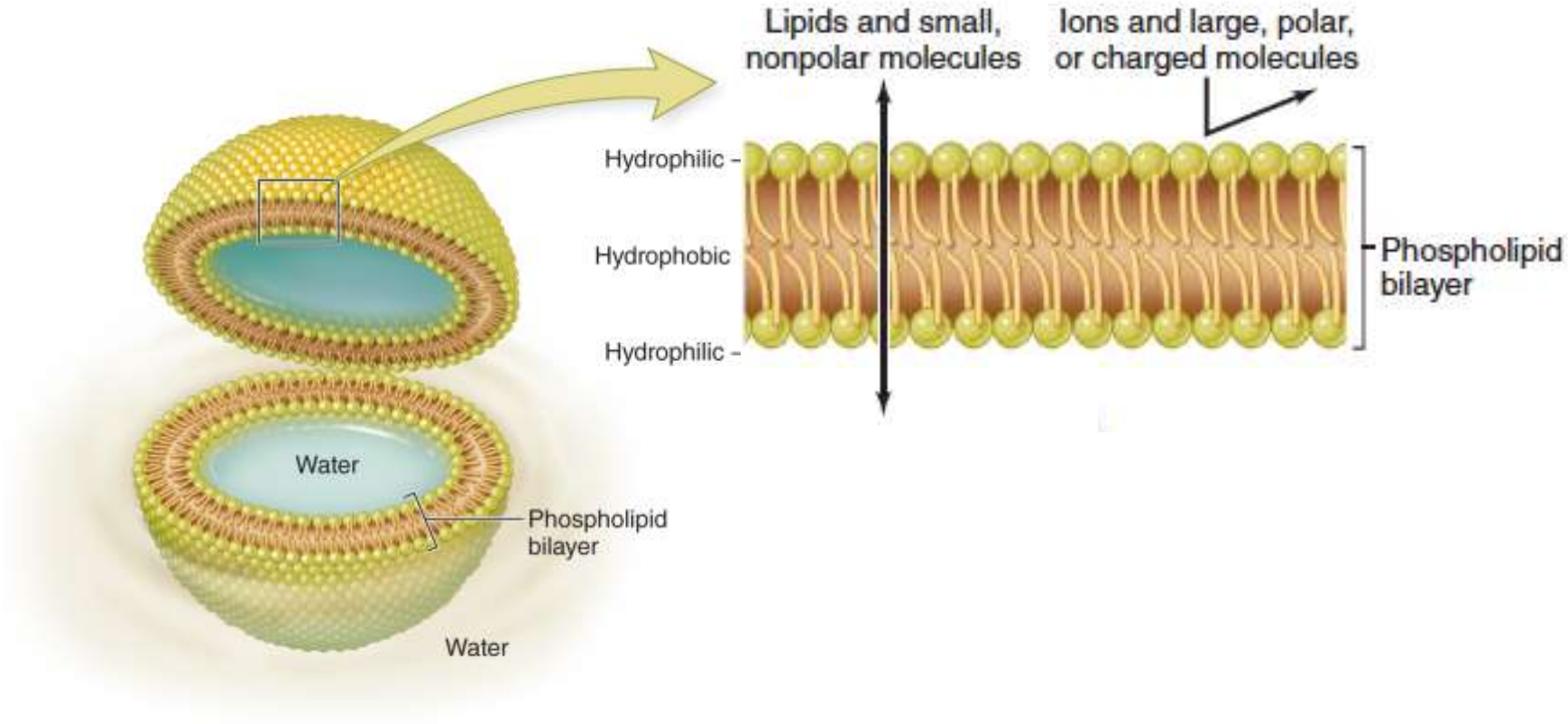


Figure 3.11

A Membrane Surrounds Each Cell

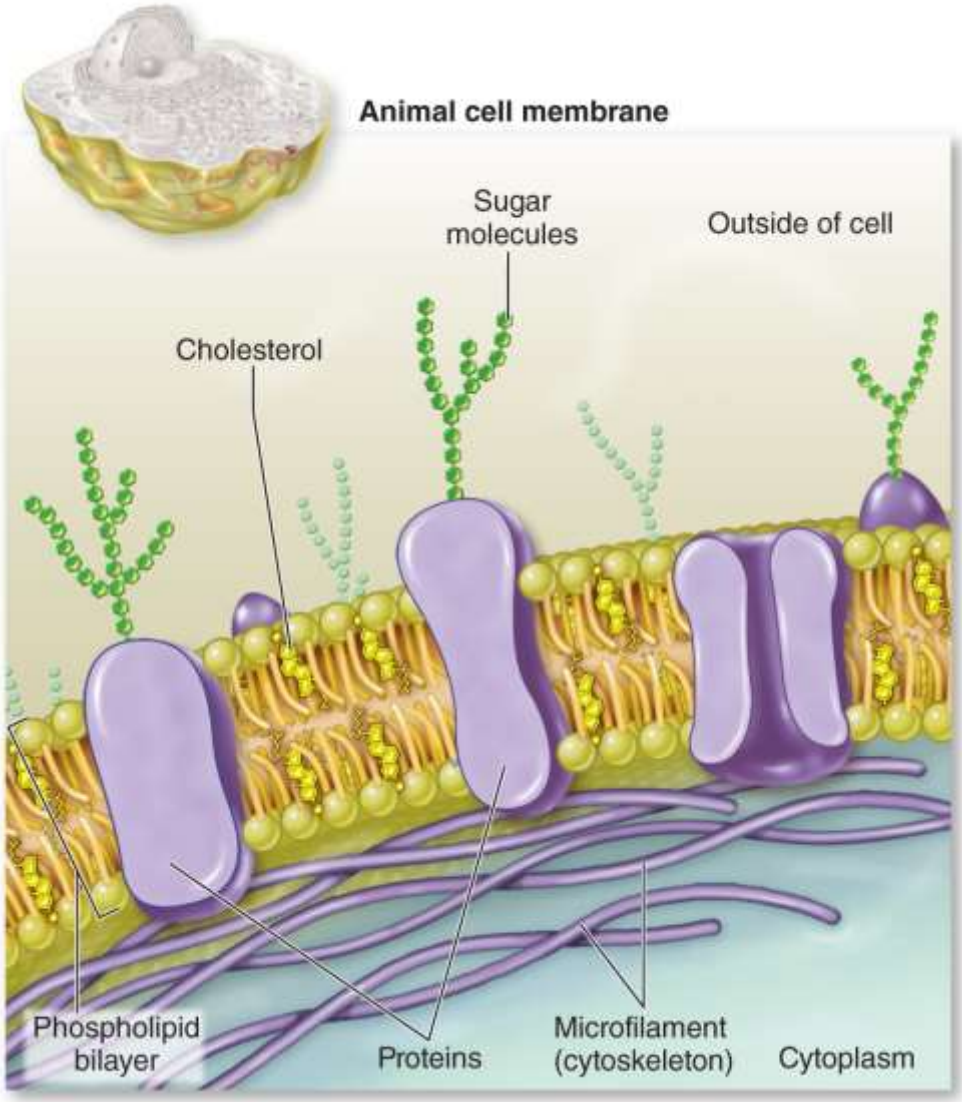
A lipid bilayer is selectively permeable to lipids and small, nonpolar molecules.



Section 3.3

Figure 3.11

A Membrane Surrounds Each Cell

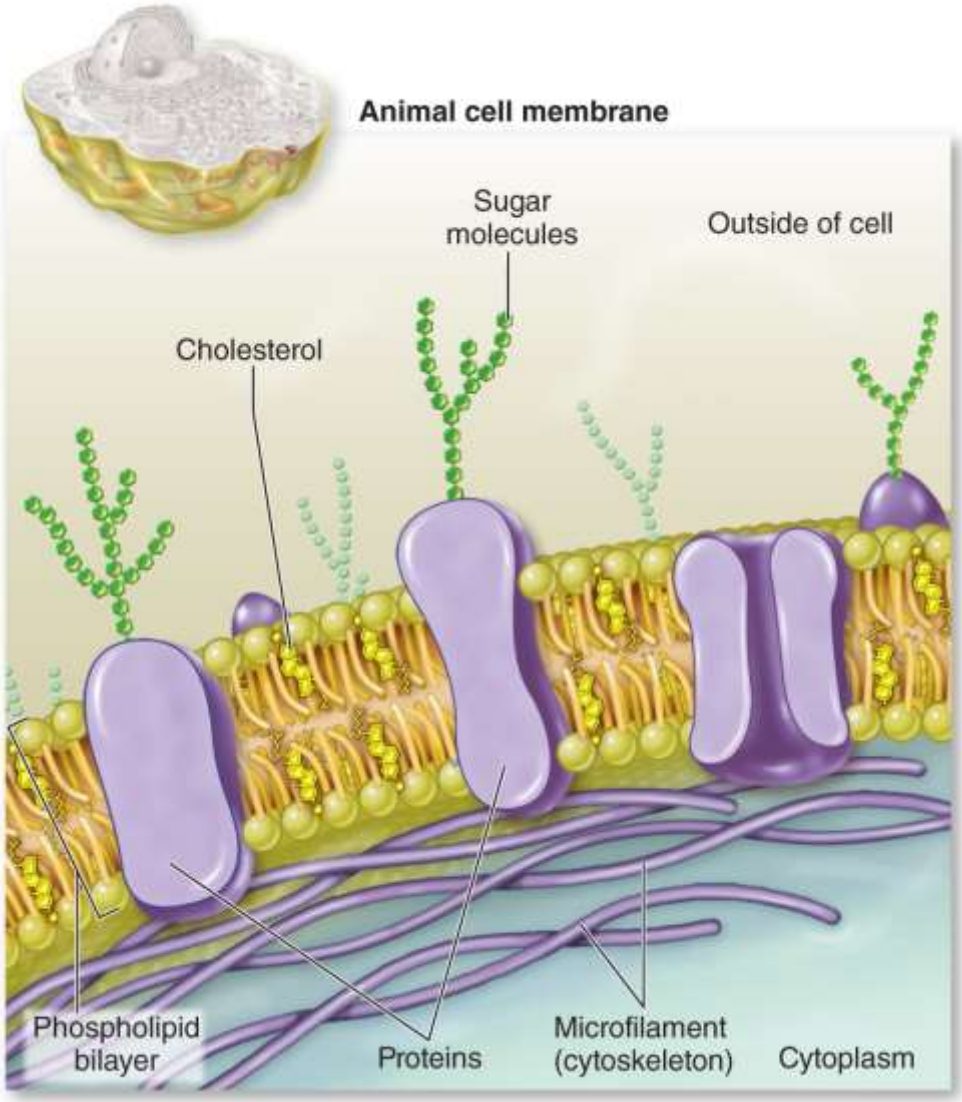


Besides phospholipids, cell membranes also contain proteins:

- Transport proteins
- Enzymes
- Recognition proteins
- Adhesion proteins
- Receptor proteins

Figure 3.12

A Membrane Surrounds Each Cell



The combination of phospholipids and movable proteins forms a **fluid mosaic**.

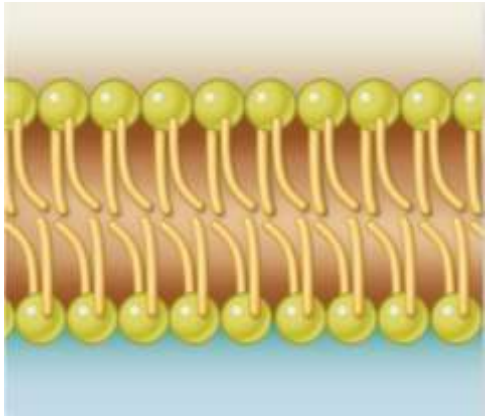
Section 3.3

Figure 3.12

Question #3

Cholesterol is a molecule in animal cell membranes. Since cholesterol is hydrophobic, where is it most likely to occur?

A. region X
B. region Y



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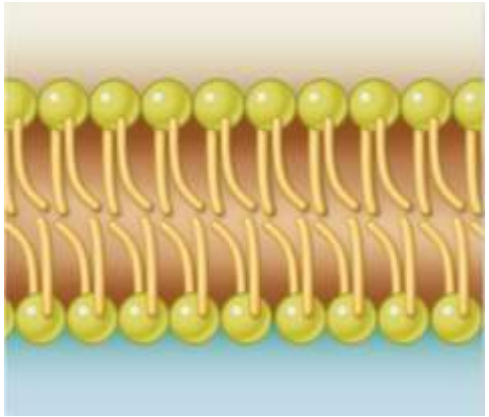
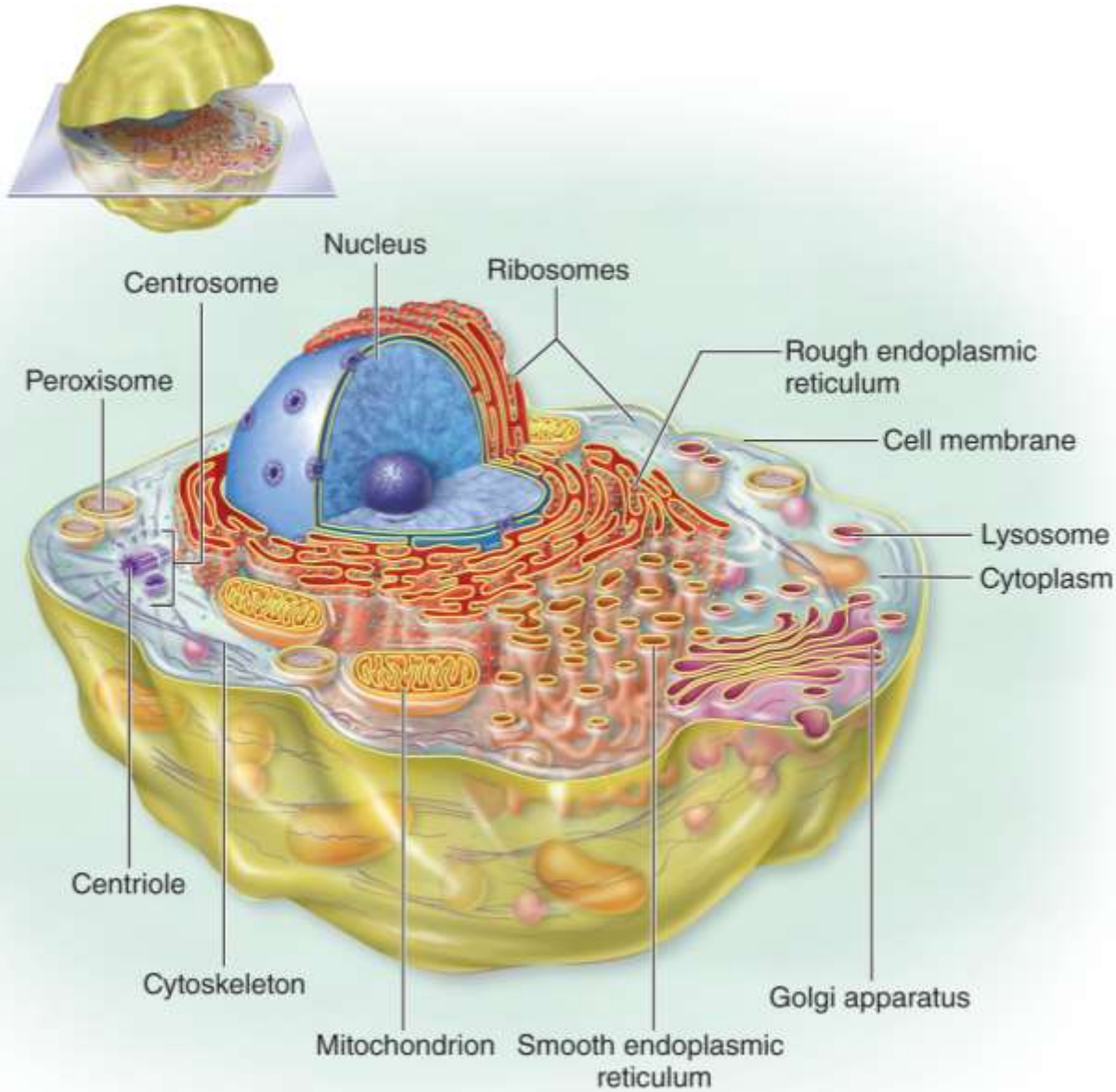


3.3 Mastering Concepts

How does the chemical structure of phospholipids enable them to form a bilayer in water?

Eukaryotic Organelles Divide Labor

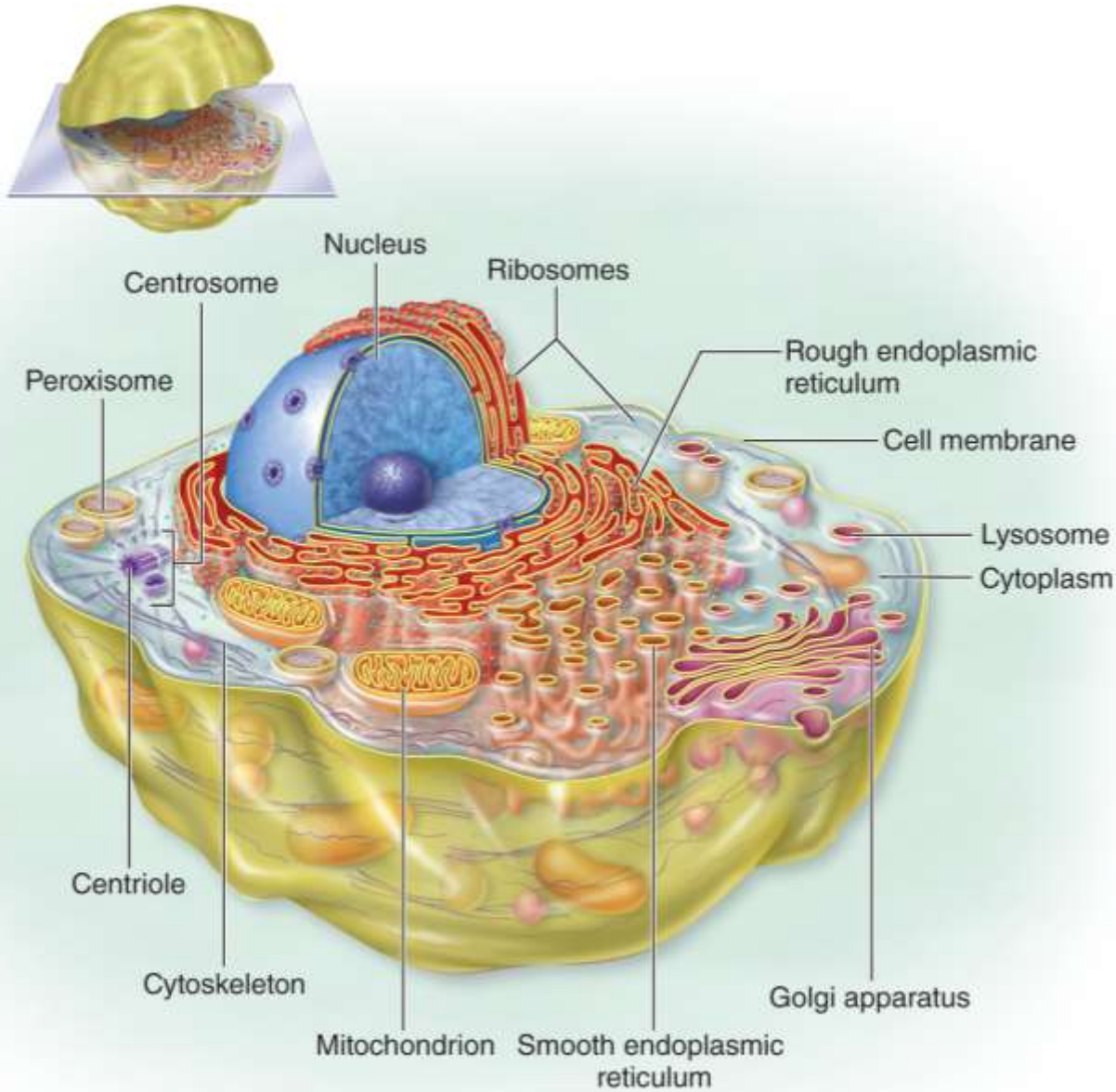


Eukaryotic cells contain organelles with specialized functions.

Section 3.4

Figure 3.8

Eukaryotic Organelles Divide Labor

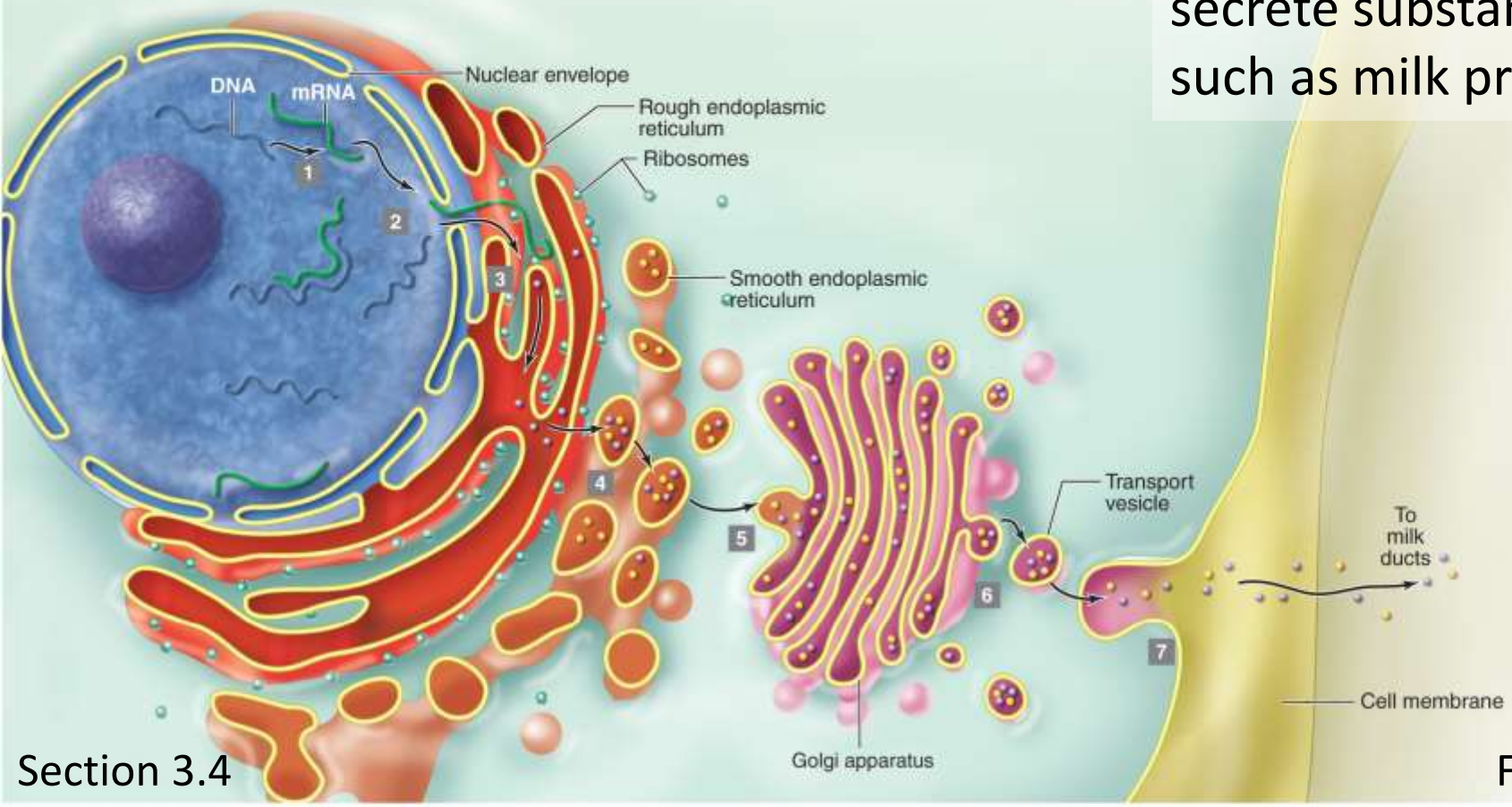


The **endomembrane system** consists of the nuclear envelope, endoplasmic reticulum, Golgi apparatus, lysosomes, vacuoles, and cell membrane.

Figure 3.8

Eukaryotic Organelles Divide Labor

The nucleus, ER, and Golgi interact to secrete substances, such as milk proteins.



Section 3.4

Figure 3.13

Eukaryotic Organelles Divide Labor

The **nucleus** contains DNA, which specifies the “recipe” for the proteins.

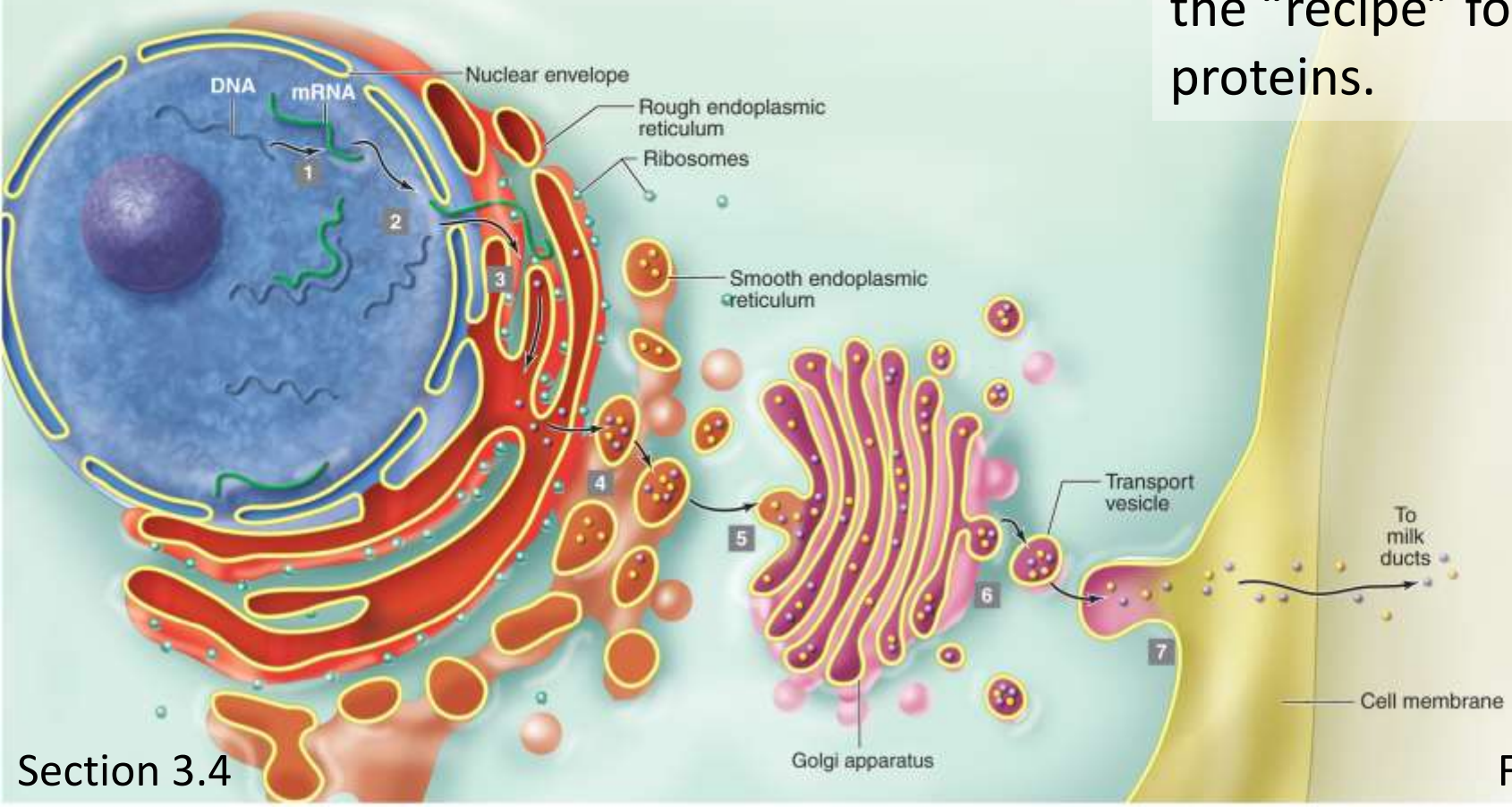
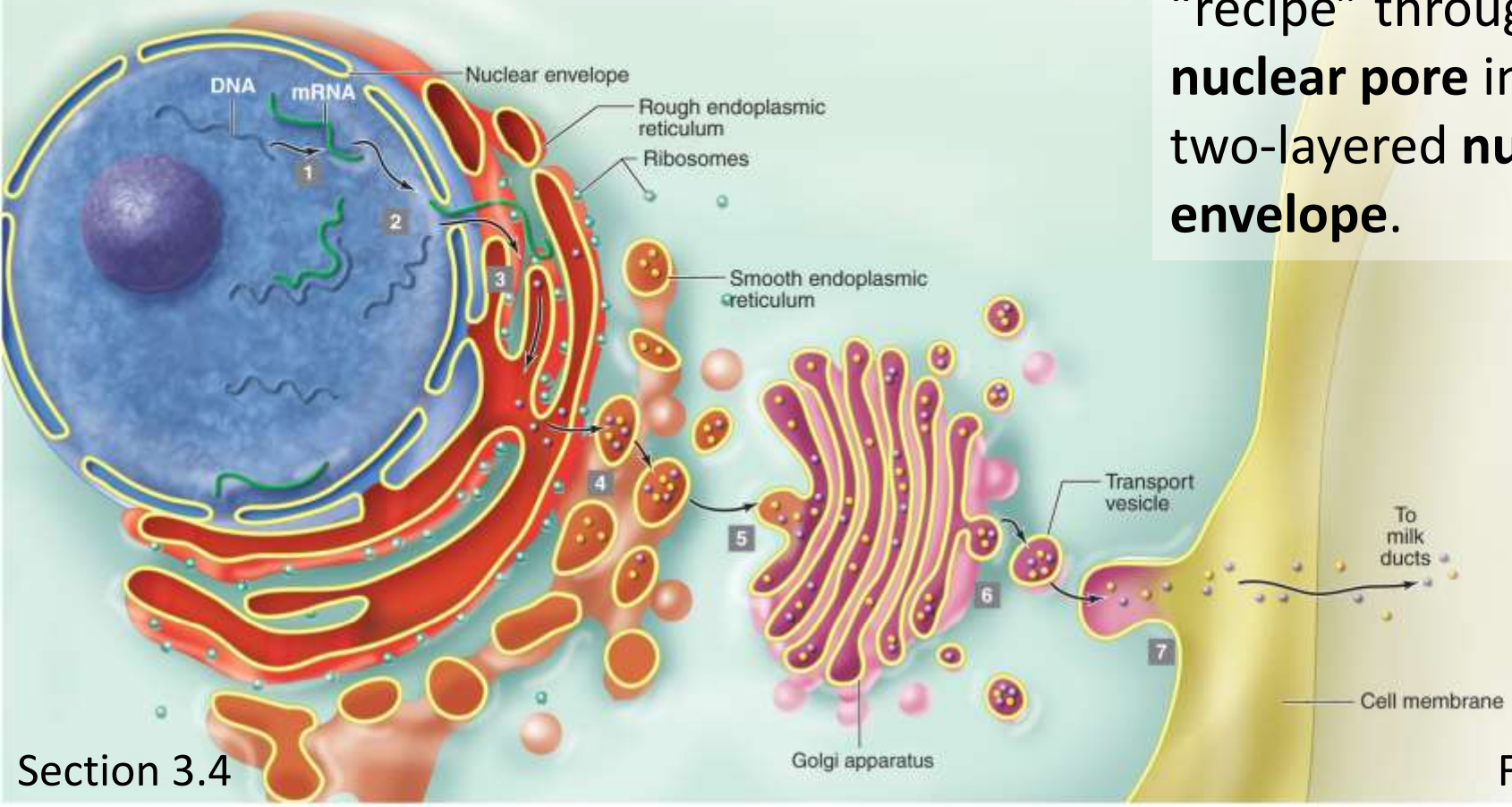


Figure 3.13

Eukaryotic Organelles Divide Labor



A messenger molecule carries the protein "recipe" through a **nuclear pore** in the two-layered **nuclear envelope**.

Figure 3.13

Eukaryotic Organelles Divide Labor

The messenger molecule meets a **ribosome**, where a protein is assembled.

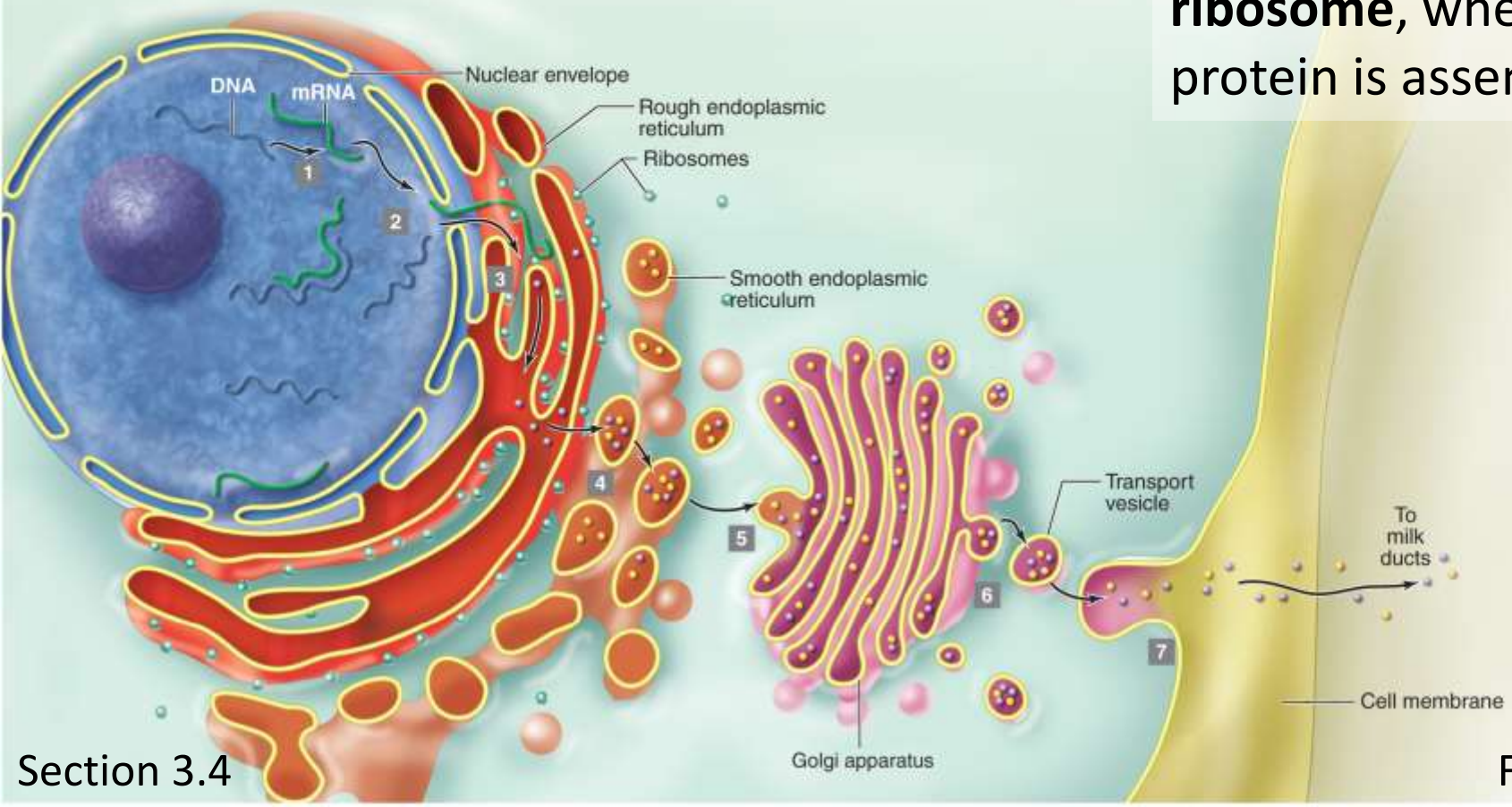


Figure 3.13

Eukaryotic Organelles Divide Labor

Some ribosomes are on the surface of the **rough ER**, a network of membranous sacs and tubules.

