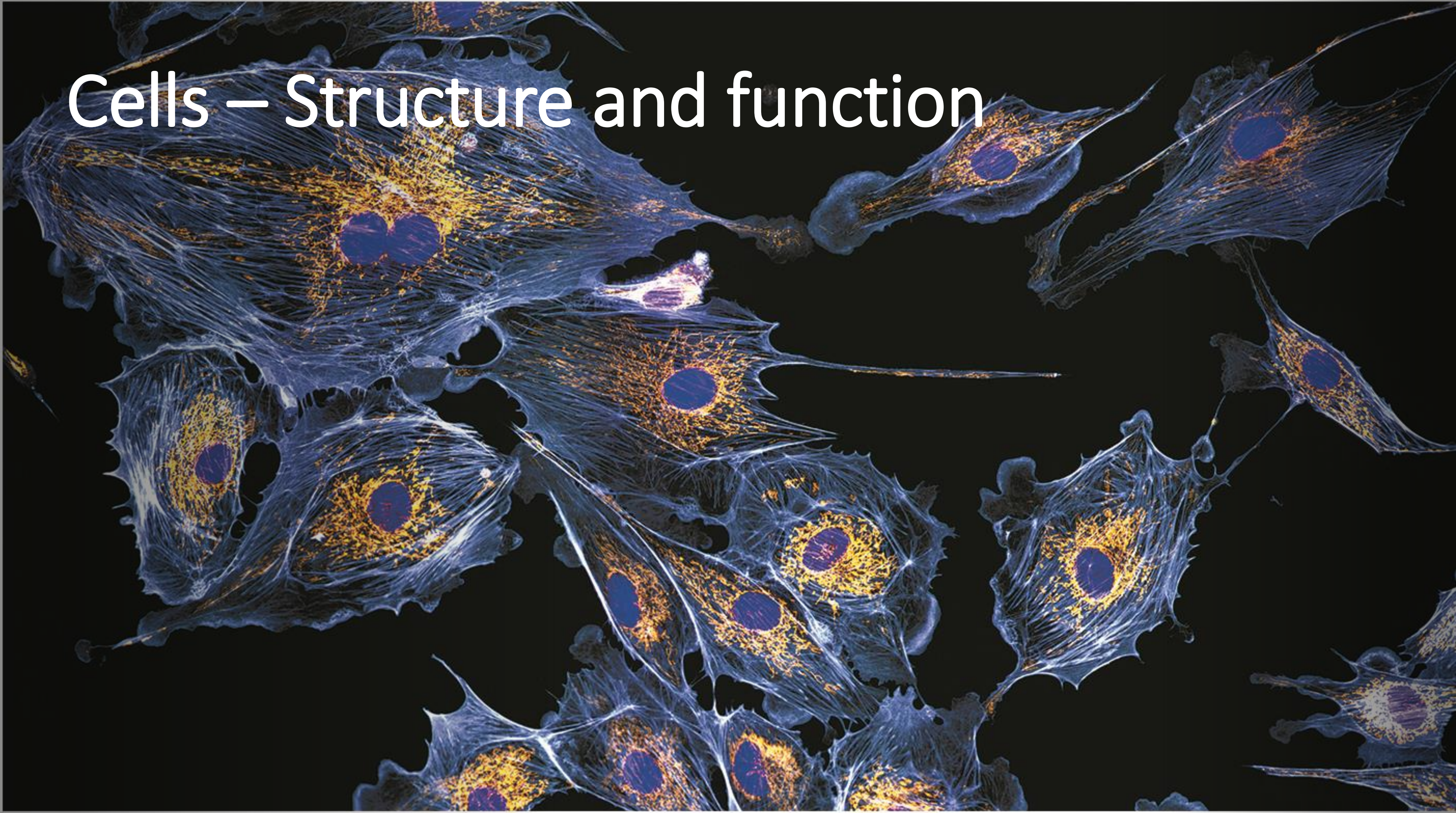
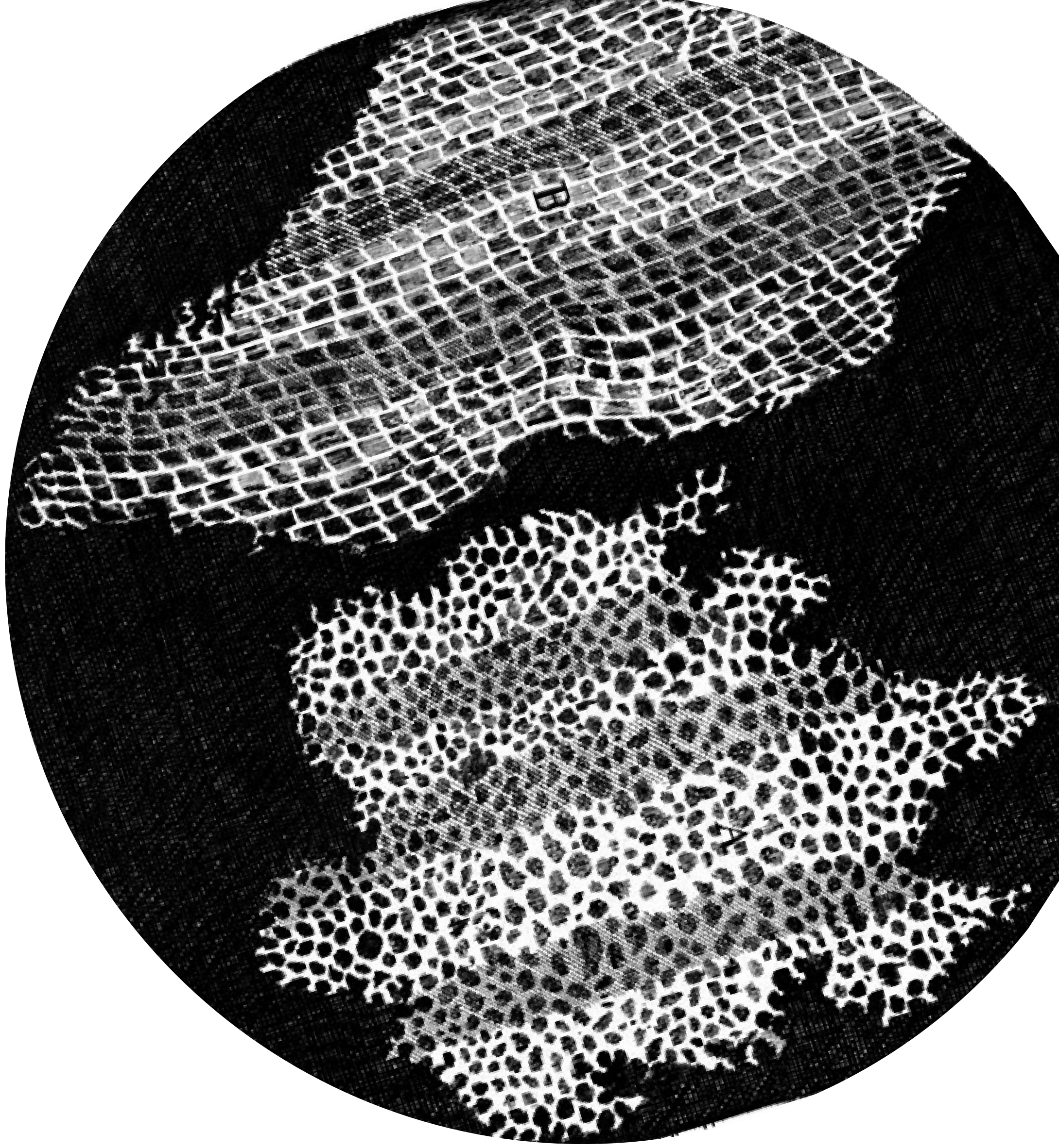
Cells – Structure and function



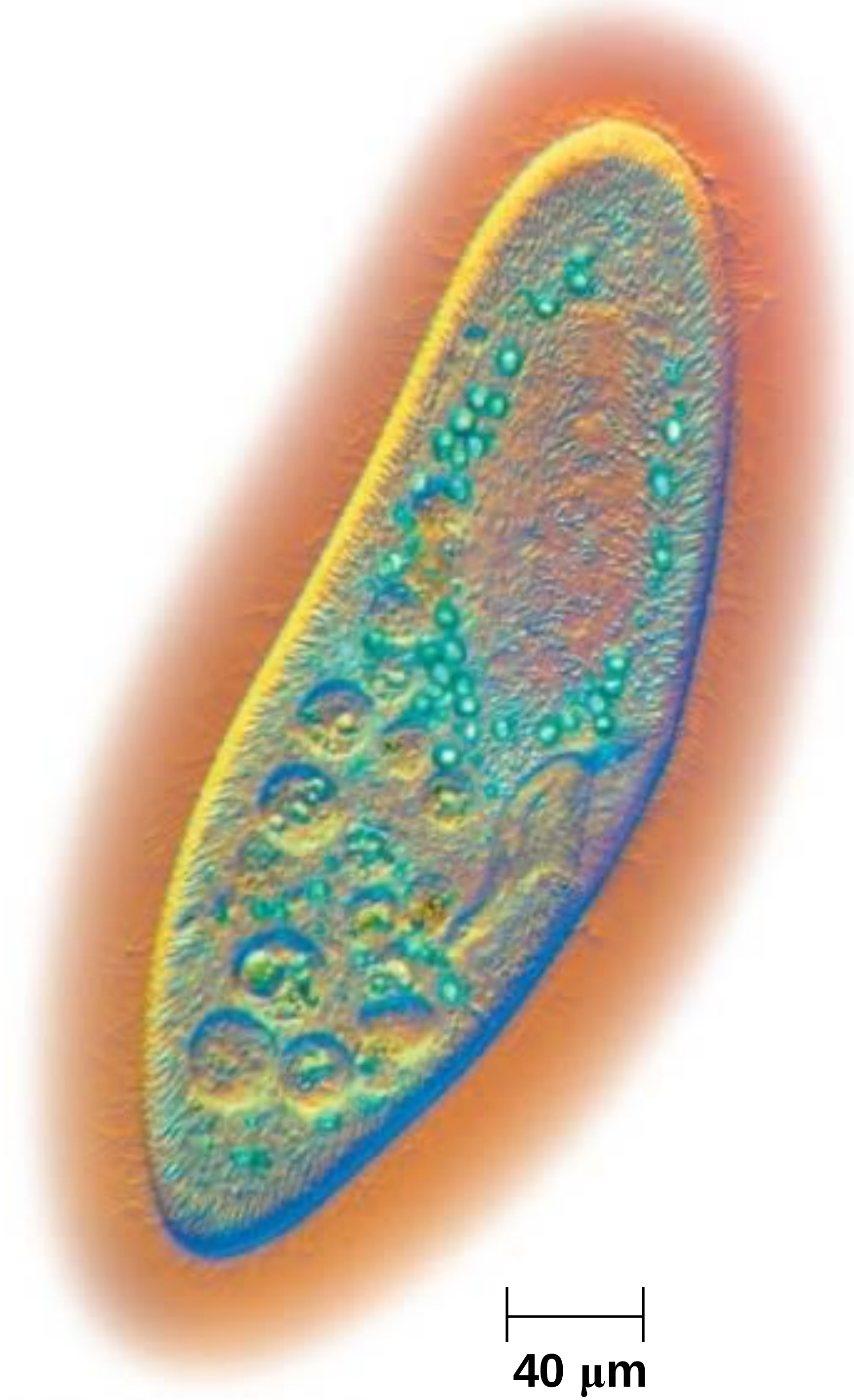
Micro-history

In 1665 Robert Hooke's observations through lenses

Blue mold- "Microscopical Mushrooms"



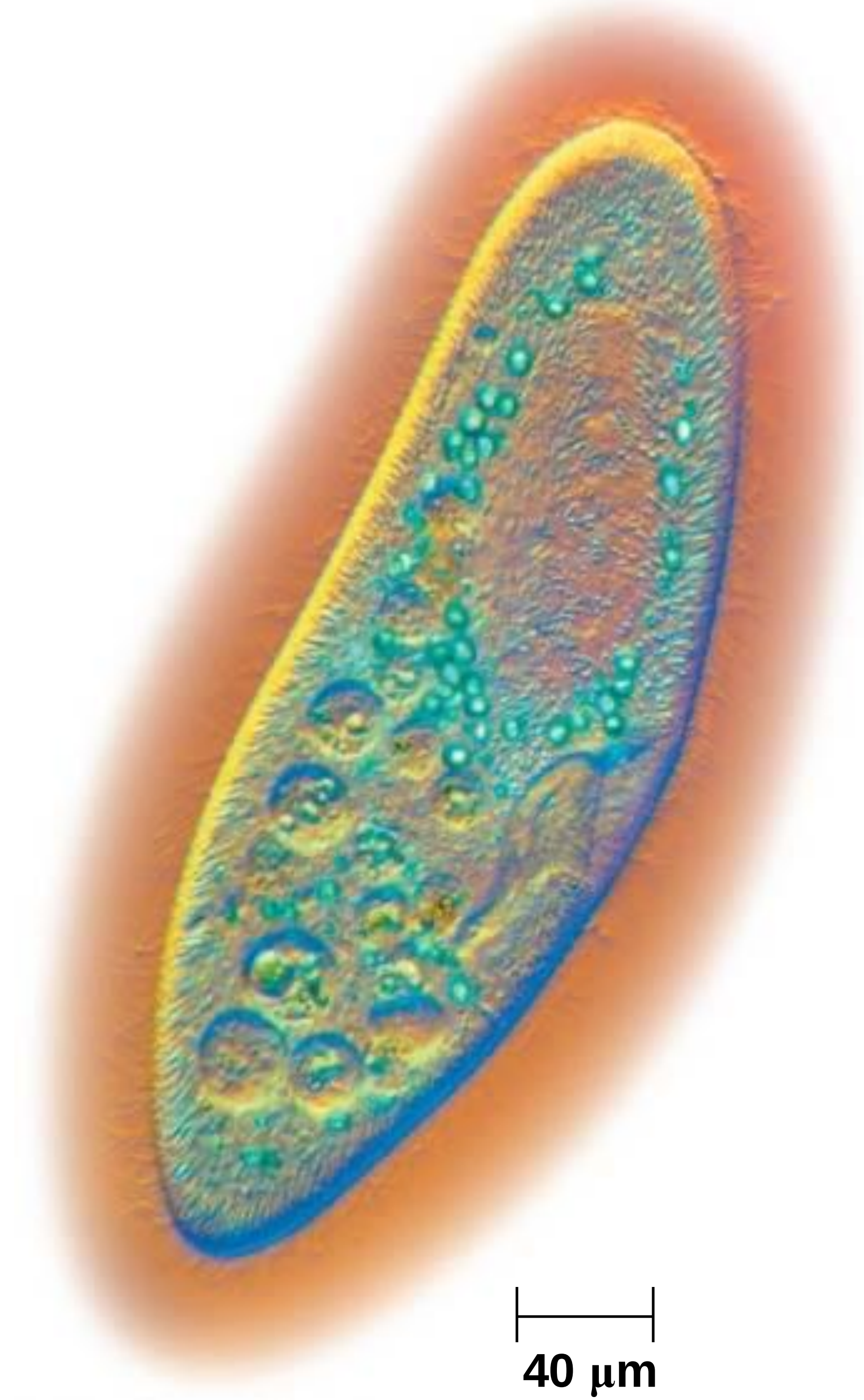
Tiny rooms in a sample of tree bark which Hooke called "cells"



Micro-history

In the mid-1800s, early studies of cells led to cell **theory**, which states that

- all living things are composed of cells and
- all cells come from other cells.