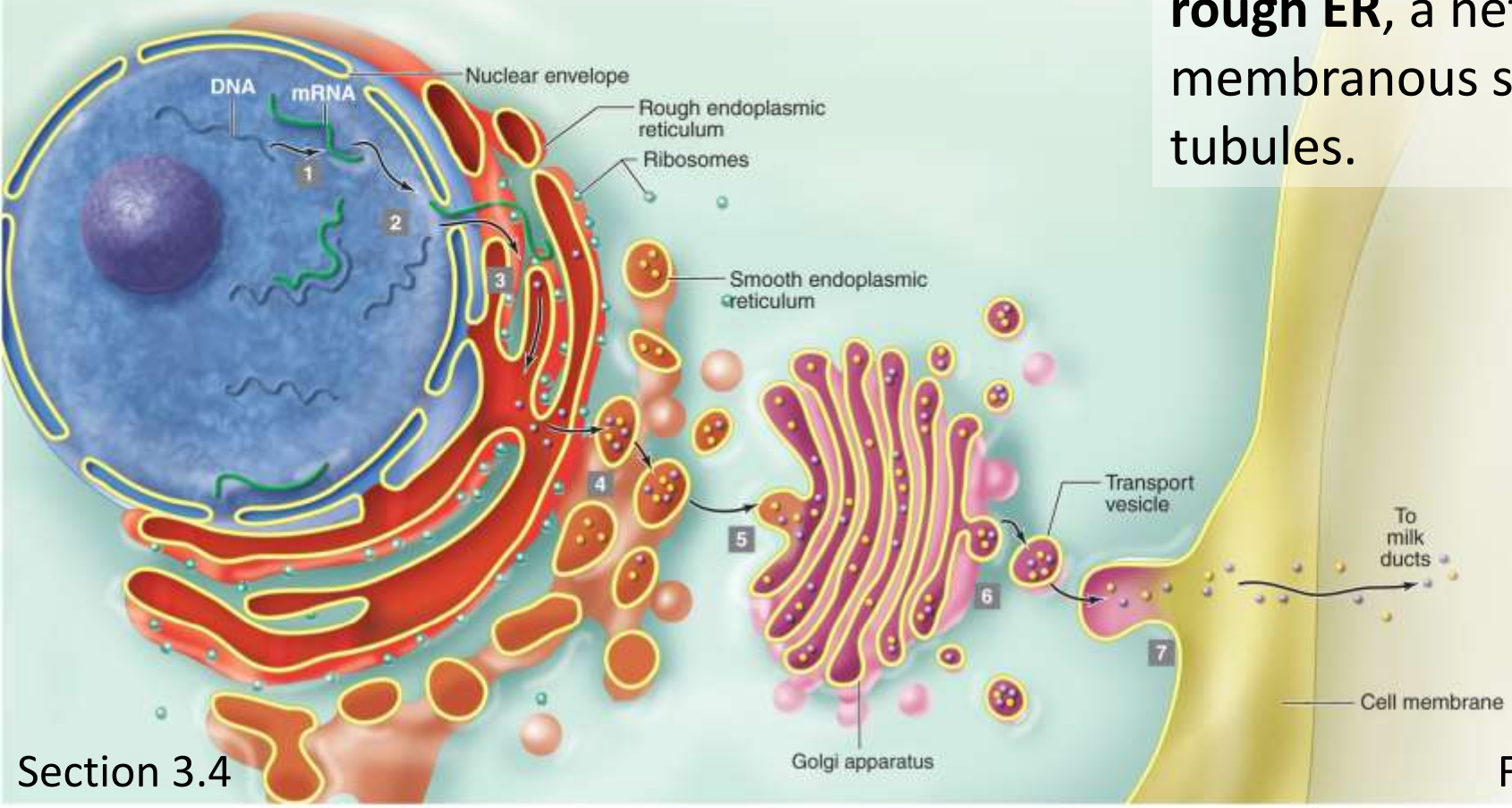
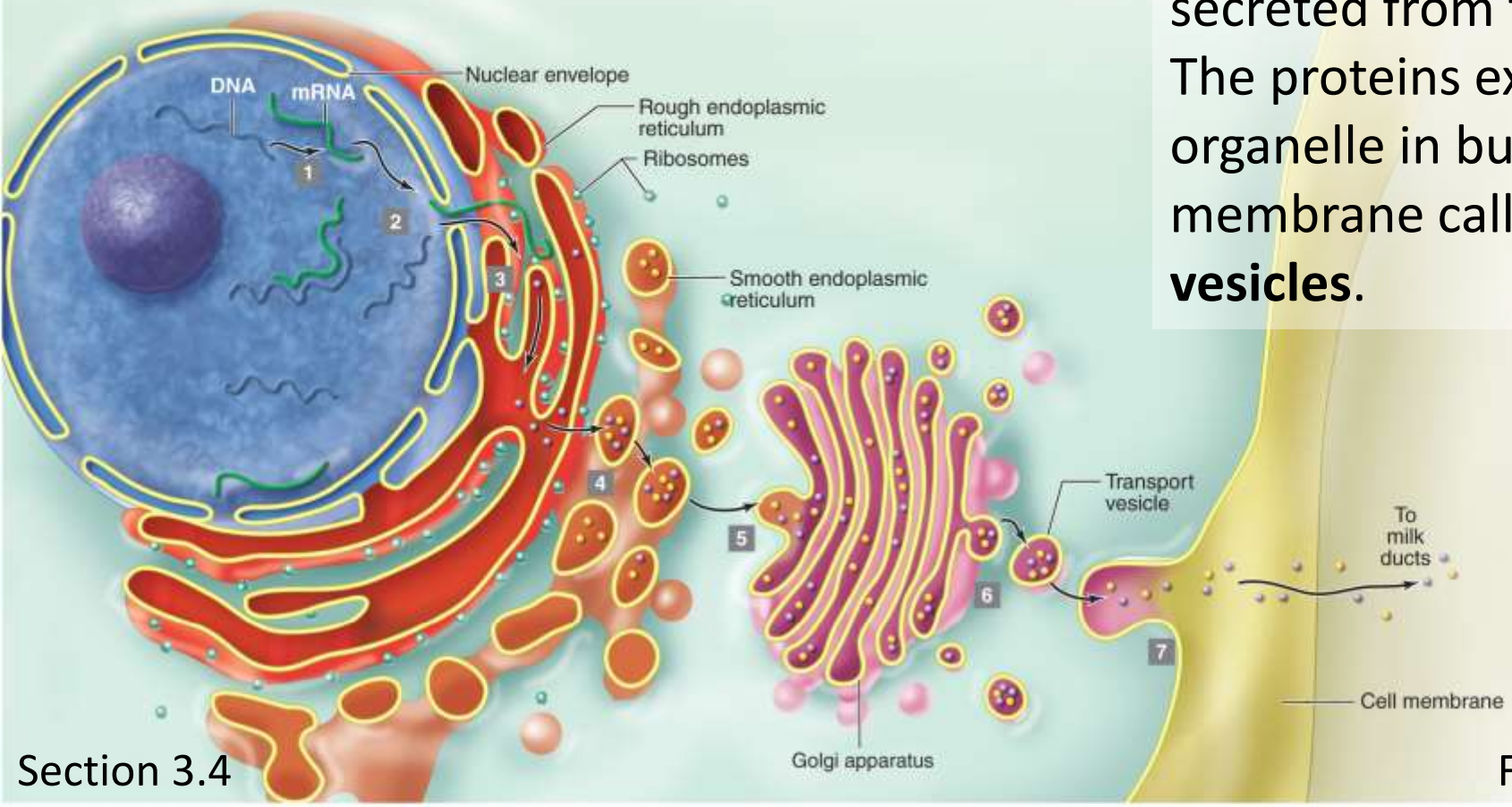


Figure 3.13

Eukaryotic Organelles Divide Labor

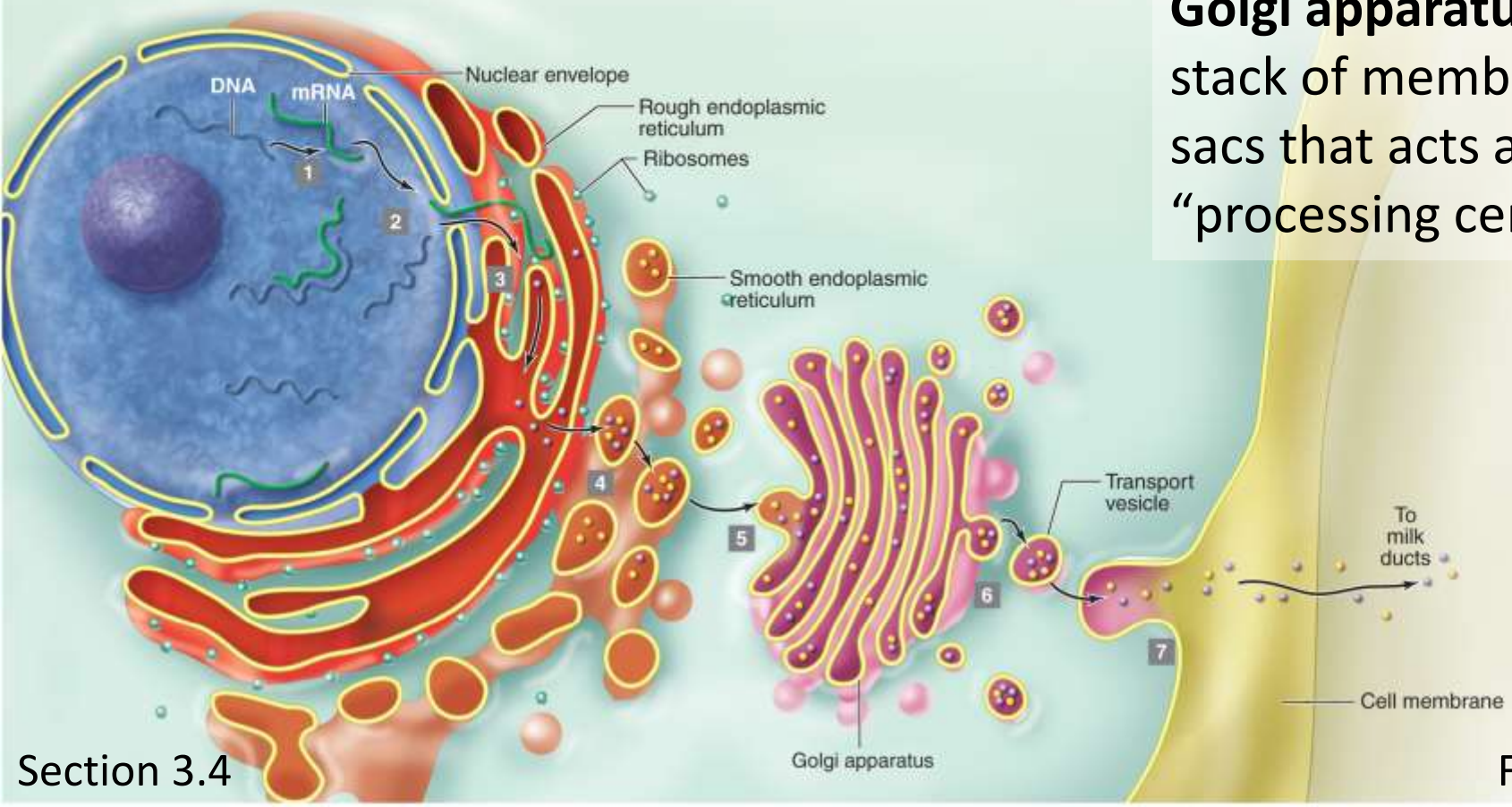


Proteins synthesized at the RER will be secreted from the cell. The proteins exit the organelle in bubbles of membrane called **vesicles**.

Section 3.4

Figure 3.13

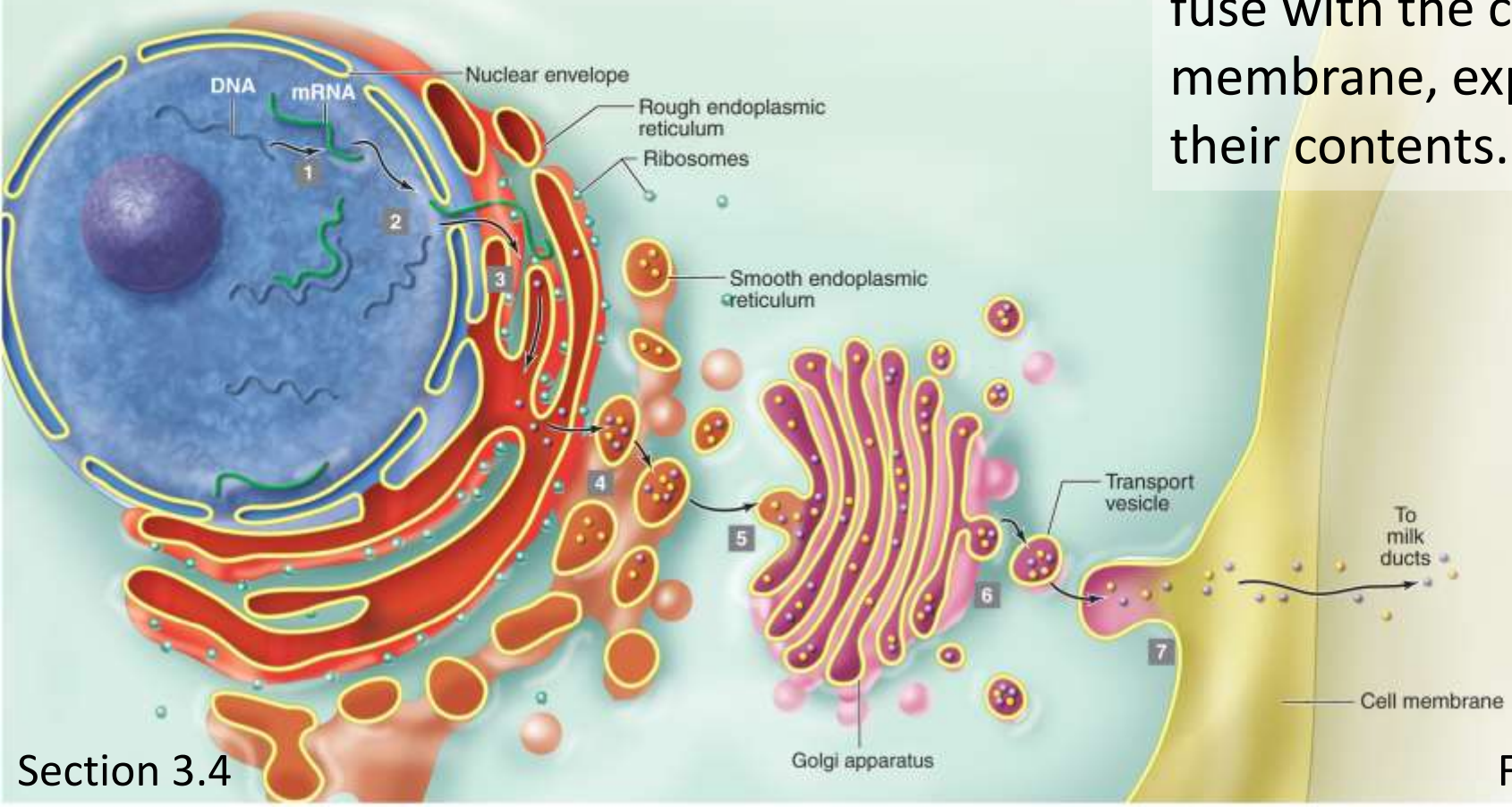
Eukaryotic Organelles Divide Labor



The vesicles leaving the RER fuse with the **Golgi apparatus**—a stack of membrane sacs that acts as a "processing center."

Figure 3.13

Eukaryotic Organelles Divide Labor



The proteins leave the Golgi in vesicles, which fuse with the cell membrane, expelling their contents.

Figure 3.13

Eukaryotic Organelles Divide Labor

Other vesicles leaving the Golgi carry digestive enzymes. These vesicles fuse with **lysosomes**, where cellular digestion occurs.

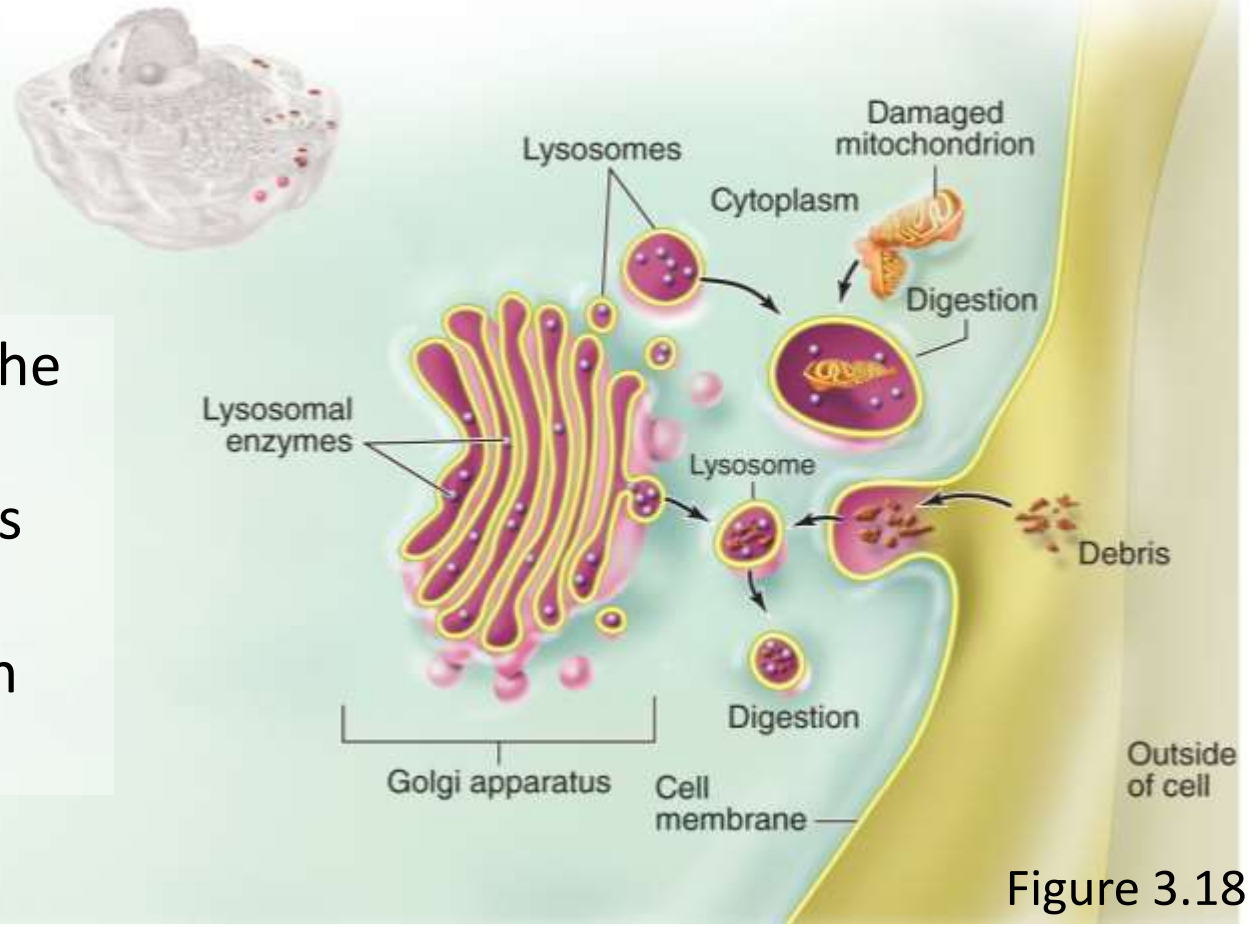
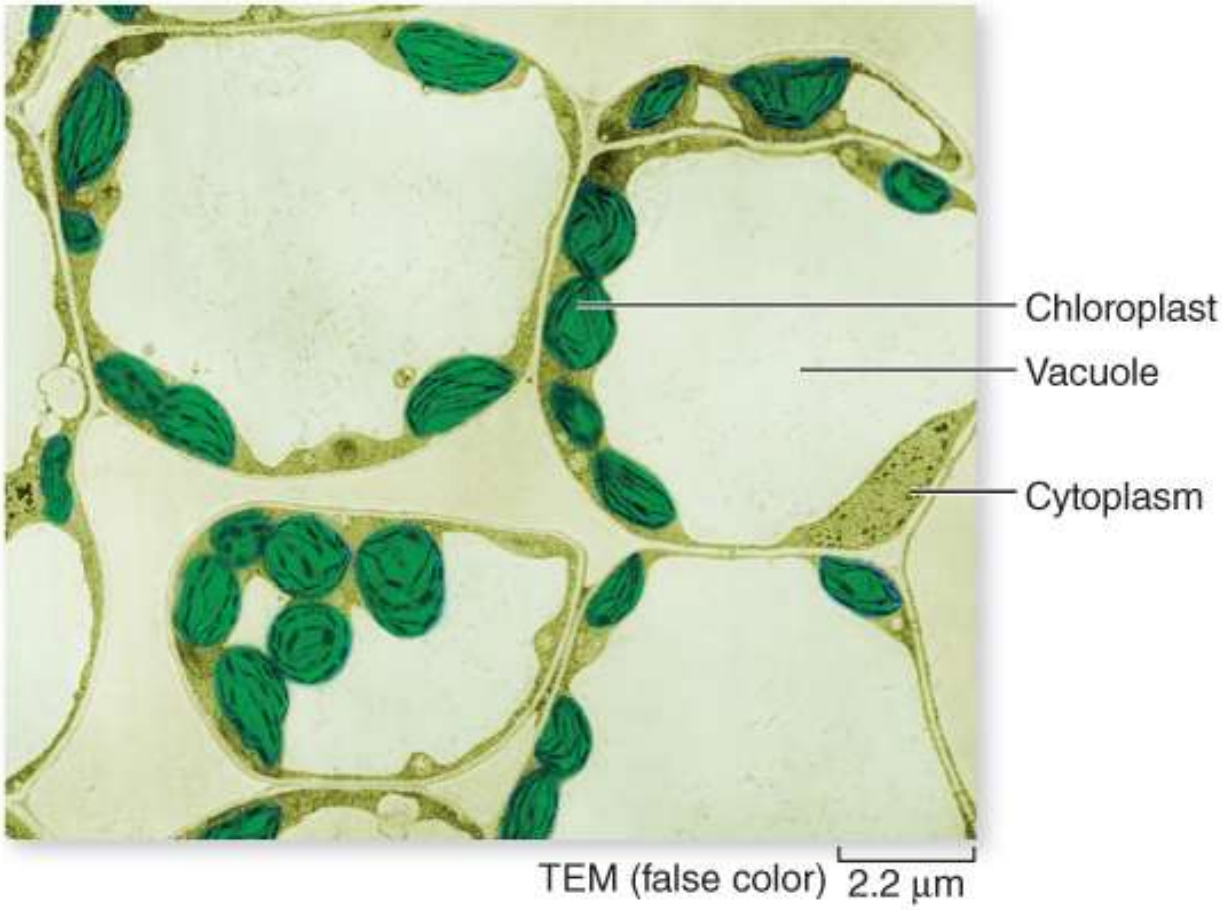


Figure 3.18

Eukaryotic Organelles Divide Labor

Most plant cells lack lysosomes. Cellular digestion occurs in large central **vacuoles**, which also help regulate the size and water balance of plant cells.

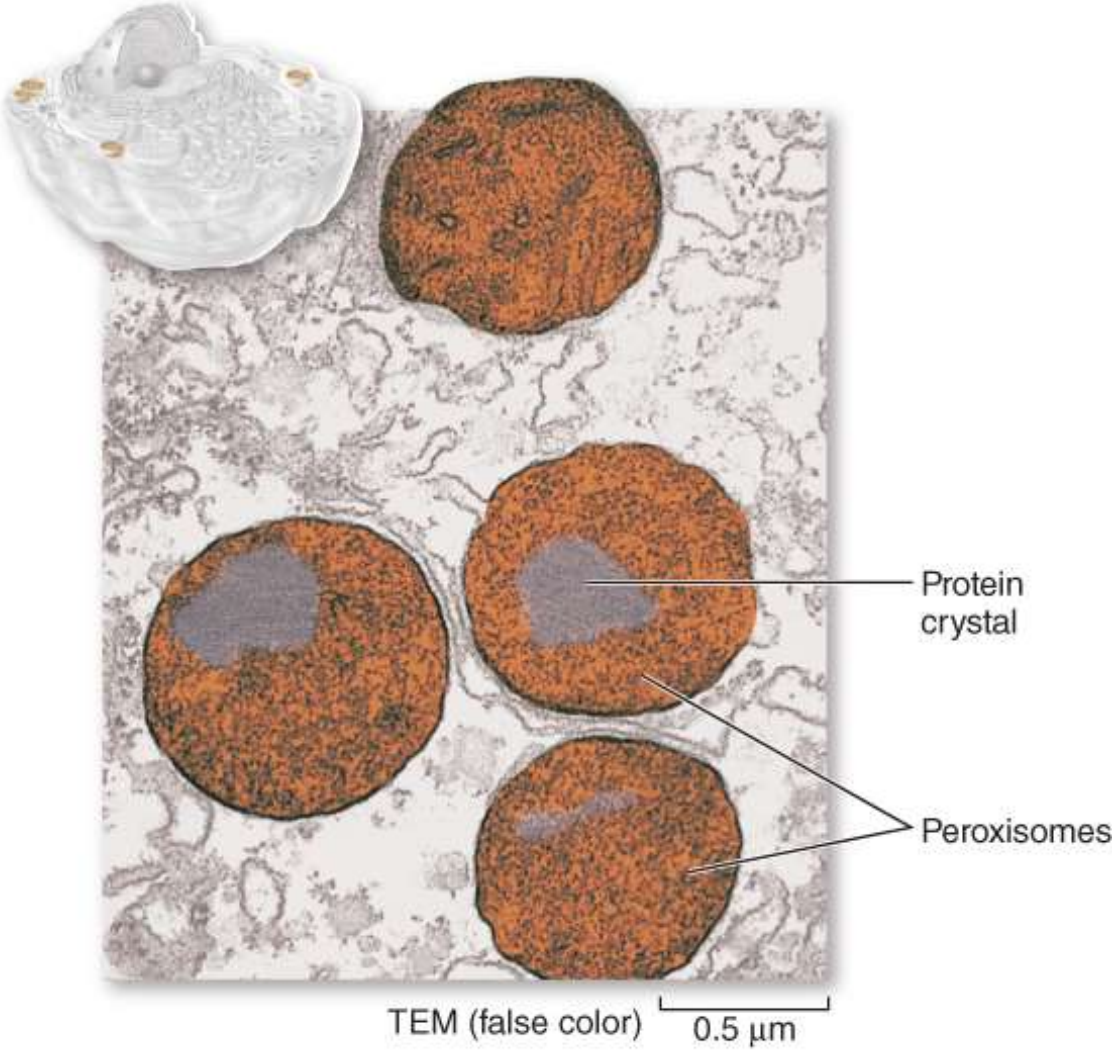


Section 3.4

Figure 3.19

Eukaryotic Organelles Divide Labor

Peroxisomes also aid in digestion. They originate at the ER and contain enzymes that break down toxic substances.



Eukaryotic Organelles Divide Labor

Ribosomes are both free in the cytoplasm and bound to the rough ER. The location of the ribosome determines the fate of the proteins it synthesizes.

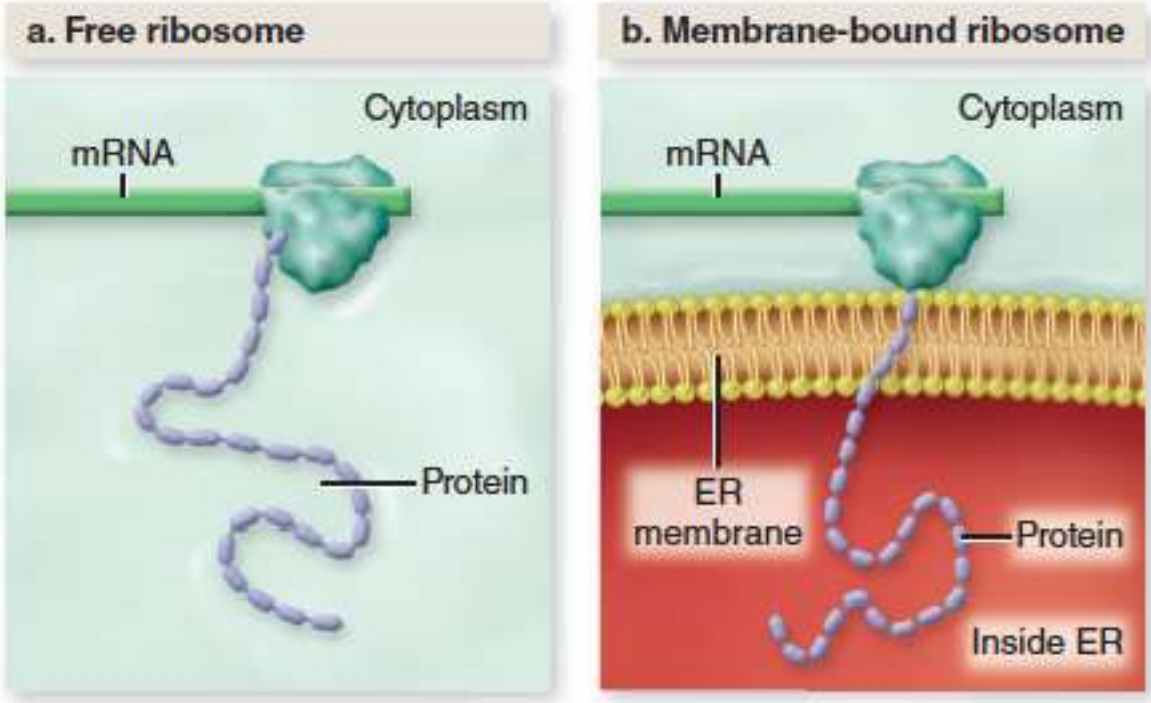
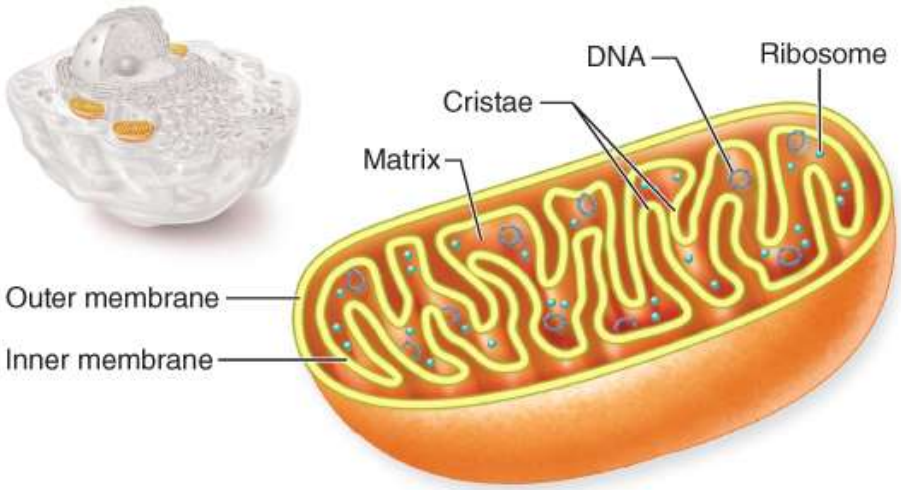
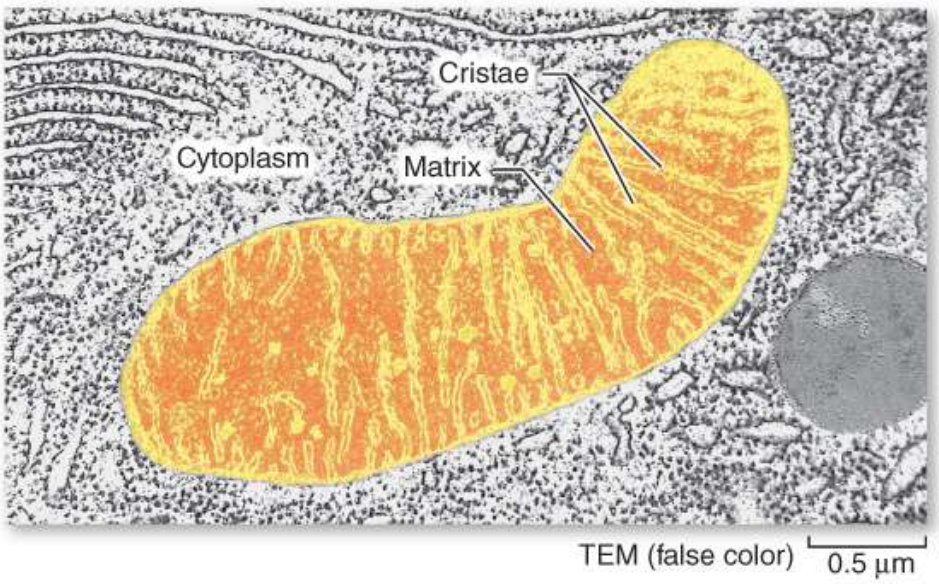


Figure 3.15

Eukaryotic Organelles Divide Labor

Many of the processes discussed so far require energy. Where does this energy come from?





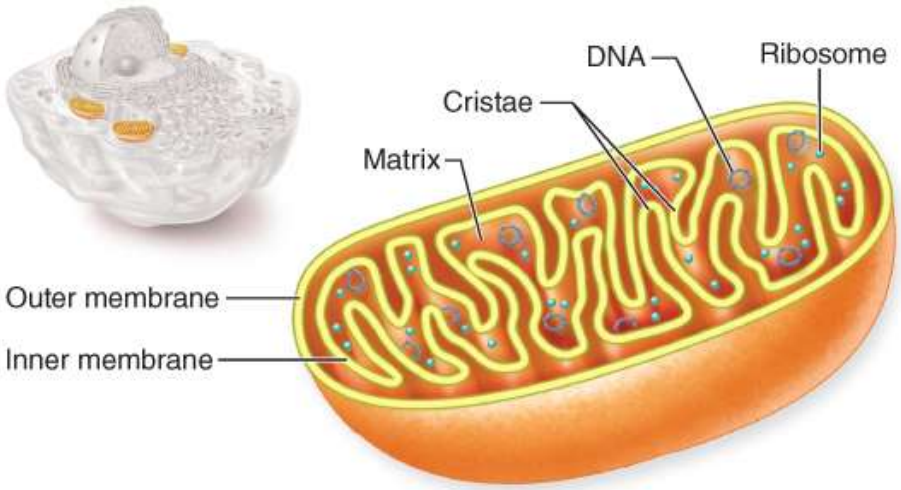
Section 3.4

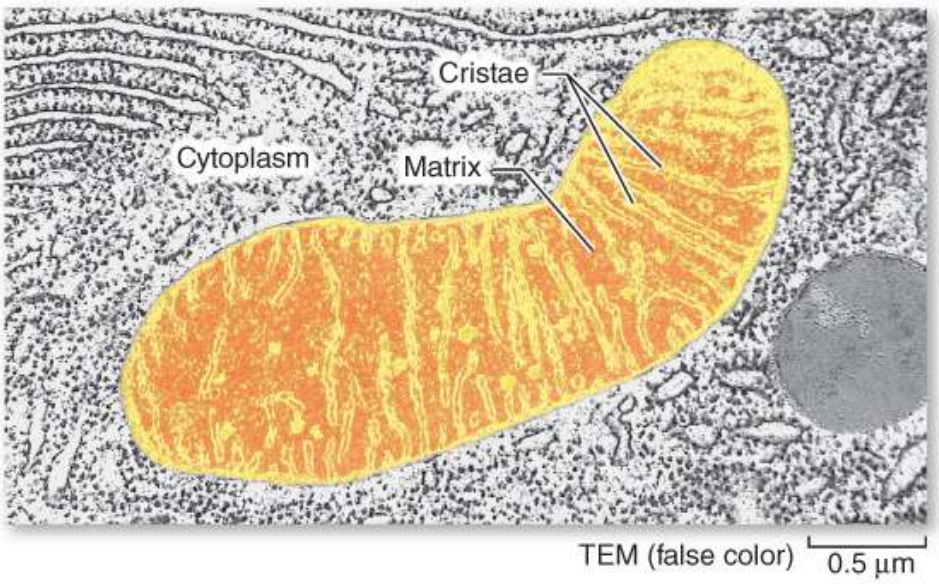
Mitochondrion © Bill Longcore/Science Source

Figure 3.21

Eukaryotic Organelles Divide Labor

Almost all eukaryotic cells have **mitochondria**, which extract energy from food.





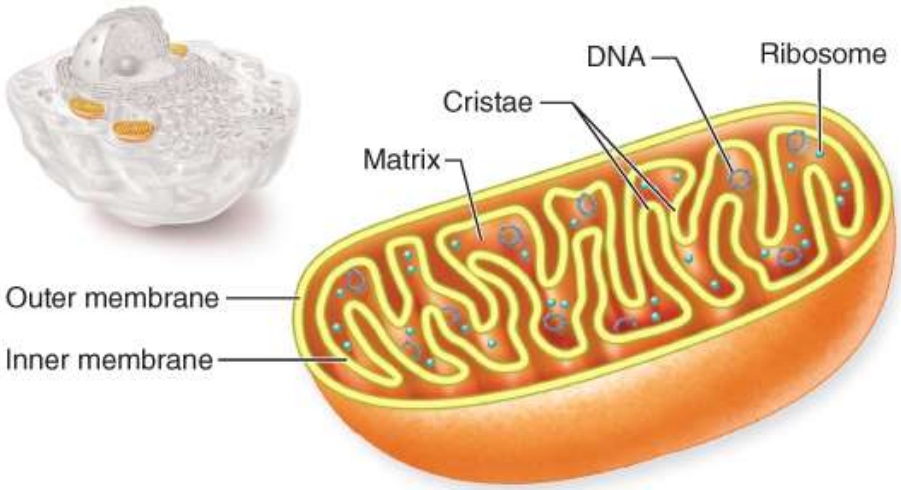
Section 3.4

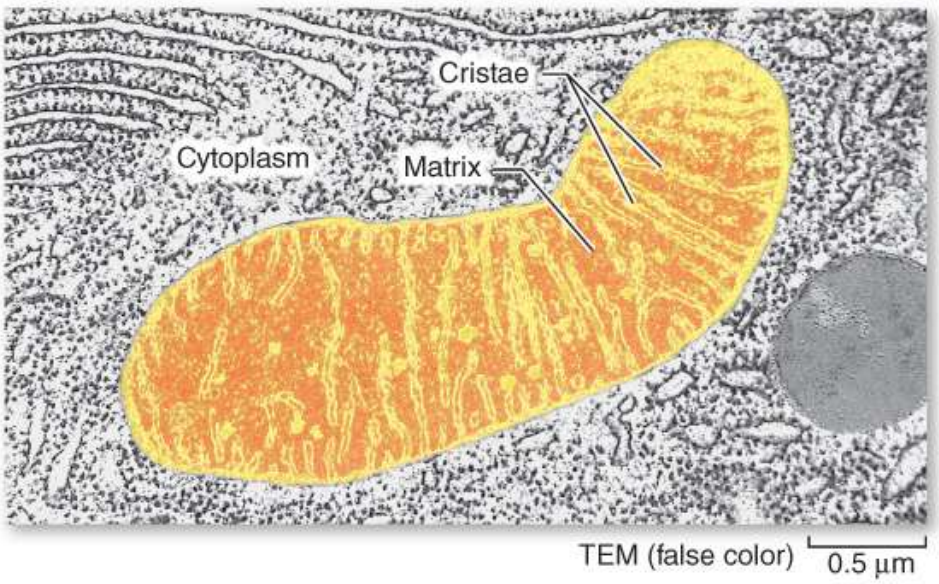
Mitochondrion © Bill Longcore/Science Source

Figure 3.21

Eukaryotic Organelles Divide Labor

Folds in the mitochondrial membrane, called **cristae**, house some of the reactions of cellular respiration.