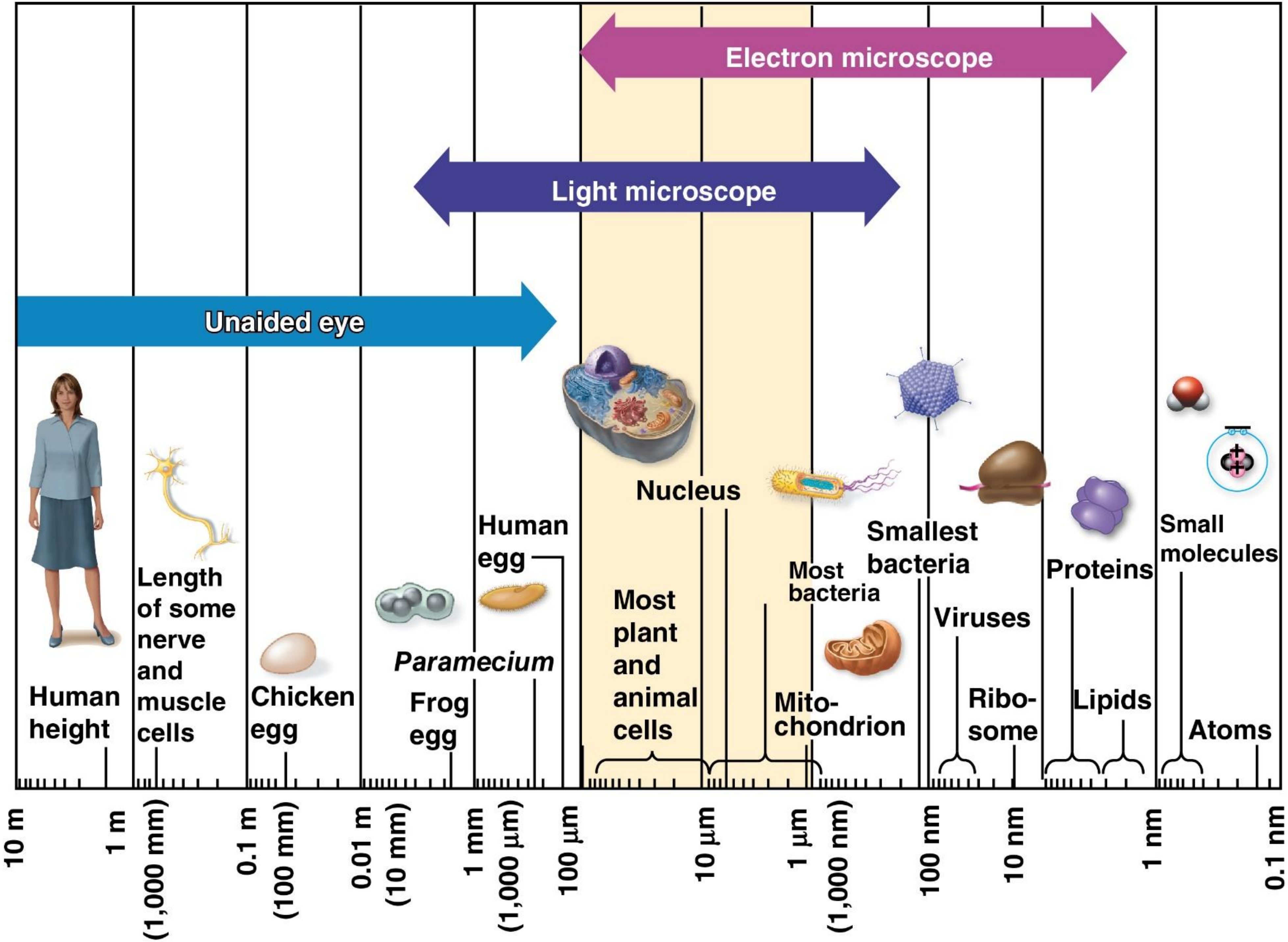


Cells are the Fundamental Units of Life

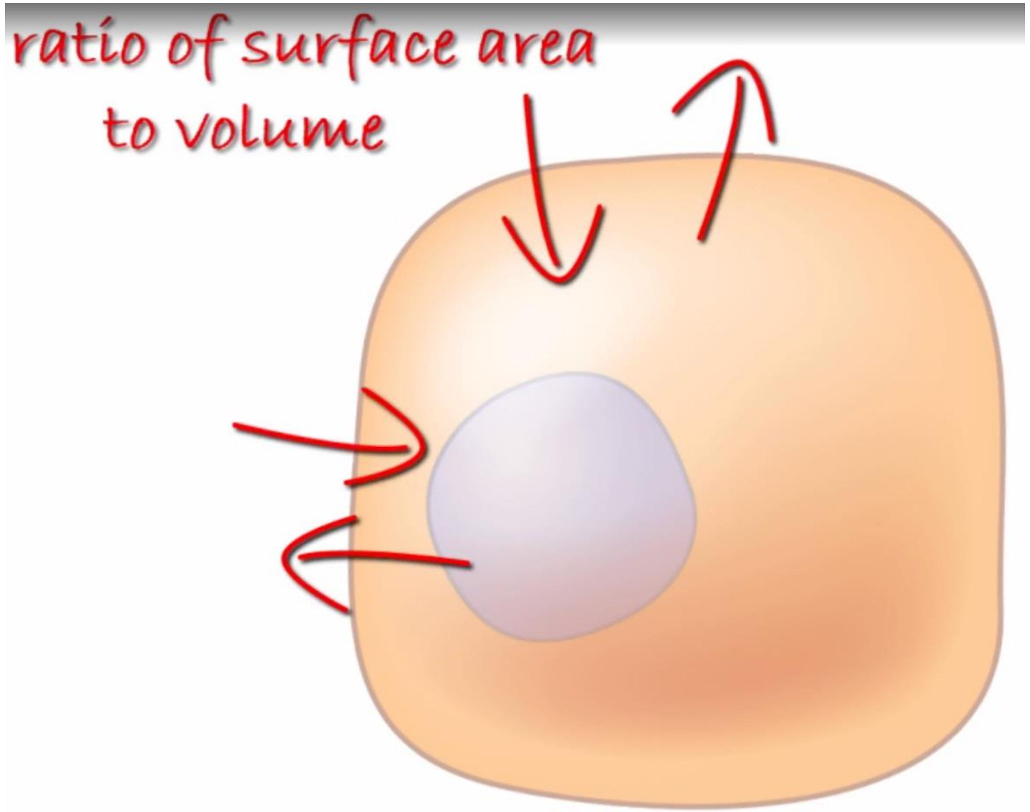
- All organisms are made of cells
- The cell is the simplest collection of matter
  that can be alive
- All cells are related by their descent from earlier cells
- Cells can differ substantially from one another but share common features

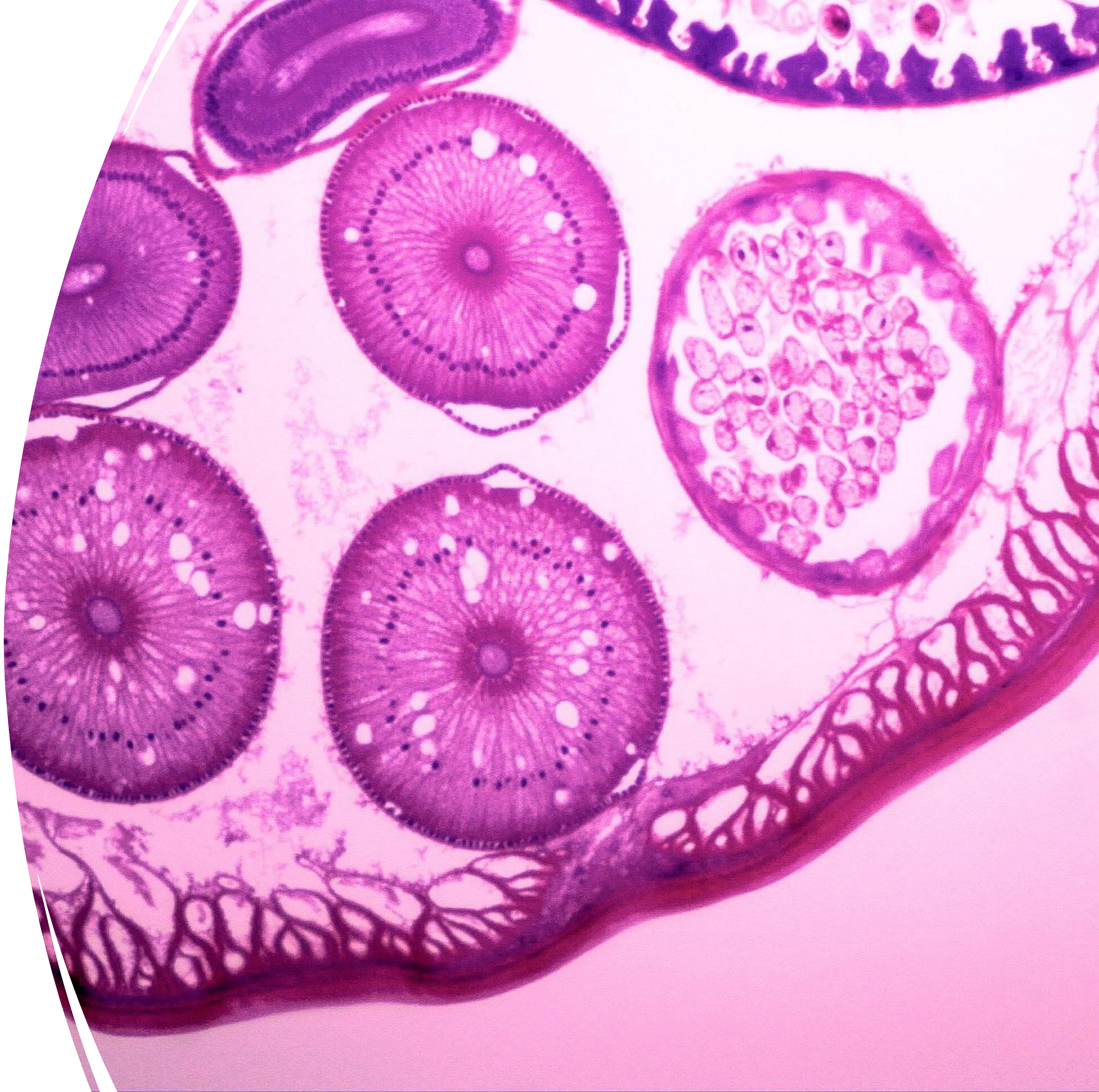
Microscopy

- Cells are usually too small to be seen by the naked eye
- Microscopes are used to visualize cells
- In a **light microscope (LM)**, visible light is passed through a specimen and then through glass lenses
- Lenses refract (bend) the light so that the image is magnified


Electron microscope
Light microscope
Unaided eye
Human height
Length of some nerve and muscle cells
Chicken egg
Frog egg
Paramecium
Human egg
Nucleus
Most plant and animal cells
Most bacteria
Mito-chondrion
Smallest bacteria
Viruses
Ribo-some
Proteins
Lipids
Small molecules
Atoms
10 m
1 m
(1,000 mm)
0.1 m
(100 mm)
0.01 m
(10 mm)
1 mm
(1,000 µm)
100 µm
10 µm
1 µm
(1,000 nm)
100 nm
10 nm
1 nm
0.1 nm

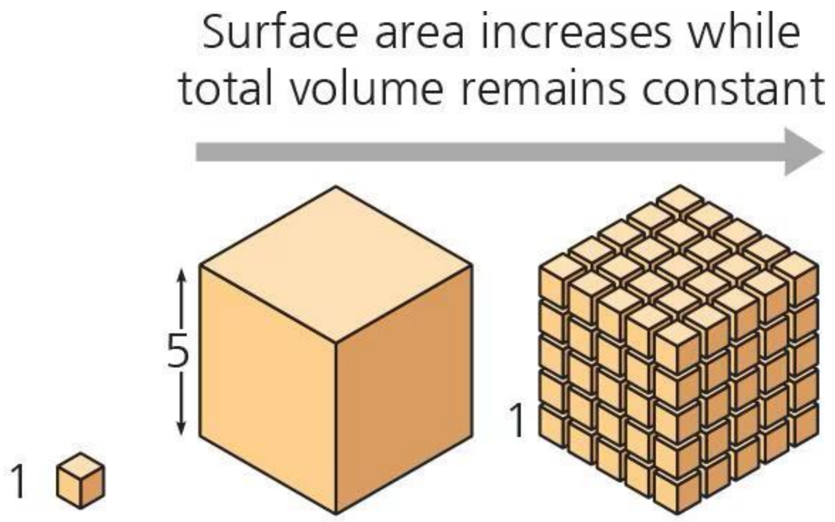
The Microscopic size of Cells Relates to the Need to Exchange Materials Across the Plasma Membrane





The Microscopic size of Cells Relates to the Need to Exchange Materials Across the Plasma Membrane

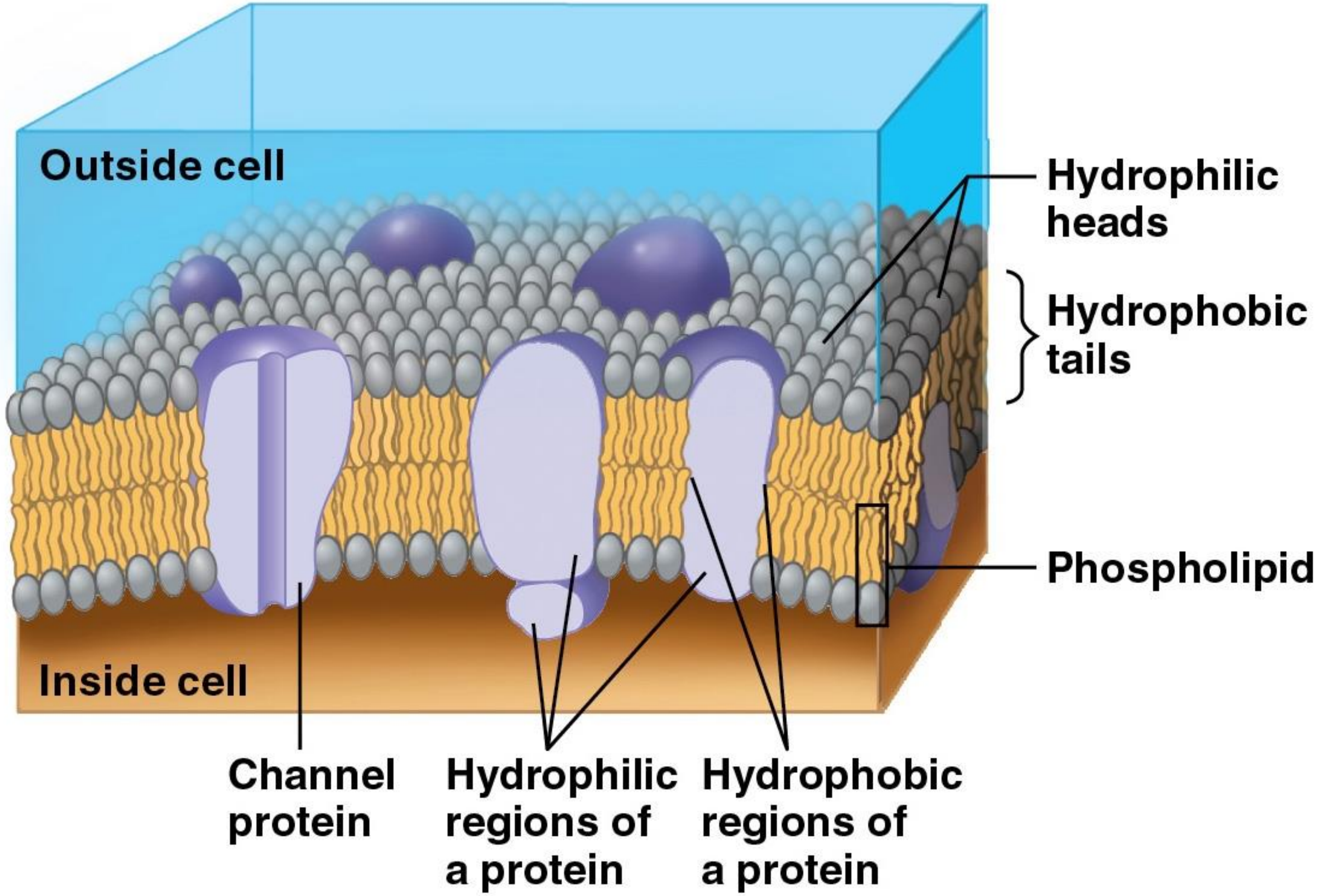
- Metabolic requirements set upper limits on the size of cells
- The surface area to volume ratio of a cell is critical
- As a cell increases in size, its volume grows proportionally more than its surface area
- The microscopic size of most cells provides a large surface-to-volume ratio



Total surface area [(height × width of 1 side) × 6 sides × number of cells]	6 $units^2$	150 $units^2$	750 $units^2$
Total volume [(height × width × length of 1 cell) × number of cells]	1 $unit^3$	125 $units^3$	125 $units^3$
Surface area-to-volume ratio [surface area ÷ volume]	6	1.2	6

Prokaryotic and Eukaryotic Cells

- Basic features of all cells:
  - Plasma membrane
  - Semifluid substance called **cytosol**
  - Chromosomes (carry genes)
  - Ribosomes (make proteins)

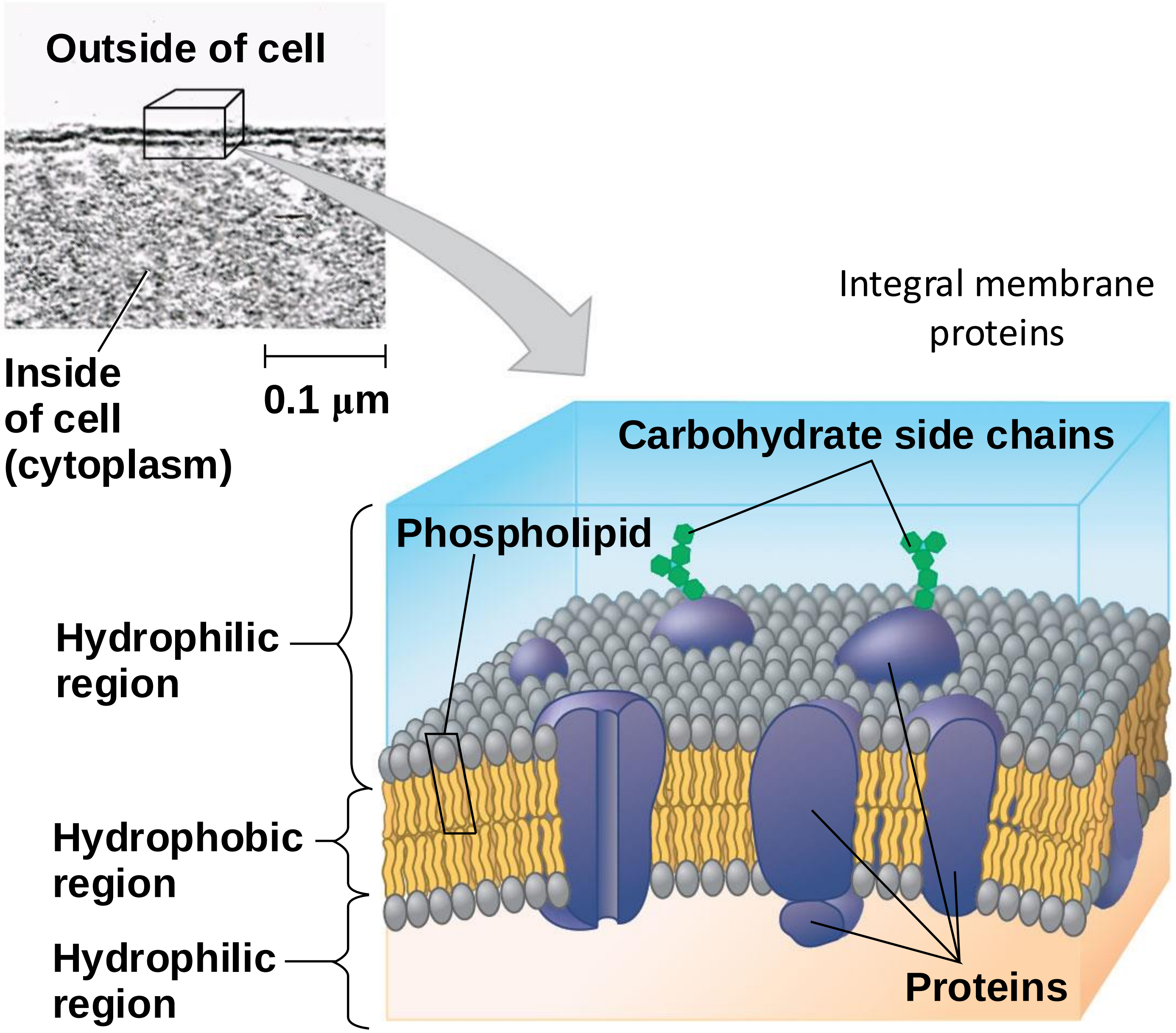


All cells have a plasma membrane, DNA, ribosomes, and **cytosol**.

Plasma Membrane

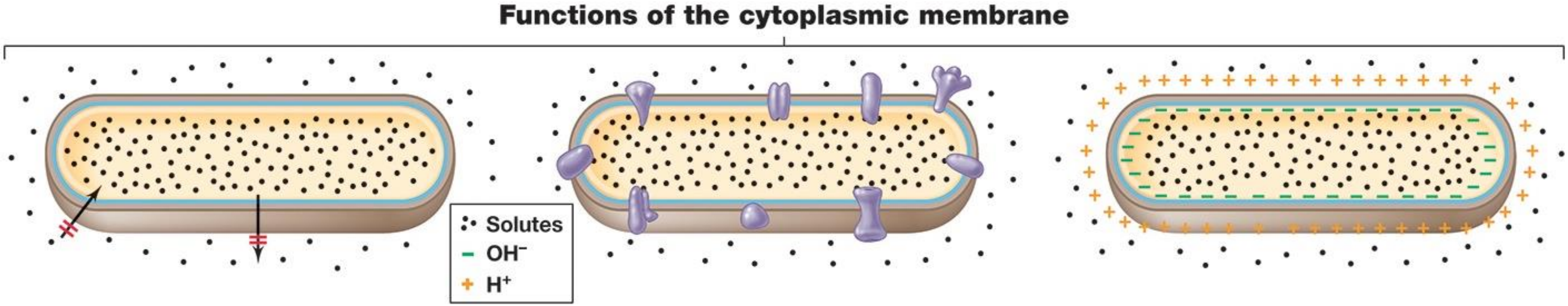
- The **plasma membrane** is a phospholipid bilayer with embedded proteins

- It is a selective barrier that allows passage of:
  - Oxygen
  - Nutrients
  - Signaling molecules
  - Waste



Structure of the plasma membrane

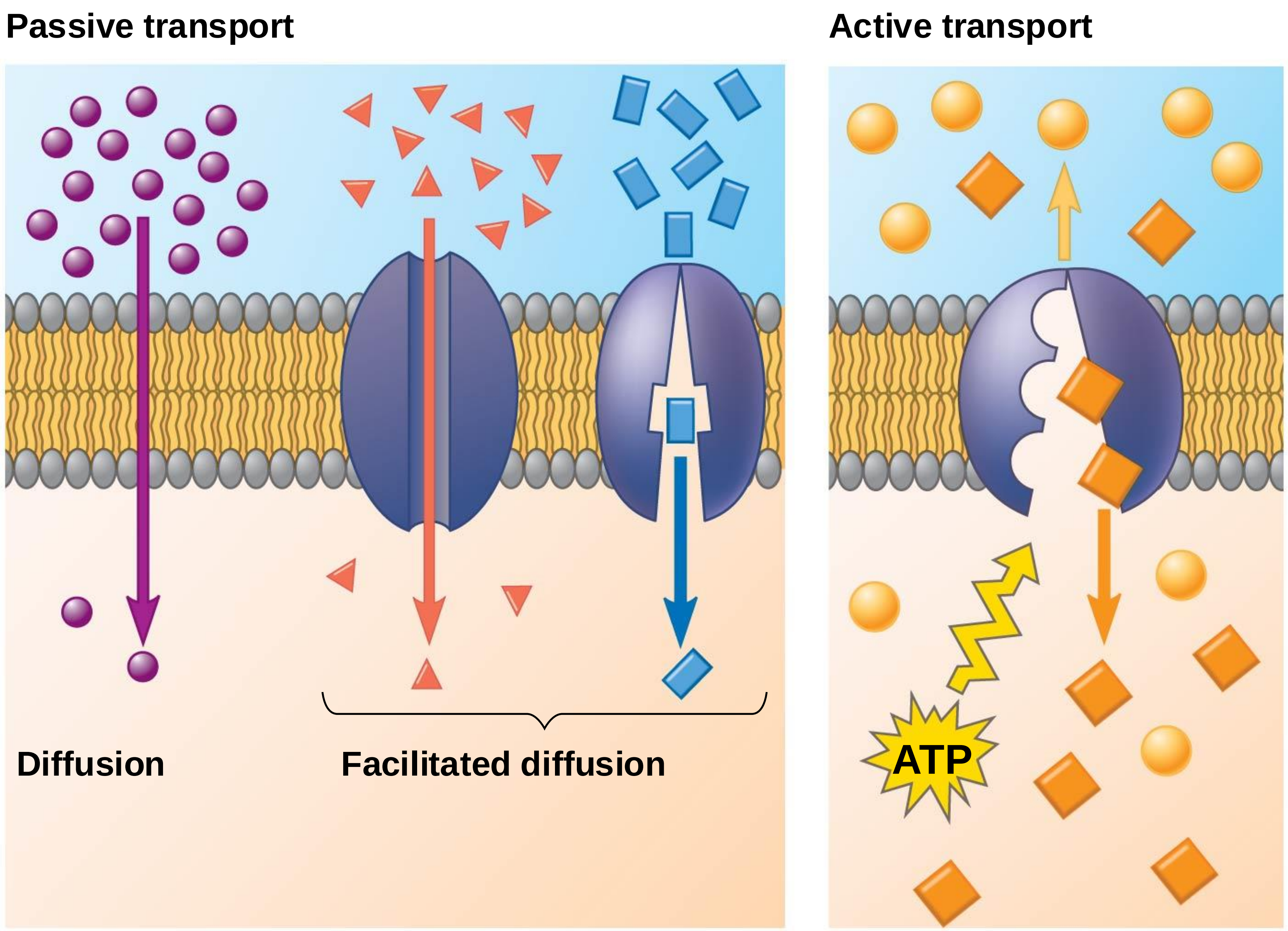
The Major Functions of the Cytoplasmic Membrane



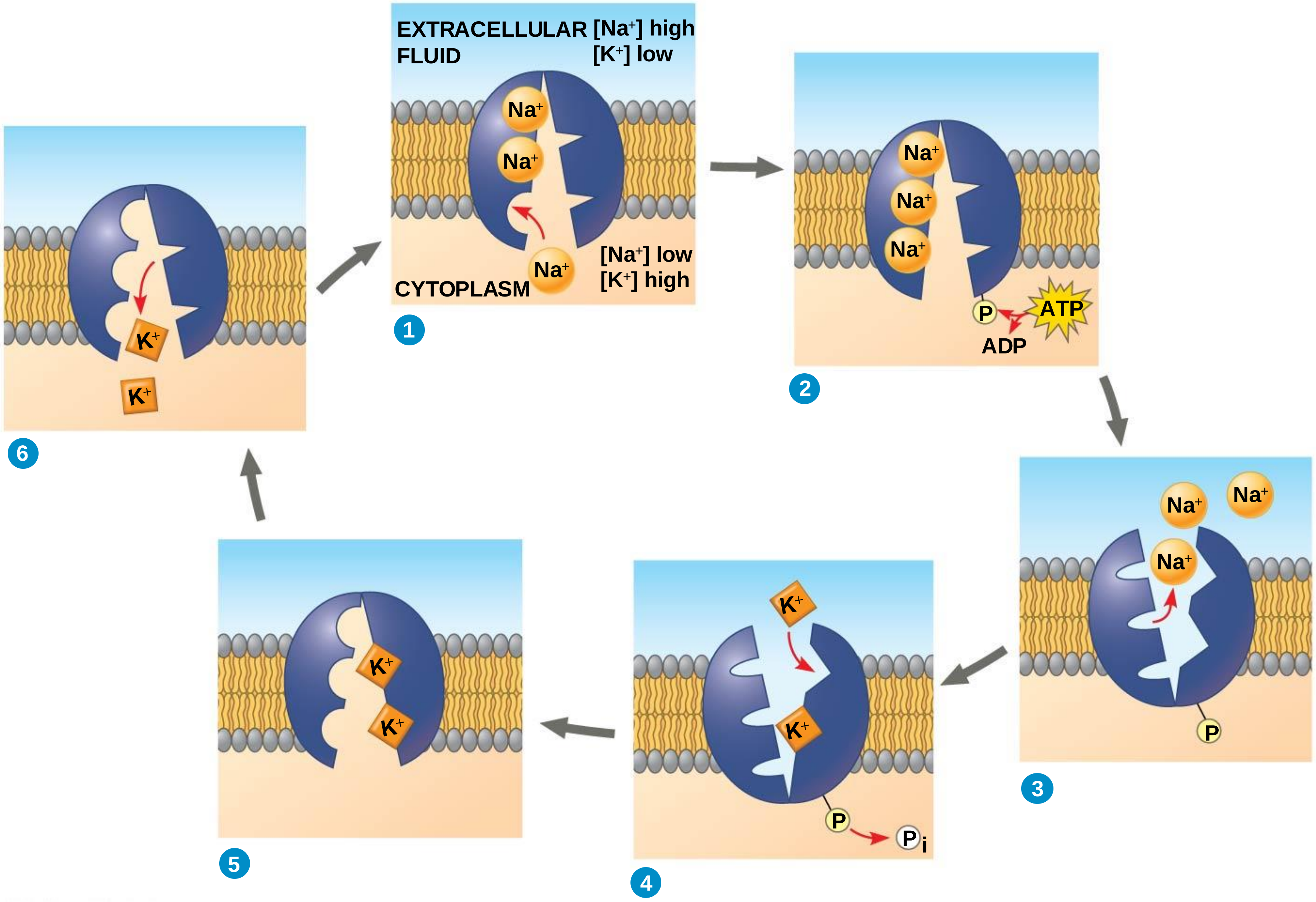
(a) **Permeability barrier:**
Prevents leakage and functions as a gateway for transport of nutrients into, and wastes out of, the cell

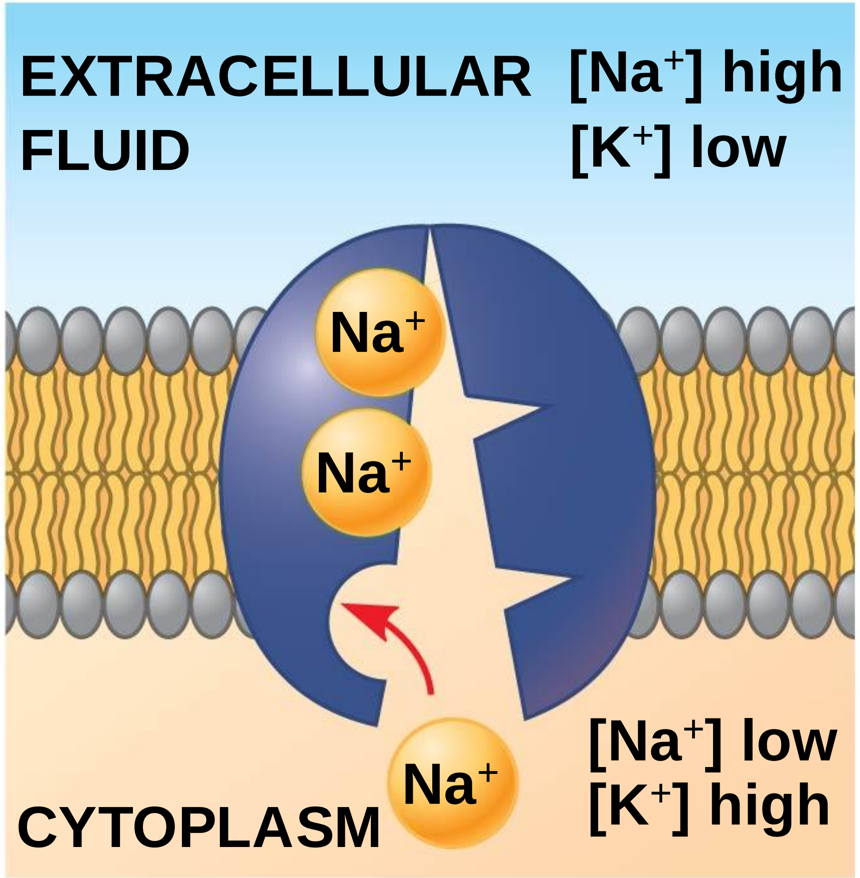
(b) **Protein anchor:**
Site of proteins that participate in transport, bioenergetics, and chemotaxis

(c) **Energy conservation:**
Site of generation and dissipation of the proton motive force

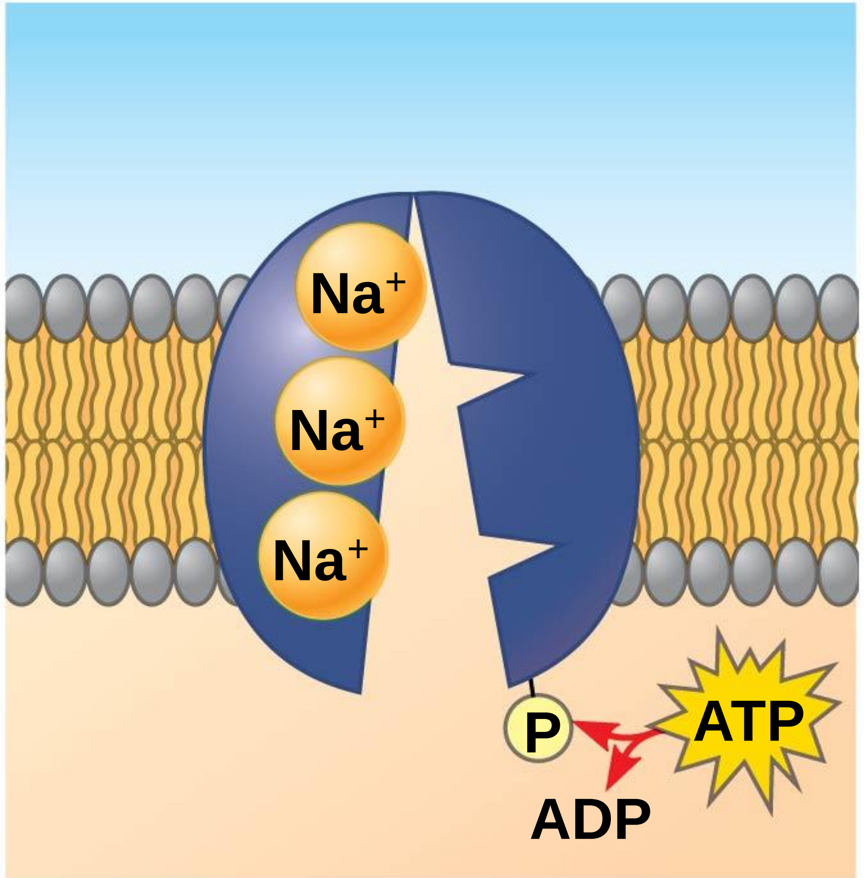


Passive transport
Active transport
Diffusion
Facilitated diffusion
ATP

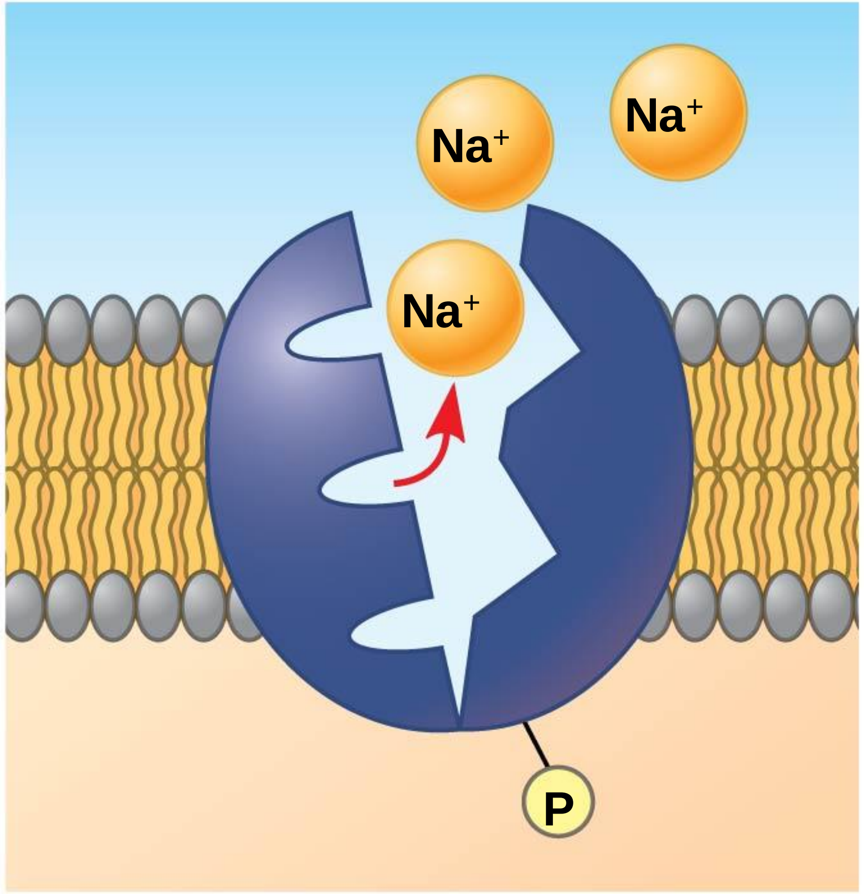

EXTRACELLULAR FLUID
[Na+] high
[K+] low
CYTOPLASM
[Na+] low
[K+] high
Na+
Na+
Na+
1
Na+
Na+
Na+
P
ATP
ADP
2
Na+
Na+
Na+
P
3
K+
K+
P
Pi
4
K+
K+
5
K+
K+
6



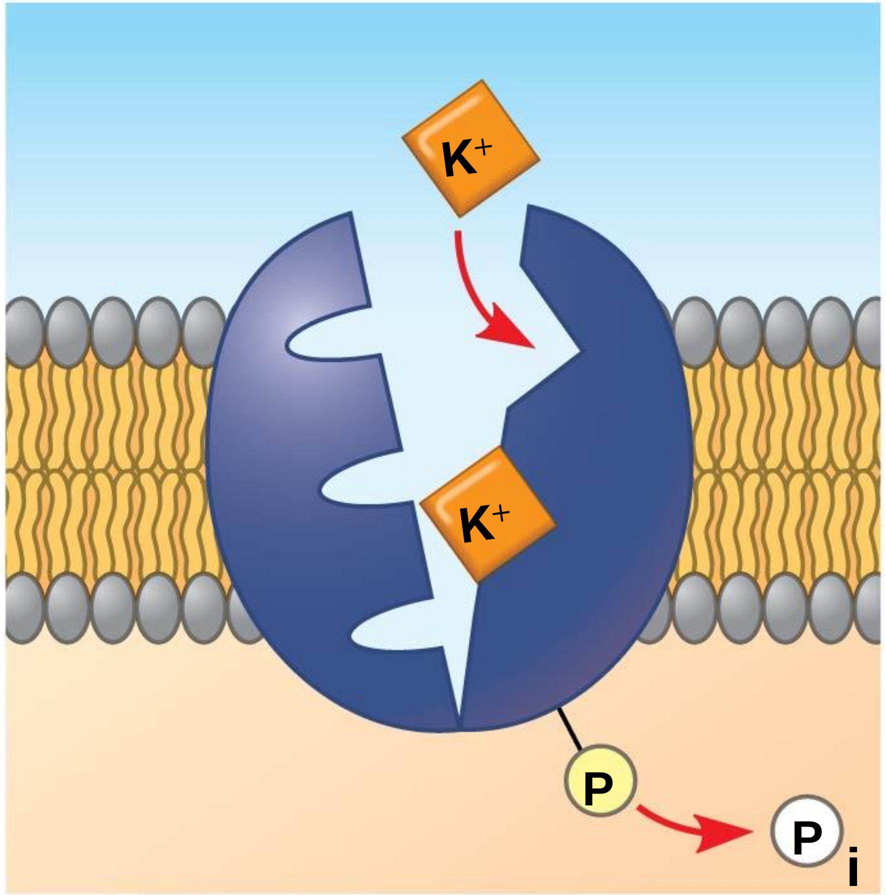
1 Cytoplasmic Na^+ binds to the sodium-potassium pump. The affinity for Na^+ is high when the protein has this shape.