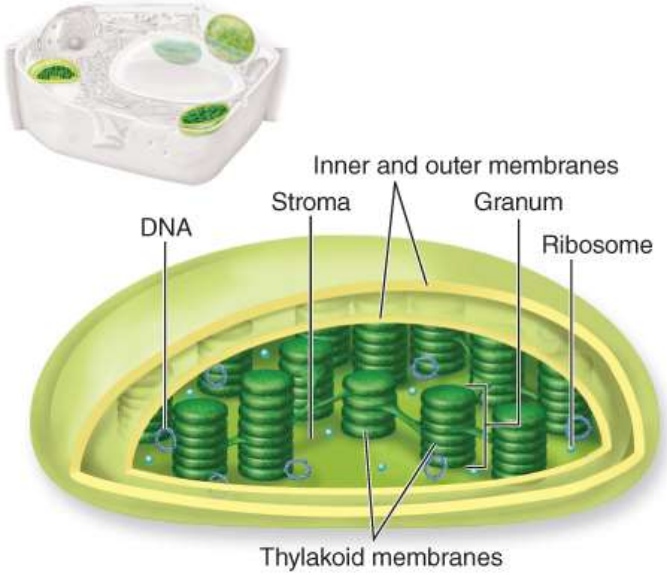
Section 3.4

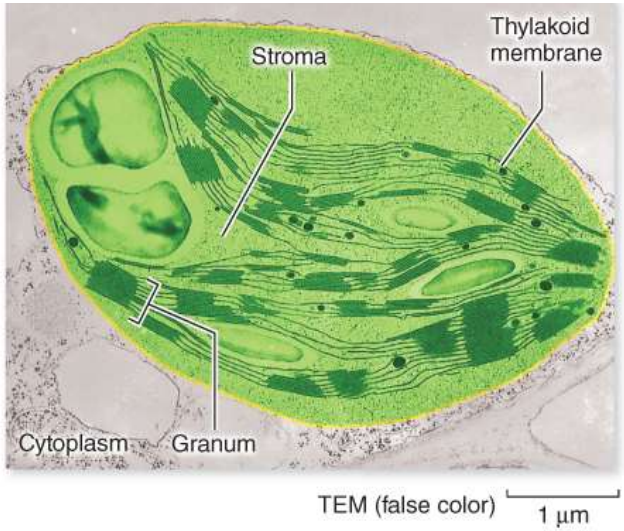
Mitochondrion © Bill Longcore/Science Source

Figure 3.21

Eukaryotic Organelles Divide Labor

Eukaryotes that carry out photosynthesis have **chloroplasts**, organelles that use sunlight to produce food for the cell.





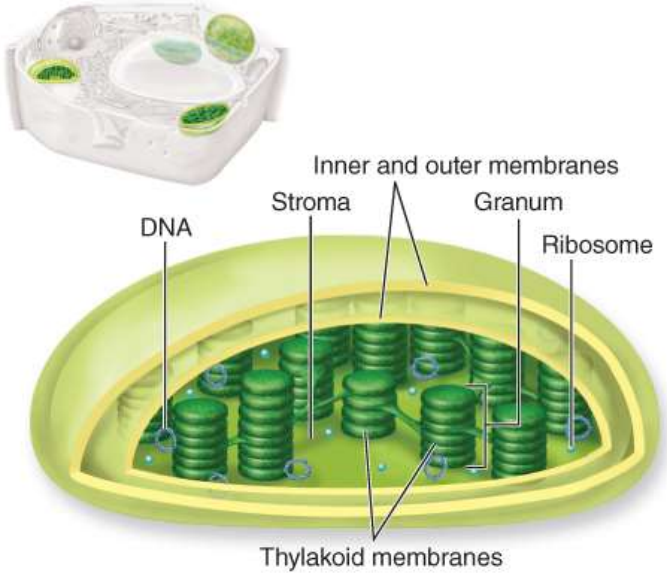
Section 3.4

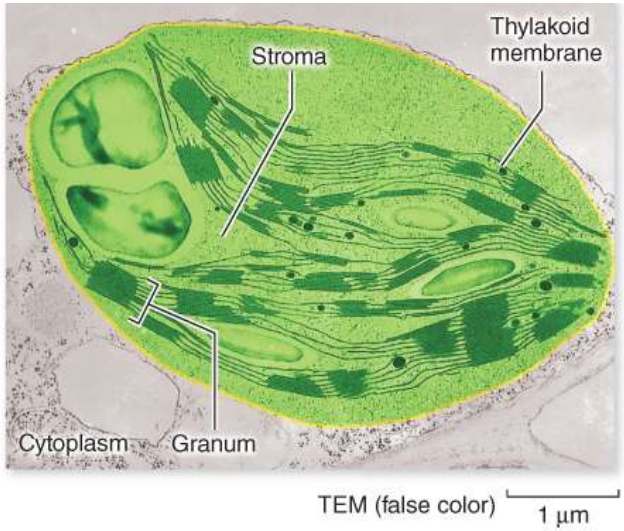
Chloroplast: © Biophoto Associates/Science Source

Figure 3.22

Eukaryotic Organelles Divide Labor

The food then travels to the mitochondria, which extract the energy used for cellular processes.





Section 3.4

Figure 3.22

Question #4

How many of these organelles occur in your skin cells?

mitochondria, ribosomes, nucleus, lysosomes, chloroplasts, vacuole, ER, nucleus

A. eight
B. seven
C. six
D. five
E. four

Question #4

How many of these organelles occur in your skin cells?

mitochondria, ribosomes, nucleus, lysosomes, chloroplasts, vacuole, ER, nucleus

A. eight
B. seven
C. six
D. five
E. four

3.4 Mastering Concepts

Which organelles interact to produce and secrete a complex substance such as milk?

A Cytoskeleton Supports Eukaryotic Cells

The **cytoskeleton** is a network of protein tracks and tubules. It has several functions:

- Structural support
- Aids in cell division
- Organelle transport
- Cell movement

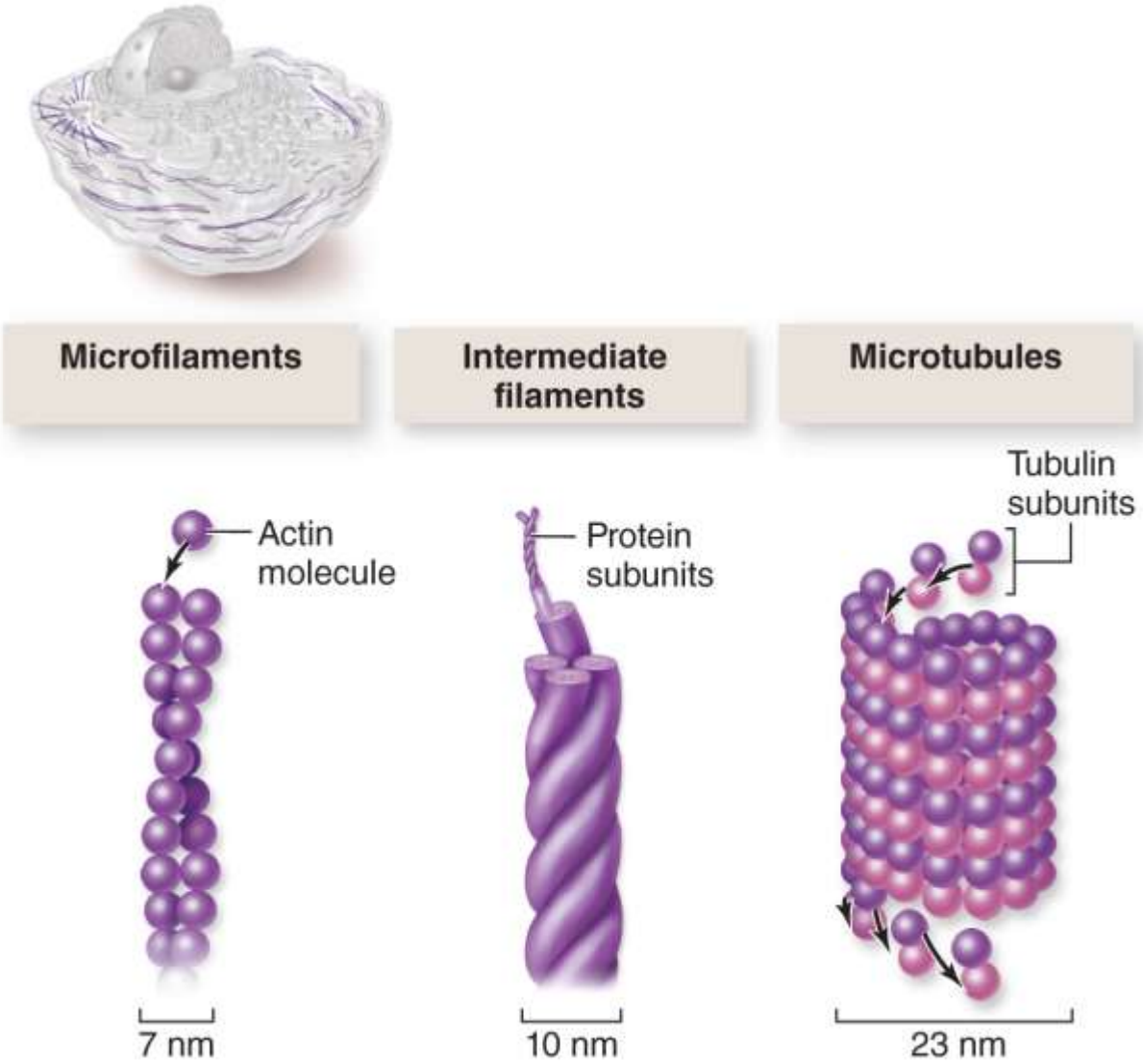
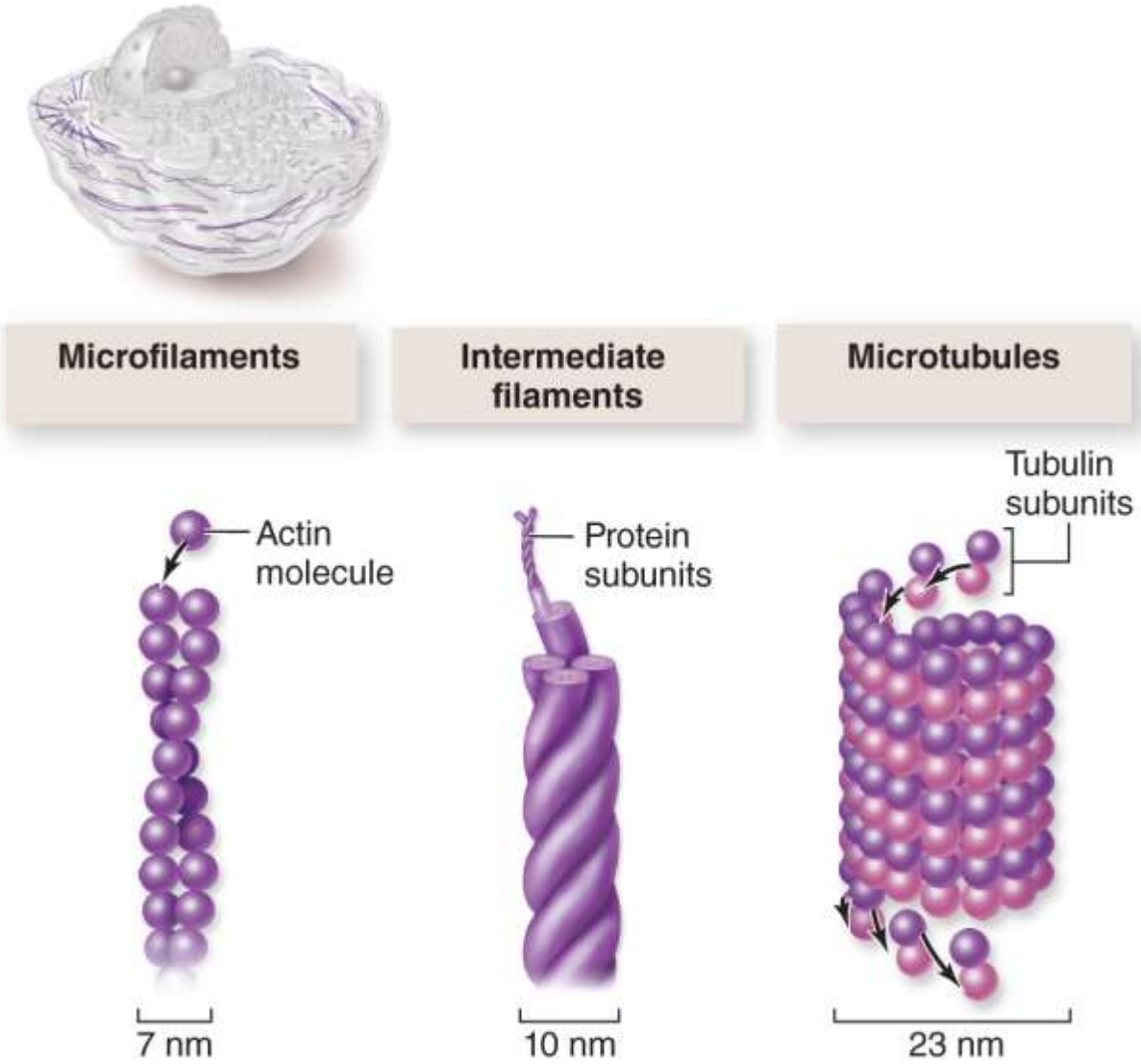


Figure 3.25

A Cytoskeleton Supports Eukaryotic Cells

The cytoskeleton has three major components:

- Microfilaments
- Intermediate filaments
- Microtubules

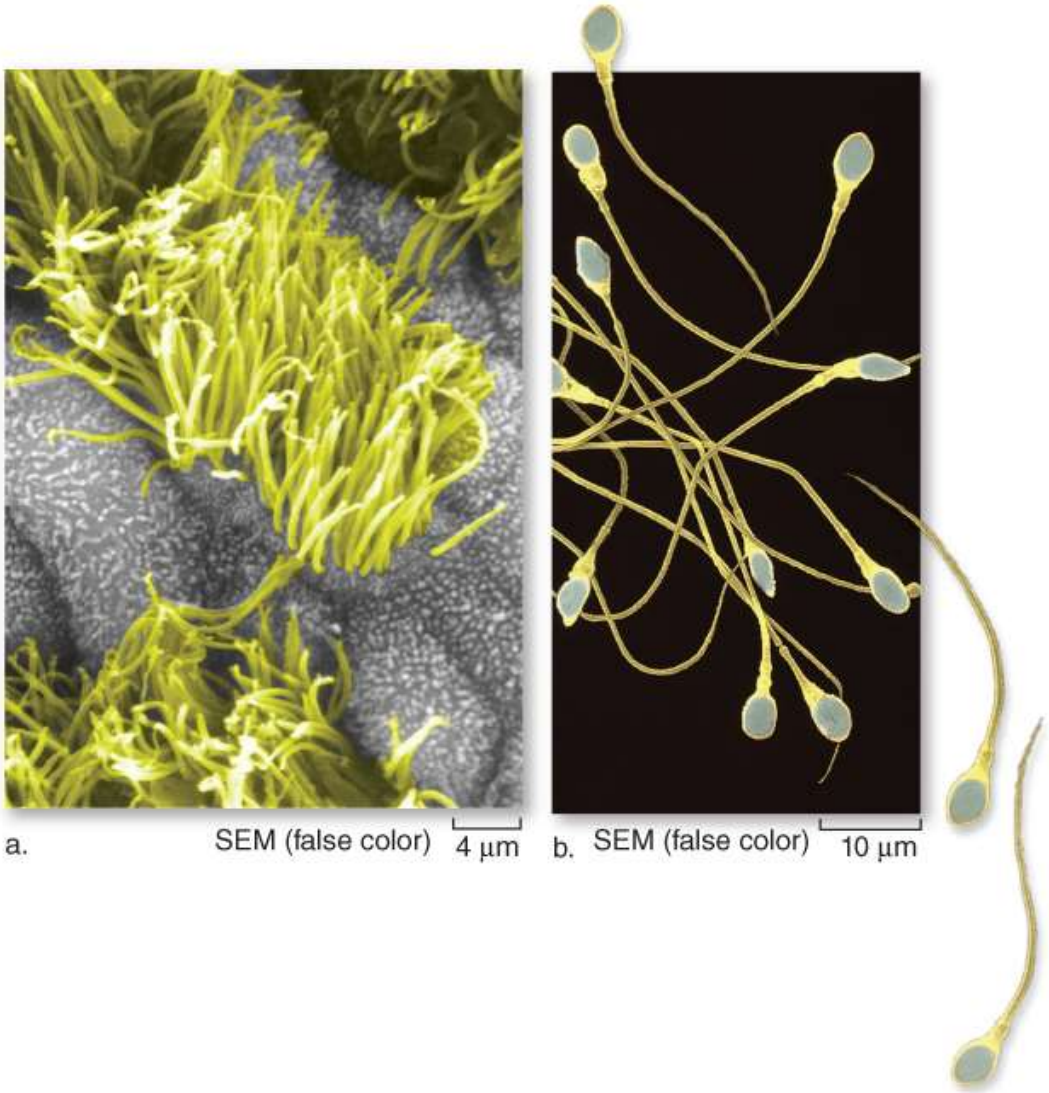


Section 3.5

Figure 3.25

A Cytoskeleton Supports Eukaryotic Cells

Microtubules form the internal framework of **cilia** and **flagella**.

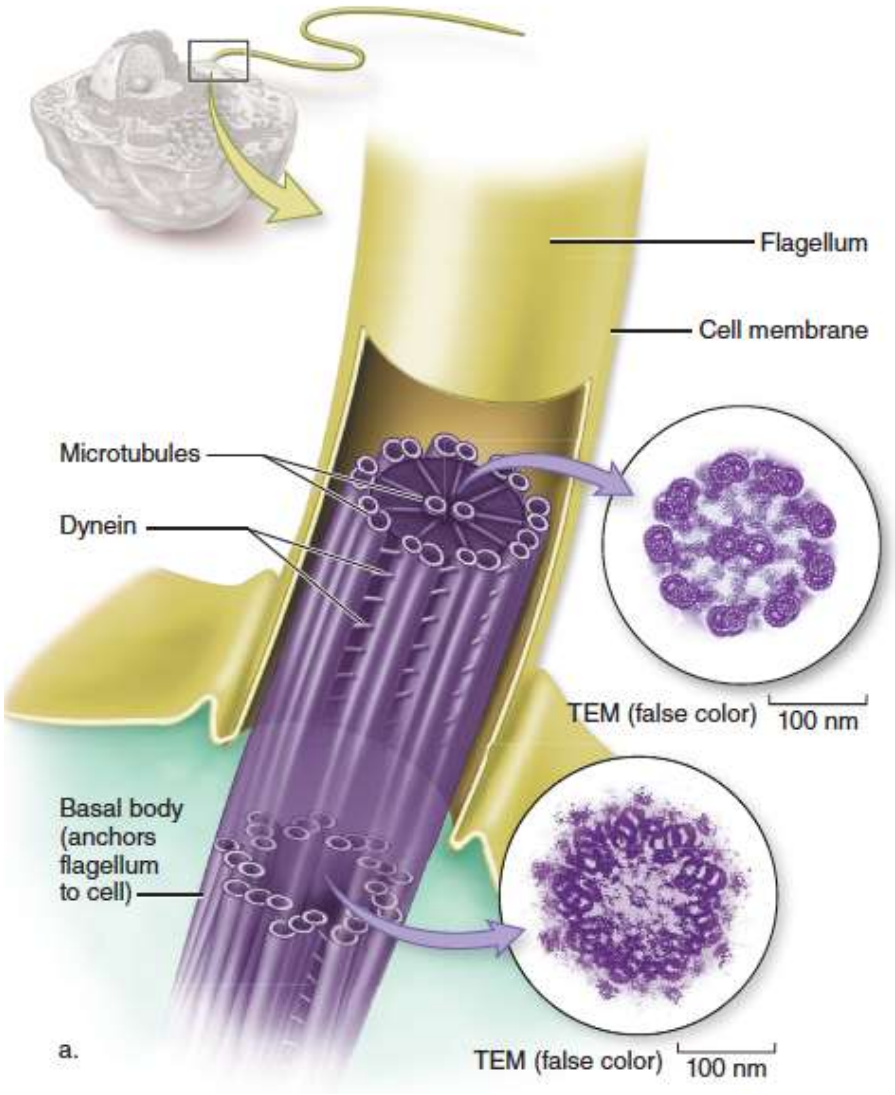


Section 3.5

Figure 3.26

A Cytoskeleton Supports Eukaryotic Cells

Adjacent microtubules slide against each other with the help of a protein called dynein. As a result, the cilium or flagellum bends.



Section 3.5

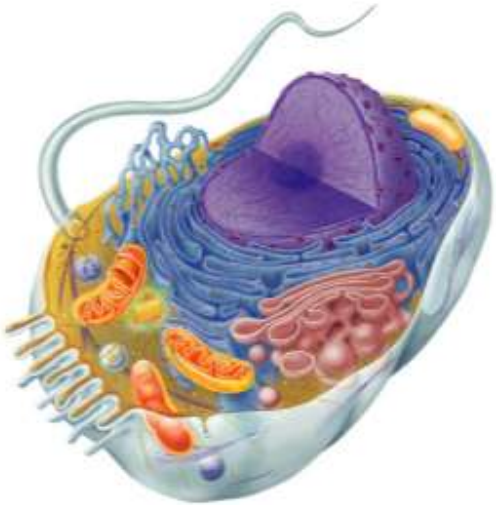
Figure 3.26

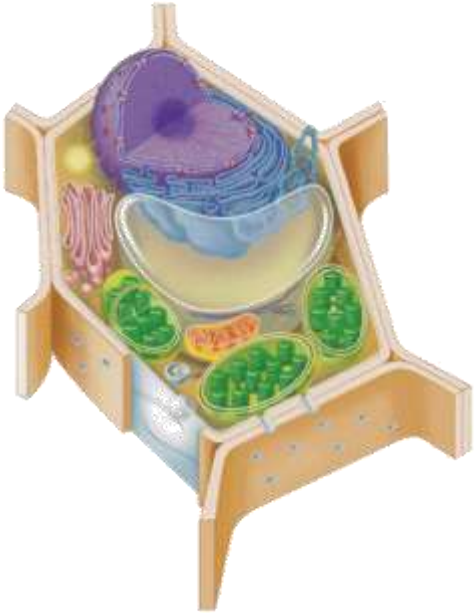
3.5 Mastering Concepts

What are some functions of the cytoskeleton?

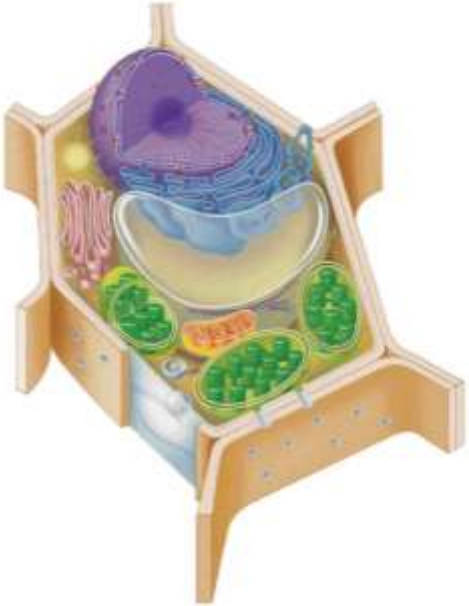
Cells gotta work to live!

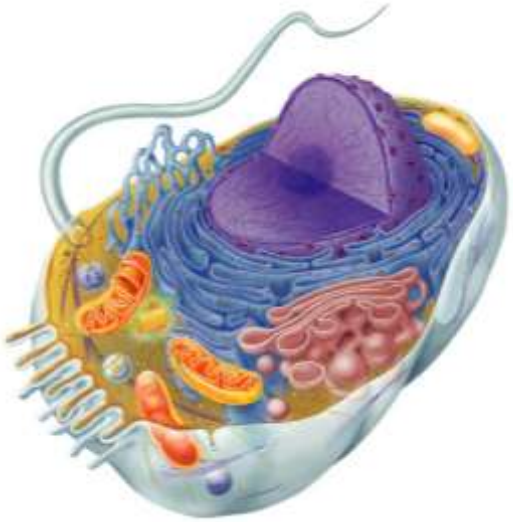
- What jobs do cells have to do?
  - make proteins
    - proteins control every cell function
  - make energy
    - for daily life
    - for growth
  - make more cells
    - growth
    - repair
    - renewal



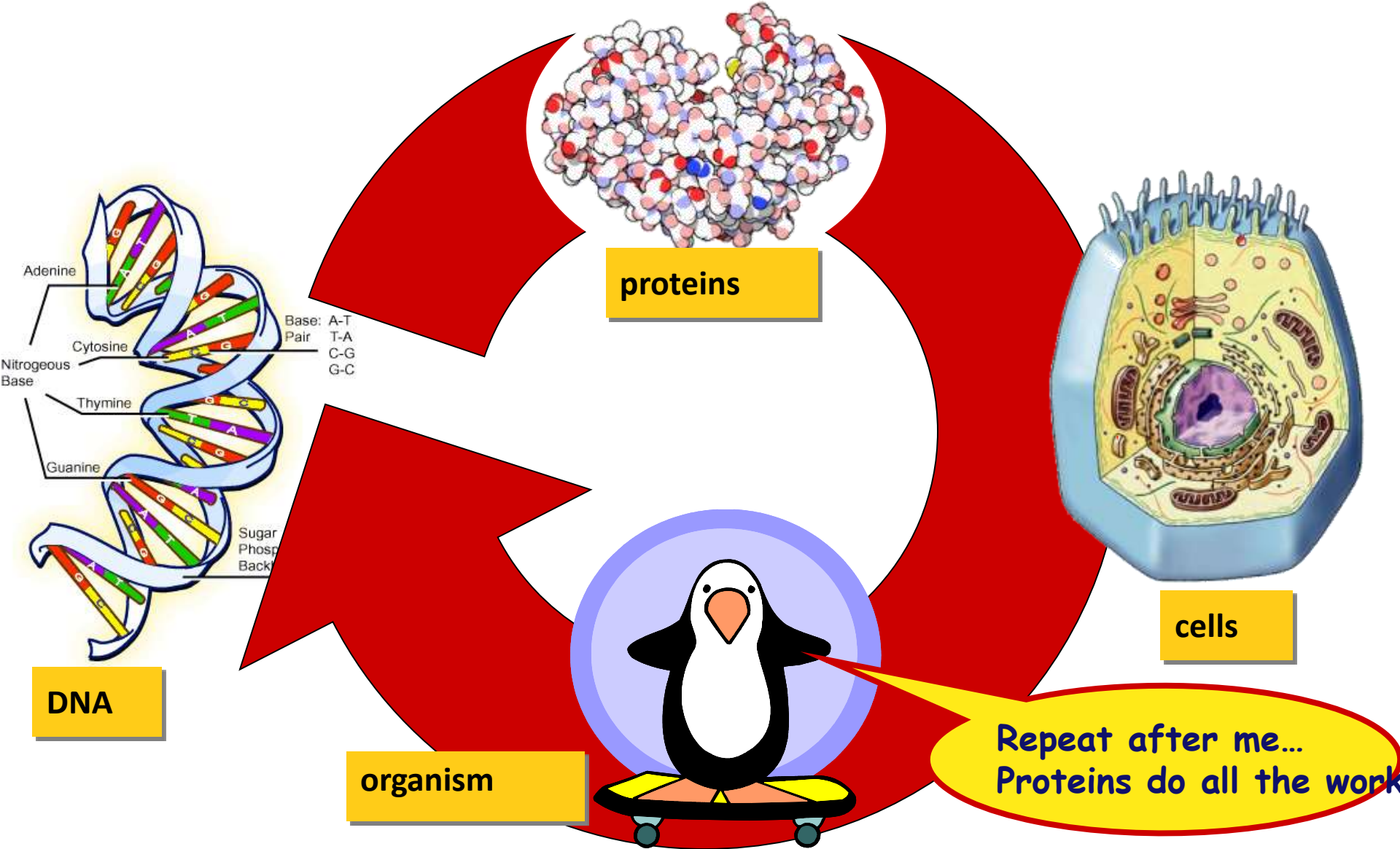


Building Proteins



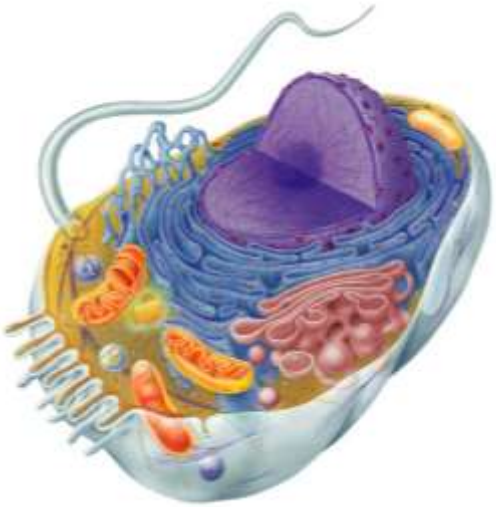


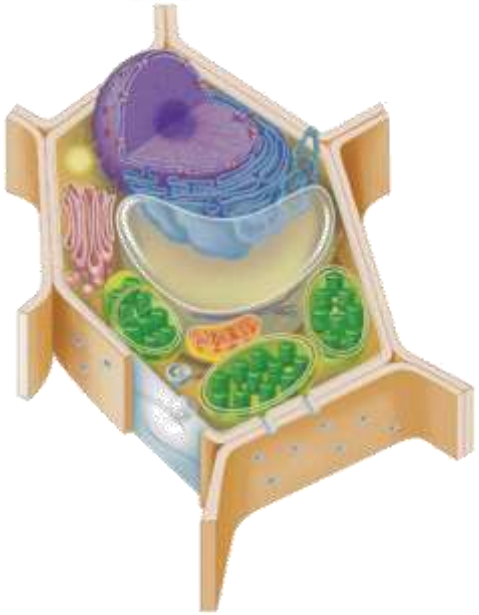
Proteins do all the work!



Cells functions

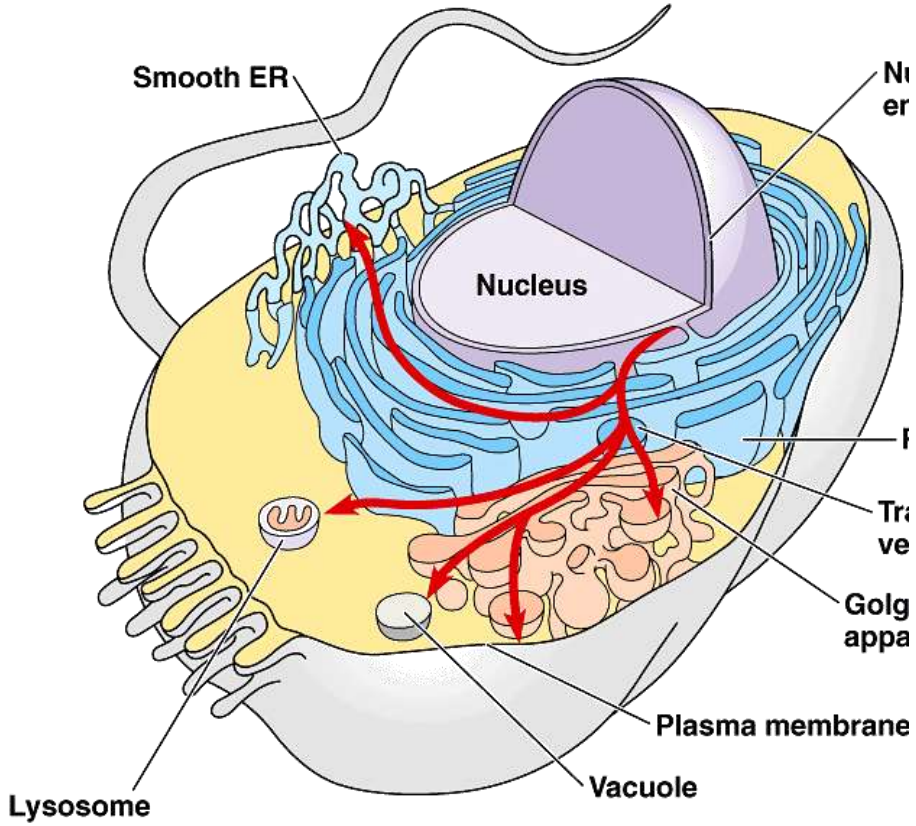
- Building proteins
  - read DNA instructions
  - build proteins
  - process proteins
    - folding
    - modifying
      - removing amino acids
      - adding other molecules
        - » e.g, making glycoproteins for cell membrane
  - address & transport proteins

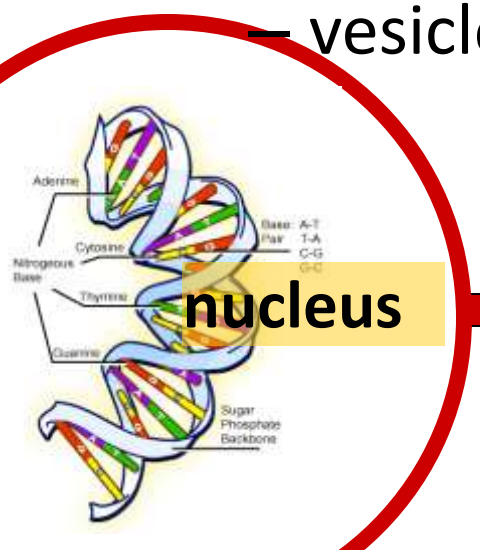




Building Proteins

- Organelles involved
  - nucleus
  - ribosomes
  - endoplasmic reticulum (ER)
  - Golgi apparatus
  - vesicles