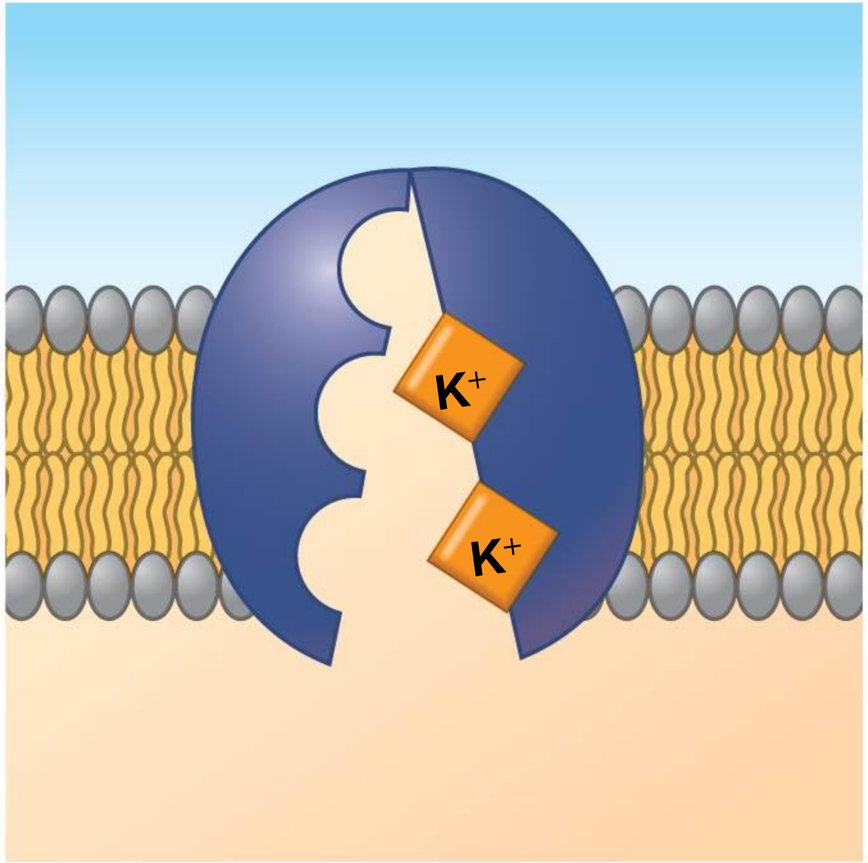
2 Na^+ binding stimulates phosphorylation by ATP.



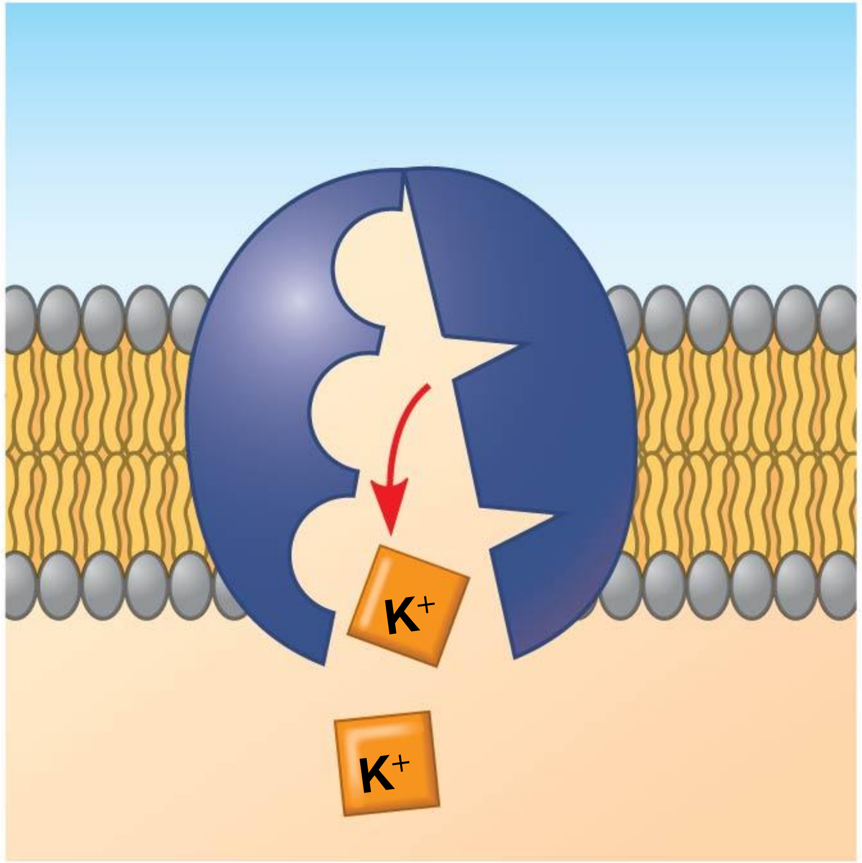
3 Phosphorylation leads to a change in protein shape, reducing its affinity for Na^+, which is released outside.



4 The new shape has a high affinity for K^+, which binds on the extracellular side and triggers release of the phosphate group.

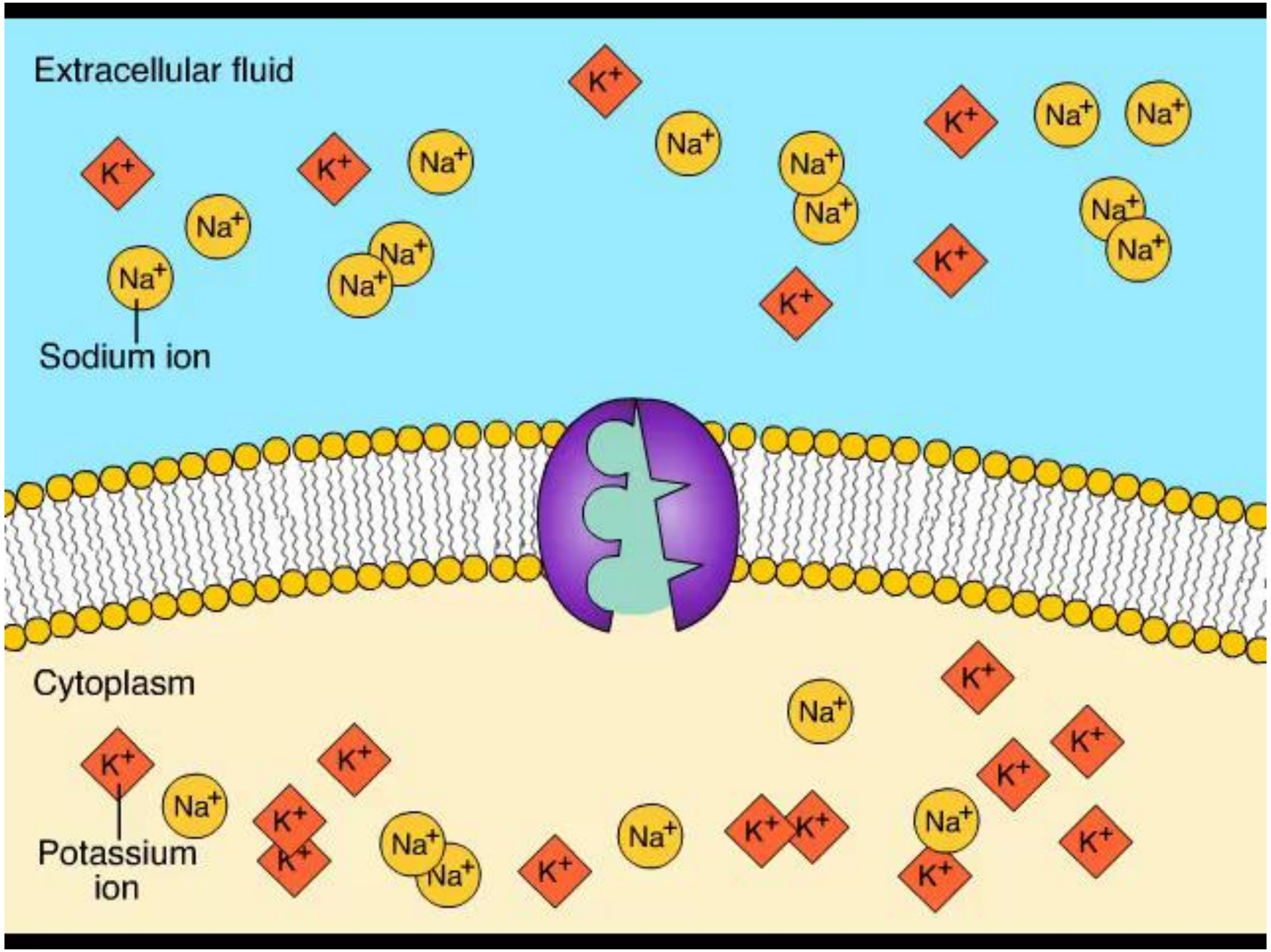


5 Loss of the phosphate group restores the protein's original shape, which has a lower affinity for K^+.



6 K^+ is released; affinity for Na^+ is high again, and the cycle repeats.

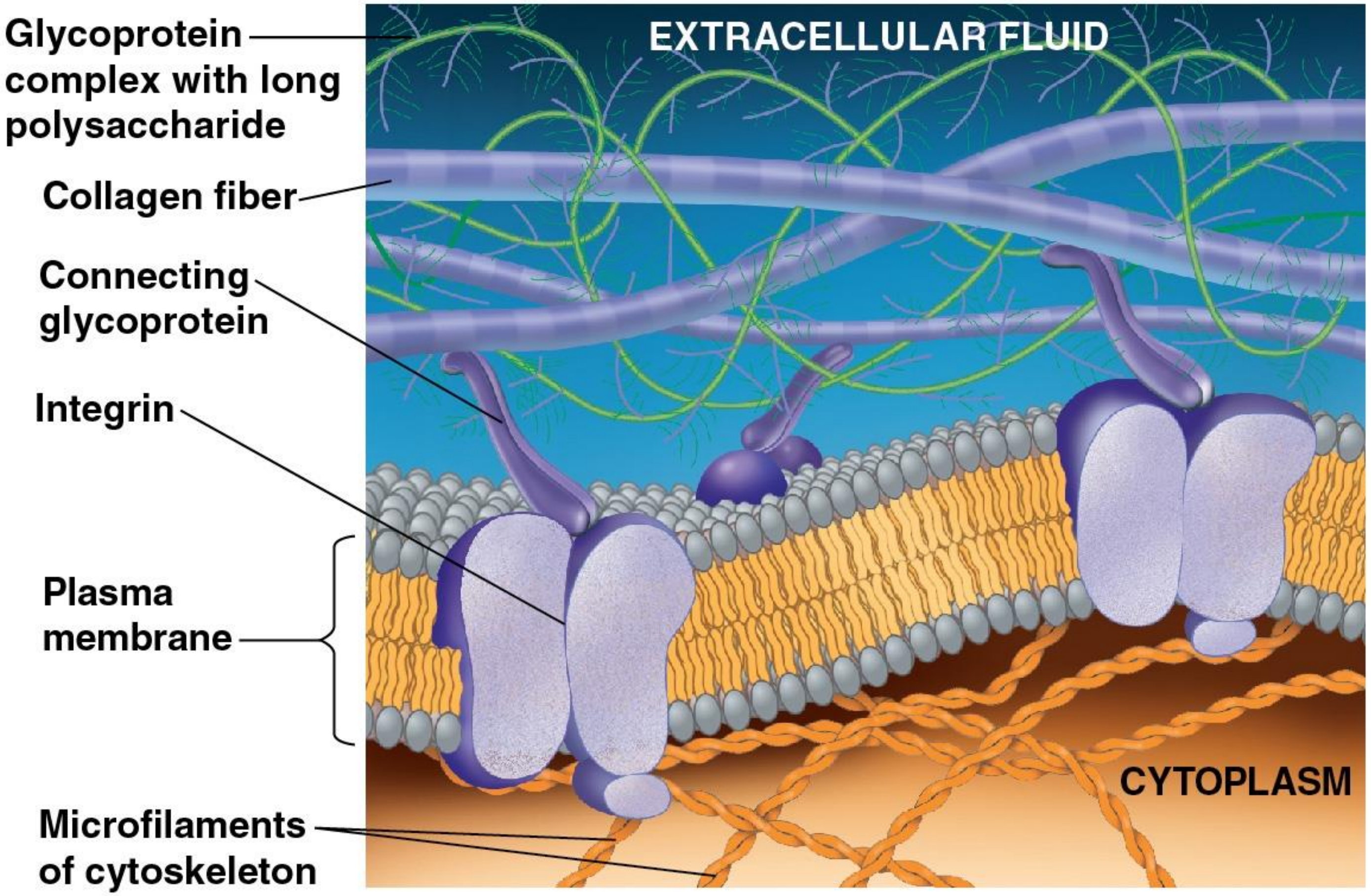
Active Transport



The Extracellular Matrix (EMS)

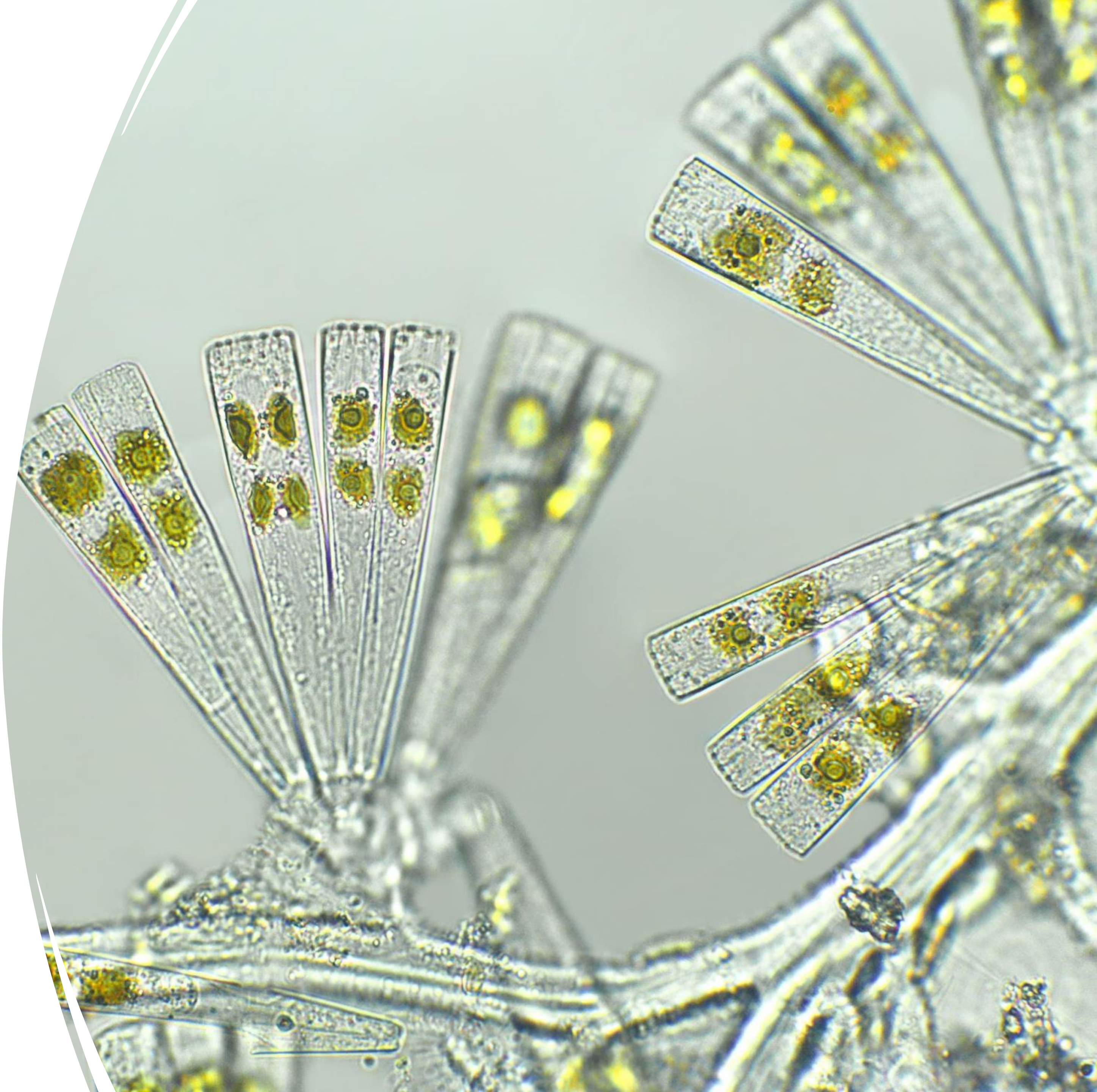
Extracellular components and connections between cells help coordinate cellular activities

- Most cells synthesize and secrete materials to the outside of the cell: **extracellular matrix (ECM)**
- ECM can regulate a cell's behavior by communicating with other cells
- The ECM around a cell can influence the activity of genes in the nucleus