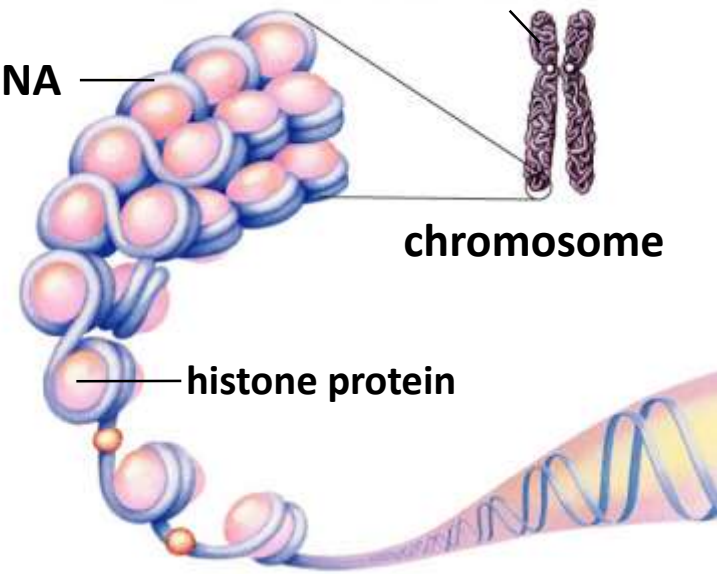




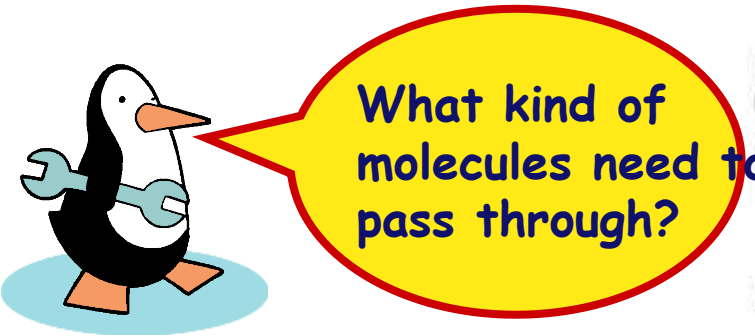
The Protein Assembly Line

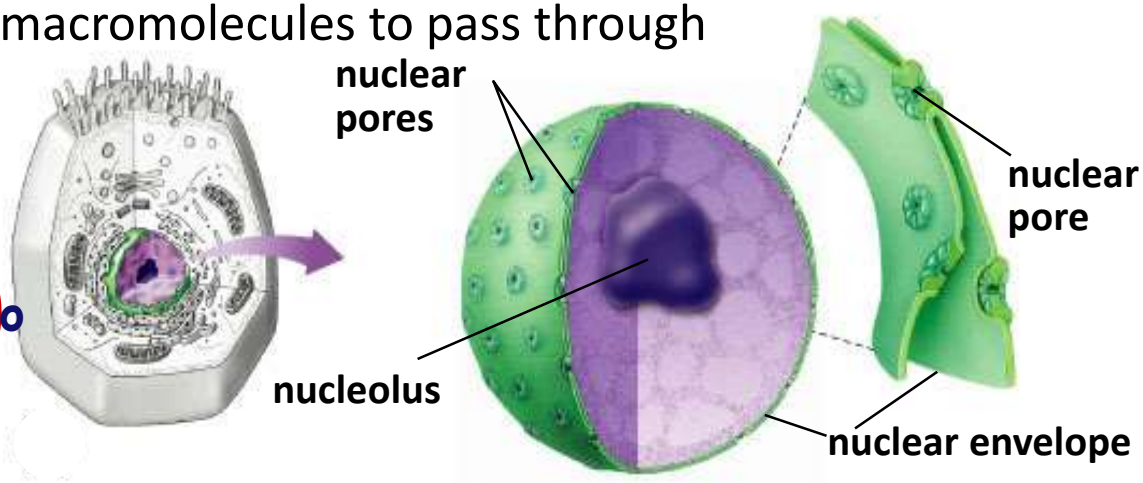
nucleus → **ribosome** → **ER** → **Golgi apparatus** → **vesicles**

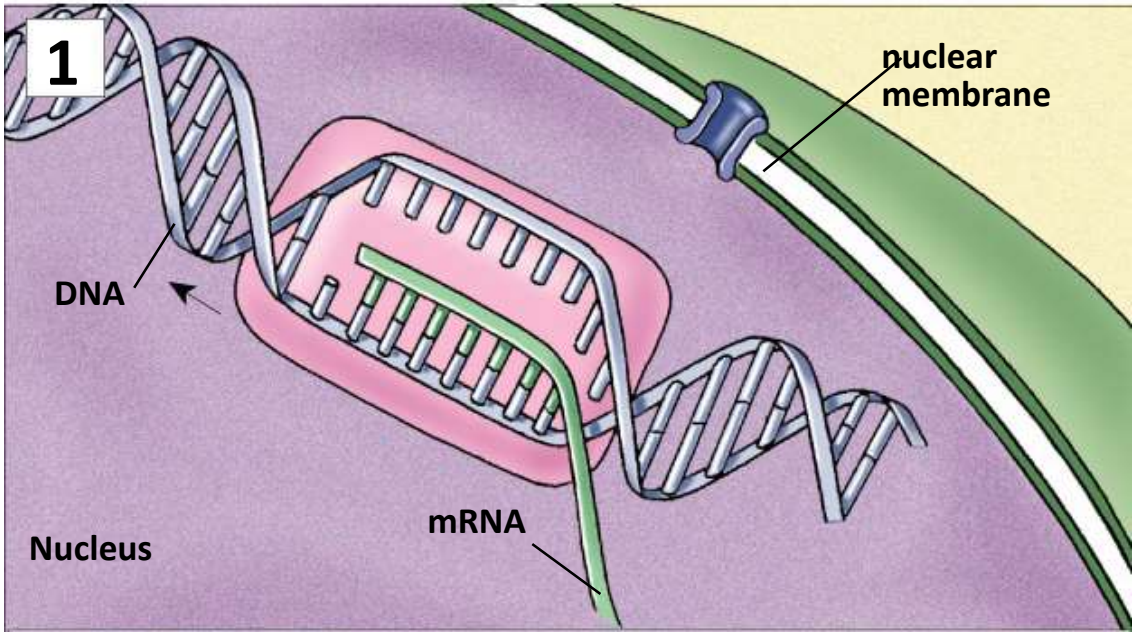
Nucleus



- Function
  - protects DNA
- Structure
  - nuclear envelope
    - double membrane
    - membrane fused in spots to create pores
      - allows large macromolecules to pass through

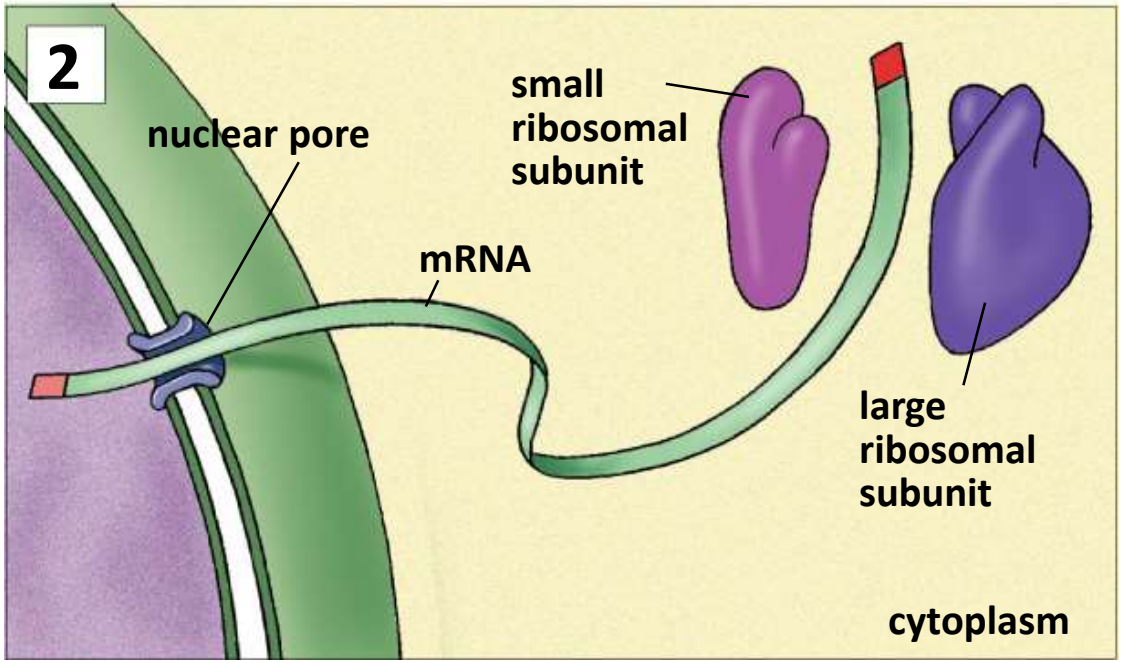


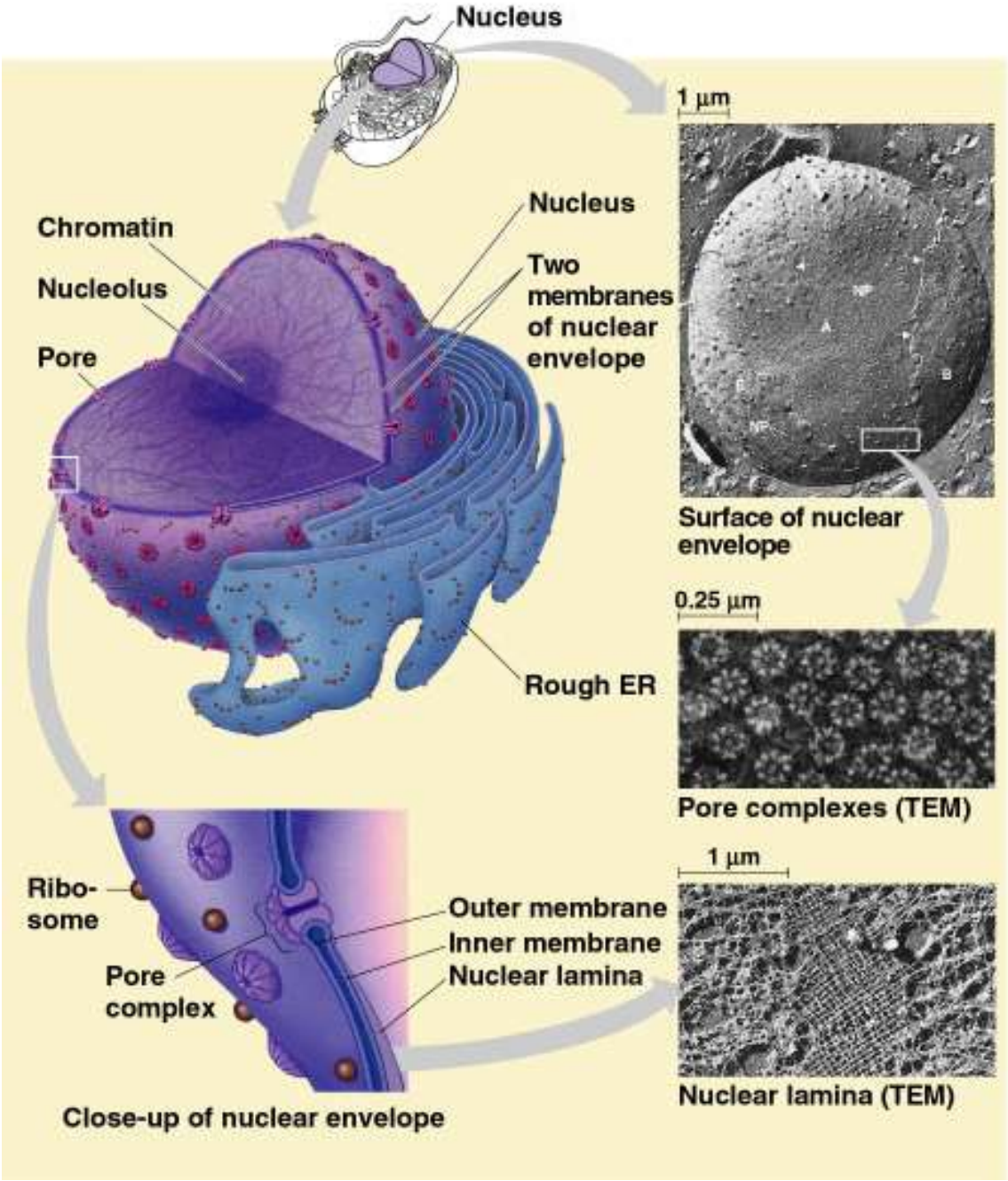


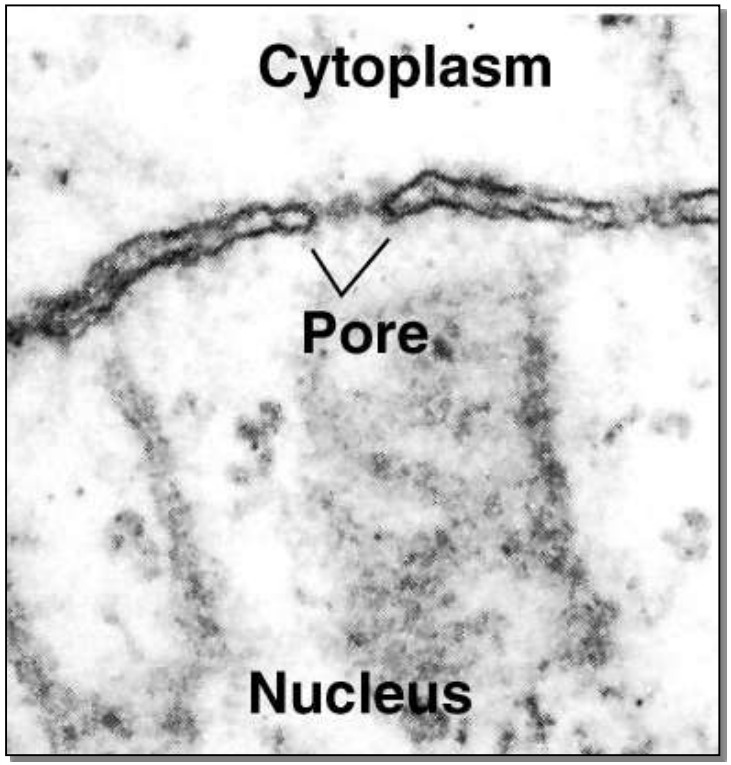


production of mRNA from DNA in nucleus

mRNA travels from nucleus to ribosome in cytoplasm through nuclear pore

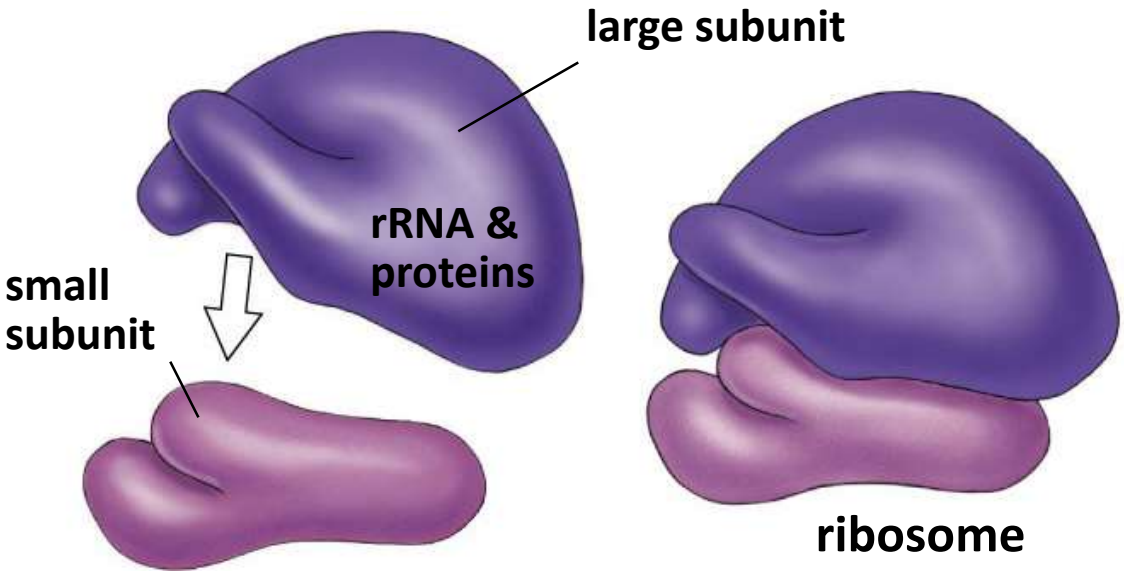


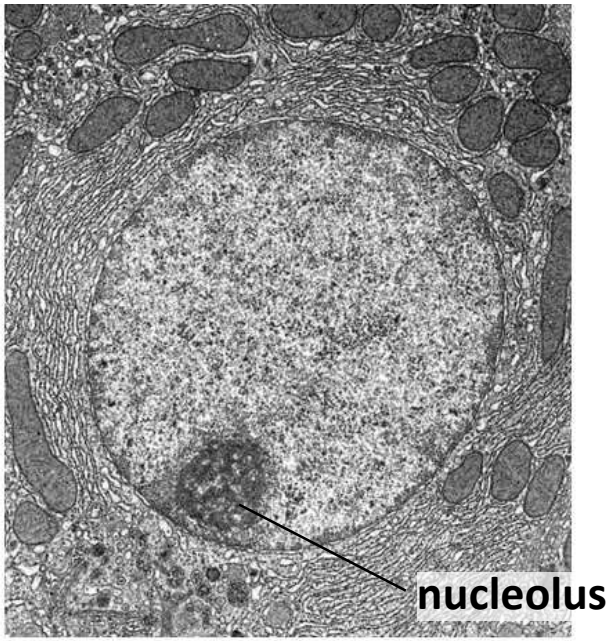

Nucleus
Chromatin
Nucleolus
Pore
Nucleus
Two membranes of nuclear envelope
Rough ER
1 µm
Surface of nuclear envelope
0.25 µm
Pore complexes (TEM)
1 µm
Nuclear lamina (TEM)
Ribo-some
Pore complex
Outer membrane
Inner membrane
Nuclear lamina
Close-up of nuclear envelope


Cytoplasm
Pore
Nucleus

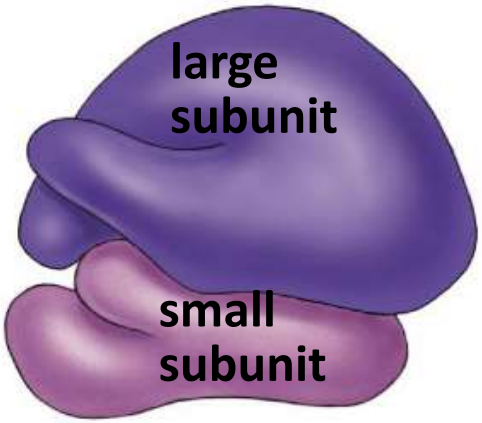
Nucleolus

- Function
  - ribosome production
    - build ribosome subunits from rRNA & proteins
    - exit through nuclear pores to cytoplasm & combine to form functional ribosomes

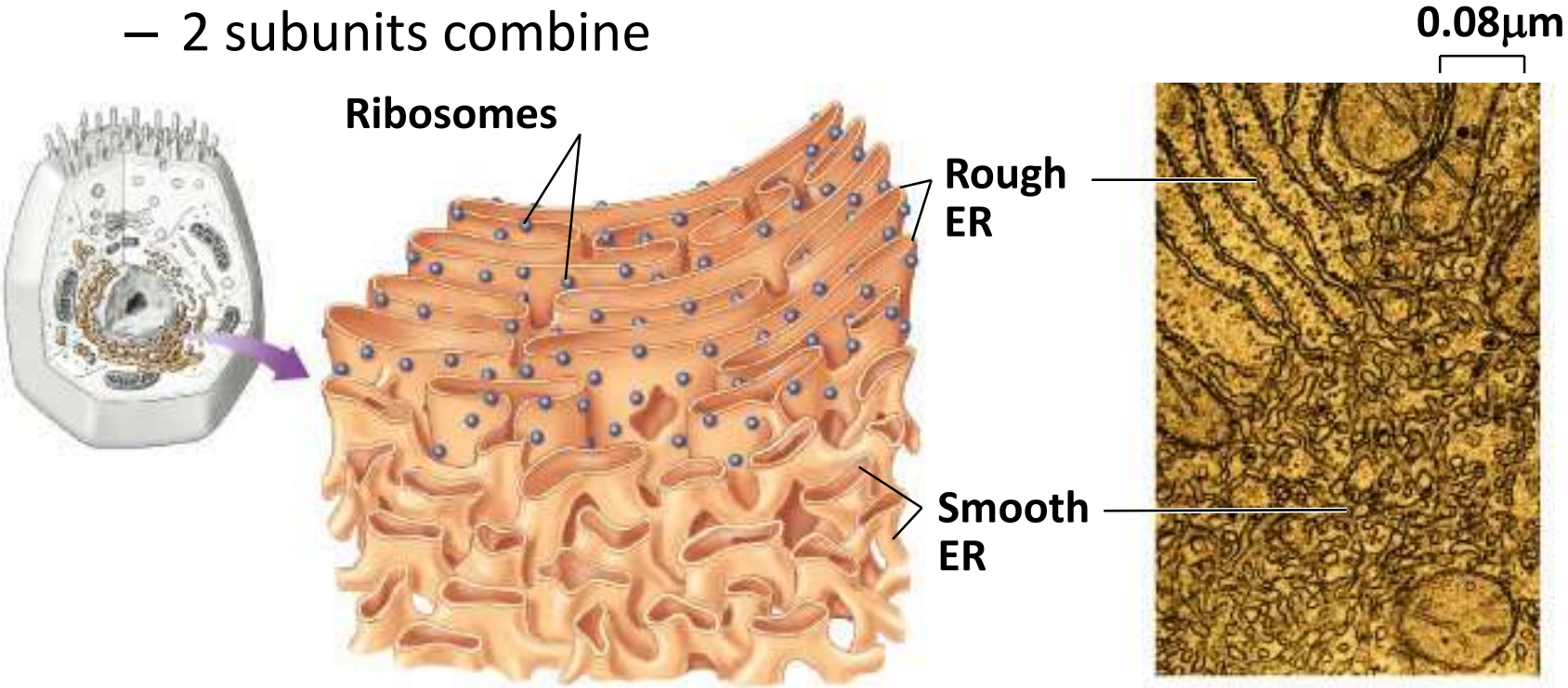




Ribosomes

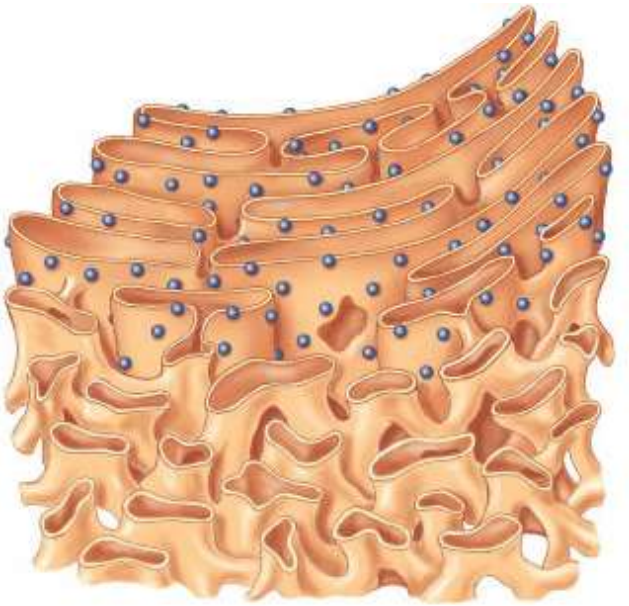


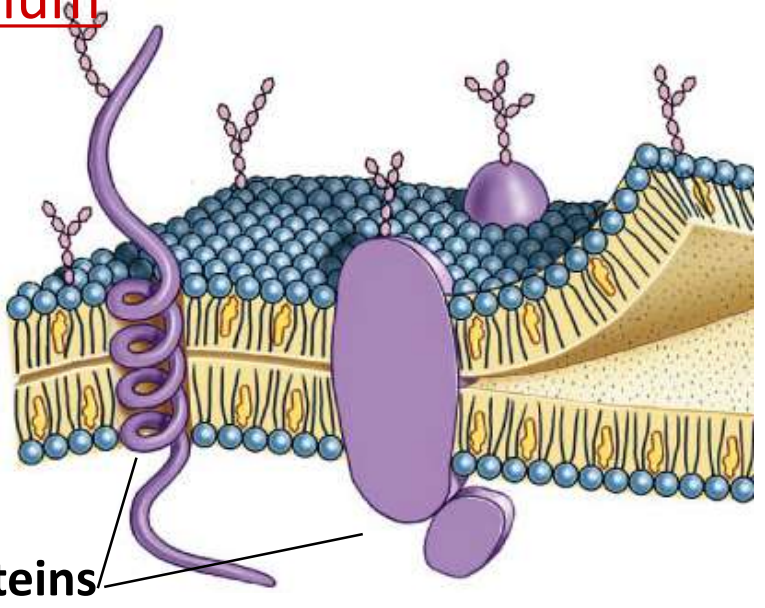
- Function
  - protein production
- Structure
  - rRNA & protein
  - 2 subunits combine



Types of Ribosomes

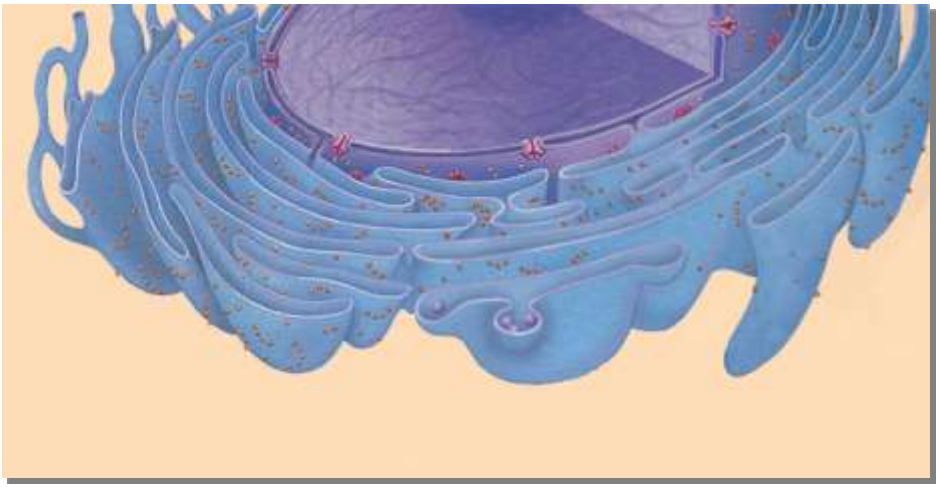
- Free ribosomes
  - suspended in cytosol
  - synthesize proteins that function in cytosol
- Bound ribosomes
  - attached to endoplasmic reticulum
  - synthesize proteins for export or for membranes



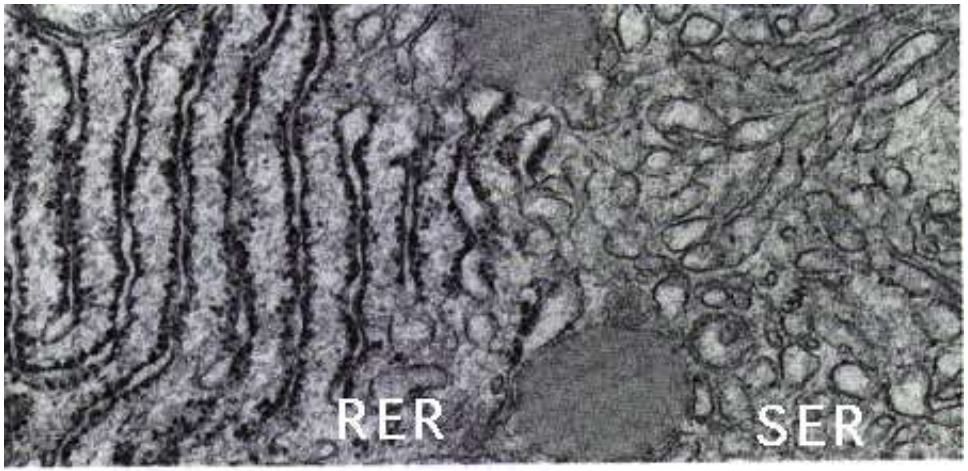


Endoplasmic Reticulum

- Function
  - processes proteins
  - manufactures membranes
  - synthesis & hydrolysis of many compounds
- Structure
  - membrane connected to nuclear envelope & extends throughout cell

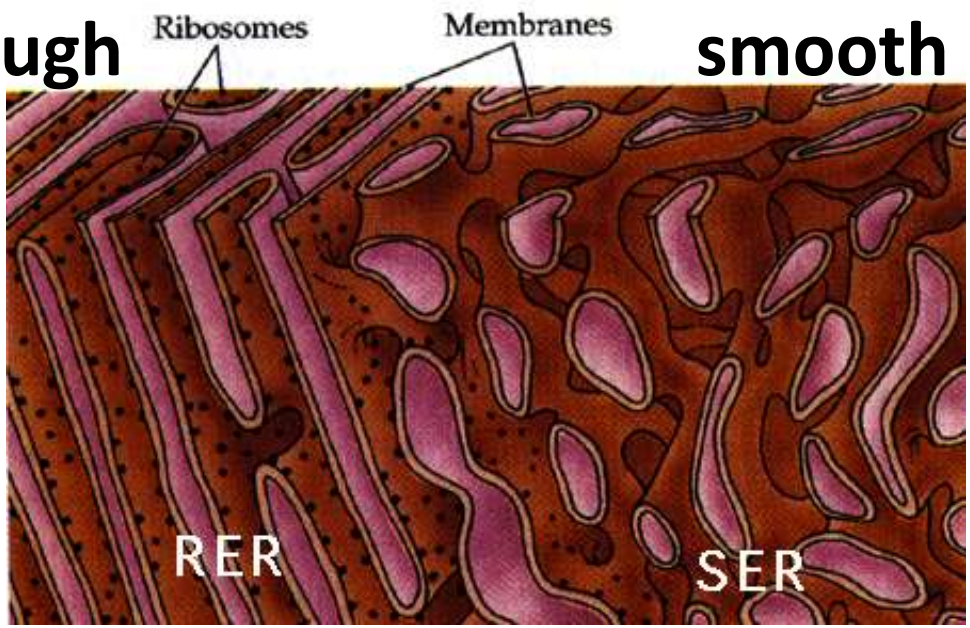


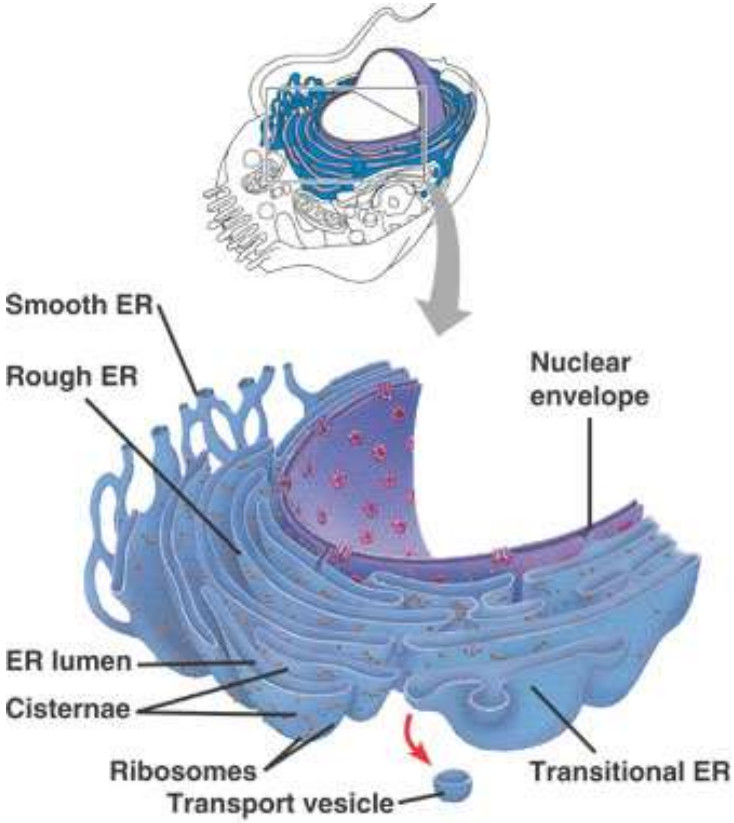
Types of ER

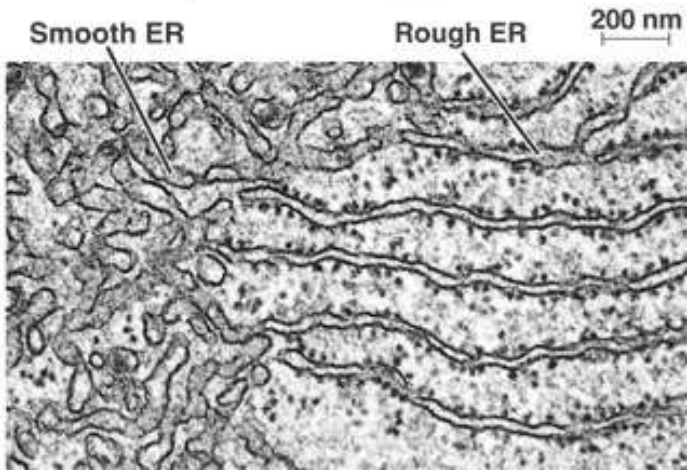


rough

smooth





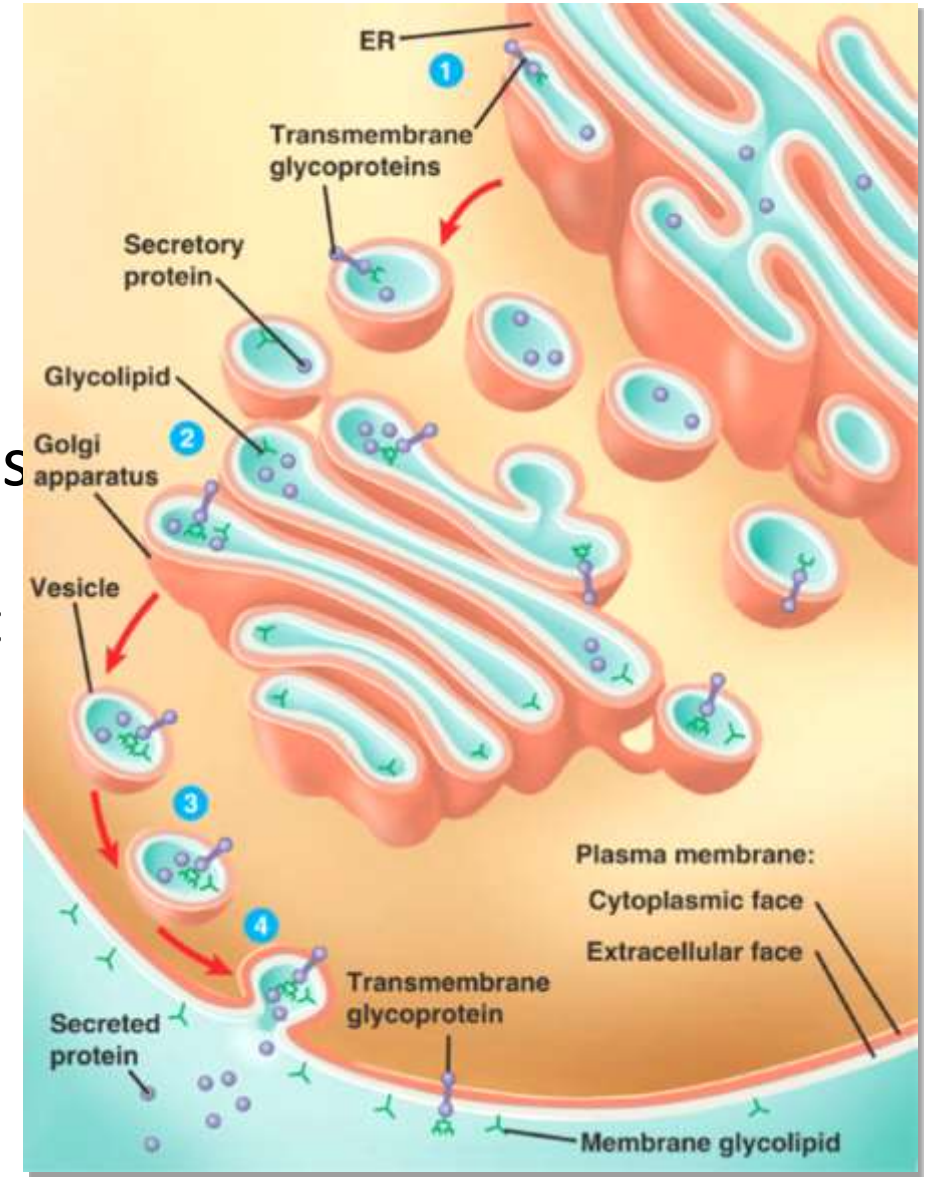


Smooth ER function

- Membrane production
- Many metabolic processes
  - synthesis
    - synthesize lipids
      - oils, phospholipids, steroids & sex hormones
  - hydrolysis
    - hydrolyze glycogen into glucose
      - in liver
    - detoxify drugs & poisons
      - in liver
      - ex. alcohol & barbiturates