Prokaryotic and Eukaryotic Cells

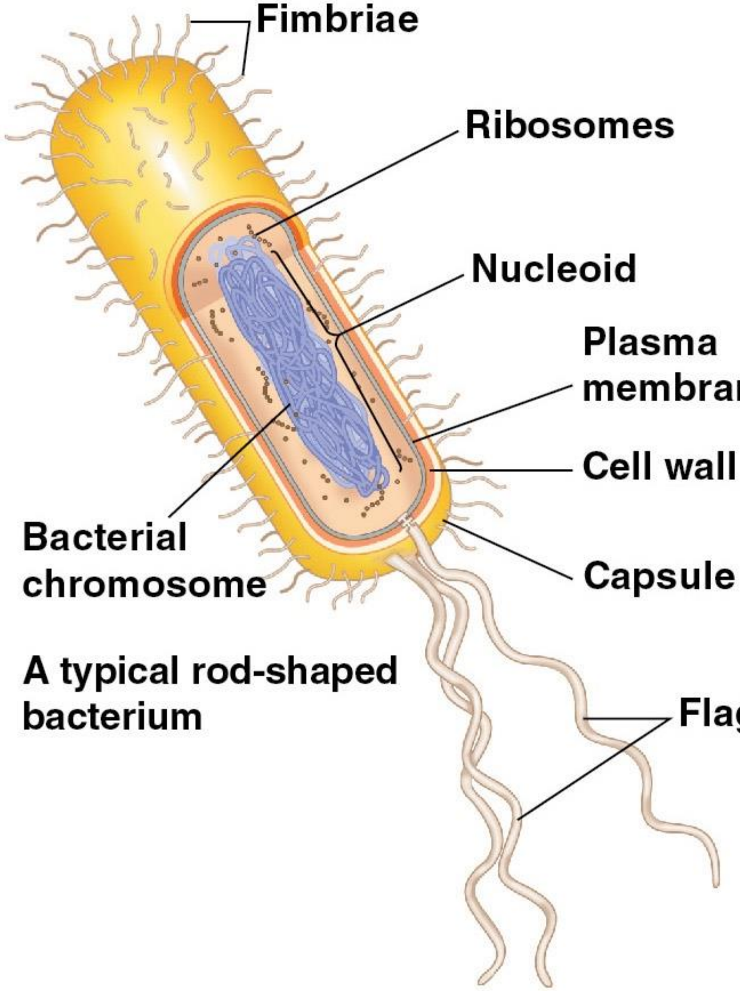
- The basic structural and functional unit of every organism is one of two types of cells: **prokaryotic** or **eukaryotic**
- Only organisms of the domains Bacteria and Archaea consist of prokaryotic cells
- Protists, fungi, animals, and plants all consist of eukaryotic cells



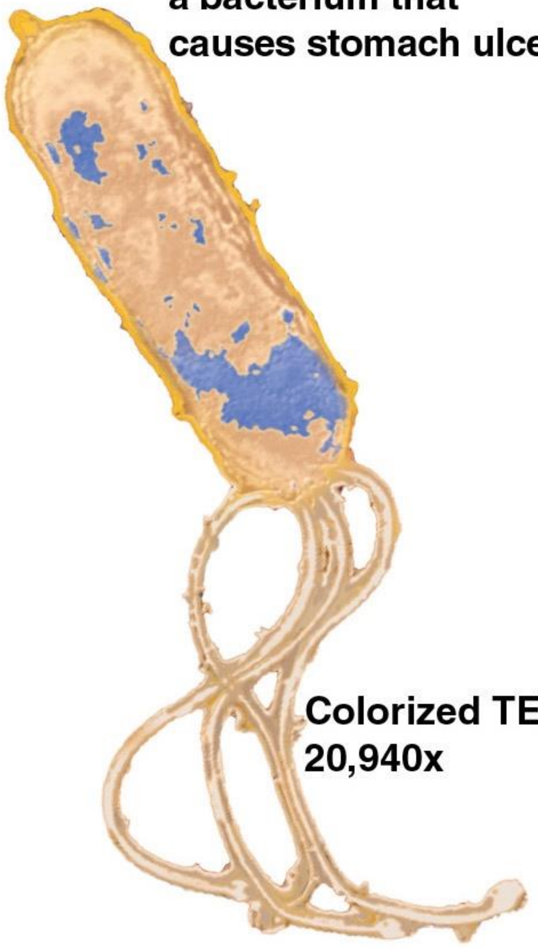
Barry James Marshall
- 1983/1984

Prokaryotic Cells

- Characterized by:
  - No nucleus
  - DNA in an unbound region called the **nucleoid**
  - No membrane-bound organelles
  - **Cytoplasm** bound by the plasma membrane



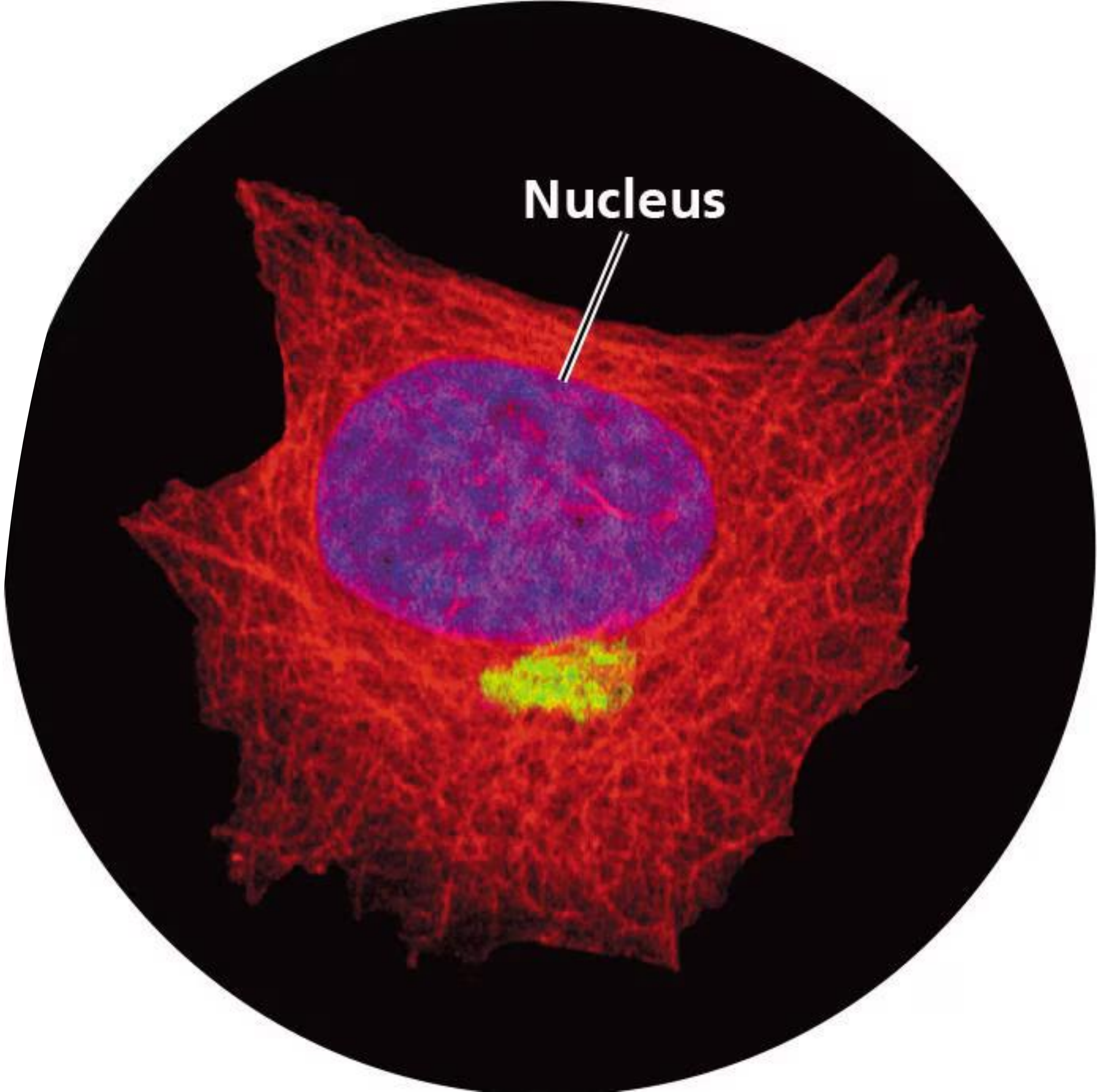
A typical rod-shaped bacterium



Helicobactor pylori, a bacterium that causes stomach ulcers

Eukaryotic Cells

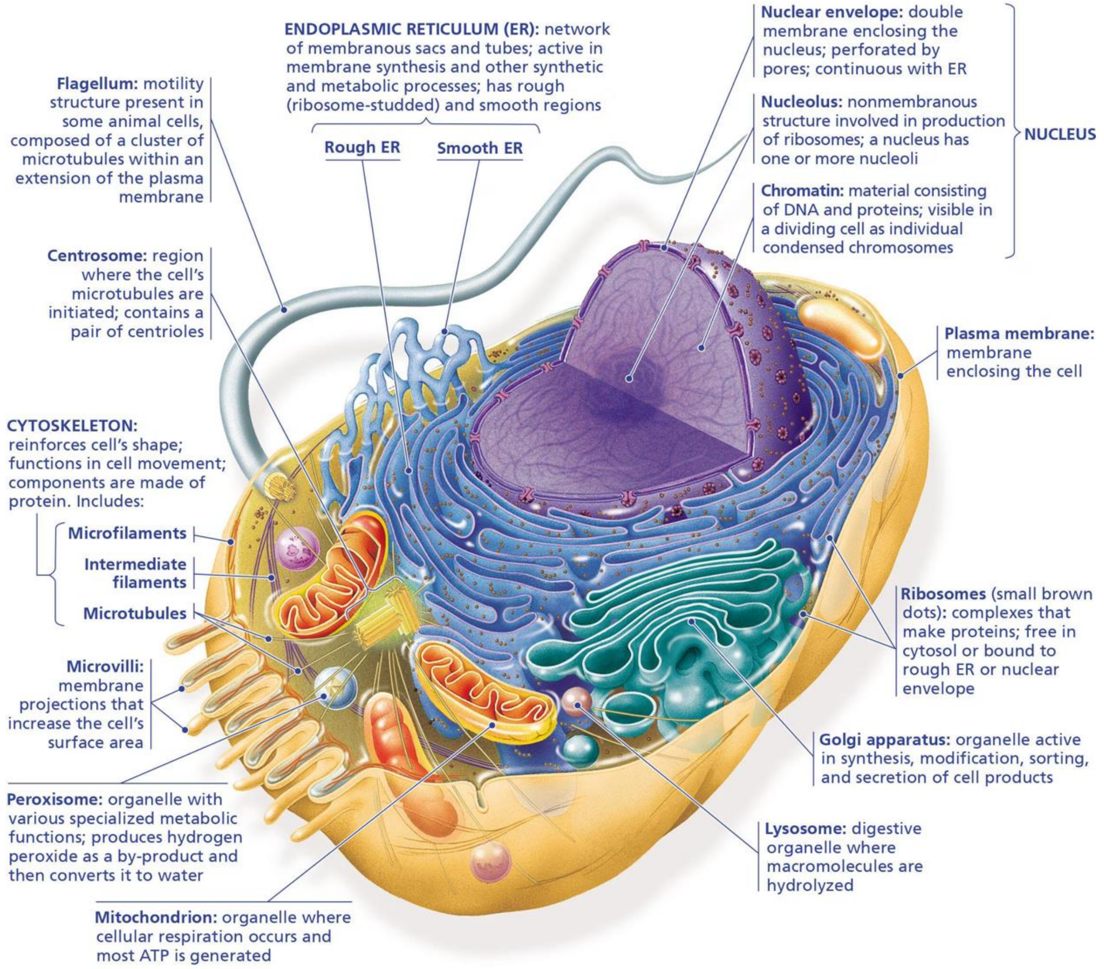
- Eukaryotic Cells Are Partitioned into Functional Compartments
  - DNA in a nucleus that is bounded by a double membrane
  - Membrane-bound organelles
- Eukaryotic cells are generally much larger than prokaryotic cells



Eukaryotic Cells

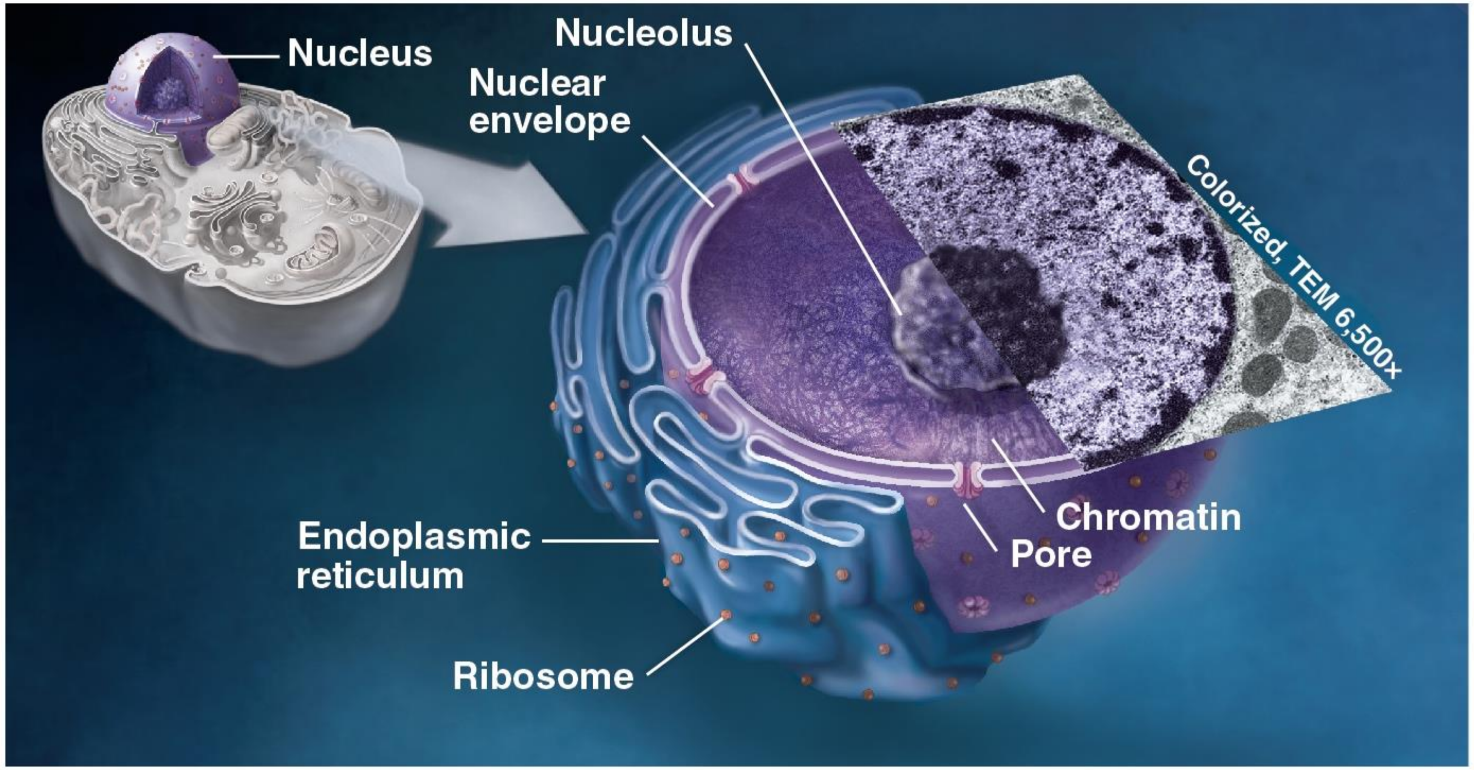
- The organelles and other structures of eukaryotic cells can be organized into four basic functional groups:

1. The *nucleus and ribosomes* carry out the genetic control of the cell.
2. Organelles involved in the manufacture, distribution, and breakdown of molecules include the *endoplasmic reticulum, Golgi apparatus, lysosomes, vacuoles, and peroxisomes*.
3. *Mitochondria* in all cells and *chloroplasts* in plant cells function in energy processing.
4. Structural support, movement, and communication between cells are the functions of the *cytoskeleton, plasma membrane, and plant cell wall*.



Eukaryotic Cells: The **Nucleus** and Ribosomes

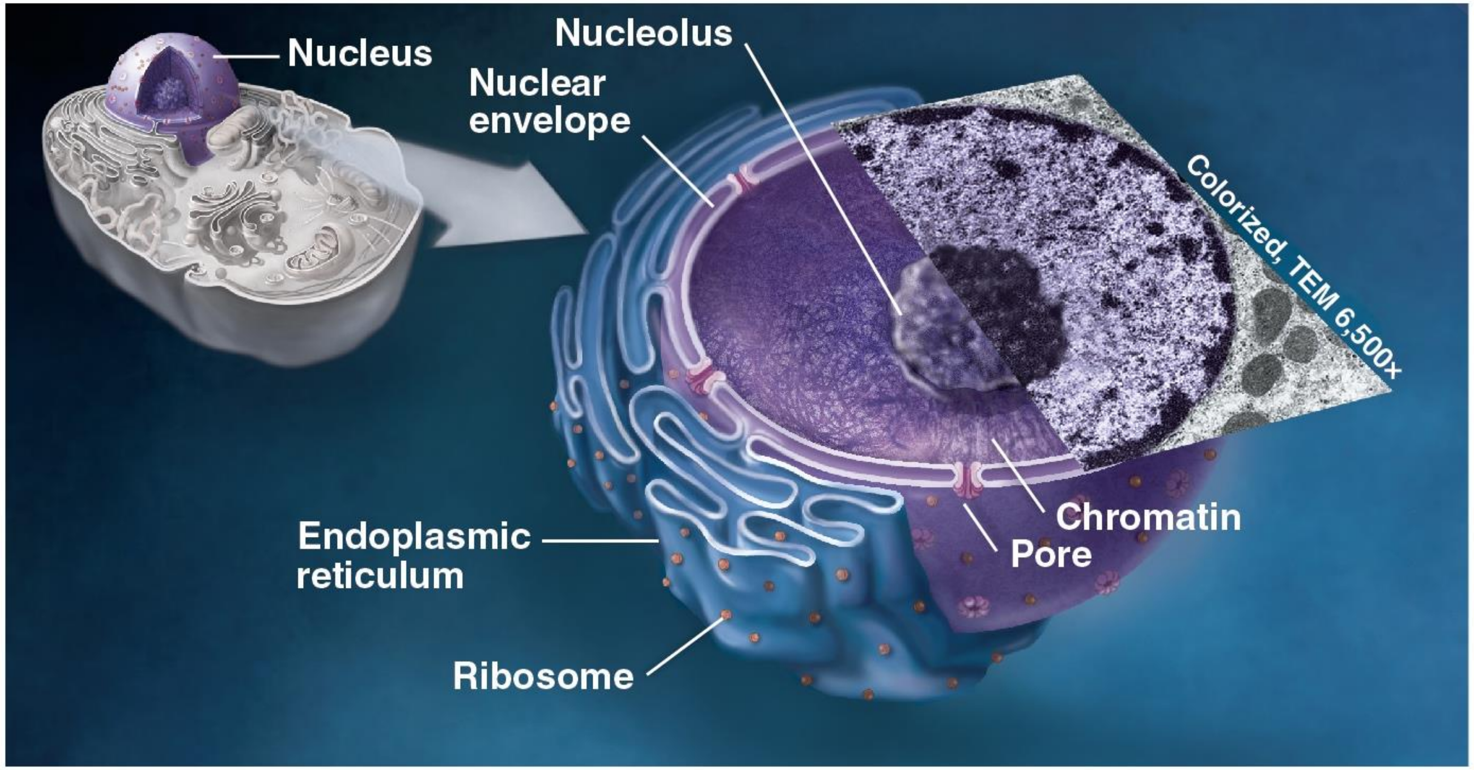
- The **nucleus** contains most of the DNA in a eukaryotic cell
  - genetic instructions
- The **nuclear envelope** encloses the nucleus, separating it from the cytoplasm
  - double membrane; each membrane consists of a lipid bilayer