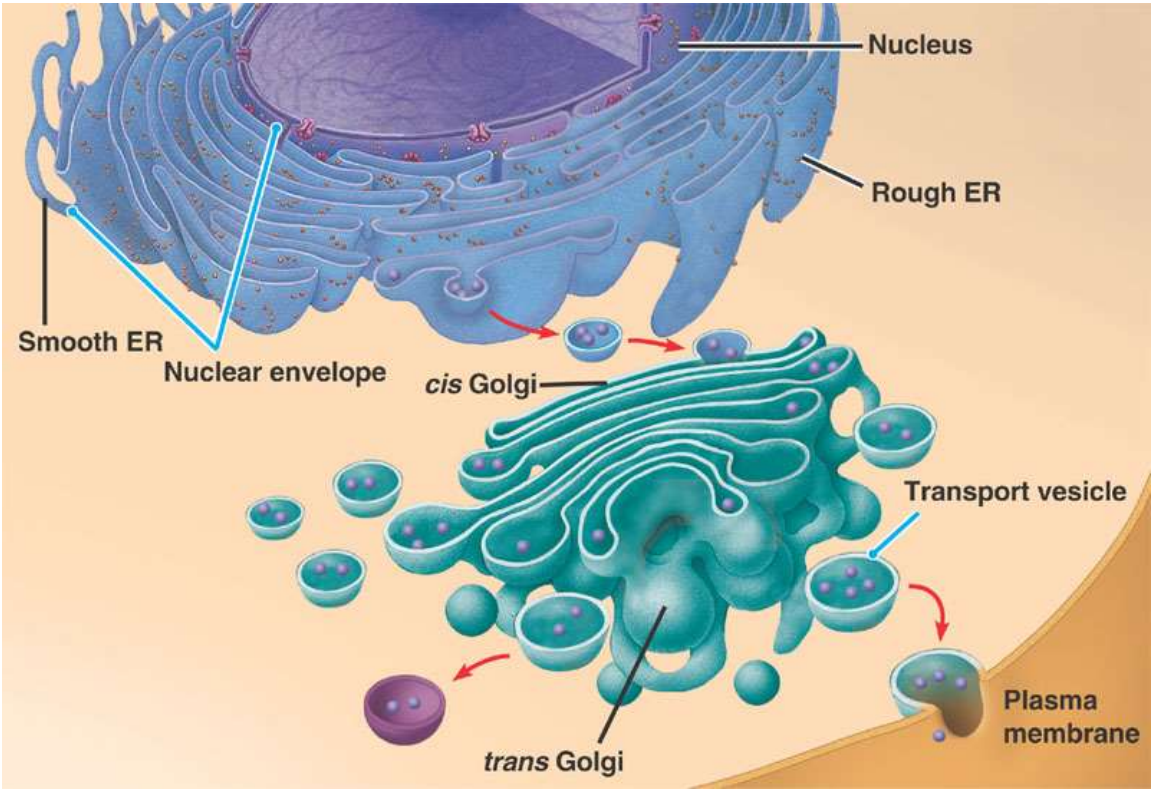
Membrane Factory

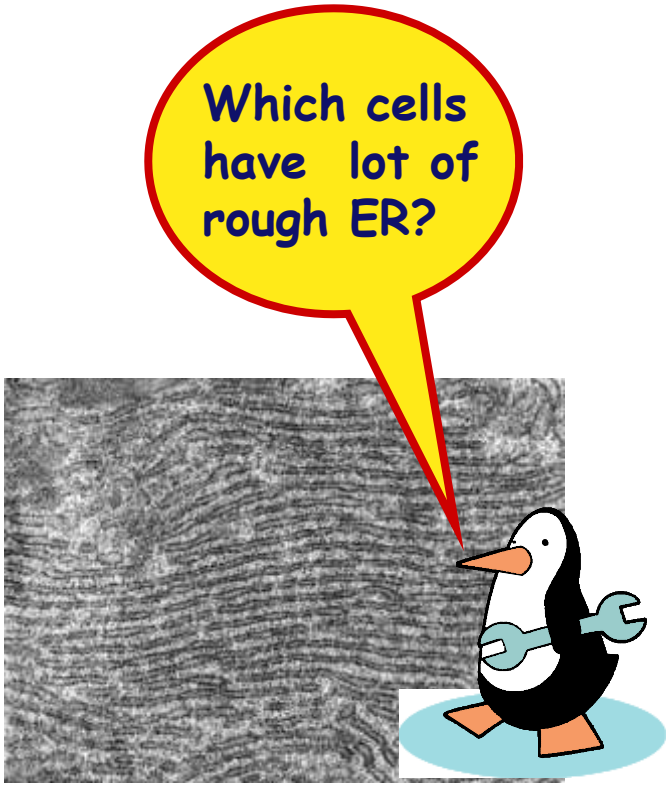
- Build new membrane
  - synthesize phospholipids
    - builds membranes
  - ER membrane expands
    - bud off & transfer to other parts of cell that need membranes



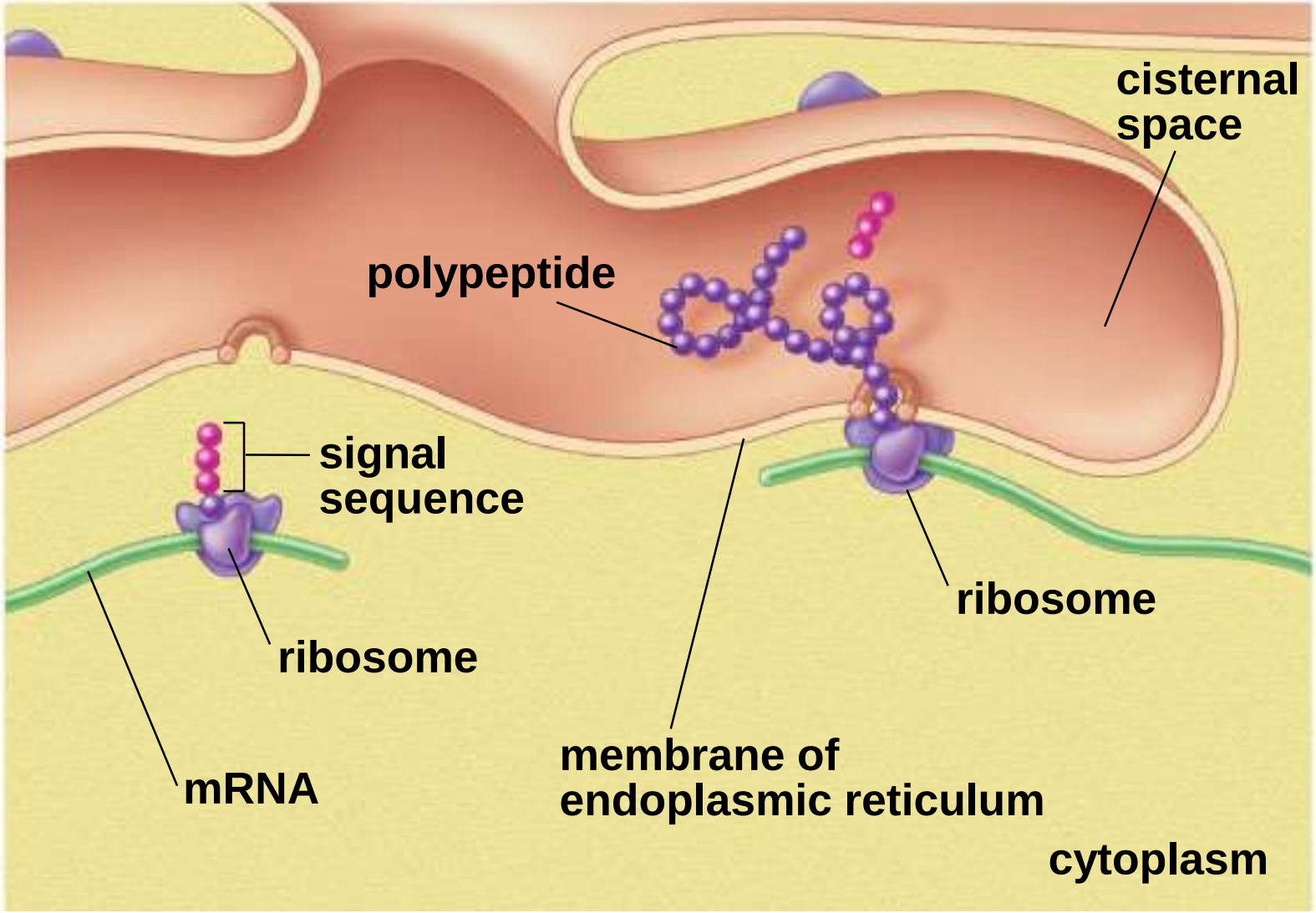
Rough ER function

- Produce proteins for export out of cell
  - protein secreting cells
  - packaged into transport vesicles for export



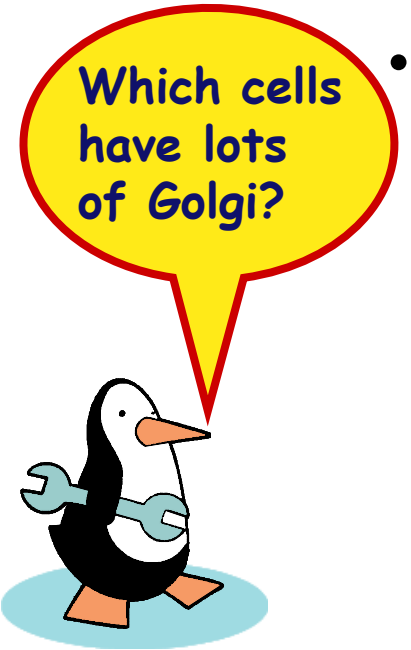


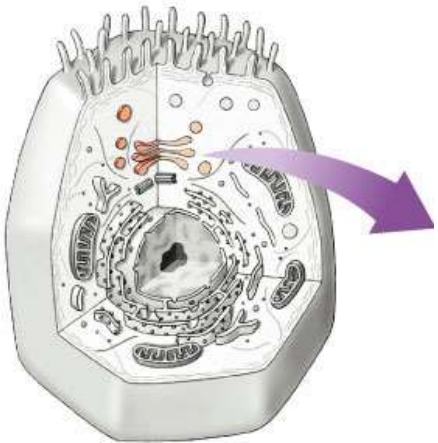
Synthesizing proteins

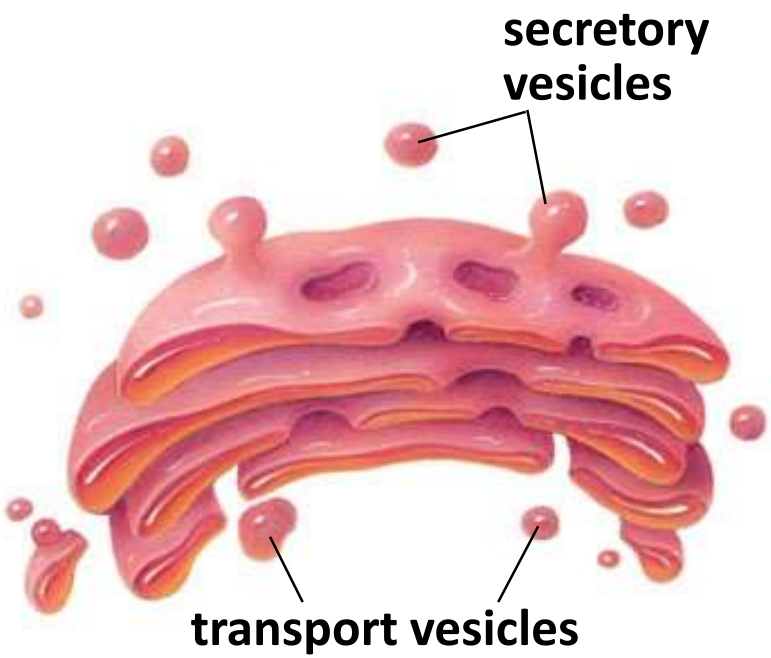


Golgi Apparatus

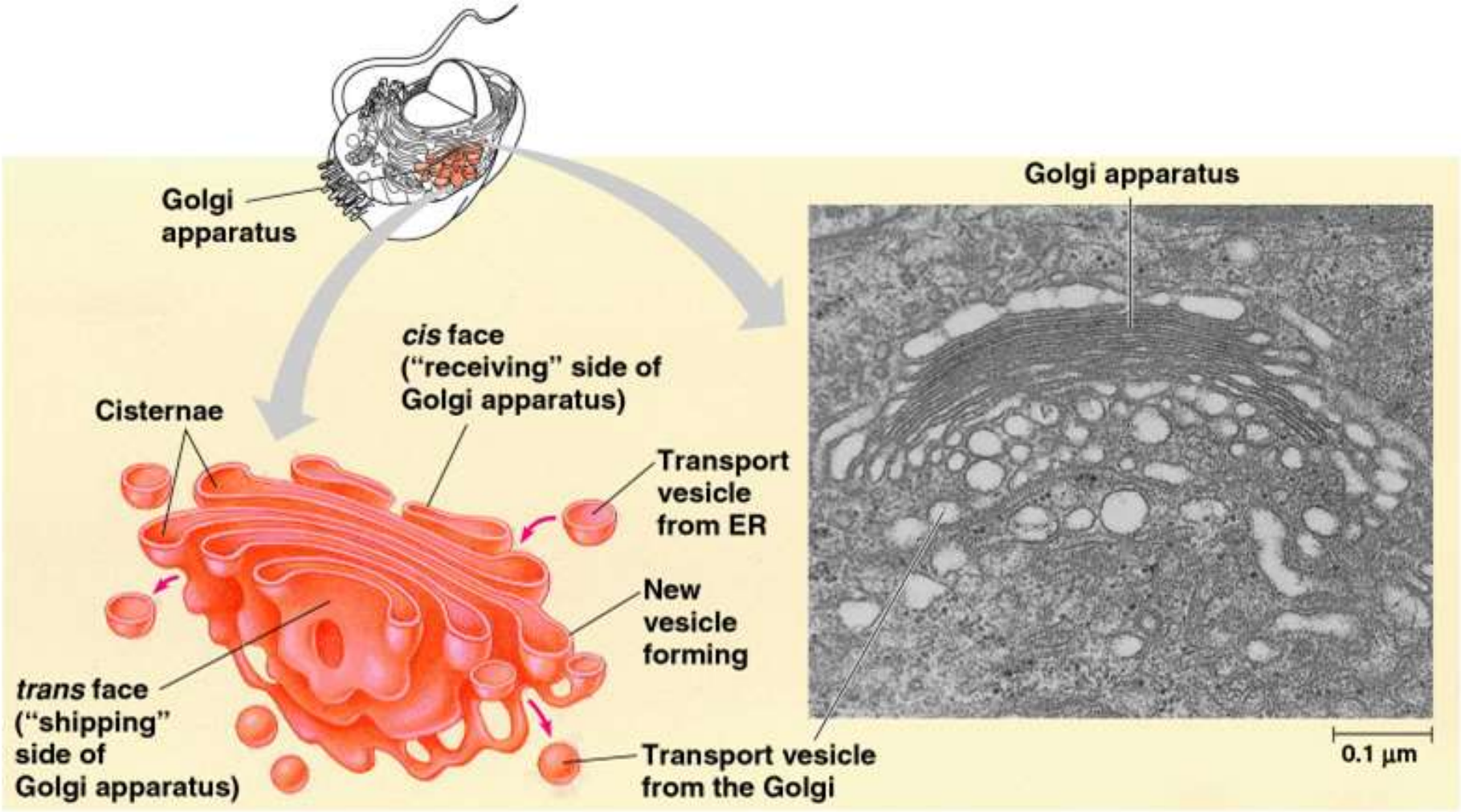
- Function
  - finishes, sorts, tags & ships cell products
    - like “UPS shipping department”
  - ships products in vesicles
    - membrane sacs
    - “UPS trucks”



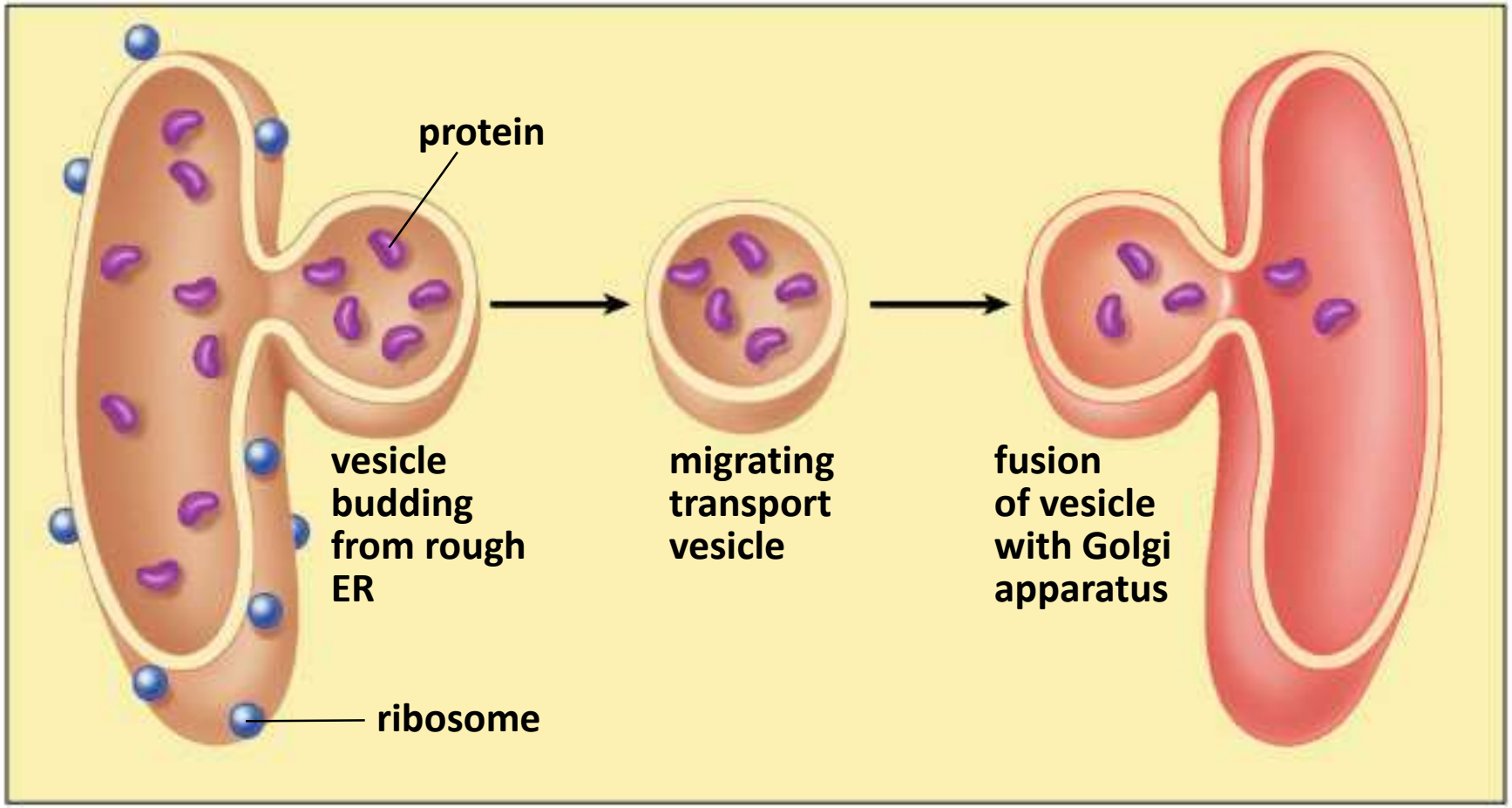




Golgi Apparatus

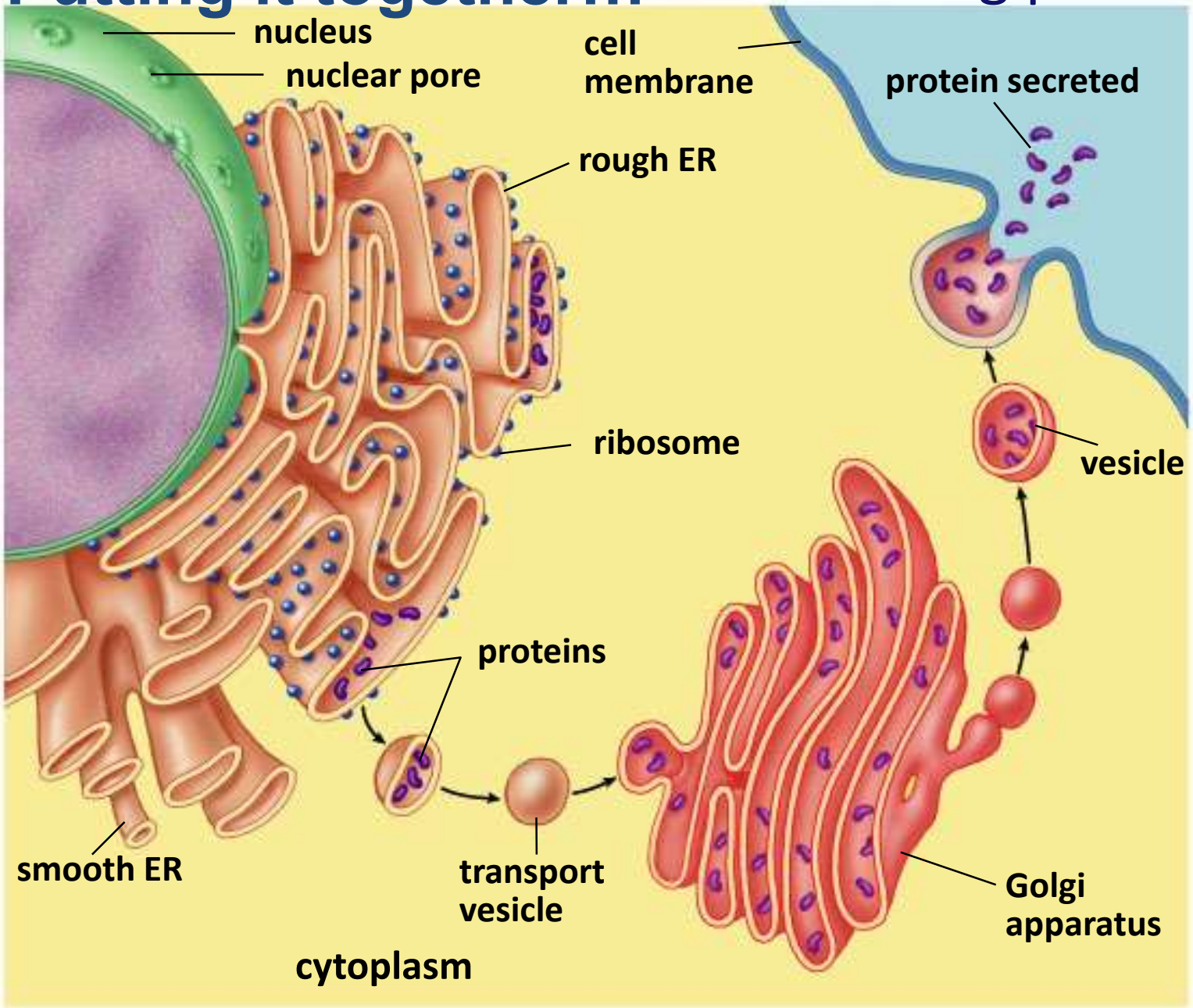


Vesicle transport



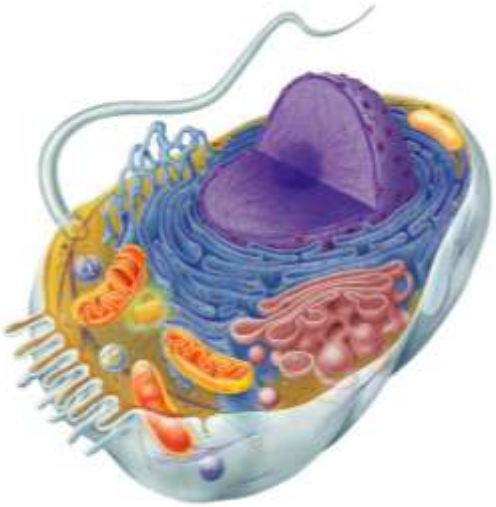
Putting it together…

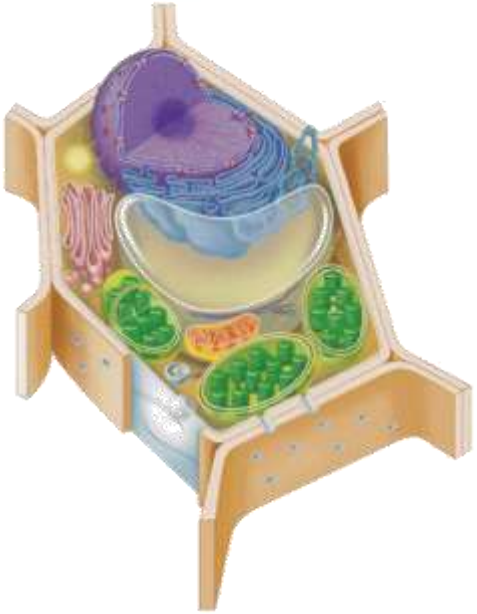
Making proteins



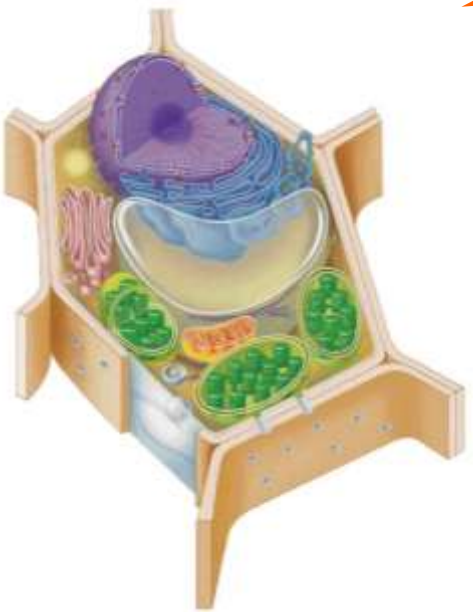
Cells gotta work to live!

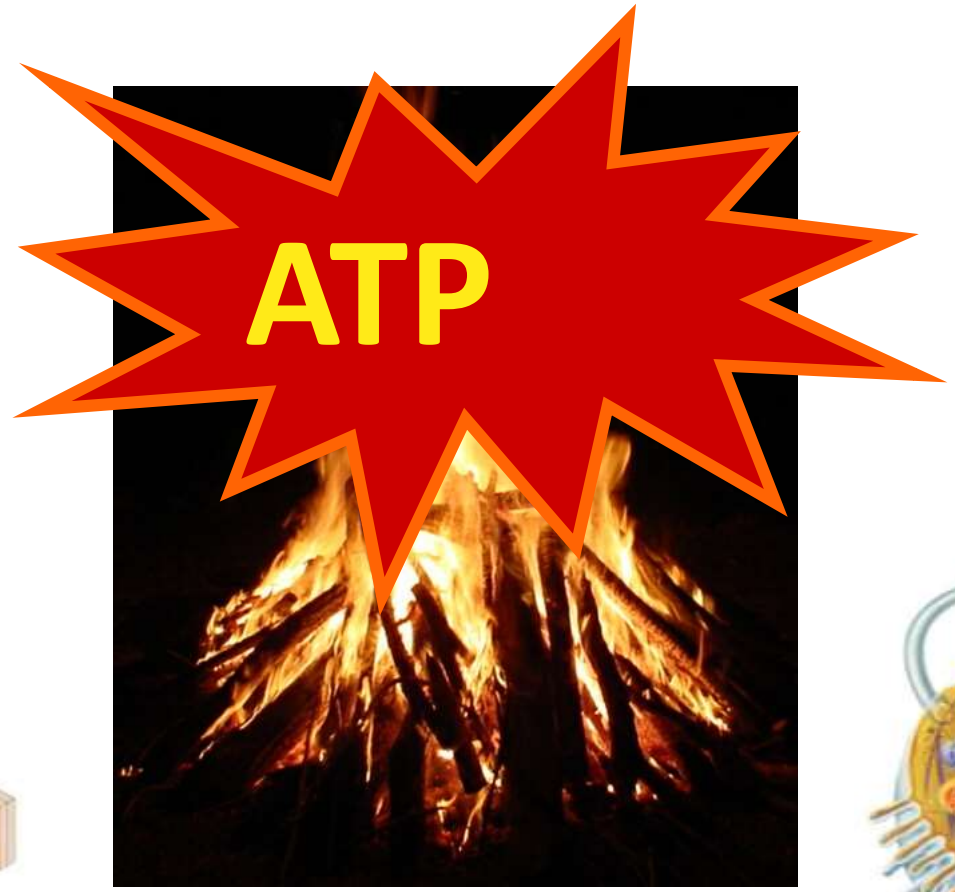
- What jobs do cells have to do?
  - make proteins
    - proteins control every cell function
  - make energy
    - for daily life
    - for growth
  - make more cells
    - growth
    - repair
    - renewal

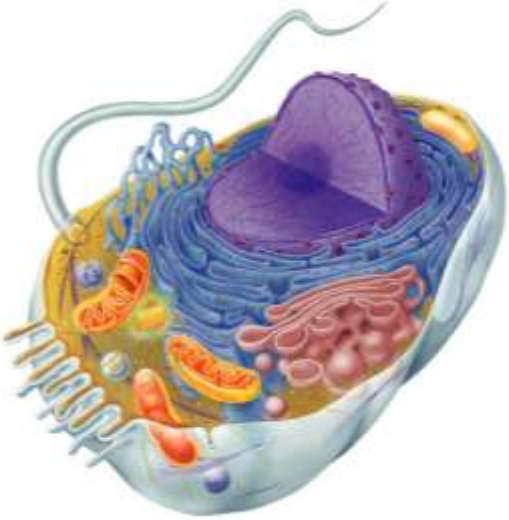




Making Energy

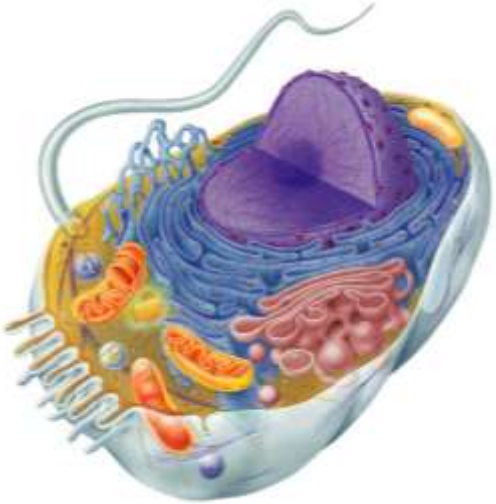


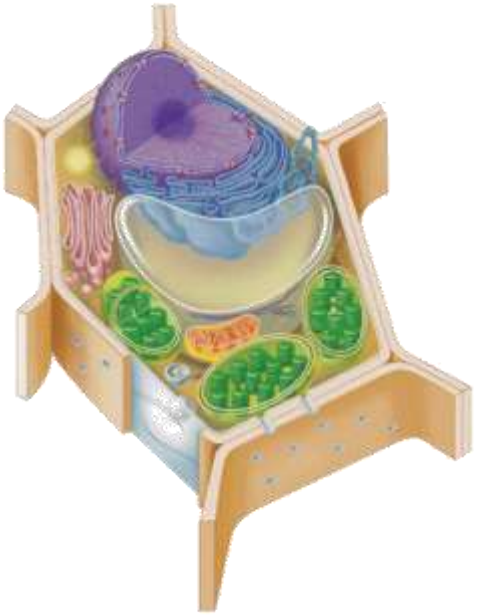




Cells need power!

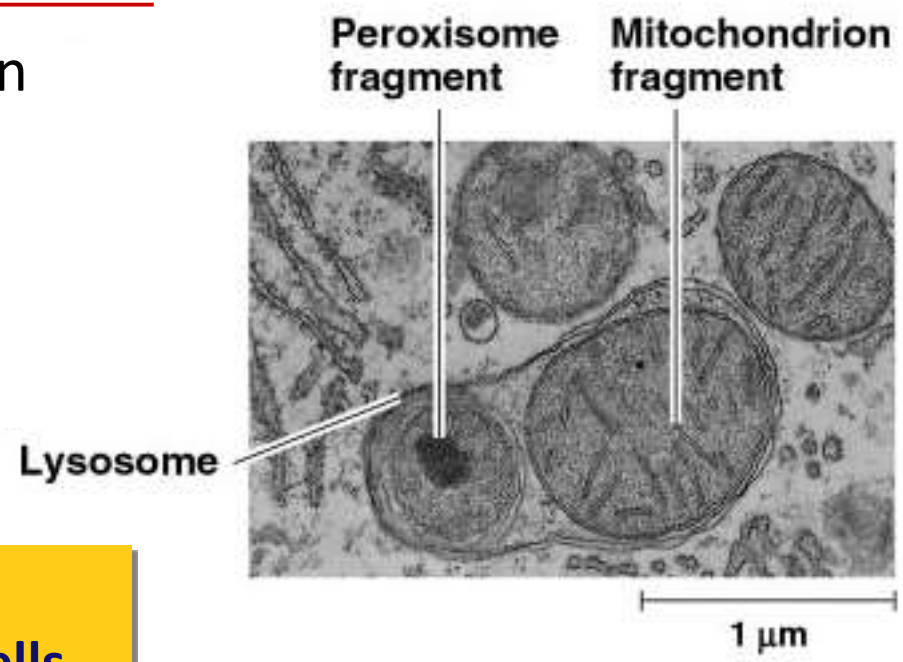
- Making energy
  - take in food & digest it
  - take in oxygen (O_2)
  - make ATP
  - remove waste





Lysosomes

- Function
  - little "stomach" of the cell
    - digests macromolecules
  - "clean up crew" of the cell
    - cleans up broken down organelles
- Structure
  - vesicles of digestive enzymes



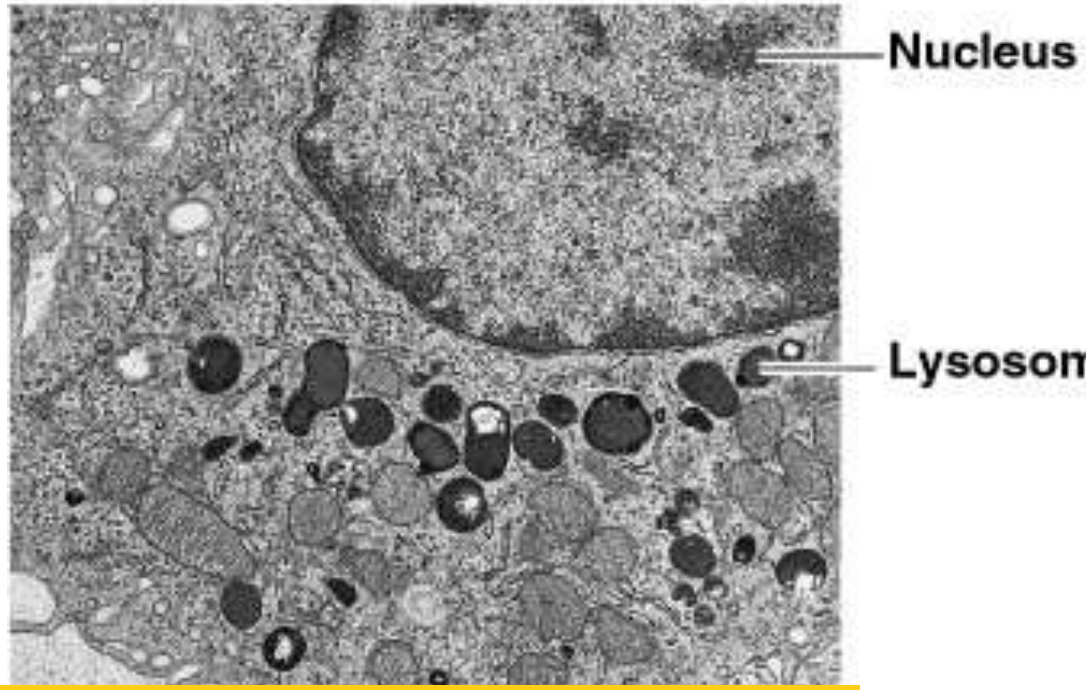
(b) A lysosome in action

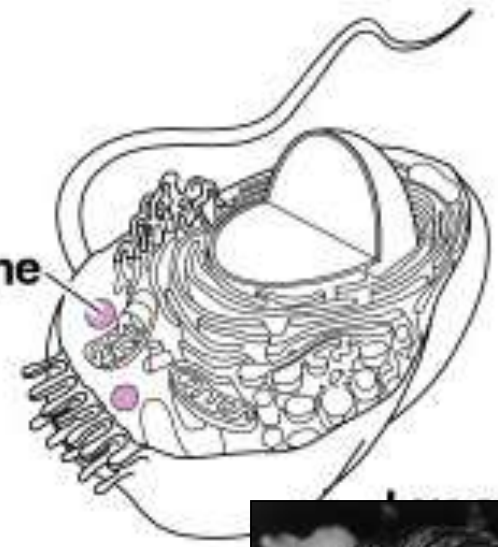
synthesized by rER, transferred to Golgi

only in animal cells

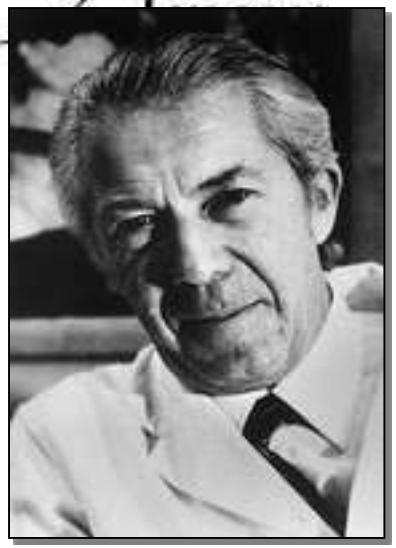
Lysosomes

1960 | 1974





white blood cells attack & destroy invaders = digest them in lysosomes

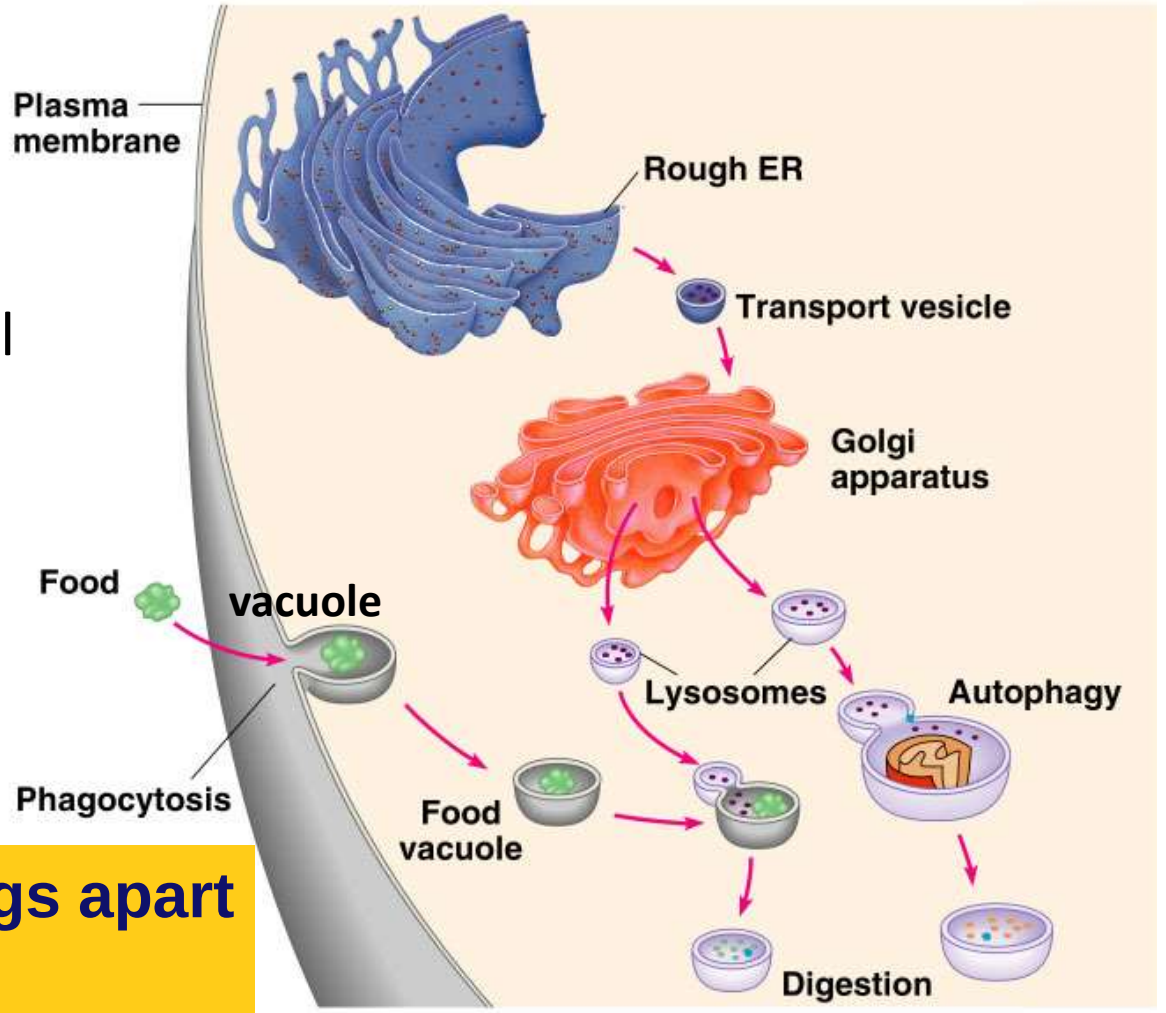


1974 Nobel prize: Christian de Duve

Lysosomes discovery in 1960s

Cellular digestion

- Lysosomes fuse with food vacuoles
  - polymers digested into monomers
    - pass to cytosol to become nutrients of cell



- **lyso– = breaking things apart**
- **–some = body**

Lysosomal enzymes

- Lysosomal enzymes work best at pH 5
  - organelle creates custom pH
  - how?
    - proteins in lysosomal membrane pump H^+ ions from the cytosol into lysosome
  - why?
    - enzymes are very sensitive to pH
  - why?
    - enzymes are proteins — pH affects structure
  - why evolve digestive enzymes which function at pH different from cytosol?
    - digestive enzymes won't function well if some leak into cytosol = don't want to digest yourself!

When things go bad…

- Diseases of lysosomes are often fatal
  - digestive enzyme not working in lysosome
  - picks up biomolecules, but can't digest one
    - lysosomes fill up with undigested material
  - grow larger & larger until disrupts cell & organ function
    - lysosomal storage diseases
      - more than 40 known diseases
    - example:
      Tay-Sachs disease
      build up undigested fat
      in brain cells

Lysosomal storage diseases

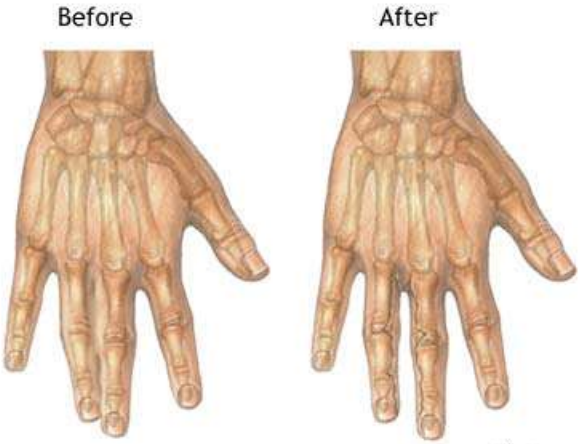
- Lipids
  - Gaucher’s disease
  - Niemann-Pick disease
  - Tay Sachs
- Glycogen & other poylsaccharides
  - Farber disease
  - Krabbe disease
- Proteins
  - Schindler’s disease

But sometimes cells need to die…

- Lysosomes can be used to kill cells when they are supposed to be destroyed
  - some cells have to die for proper development in an organism
    - apoptosis
      - "auto-destruct" process
      - lysosomes break open & kill cell
    - ex: tadpole tail gets re-absorbed when it turns into a frog
    - ex: loss of webbing between your fingers during fetal development

Fetal developme

syndactyly



Apoptosis

- programmed destruction of cells in multi-cellular organisms
  - programmed development
  - control of cell growth
    - example:
      if cell grows uncontrollably this self-destruct mechanism is triggered to remove damaged cell
    - cancer must over-ride this to enable tumor growth

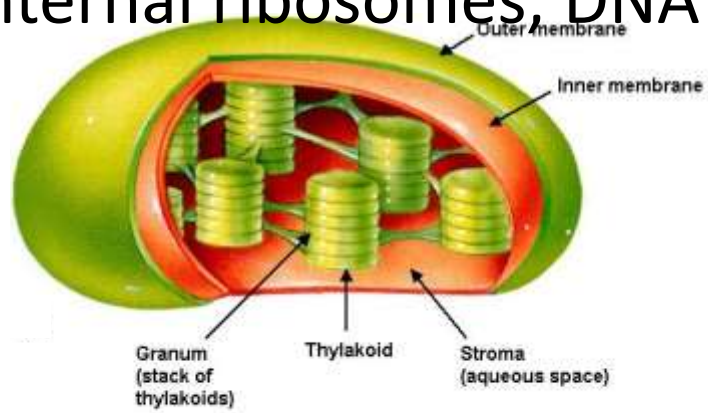
Making Energy

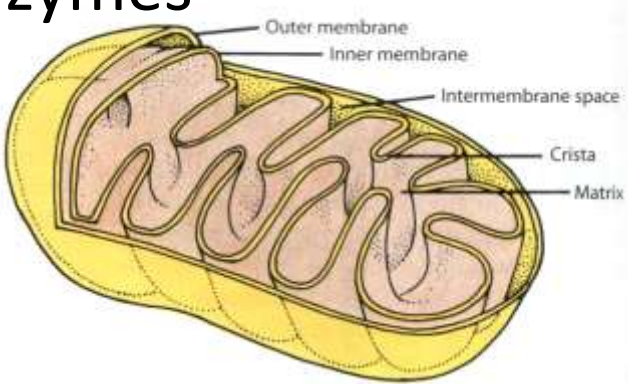
- Cells must convert incoming energy to forms that they can use for work
  - mitochondria:
    from glucose to ATP

  - chloroplasts:
    from sunlight to ATP & carbohydrates
    - ATP = active energy
    - carbohydrates = stored energy

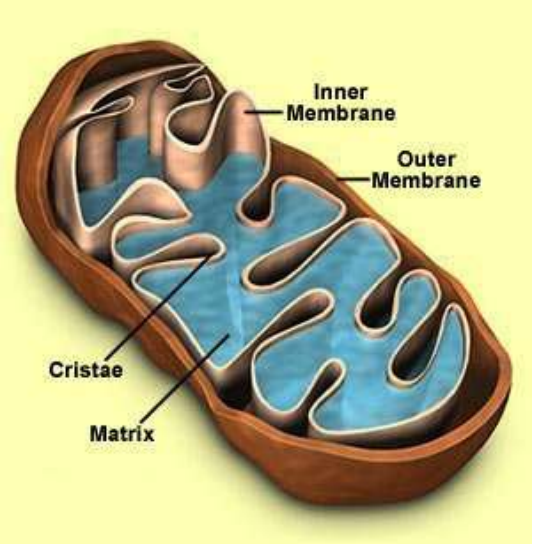
Mitochondria & Chloroplasts

- Important to see the similarities
  - transform energy
    - generate ATP
  - double membranes = 2 membranes
  - semi-autonomous organelles
    - move, change shape, divide
  - internal ribosomes, DNA & enzymes





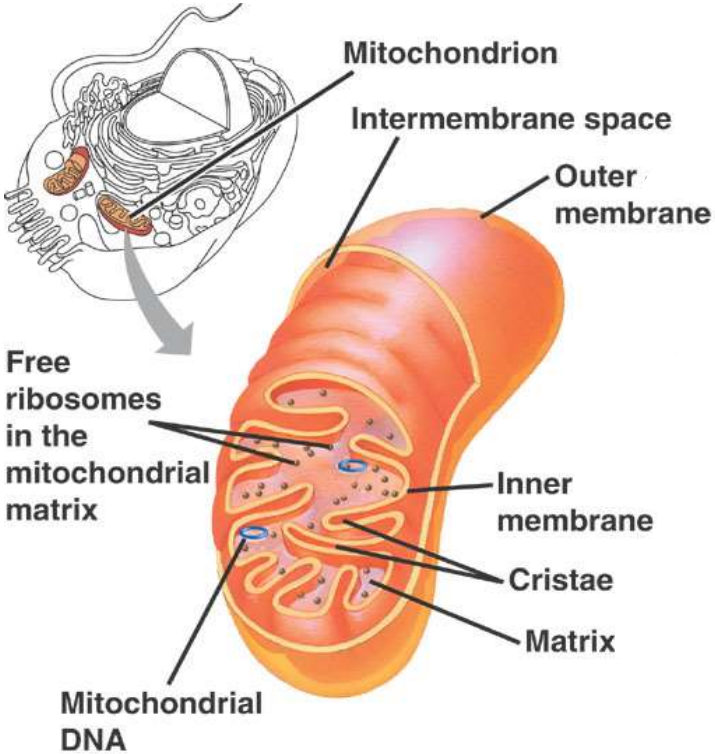
Mitochondria



- Function
  - cellular respiration
  - generate ATP
    - from breakdown of sugars, fats & other fuels
    - in the presence of oxygen
      - break down larger molecules into smaller to generate energy = catabolism
      - generate energy in presence of O_2 = aerobic respiration

Mitochondria

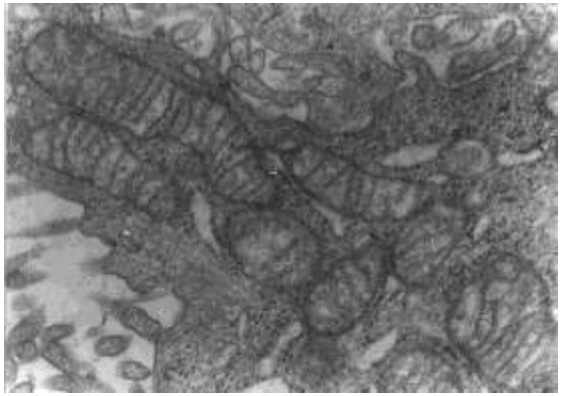
- Structure
  - 2 membranes
    - smooth outer membrane
    - highly folded inner membrane
      - cristae
  - fluid-filled space between 2 membranes
  - internal fluid-filled space
    - mitochondrial matrix
    - DNA, ribosomes & enzymes

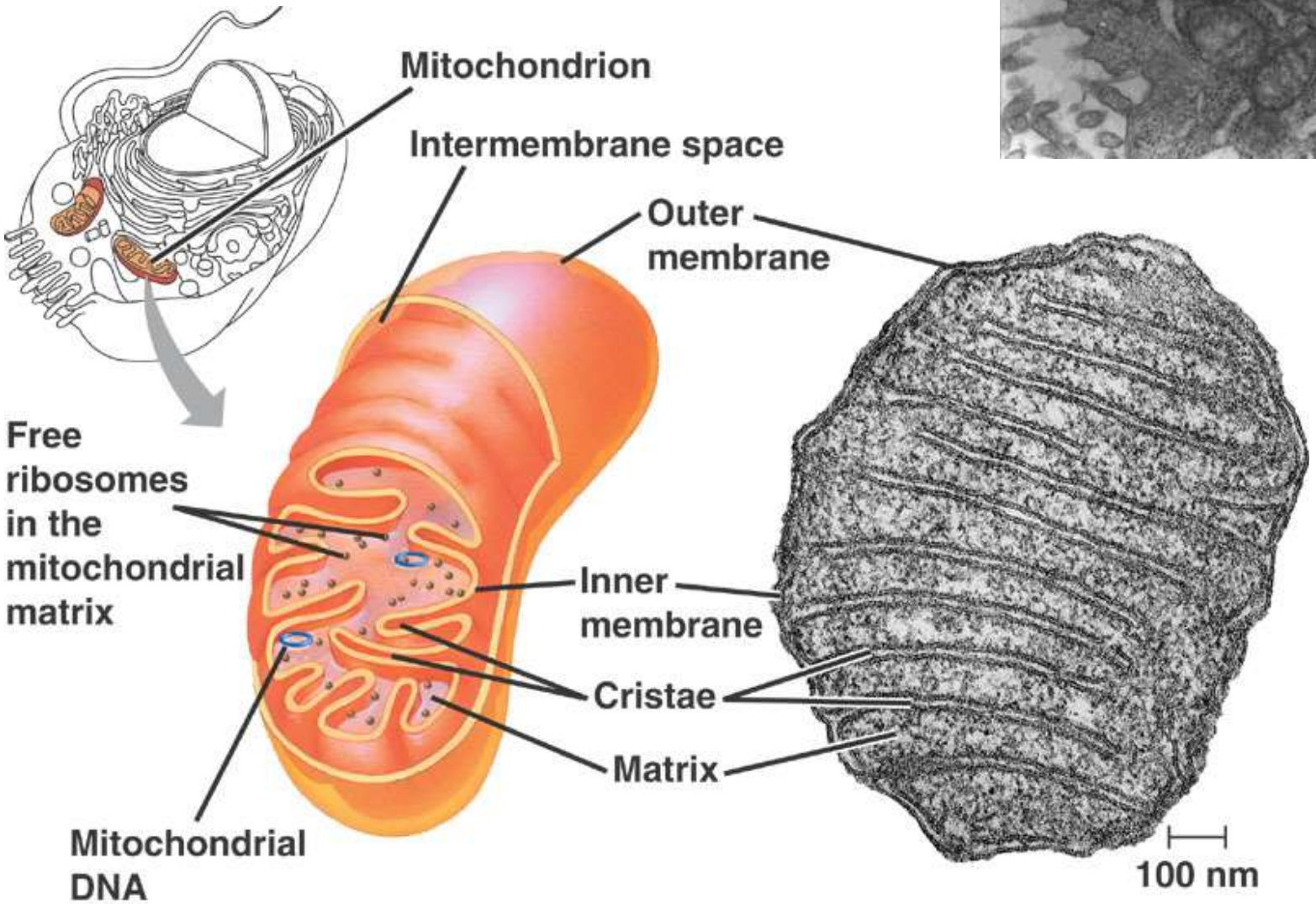


Why 2 membranes?

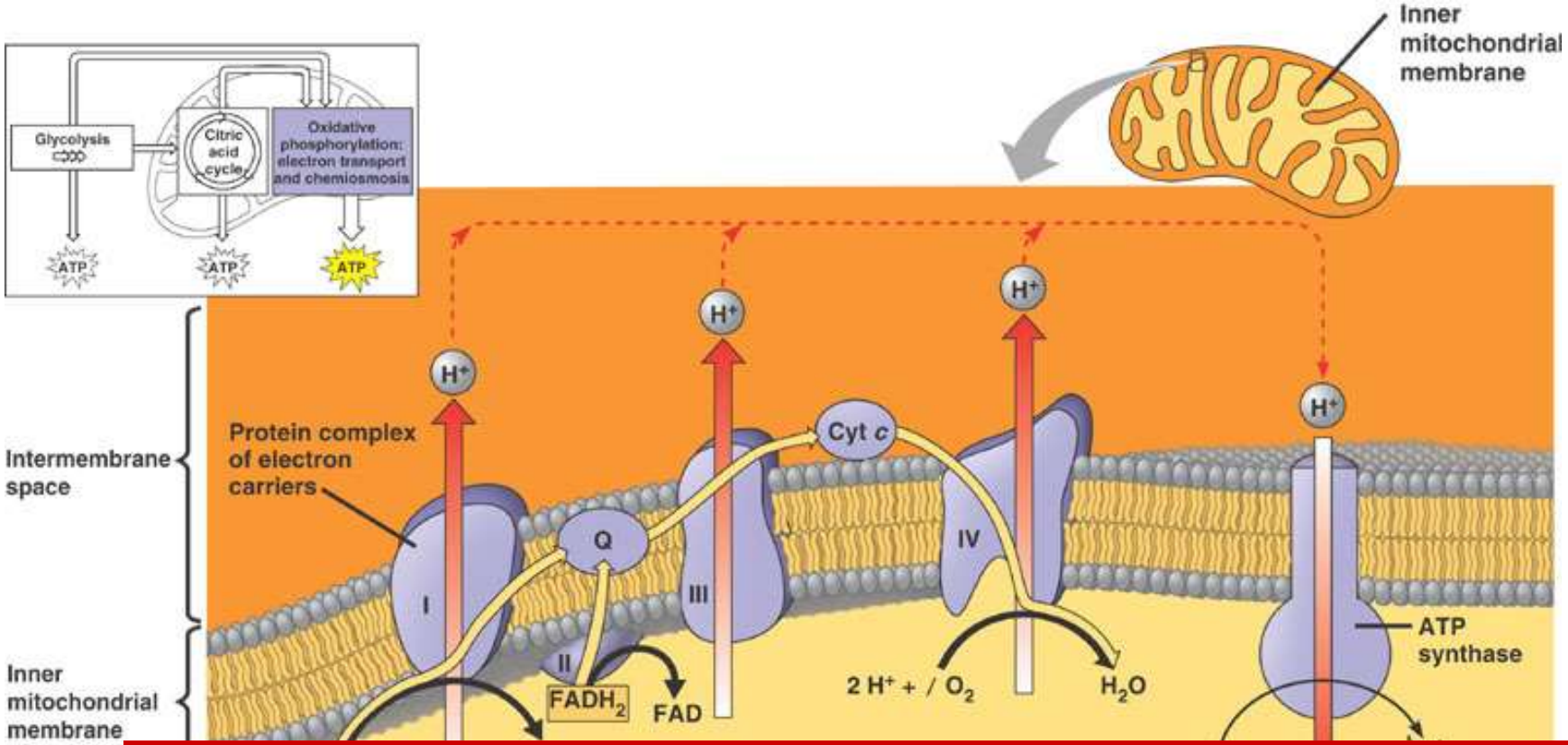
increase surface area for membrane-bound enzymes that synthesize ATP

Mitochondria





Membrane-bound Enzymes

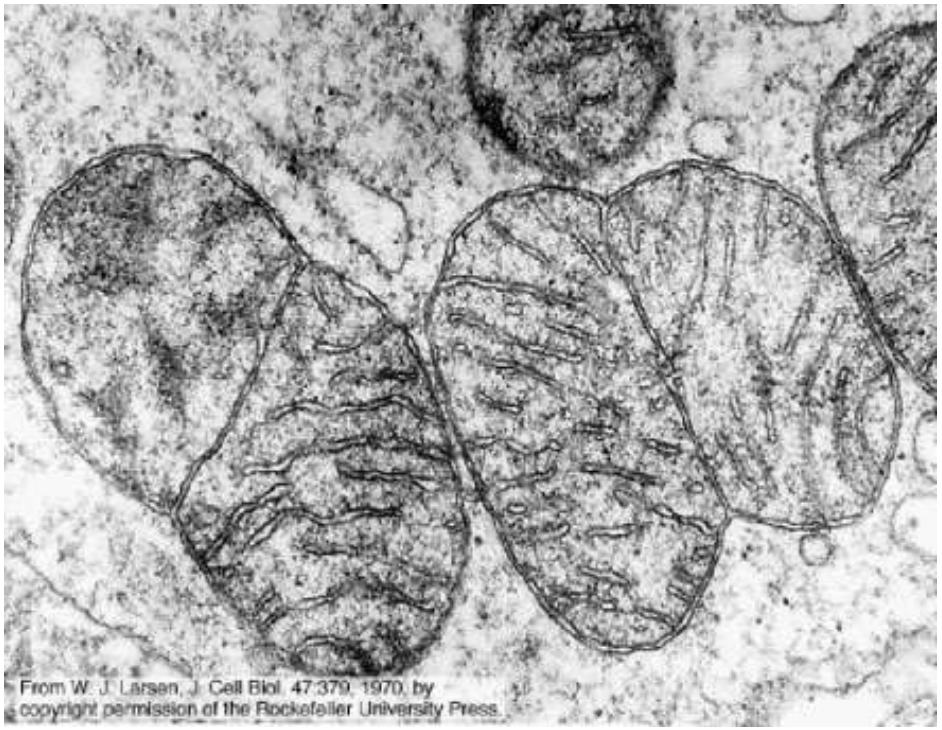


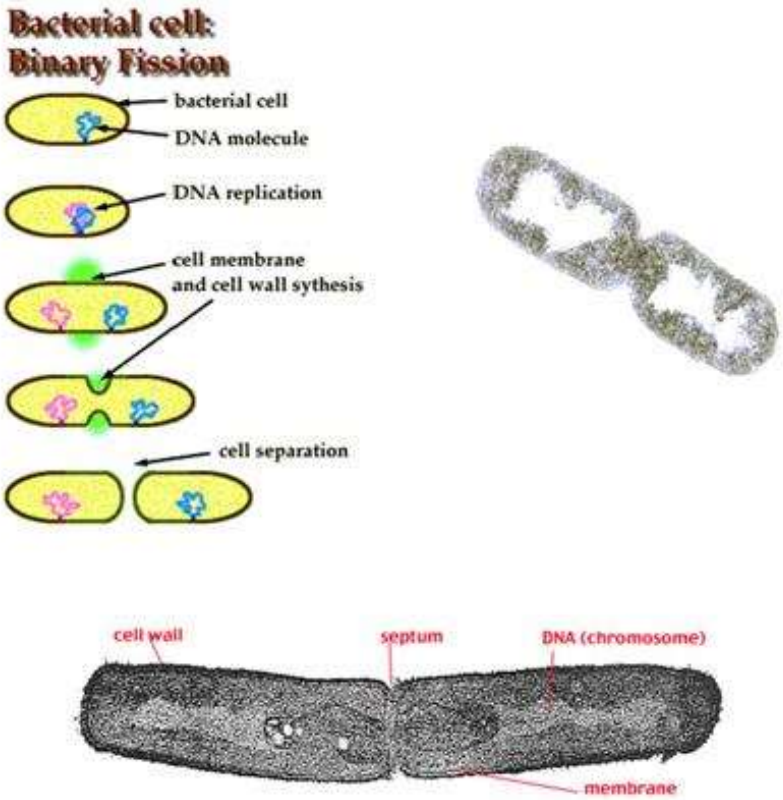
glucose + oxygen → carbon + water + energy
dioxide

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + ATP$$

Dividing Mitochondria

Who else divides like that?





What does this tell us about the evolution of eukaryotes?

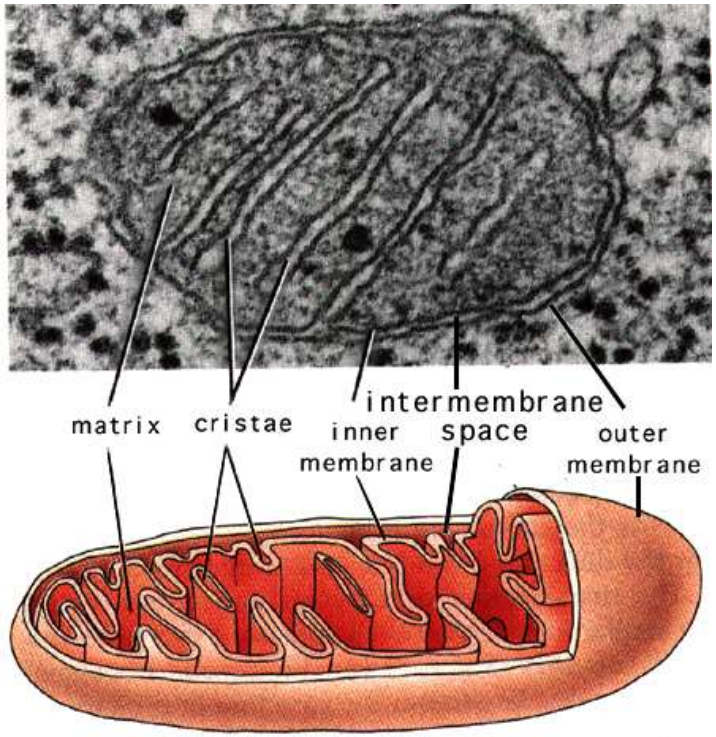
Mitochondria

- Almost all eukaryotic cells have mitochondria
  - there may be 1 very large mitochondrion or 100s to 1000s of individual mitochondria
  - number of mitochondria is correlated with aerobic metabolic activity
    - more activity = more energy needed = more mitochondria

What cells would have a lot of mitochondria?

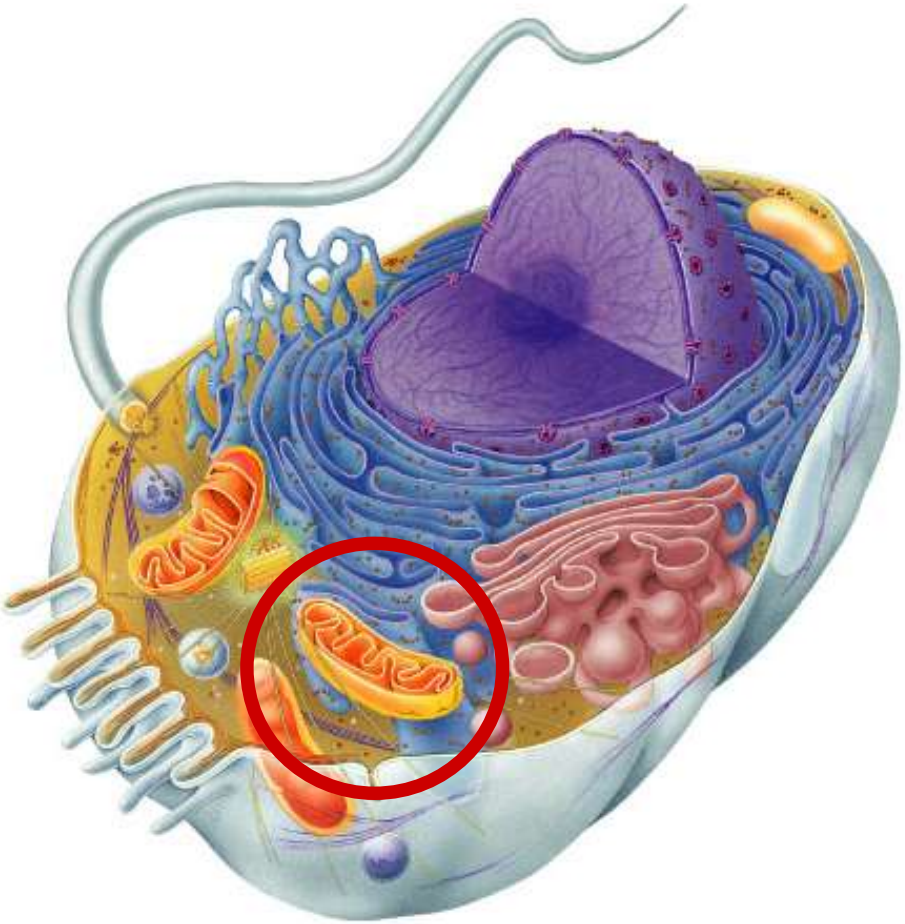
active cells:

- **muscle cells**
- **nerve cells**

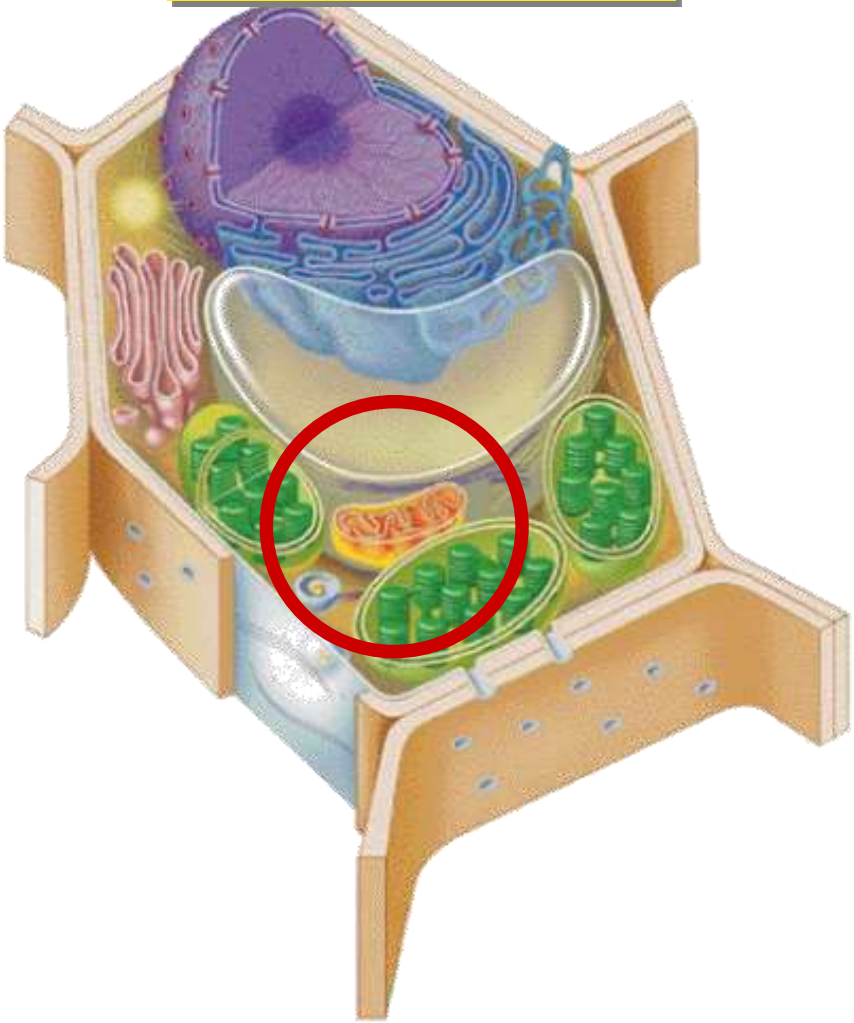


Mitochondria are everywhere!!

animal cells

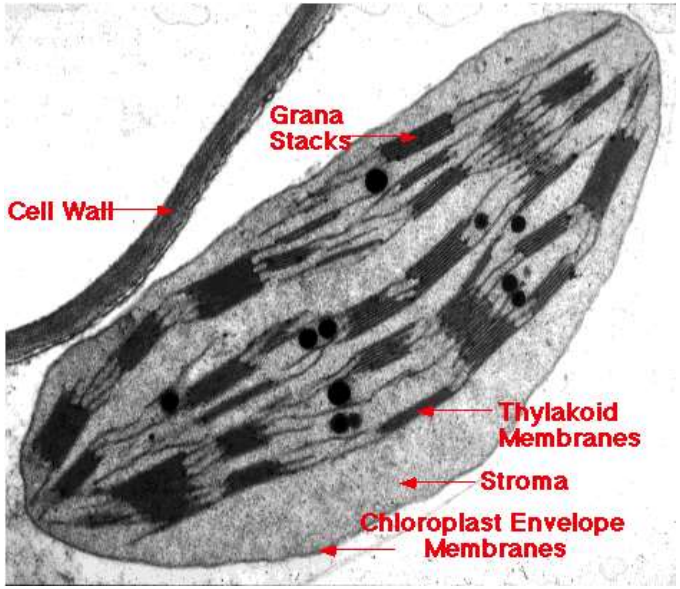


plant cells

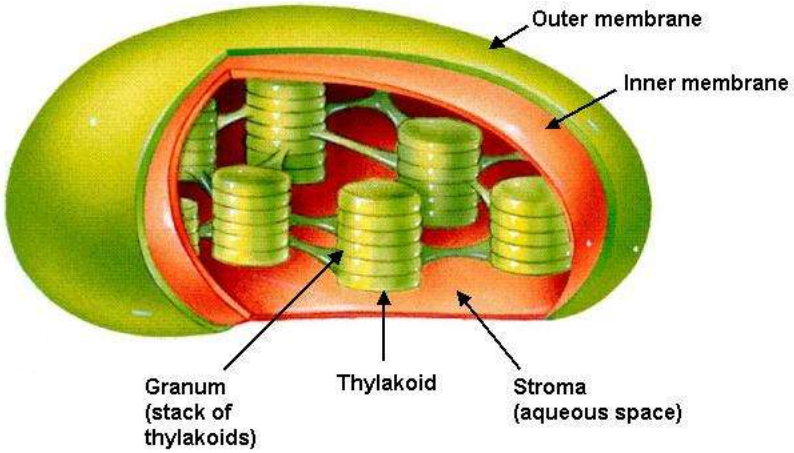


Chloroplasts

- Chloroplasts are plant organelles
  - class of plant structures = plastids
    - amyloplasts
      - store starch in roots & tubers
    - chromoplasts
      - store pigments for fruits & flowers
    - chloroplasts
      - store chlorophyll & function in photosynthesis
      - in leaves, other green structures of plants & in eukaryotic algae



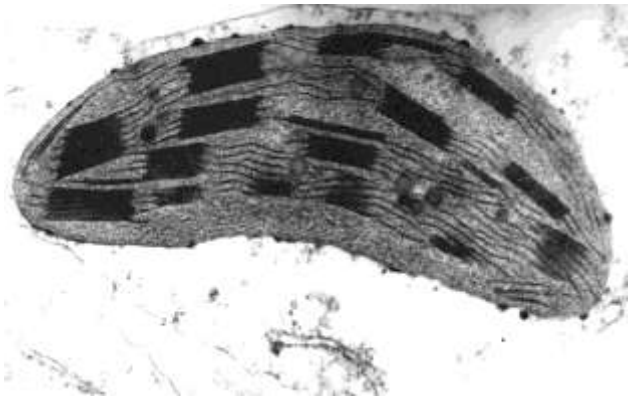
Chloroplasts



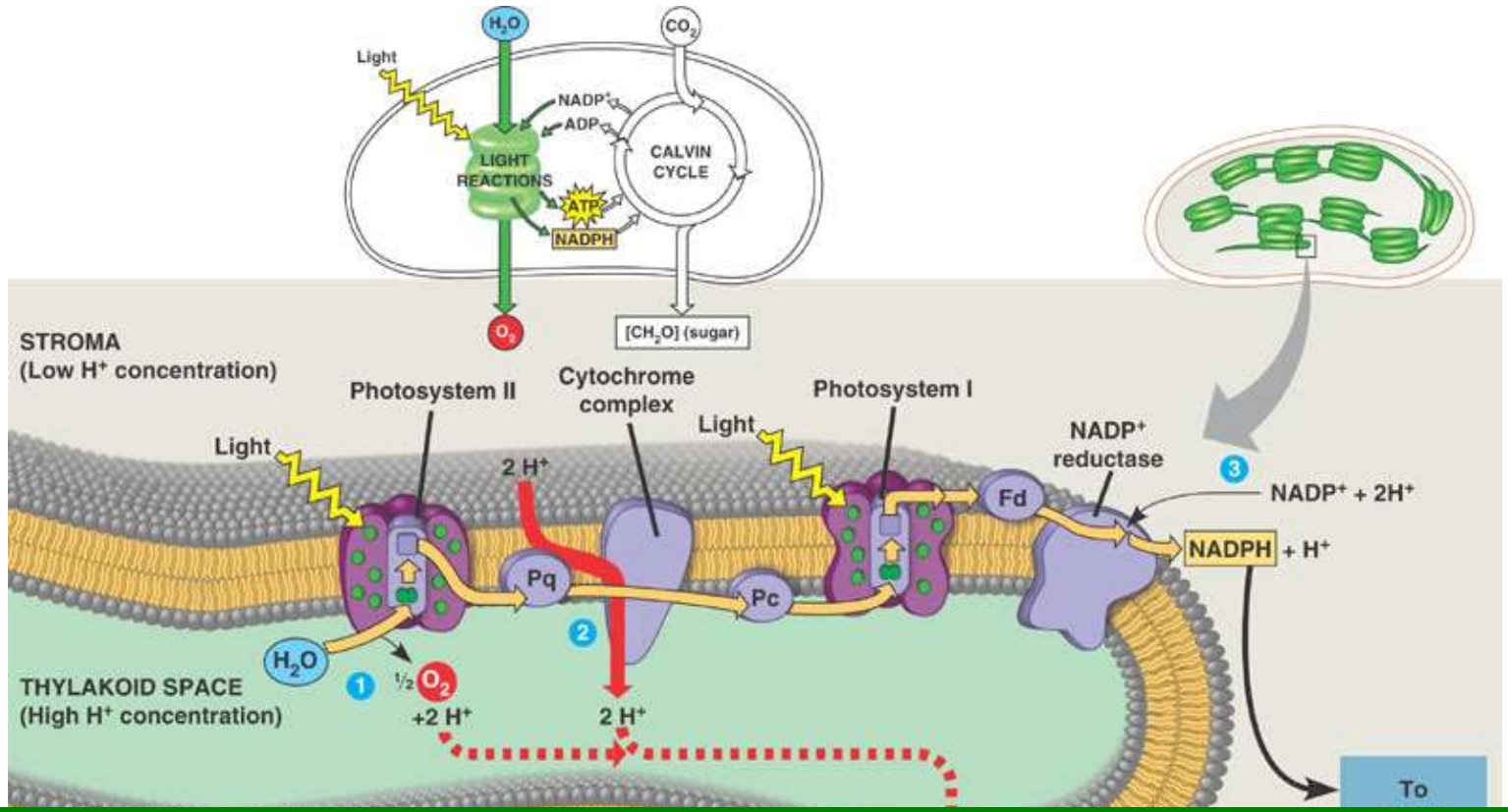
- Structure
  - 2 membranes
  - stroma = internal fluid-filled space
    - DNA, ribosomes & enzymes
    - thylakoids = membranous sacs where ATP is made
    - grana = stacks of thylakoids

Why internal sac membranes?

increase surface area for membrane-bound enzymes that synthesize ATP



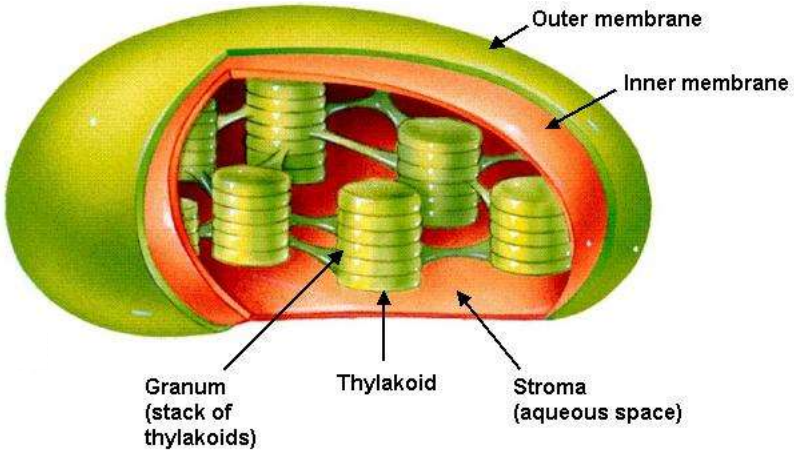
Membrane-bound Enzymes



carbon dioxide + water + energy → glucose + oxygen

$$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

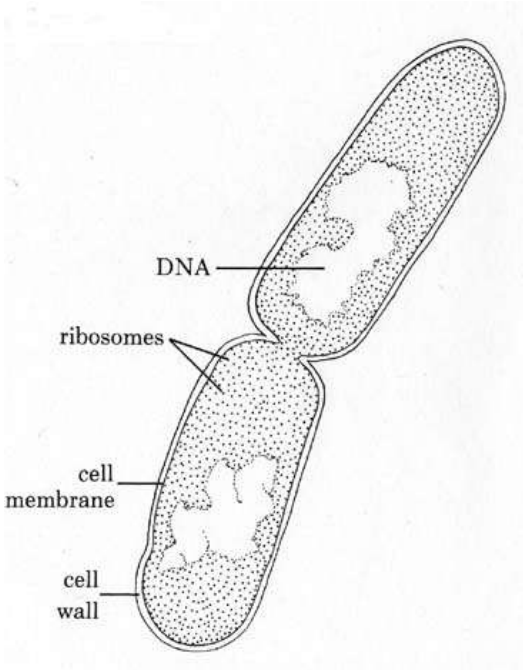
Chloroplasts



- Function
  - photosynthesis
  - generate ATP & synthesize sugars
    - transform solar energy into chemical energy
    - produce sugars from CO_2 & H_2O
- Semi-autonomous
    - moving, changing shape & dividing
    - can reproduce by pinching in two

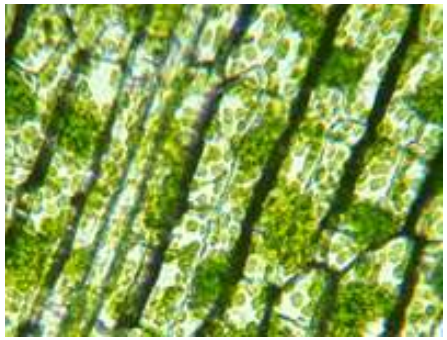
Who else divides like that?