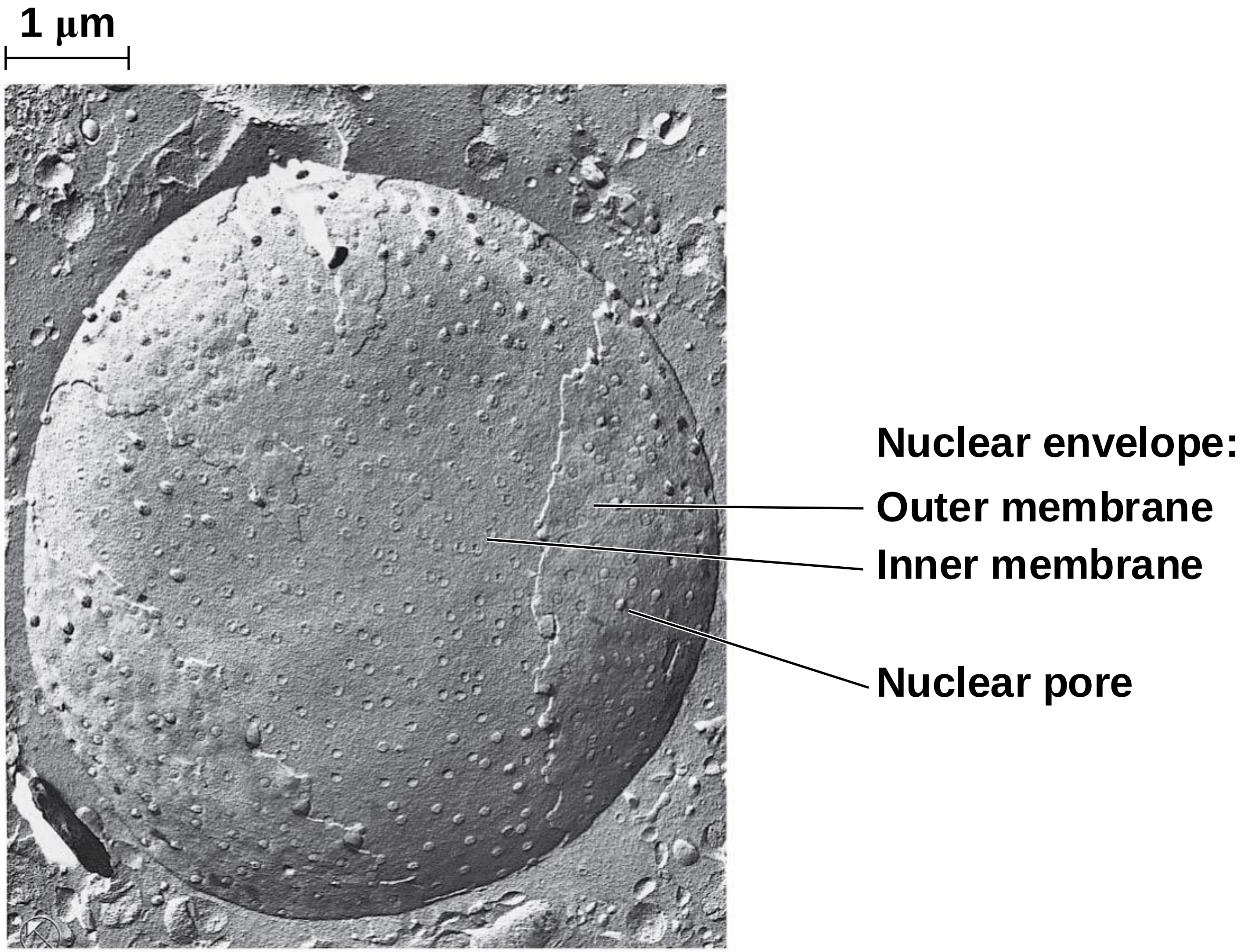


Eukaryotic Cells: The **Nucleus** and Ribosomes

- In the nucleus, DNA is organized into discrete units called **chromosomes**
  - chromosome contains one DNA molecule associated with proteins, called **chromatin**

- The **nucleolus**, located within the nucleus, is the site of **ribosomal RNA (rRNA) synthesis**



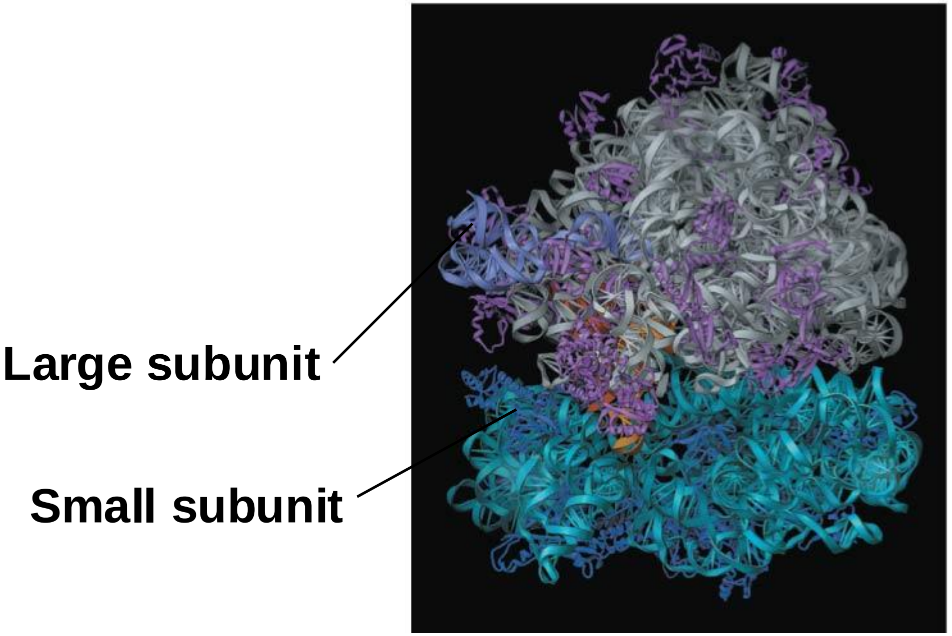


Surface of nuclear envelope (TEM)

The nucleus and its envelope

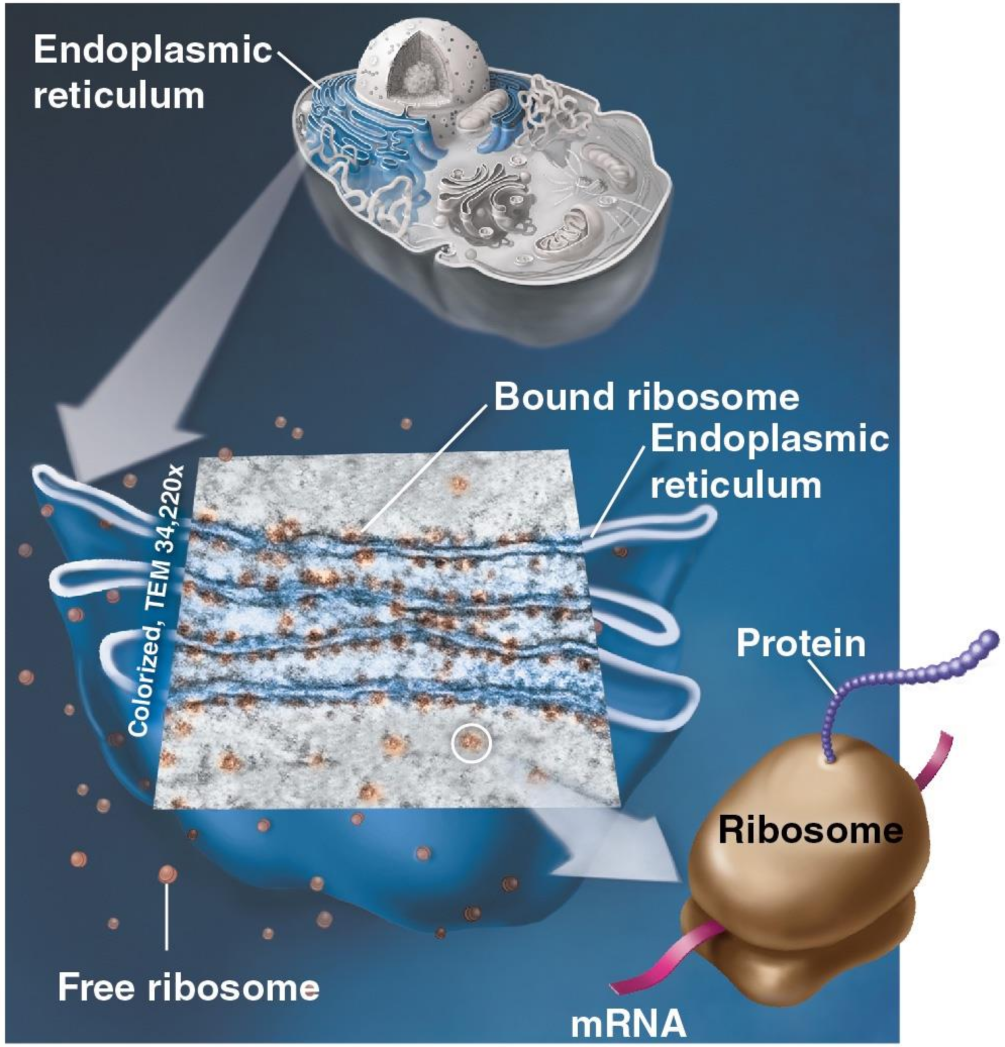
Eukaryotic Cells: The Nucleus and **Ribosomes**

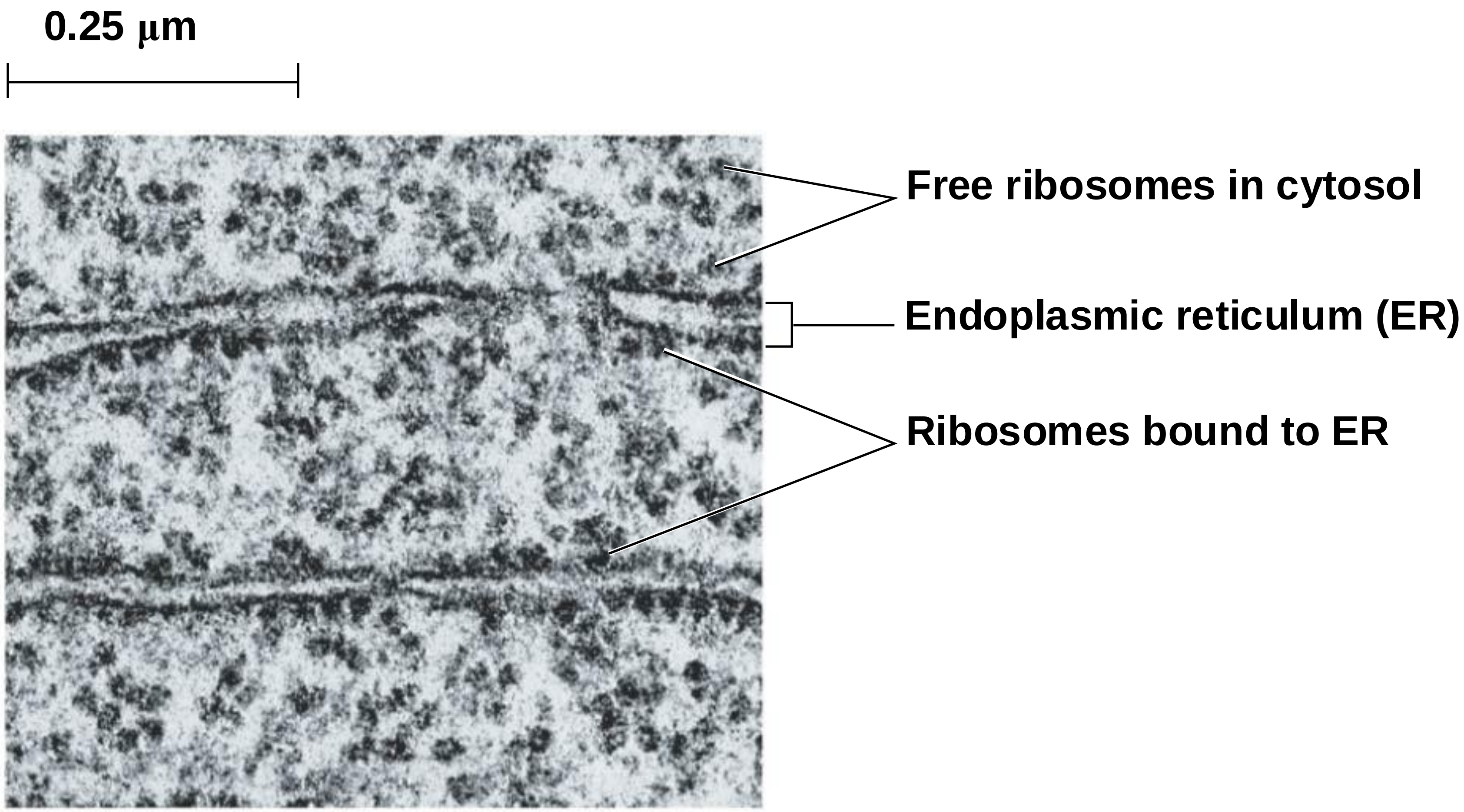
- Ribosomes
  - composed of *ribosomal RNA* and *proteins*
  - synthesize proteins according to directions from DNA



Computer model of a ribosome

Protein Factories



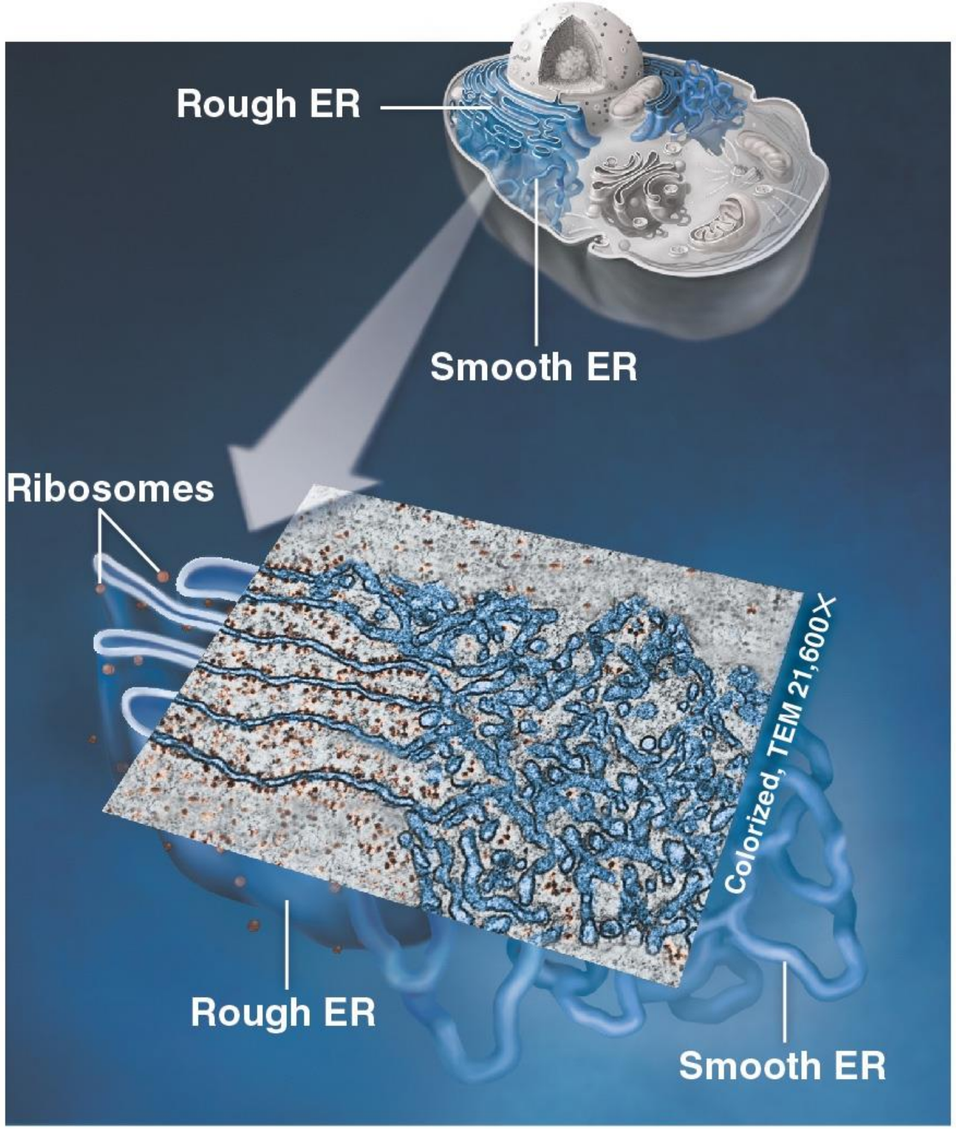


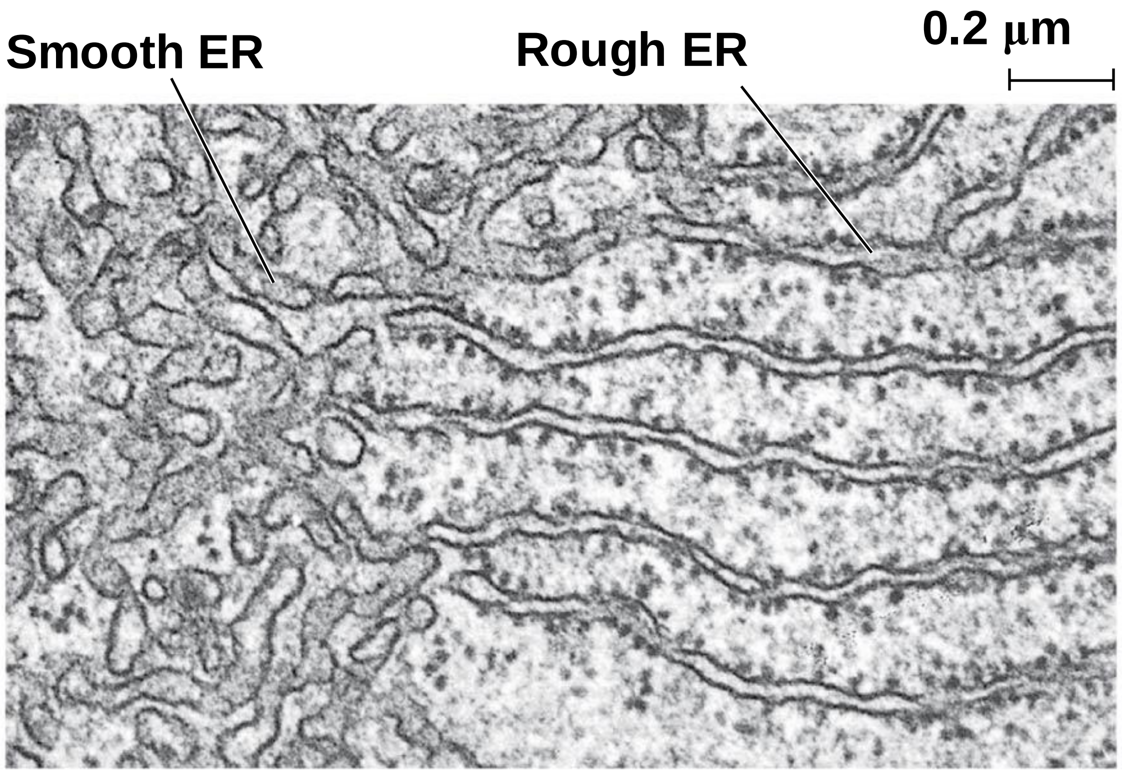
TEM showing ER and ribosomes

Eukaryotic Cells: The Endomembrane System

- Many of the membranes within a eukaryotic cell are part of the **endomembrane system**.