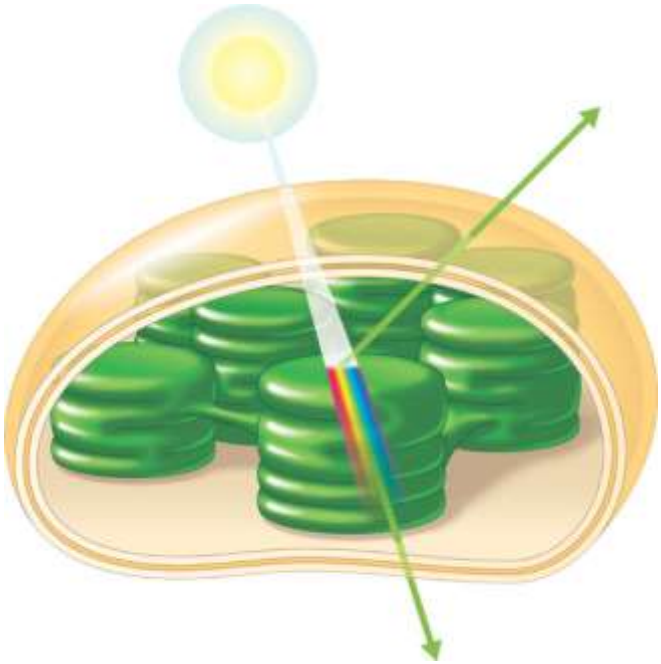
bacteria!

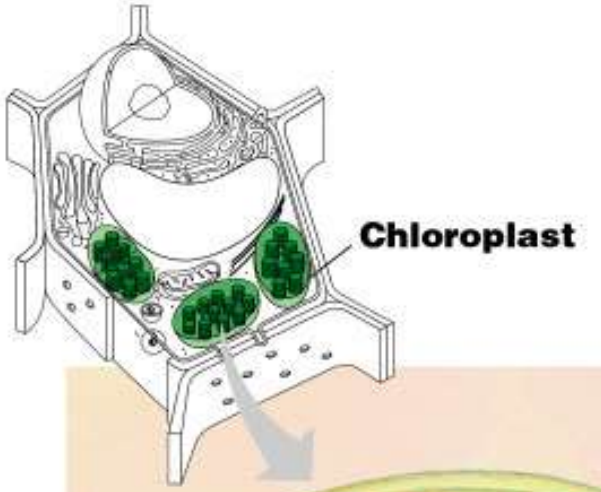


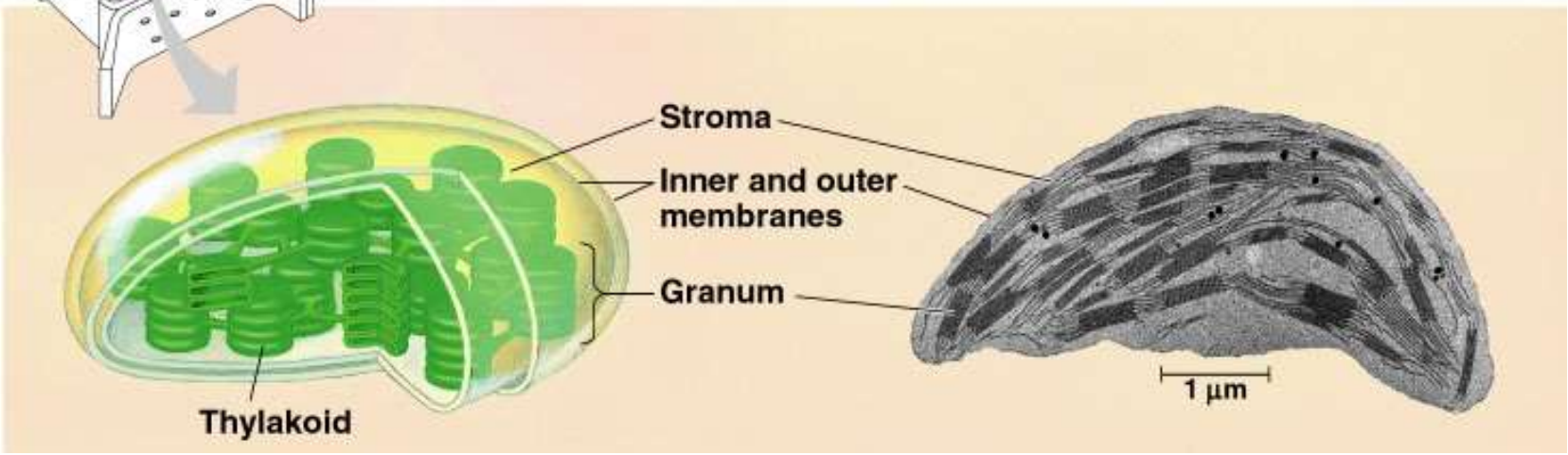
Chloroplasts

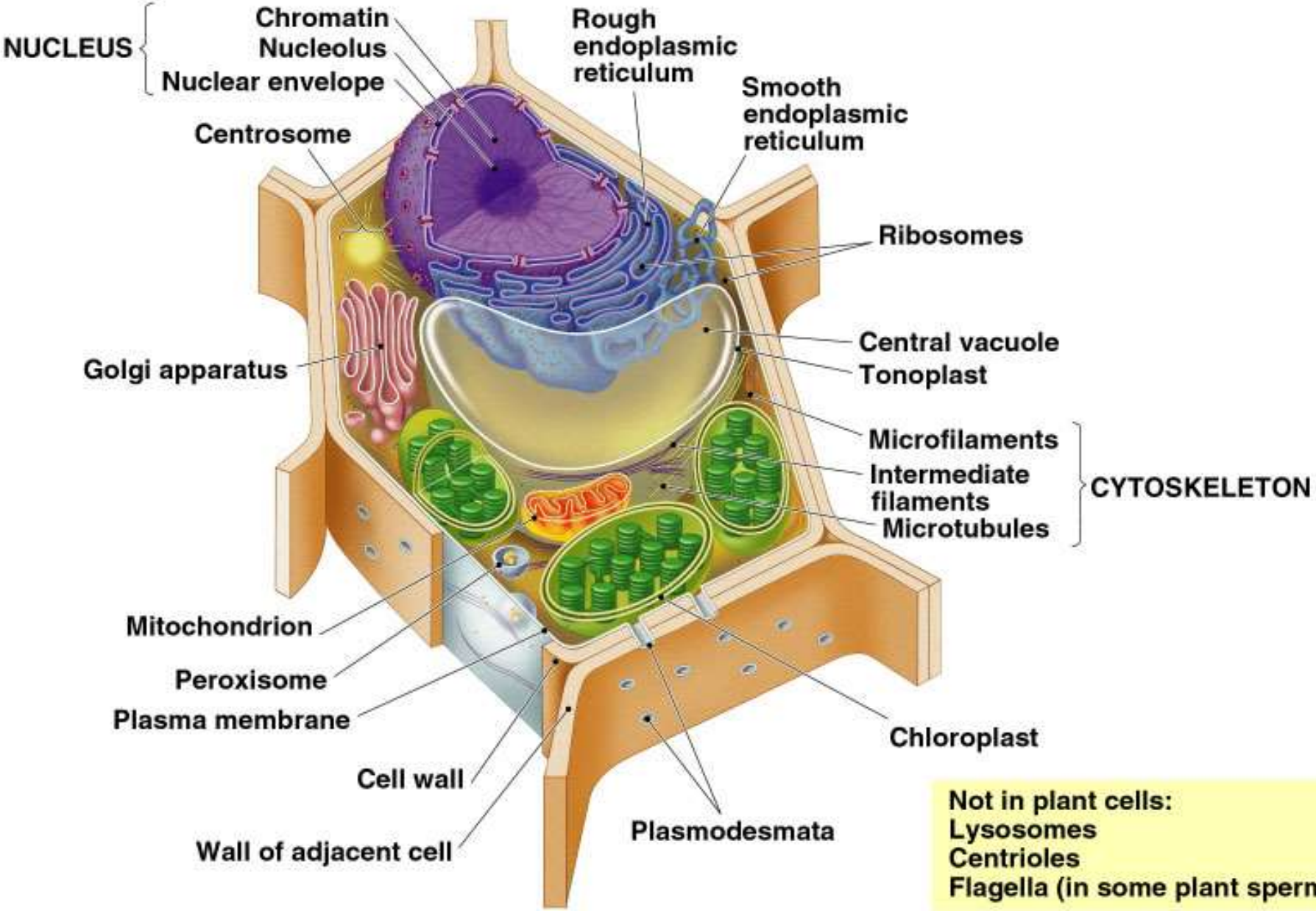
Why are chloroplasts green?









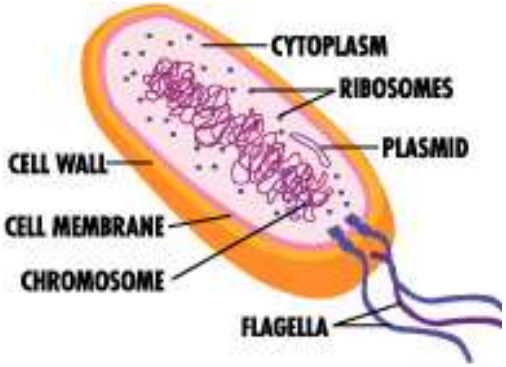

NUCLEUS
Chromatin
Nucleolus
Nuclear envelope
Centrosome
Rough endoplasmic reticulum
Smooth endoplasmic reticulum
Ribosomes
Golgi apparatus
Central vacuole
Tonoplast
Microfilaments
Intermediate filaments
Microtubules
CYTOSKELETON
Mitochondrion
Peroxisome
Plasma membrane
Cell wall
Wall of adjacent cell
Plasmodesmata
Chloroplast
Not in plant cells:
Lysosomes
Centrioles
Flagella (in some plant sperm)

Mitochondria & chloroplasts are different

- Organelles not part of endomembrane system
- Grow & reproduce
  - semi-autonomous organelles
- Proteins primarily from free ribosomes in cytosol & a few from their own ribosomes
- Own circular chromosome
  - directs synthesis of proteins produced by own internal ribosomes
    - ribosomes like bacterial ribosomes

Who else has a circular chromosome not bound within a nucleus?

bacteria



Endosymbiosis theory

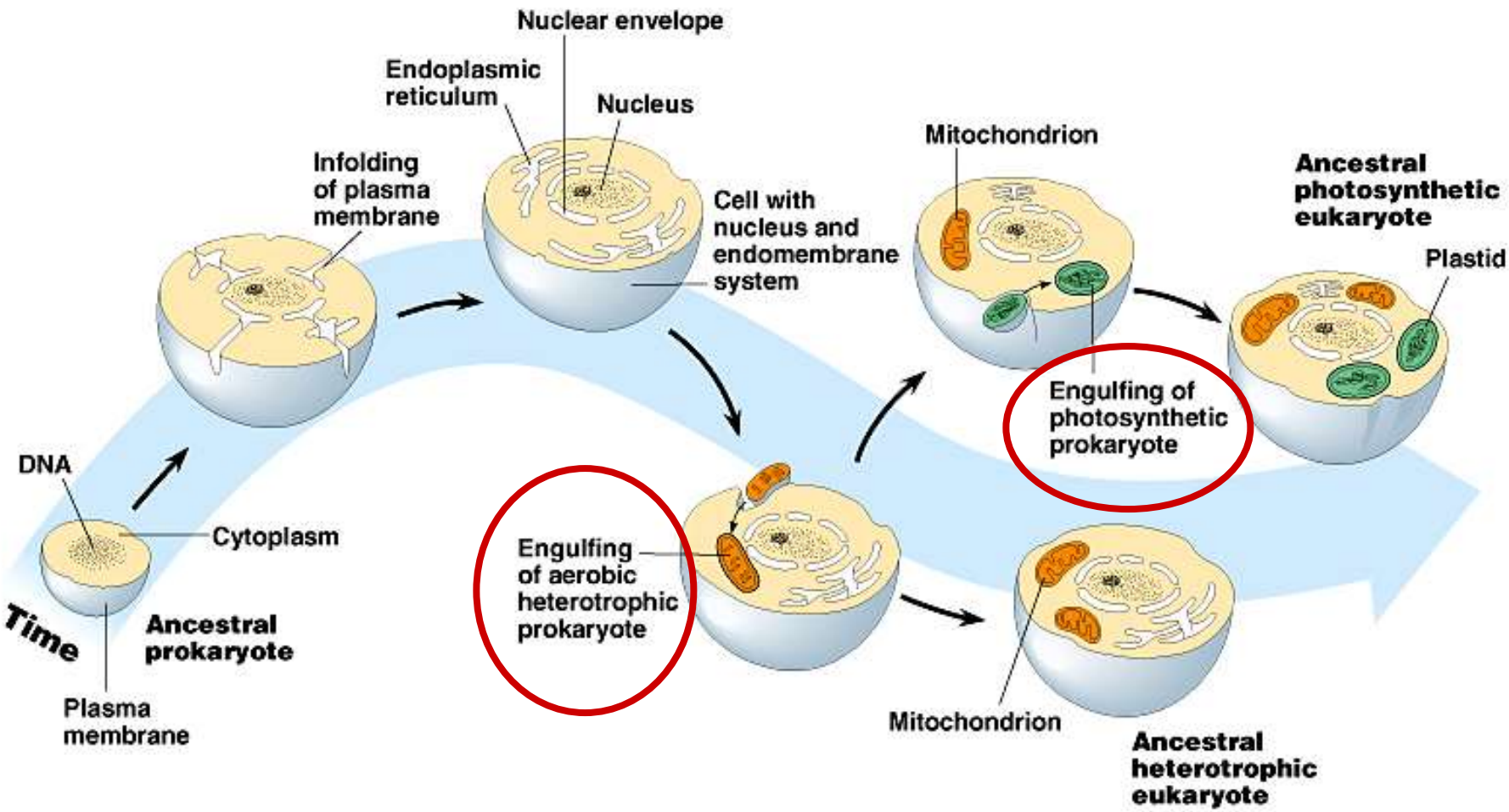
1981 | ??

- Mitochondria & chloroplasts were once free living bacteria
  - engulfed by ancestral eukaryote
- Endosymbiont
  - cell that lives within another cell (host)
    - as a partnership
    - evolutionary advantage for both
      - one supplies energy
      - the other supplies raw materials & protection

Lynn Margulis
U of M, Amherst

Endosymbiosis theory

Evolution of eukaryotes



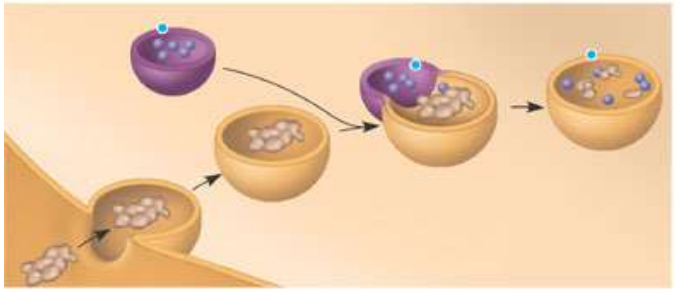
Endosymbiosis theory: Evidence

Evolution of eukaryotes

- New mitochondria are formed through a process similar to how bacteria divide (**e.g. binary fission**)
- If cell's mitochondria or chloroplast are removed, the cell cannot create new ones
- Transport proteins are found on the outer membranes of mitochondria and chloroplast are also found in bacterial cells
- Both mitochondria and plastids contain single circular DNA that is different from that of the cell nucleus and that is similar to that of bacteria (both in their size and structure)
- The genomes, including the specific genes, are basically similar between mitochondria and the Rickettsial bacteria
- Decreased genome sizes show increased dependability

Vacuoles & vesicles

- Function
  - little "transfer ships"
    - Food vacuoles
      - phagocytosis, fuse with lysosomes
    - Contractile vacuoles
      - in freshwater protists, pump excess H_2O out of cell
    - Central vacuoles
      - in many mature plant cells



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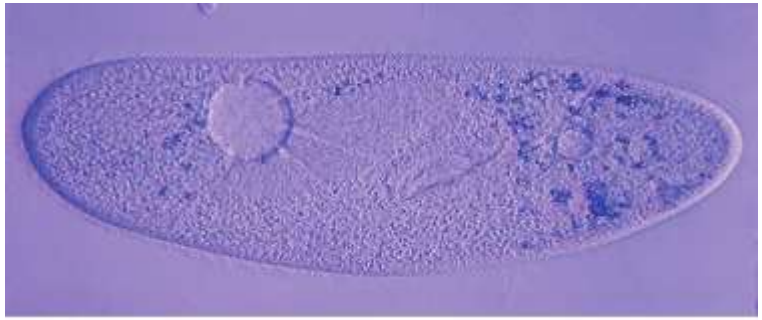
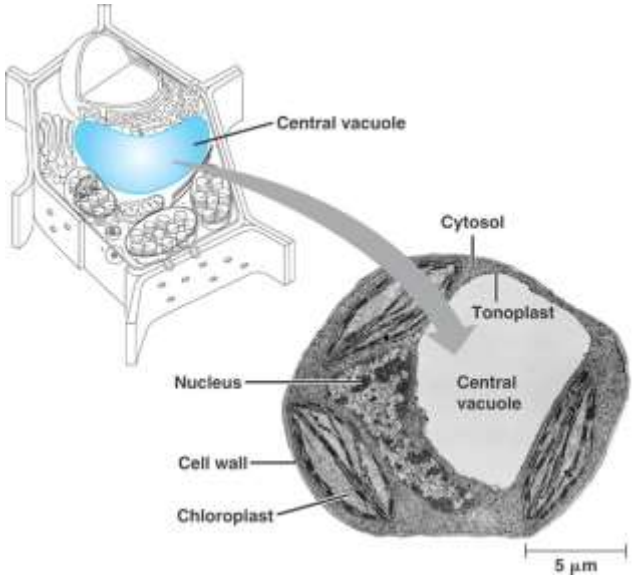
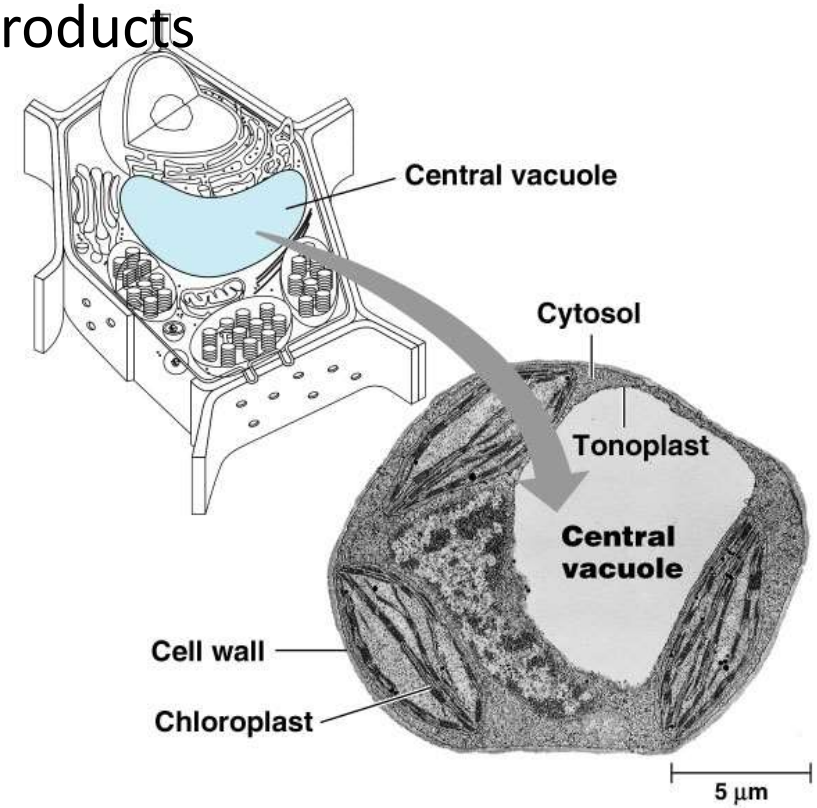




Vacuoles in plants

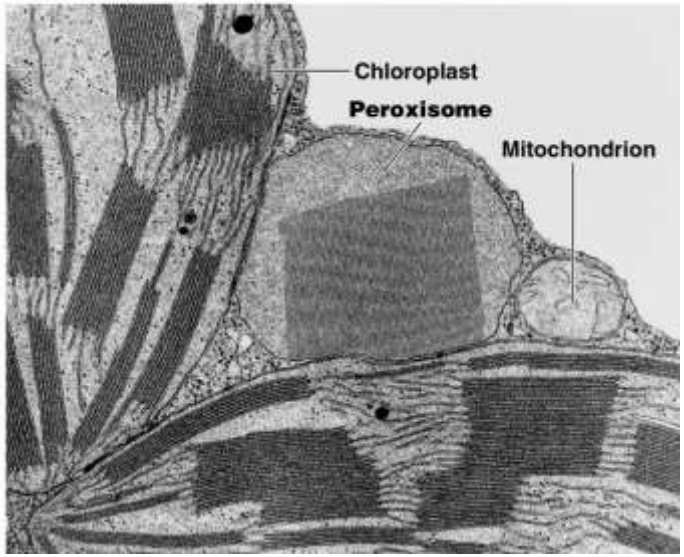
- Functions
  - storage
    - stockpiling proteins or inorganic ions
    - depositing metabolic byproducts
    - storing pigments
    - storing defensive compounds against herbivores
    - selective membrane
      - control what comes in or goes out



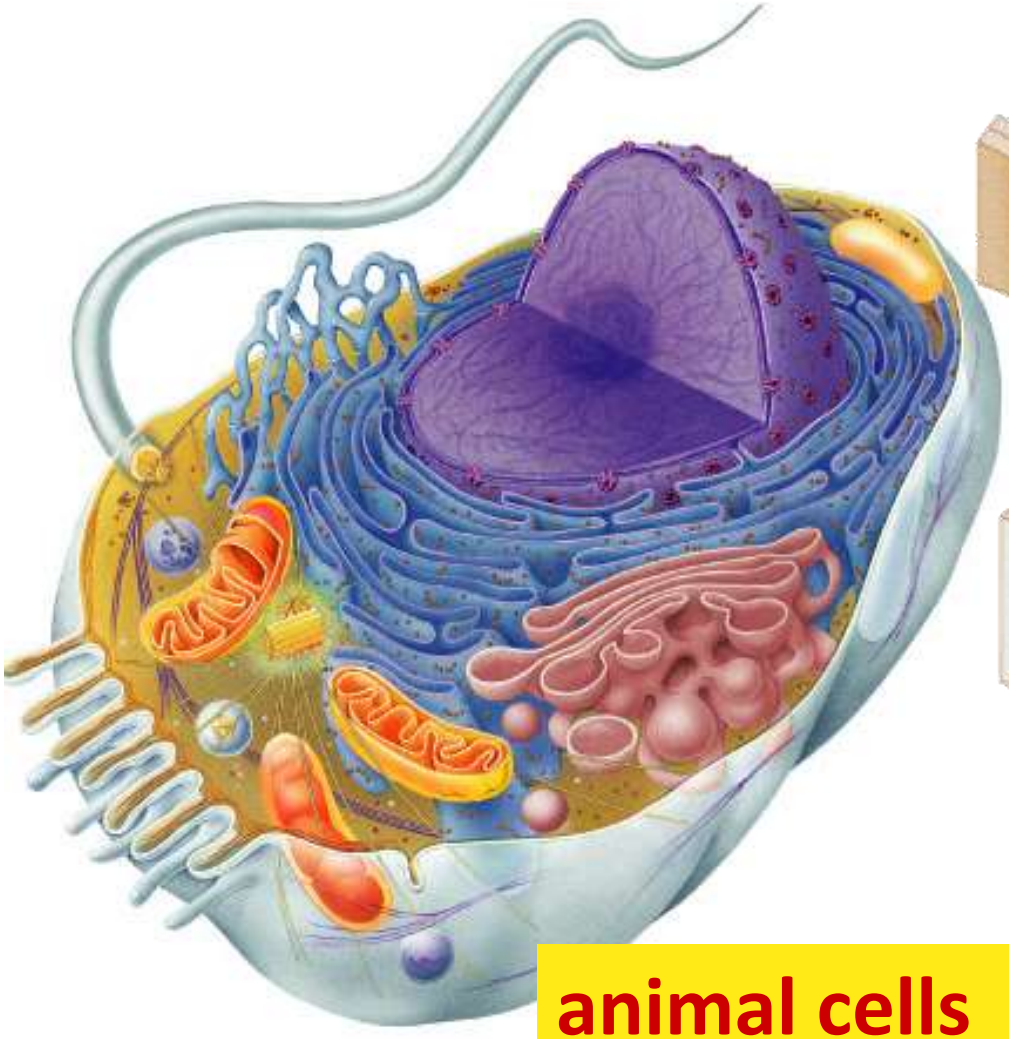
Peroxisomes

- Other digestive enzyme sacs
  - in both animals & plants
  - breakdown fatty acids to sugars
    - easier to transport & use as energy source
  - detoxify cell
    - detoxifies alcohol & other poisons
  - produce peroxide (H_2O_2)
    - must breakdown

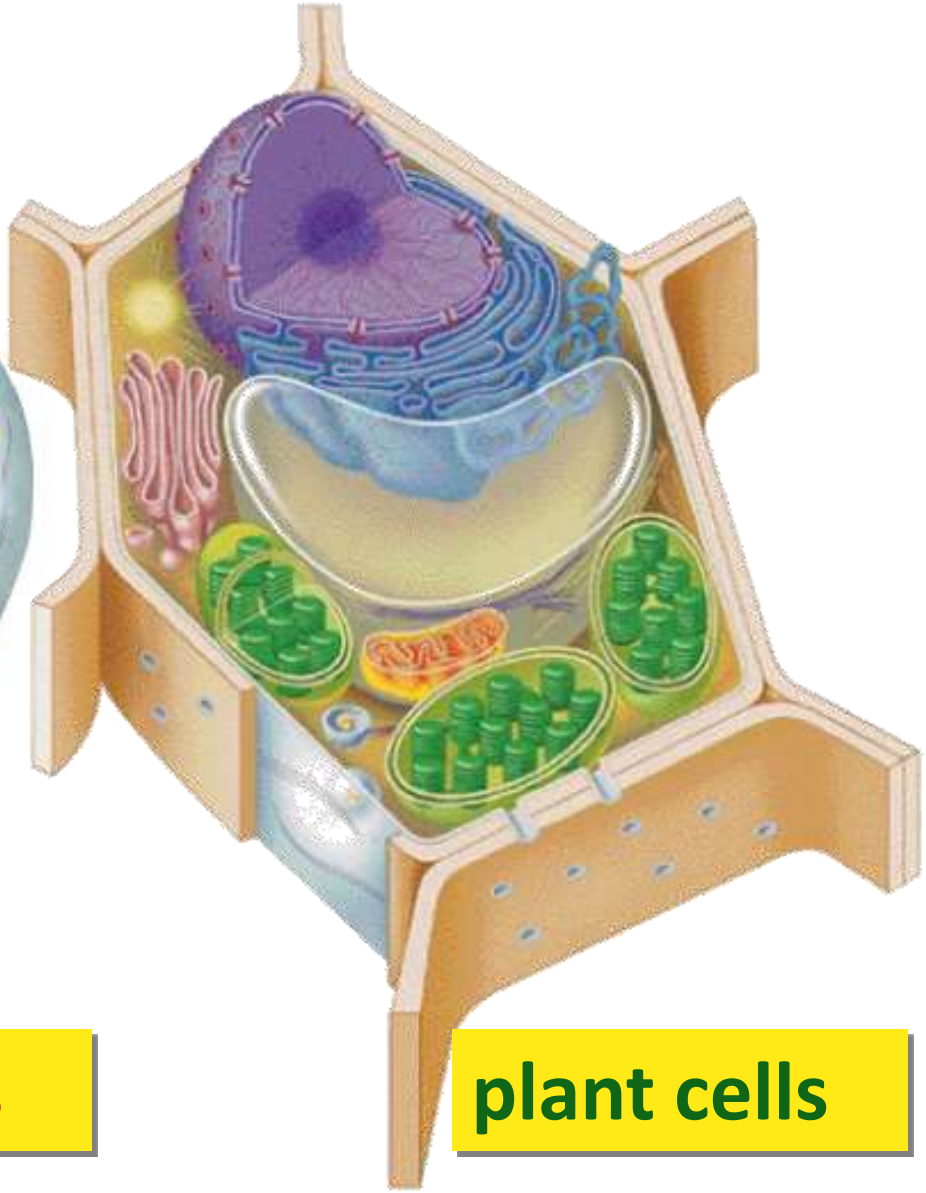
      $H_2O_2 \rightarrow H_2O$



Putting it all together



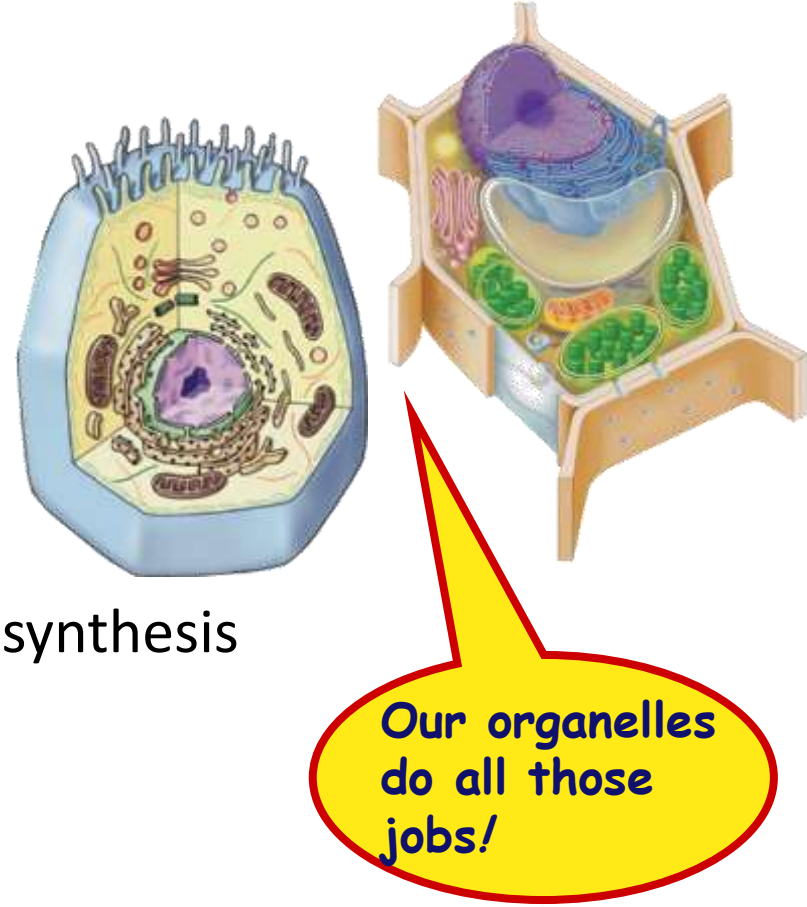
animal cells



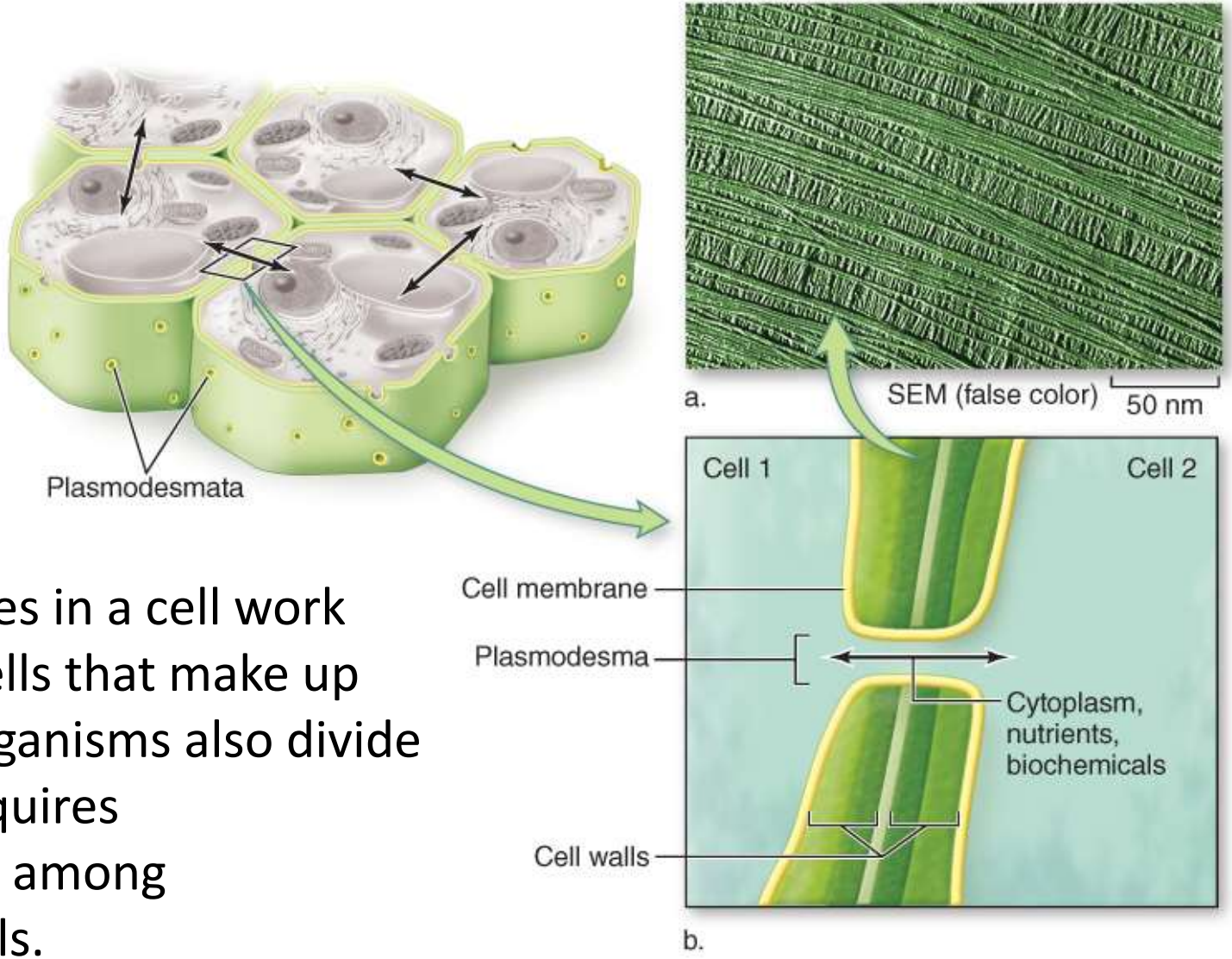
plant cells

Cell Summary

- Cells have 3 main jobs
  - make energy
    - need food + O_2
    - cellular respiration & photosynthesis
    - need to remove wastes
  - make proteins
    - need instructions from DNA
    - need to chain together amino acids & "finish" & "ship" the protein
  - make more cells
    - need to copy DNA & divide it up to daughter cells