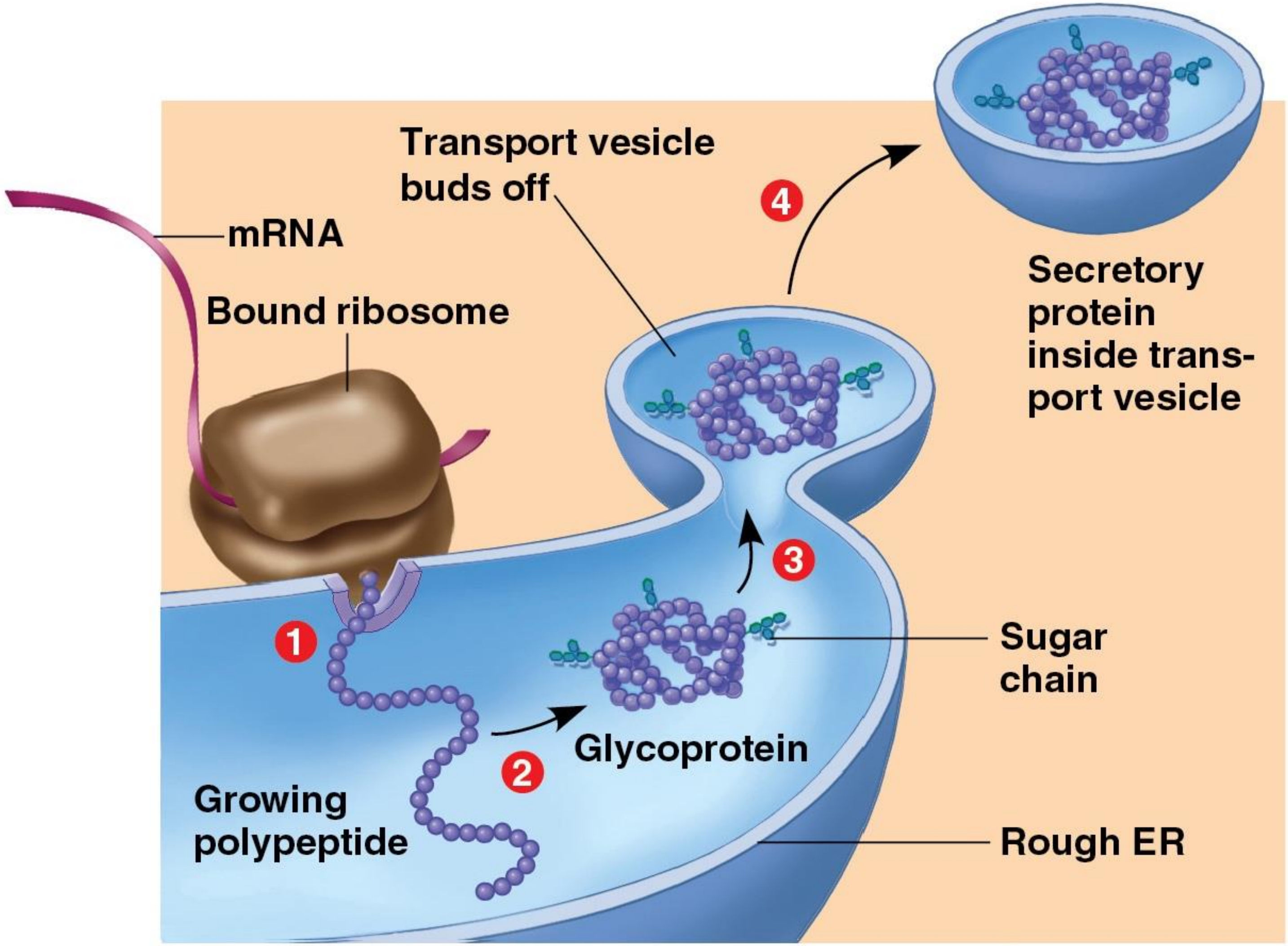
- Endoplasmic Reticulum:
- The **ER** is a membranous network of tubes and sacs.
  - **Smooth ER** synthesizes lipids and processes toxins
  - **Rough ER** ribosomes on its surface make membrane and secretory proteins




Smooth ER
Rough ER
0.2 μm

Eukaryotic Cells: The Endomembrane System

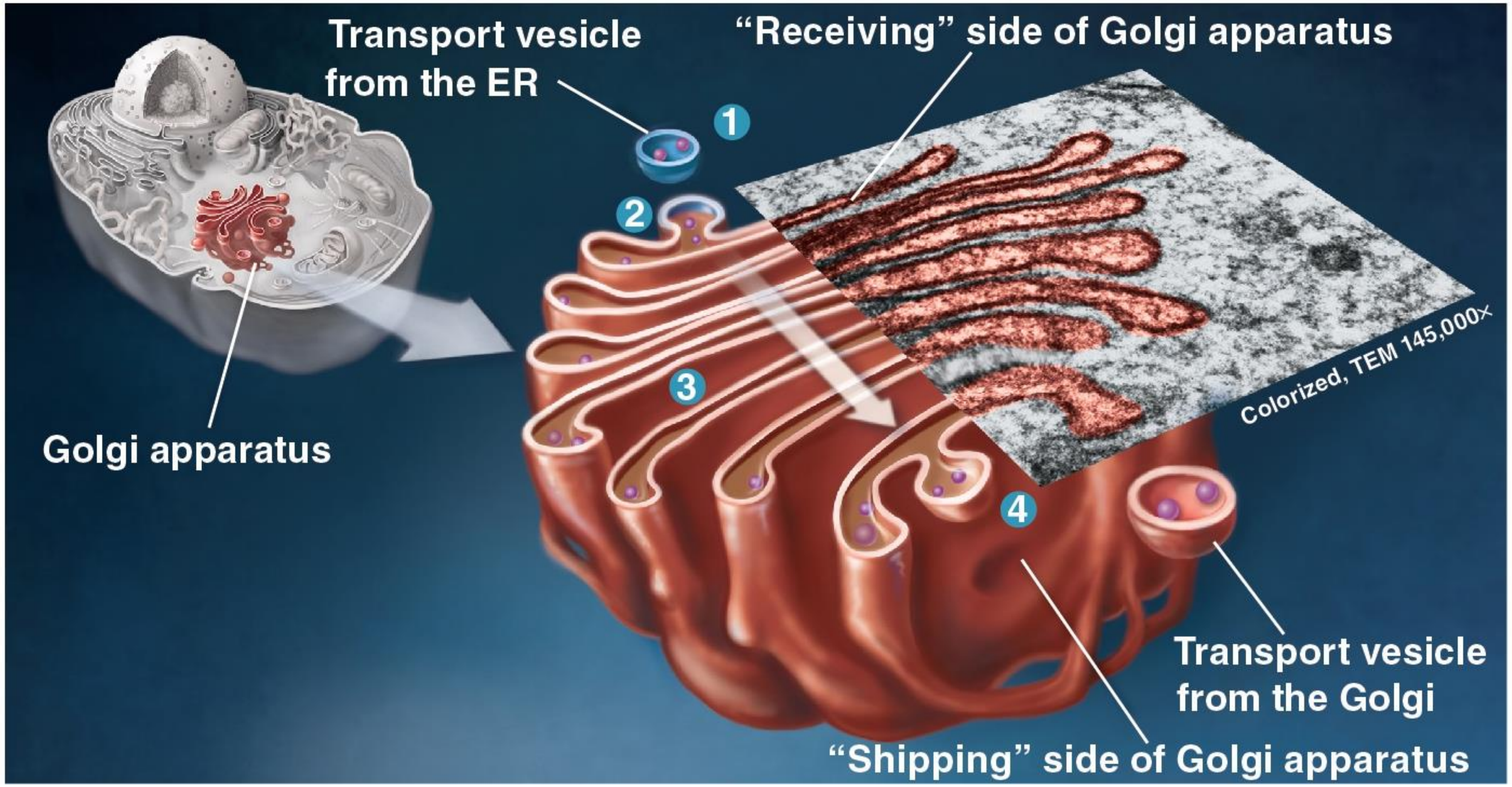
- Synthesis and packaging of a secretory protein by the rough ER

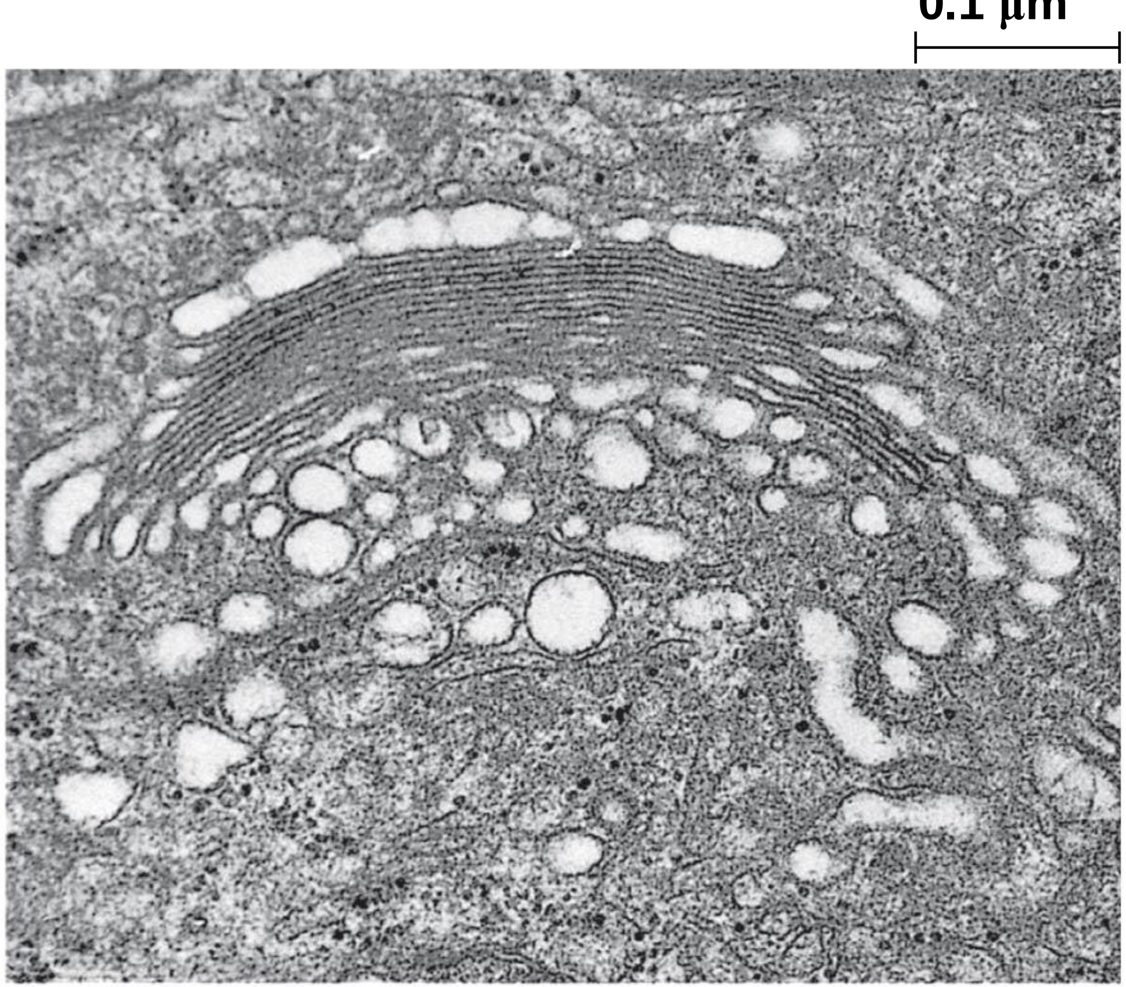


Eukaryotic Cells: The Endomembrane System

- Golgi apparatus modifies, sorts, and ships cell products

- The Golgi apparatus consists of stacks of sacs in which products of the ER are processed and then sent to other organelles or to the cell surface

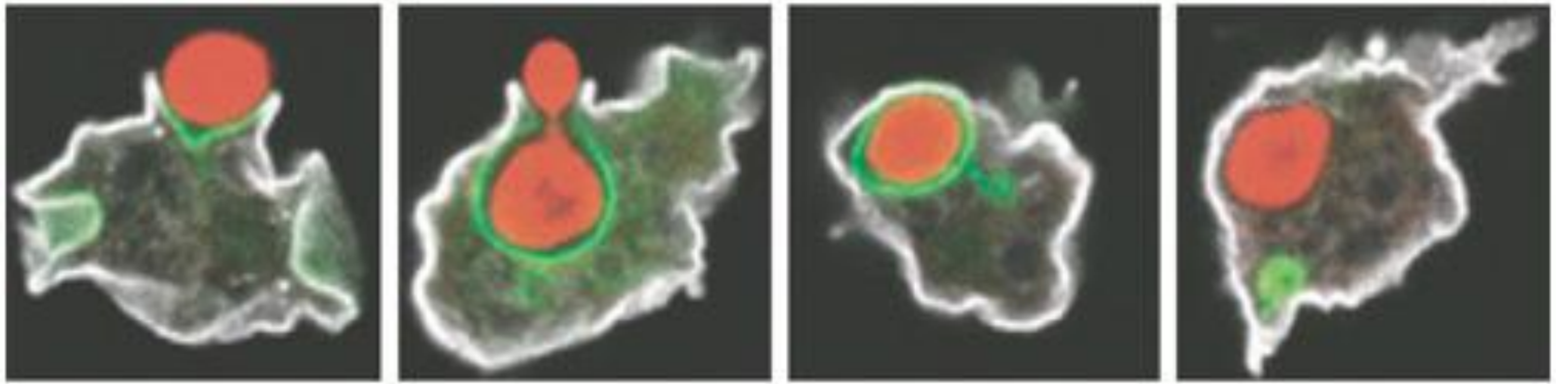




TEM of Golgi apparatus

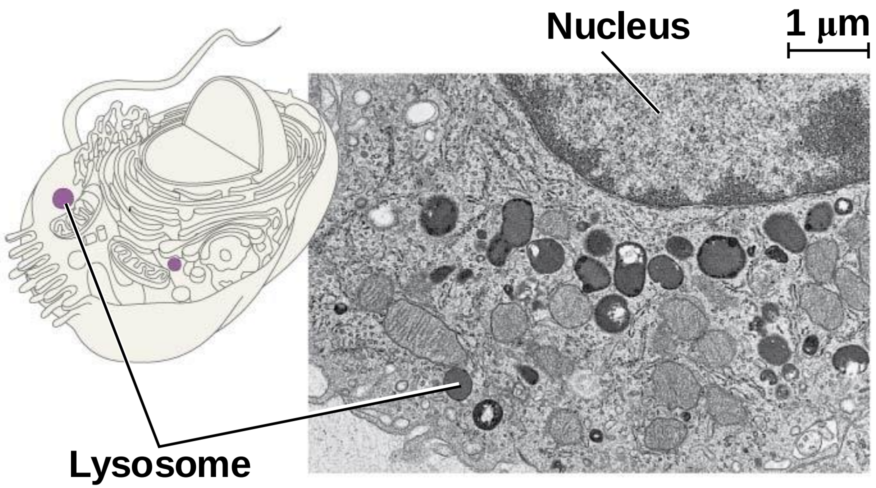
Eukaryotic Cells: Lysosomes

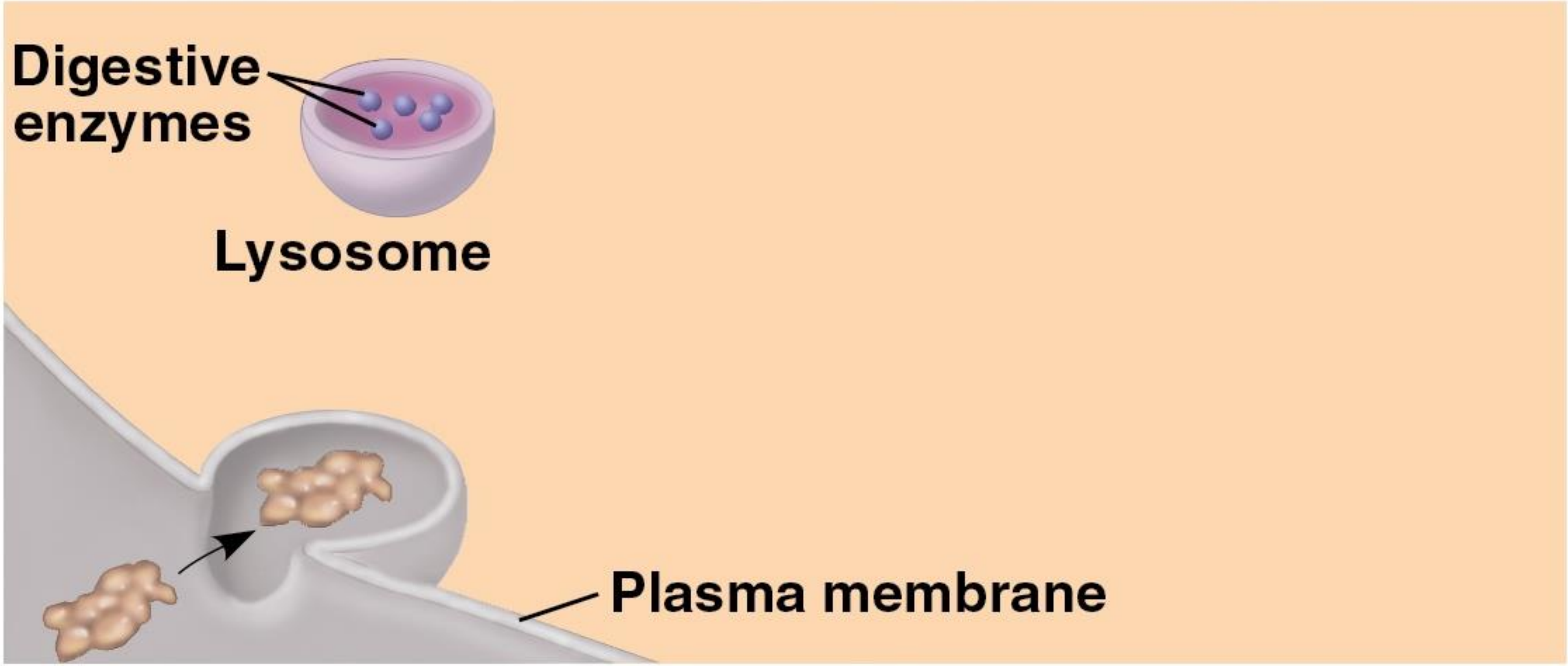
- Lysosomes are digestive compartments within a cell
- A **lysosome** is a membranous sac of enzymes that can digest macromolecules
  - These enzymes work best in the acidic environment inside the lysosome
- Lysosomes also use enzymes to recycle the cell's own organelles and macromolecules,
  a process called autophagy
- Some types of cell can engulf another cell by **phagocytosis**; this forms a food vacuole