Cells Stick Together and Communicate

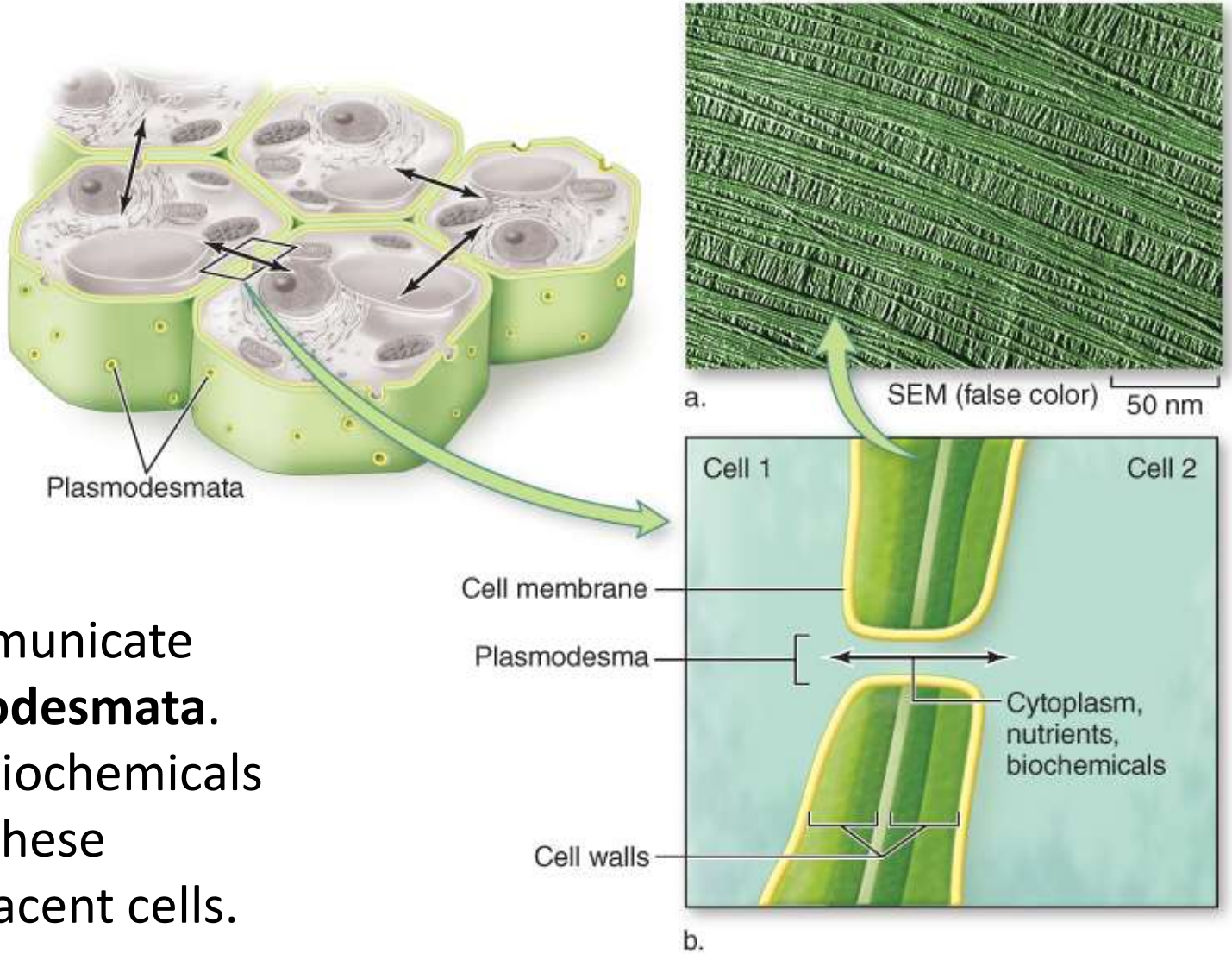


Just as organelles in a cell work together, the cells that make up multicellular organisms also divide labor, which requires communication among neighboring cells.

Section 3.6

Figure 3.28

Cells Stick Together and Communicate



Plant cells communicate through **plasmodesmata**. Nutrients and biochemicals travel through these channels to adjacent cells.

Section 3.6

Figure 3.28

Cells Stick Together and Communicate

Gap junctions connecting animal cells are analogous to plasmodesmata. A protein channel links the cytoplasm of neighboring cells.

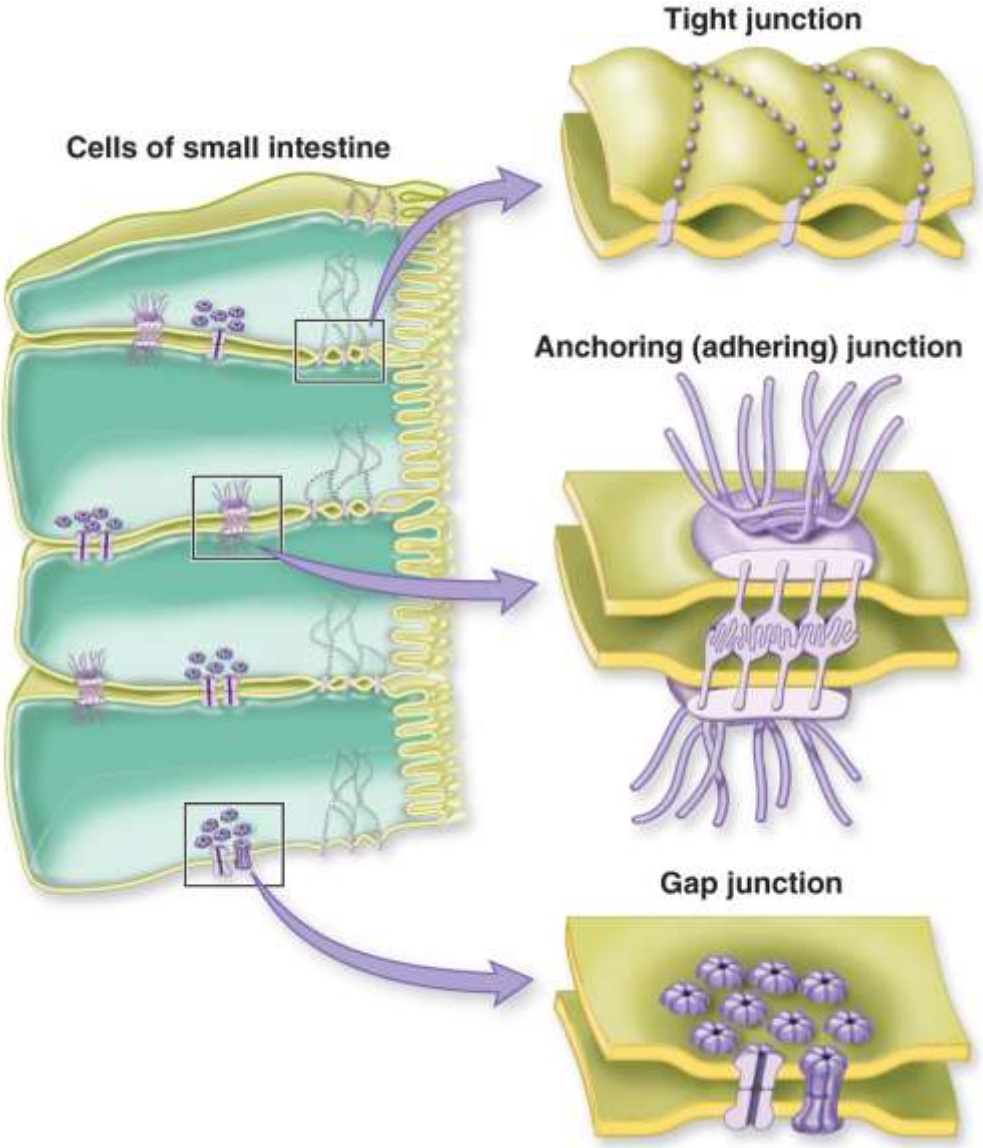


Figure 3.27

Cells Stick Together and Communicate

Tight junctions fuse the membranes of adjacent animal cells together, preventing substances from flowing between the cells.

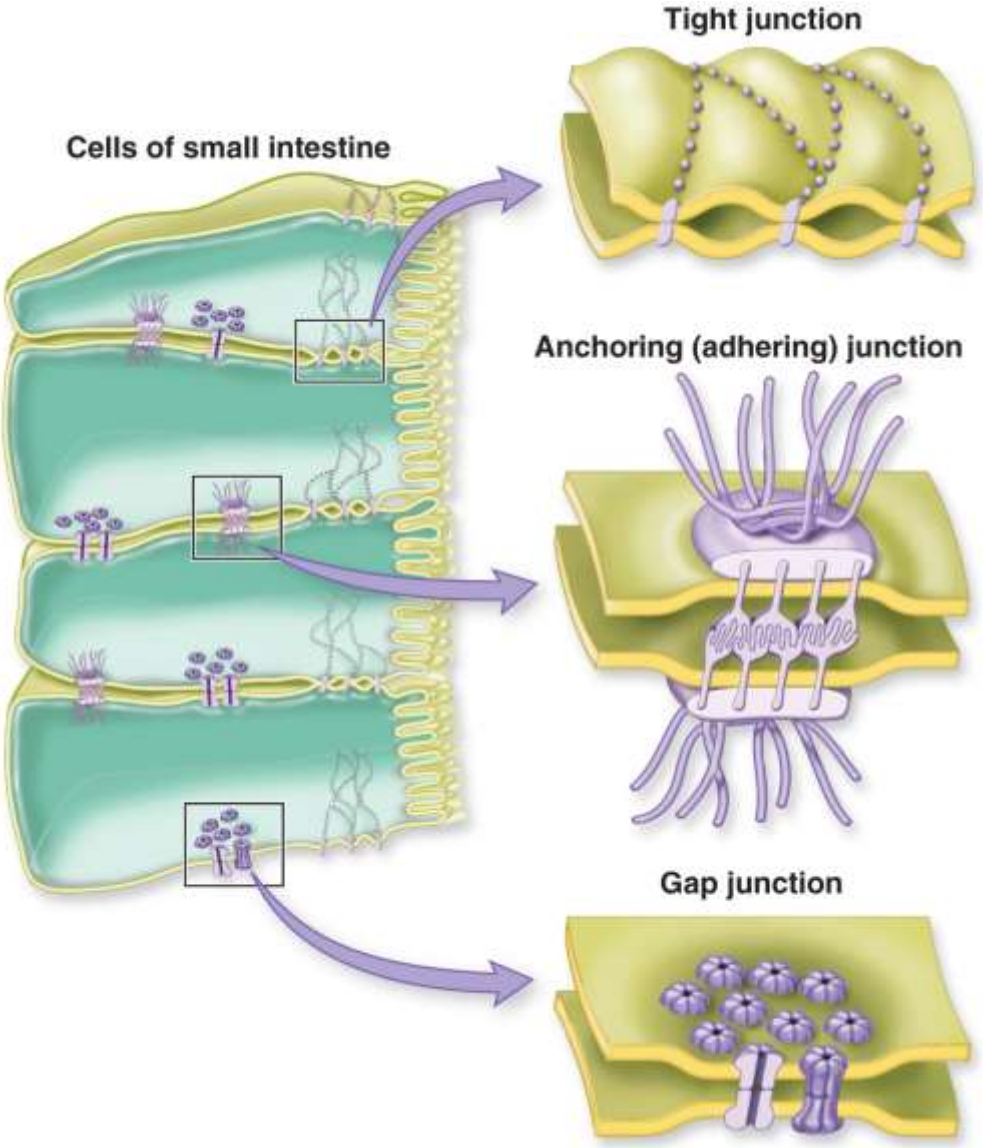


Figure 3.27

Cells Stick Together and Communicate

Anchoring junctions use intermediate filaments to hold cells together.

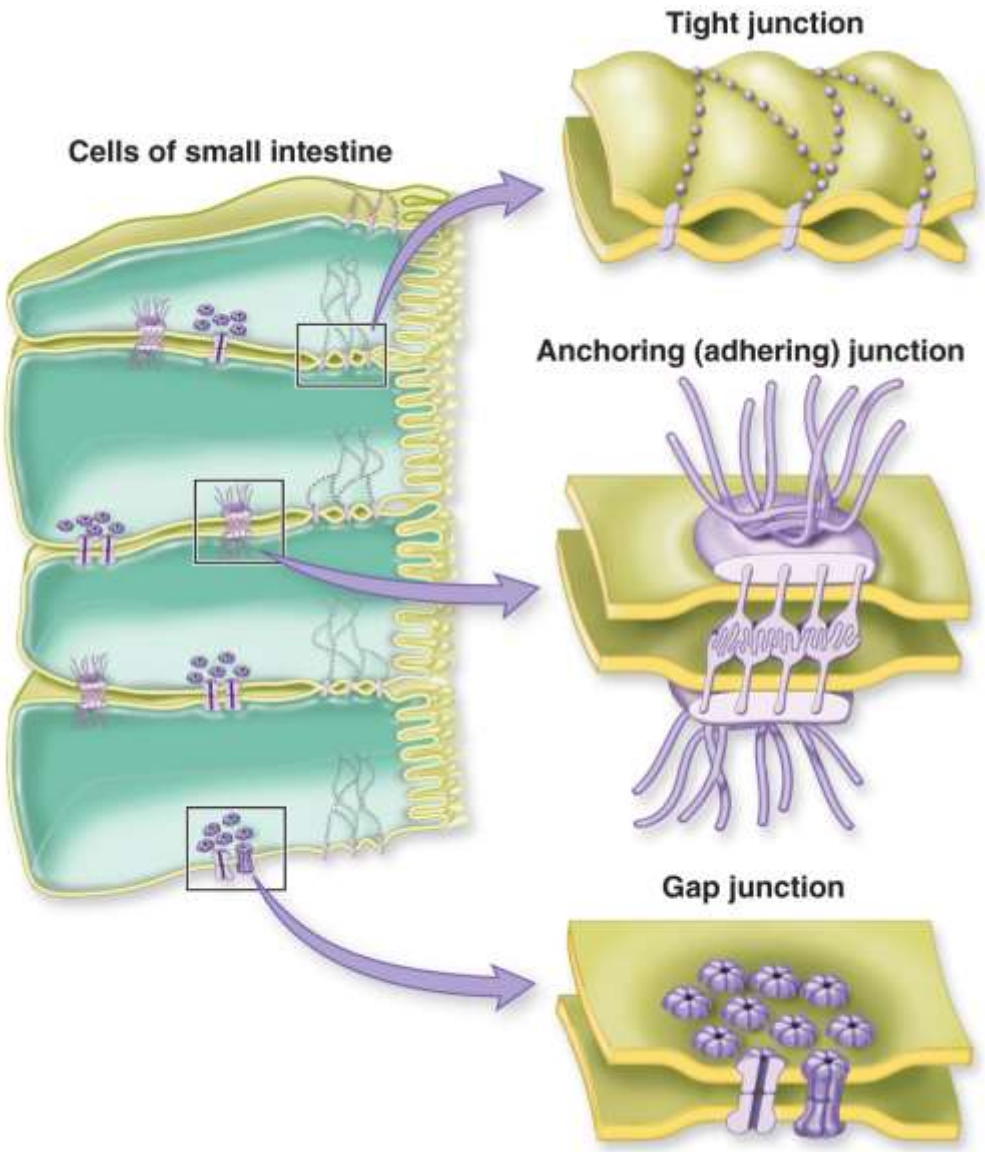


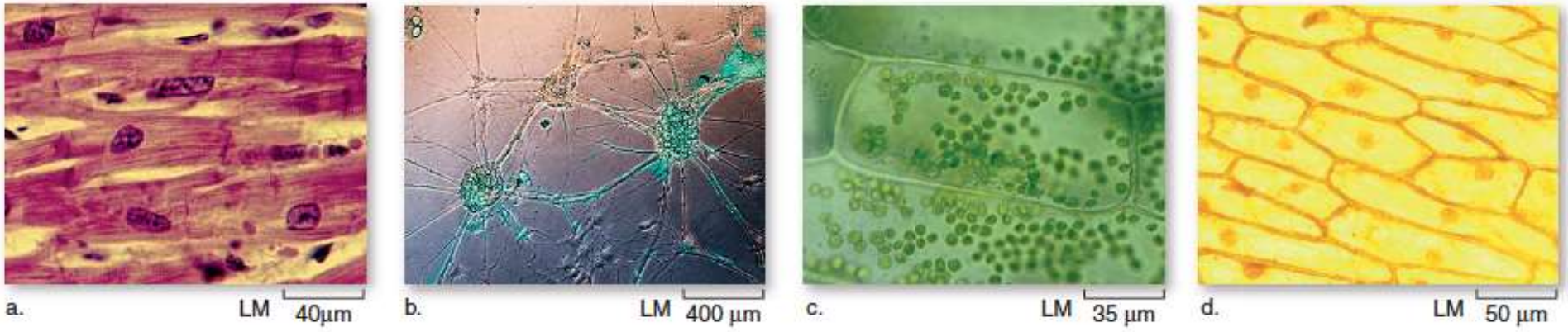
Figure 3.27

3.6 Mastering Concepts

What are the three types of junctions that link cells in animals?

Eukaryotic Organelles Divide Labor

Organelle composition determines a cell's specialized function.

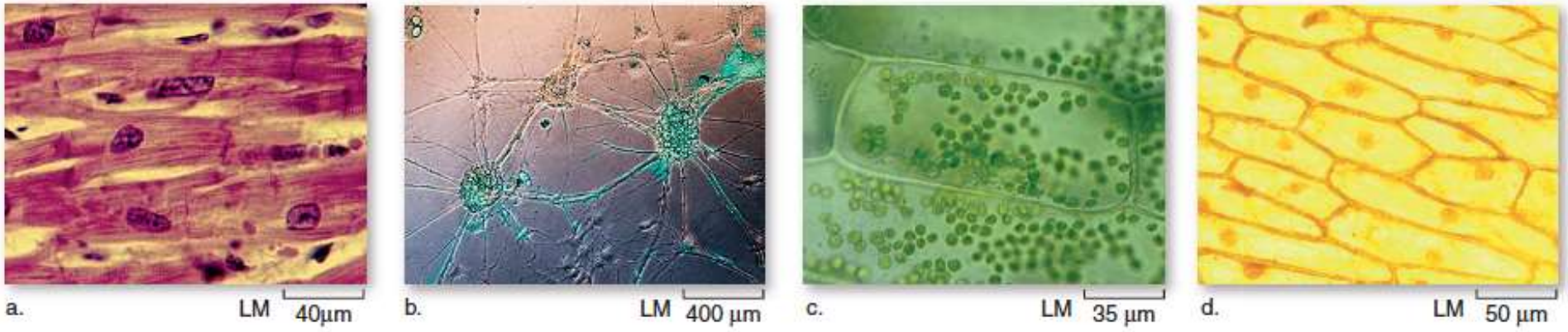


Section 3.4

Figure 3.23

Not All Cells Are Equal

We've talked about generic animal cells and plant cells, but each multicellular individual has a variety of cell types.



Section 3.4

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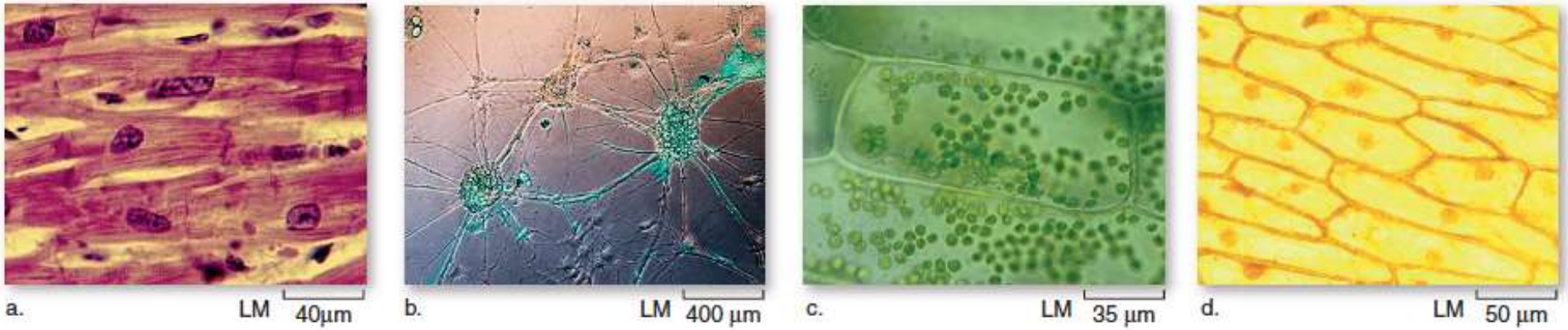
Figure 3.23

Not All Cells Are Equal

For example …
… muscle cells look and behave differently from neurons …

… and leaf cells have chloroplasts, but underground plant tissues do not.



Section 3.4

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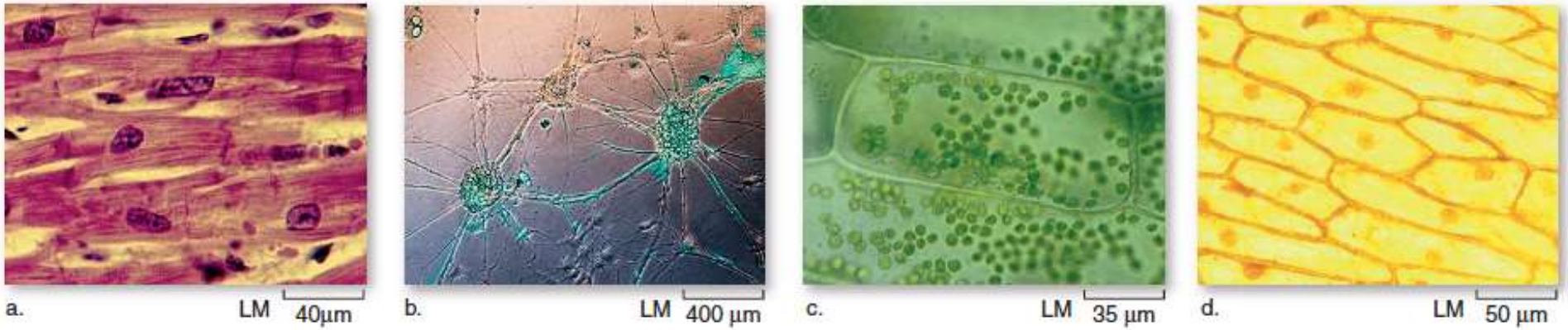
Figure 3.24

Not All Cells Are Equal

Communication among specialized cells, each anchored in place within a multicellular organism, allows cells to quickly and efficiently divide labor.



Section 3.4

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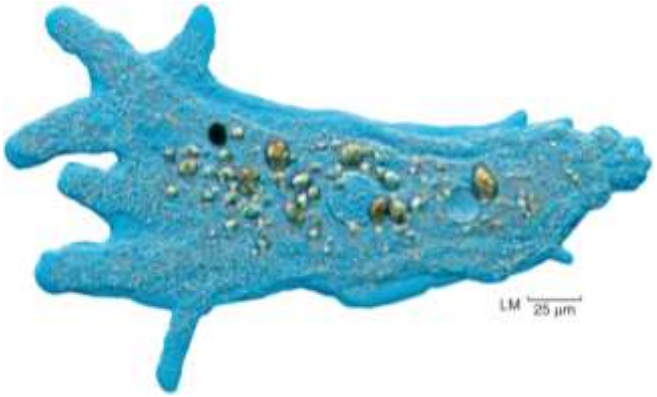
Figure 3.24

Question #5

Which structure is most likely to occur in an amoeba?

A. cytoskeleton
B. plasmodesma
C. tight junction
D. chloroplast
E. flagellum



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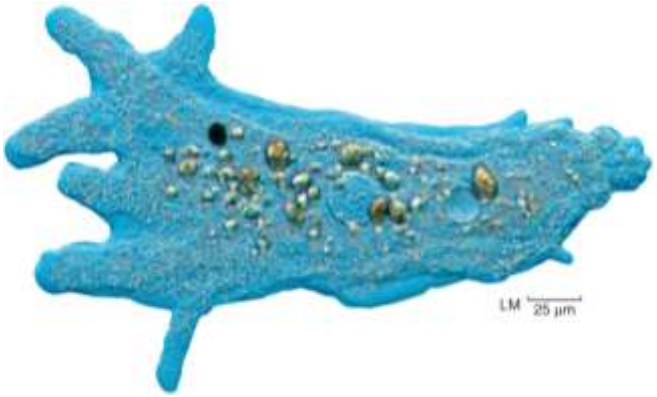
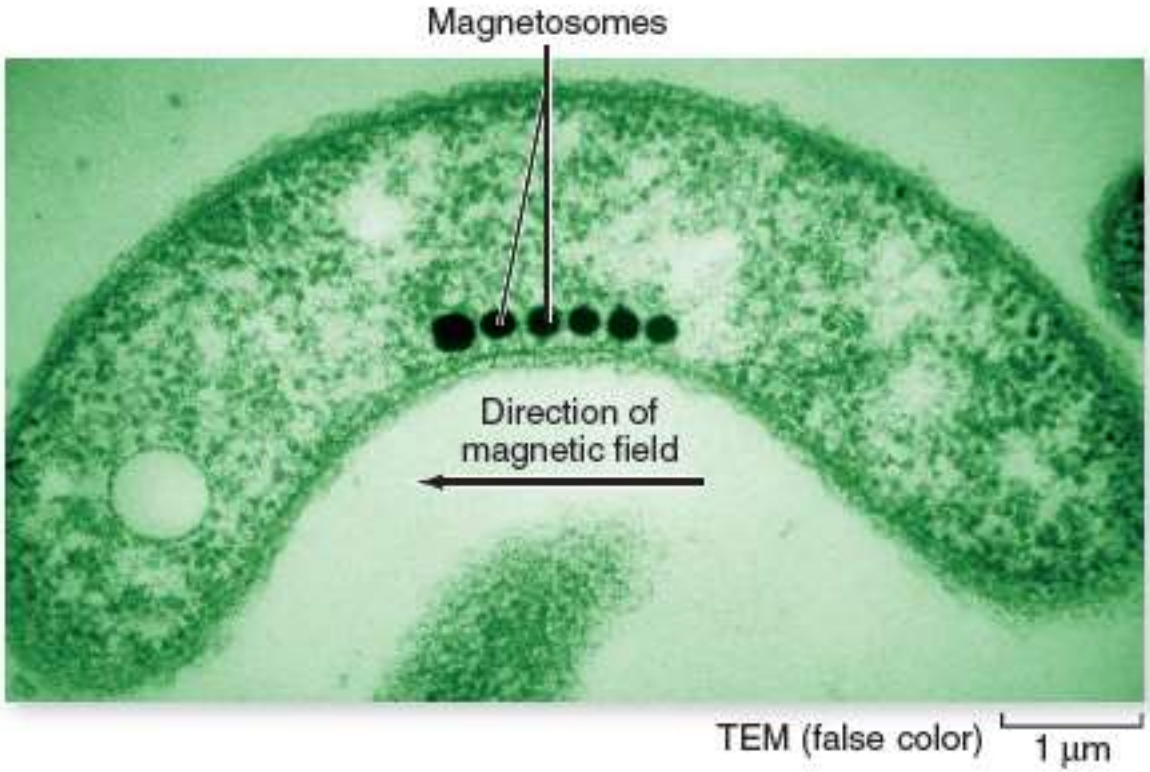


Investigating Life: The Tiniest Compass

A couple decades ago, scientists discovered membrane bubbles containing magnetic iron crystals in bacteria. What is the function of these structures?



Section 3.7

Figure 3.29

Investigating Life: The Tiniest Compass

A carefully designed experiment showed that the "magnetosomes" orient bacteria to magnetic field lines.

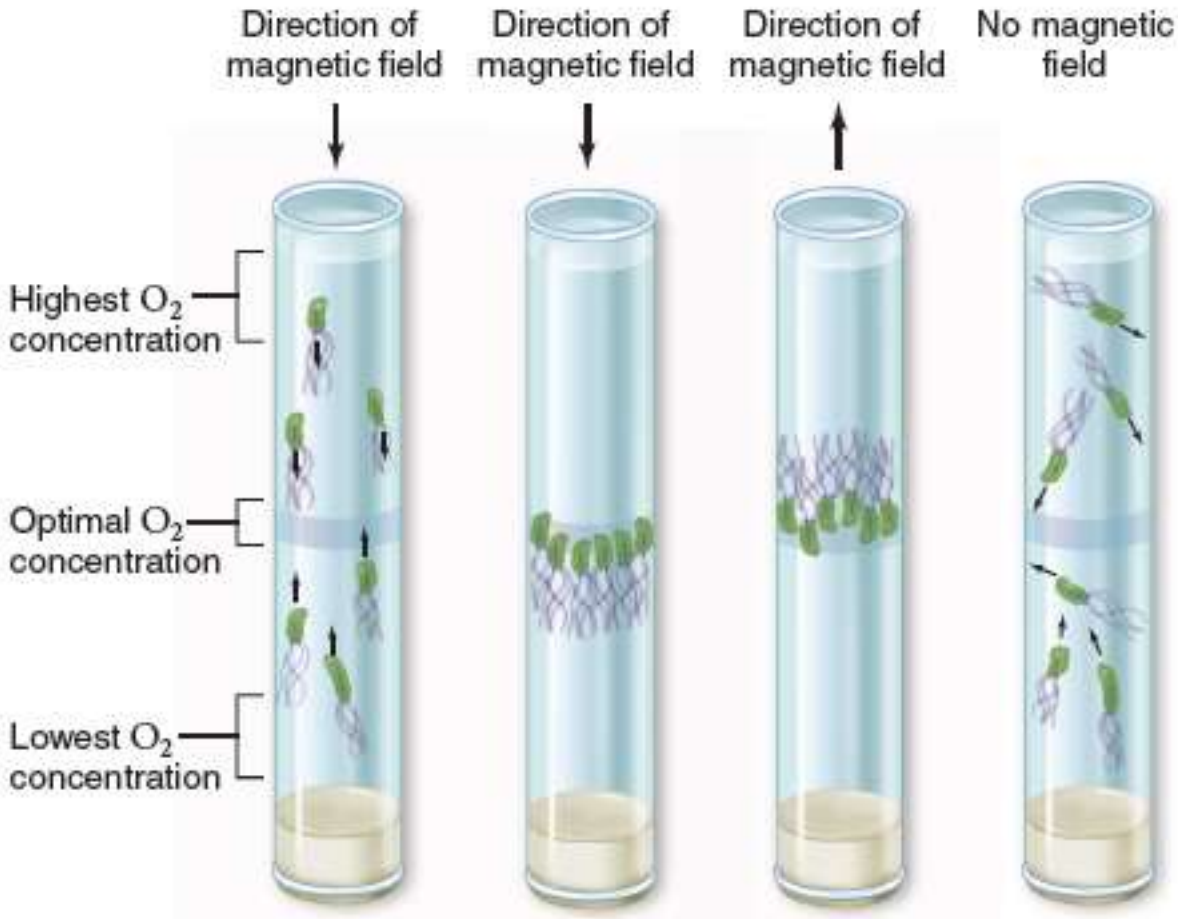


Figure 3.30

Investigating Life: The Tiniest Compass

Magnetic orienting is adaptive because it allows bacteria to swim vertically through the water column, easily adjusting to their optimal oxygen concentration.

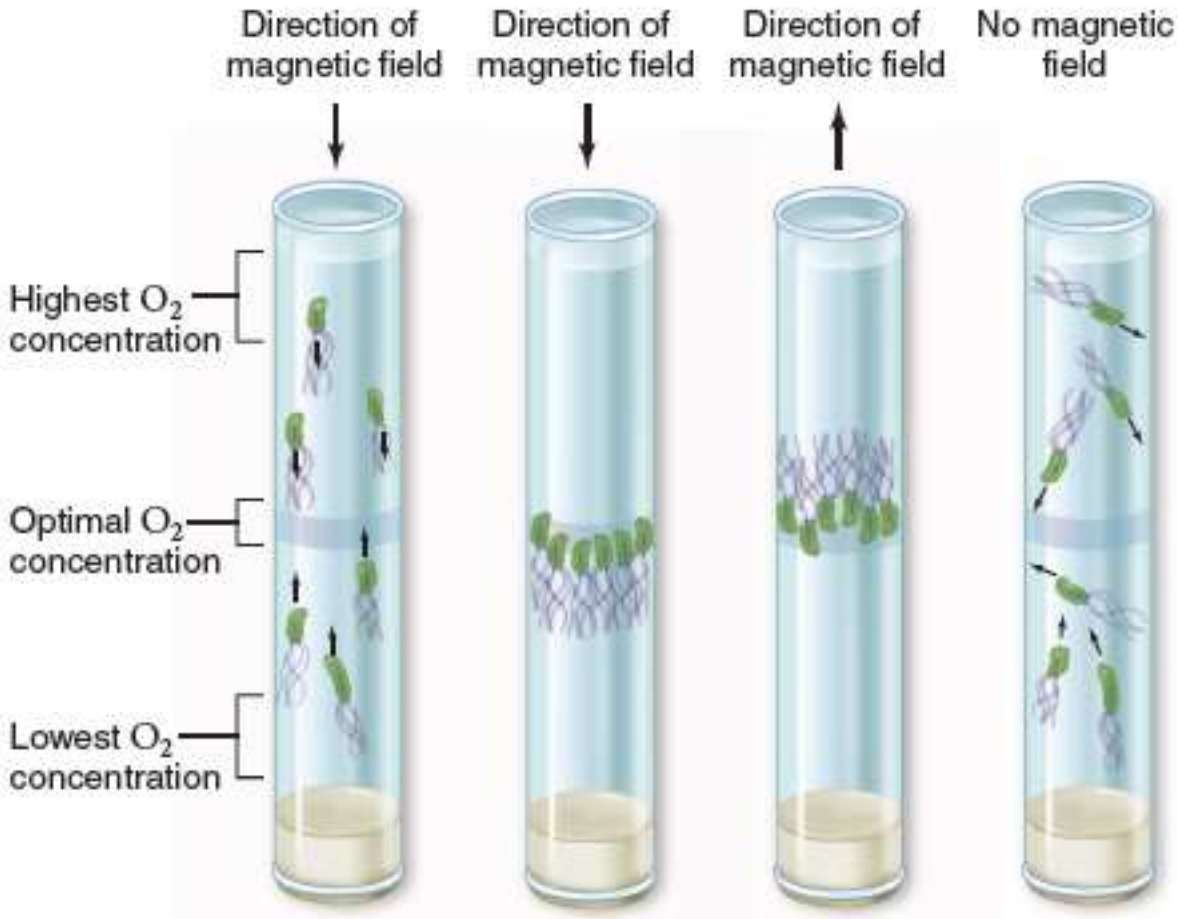


Figure 3.30