Eukaryotic Cells: Lysosomes

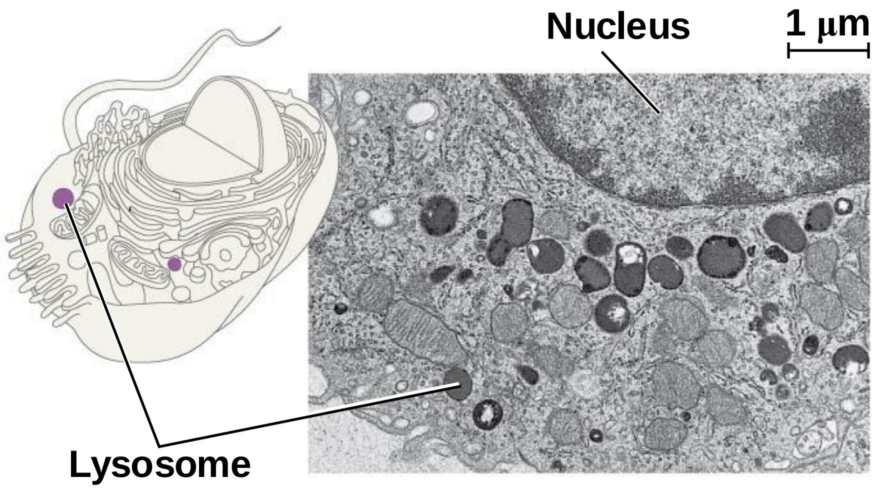
- Phagocytosis

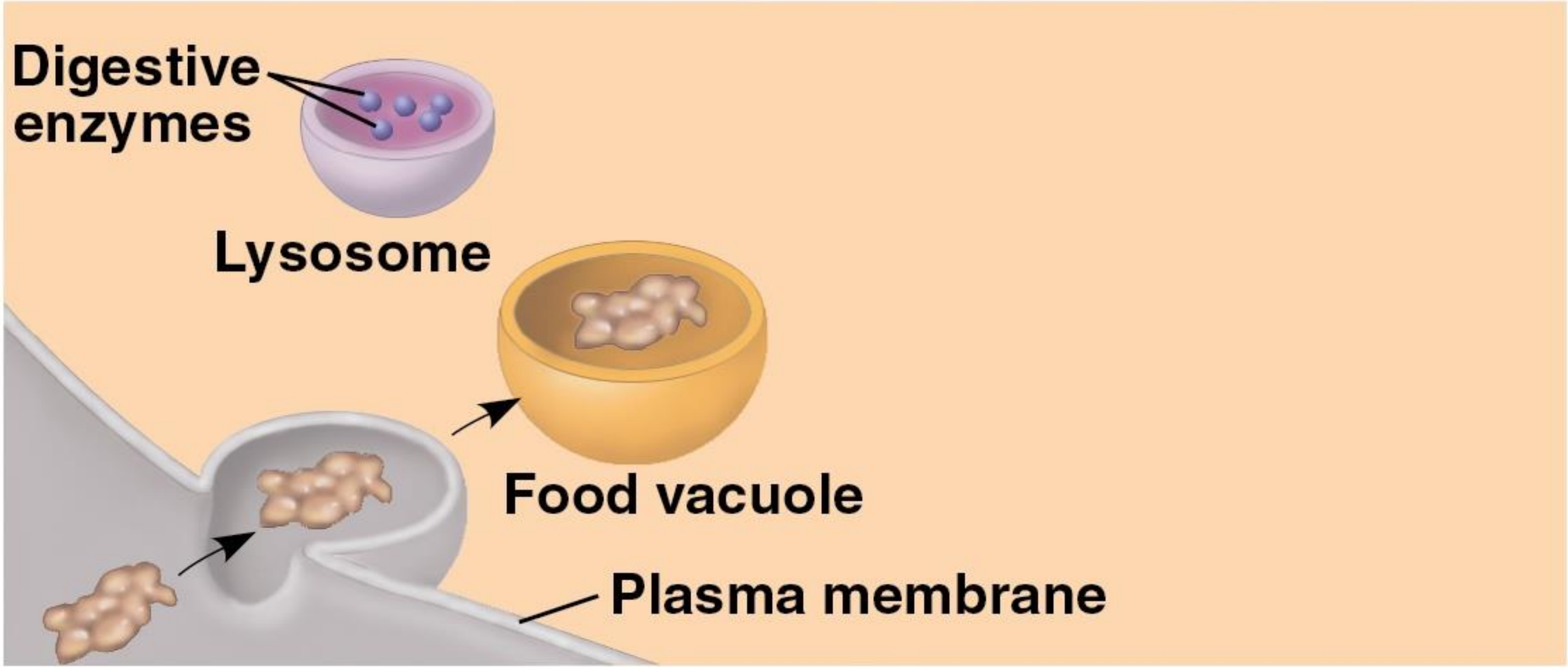




Eukaryotic Cells: Lysosomes

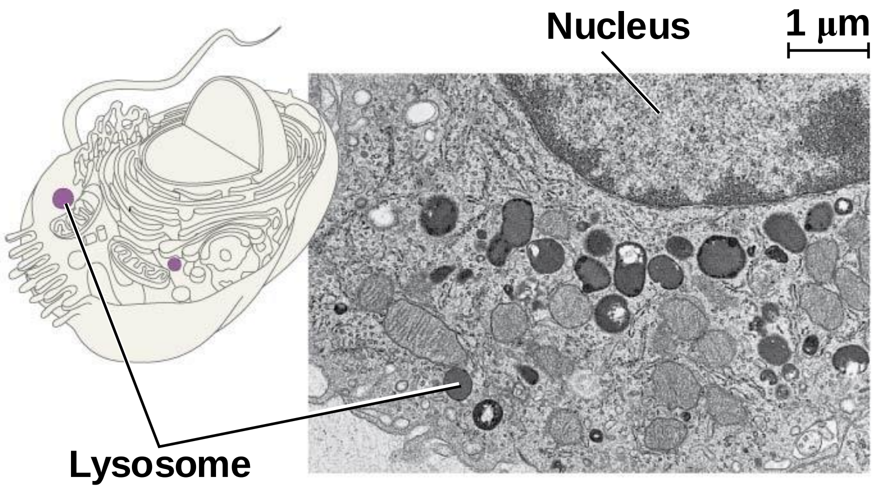
- Phagocytosis

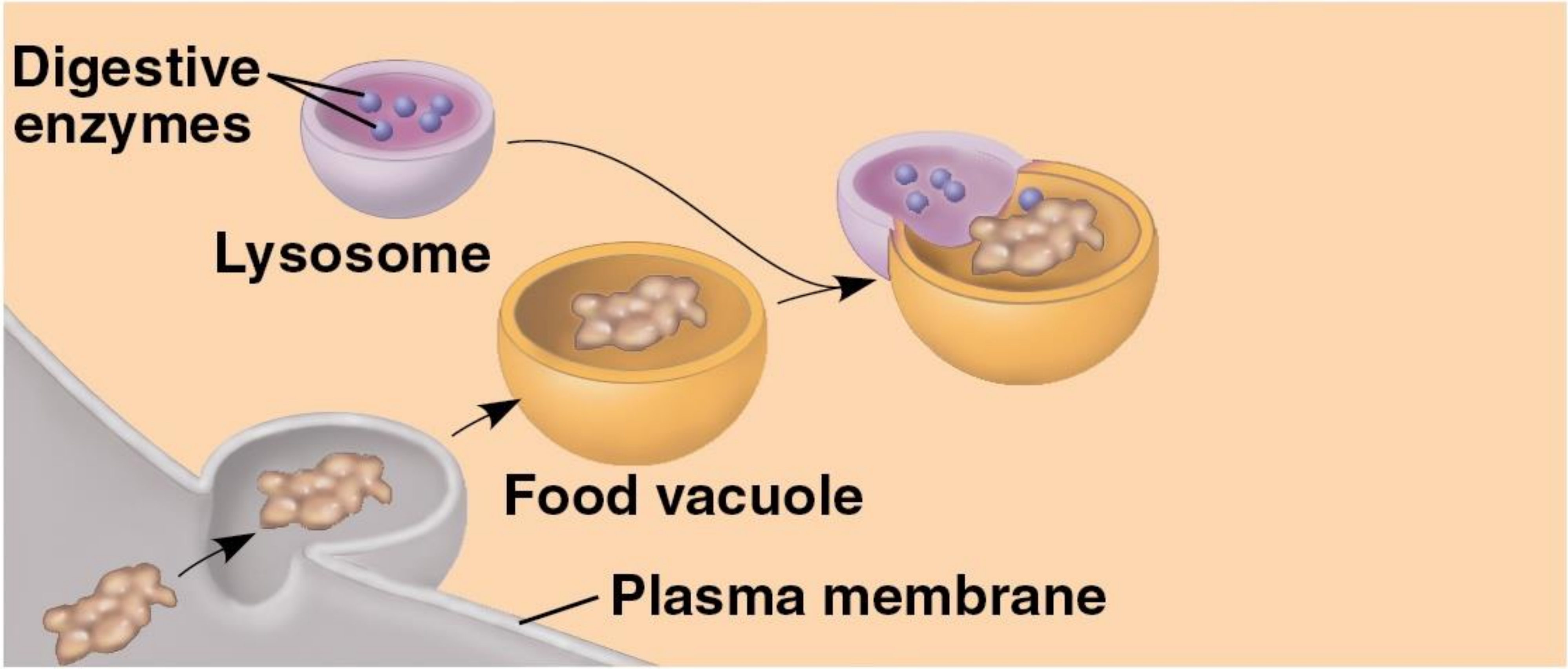




Eukaryotic Cells: Lysosomes

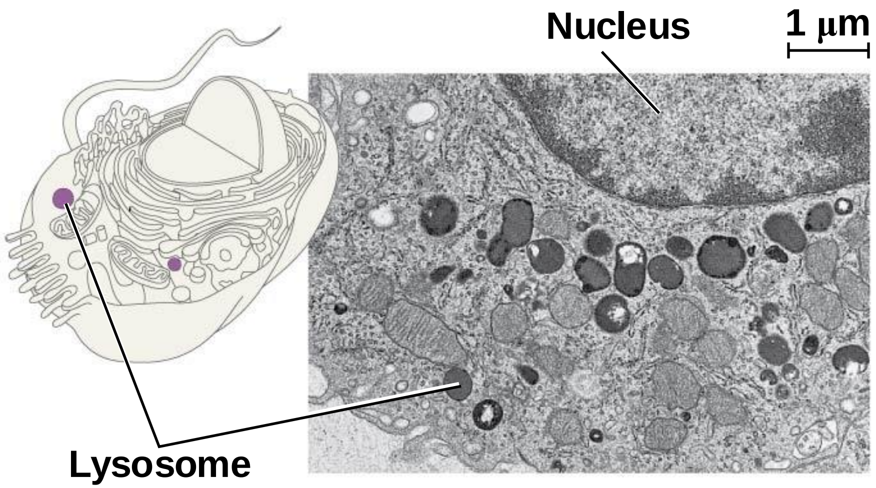
- Phagocytosis

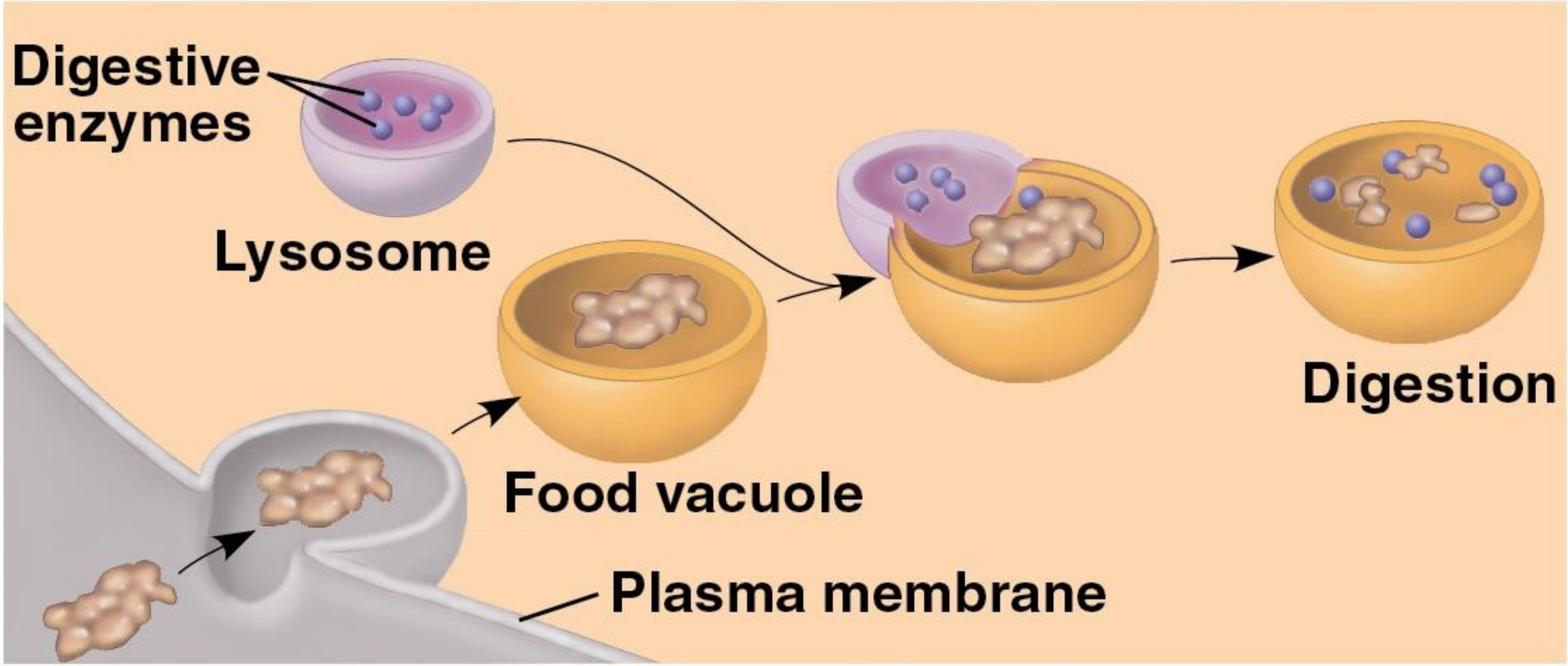




Eukaryotic Cells: Lysosomes

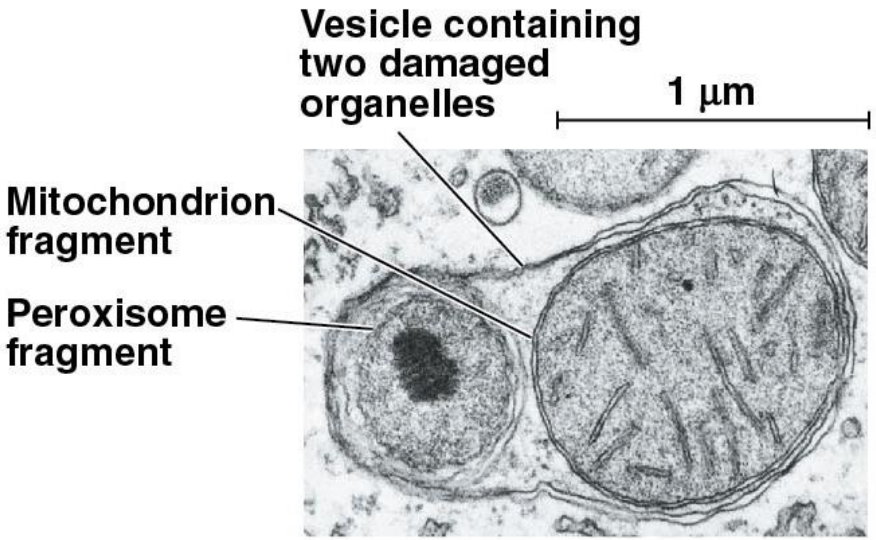
- Phagocytosis





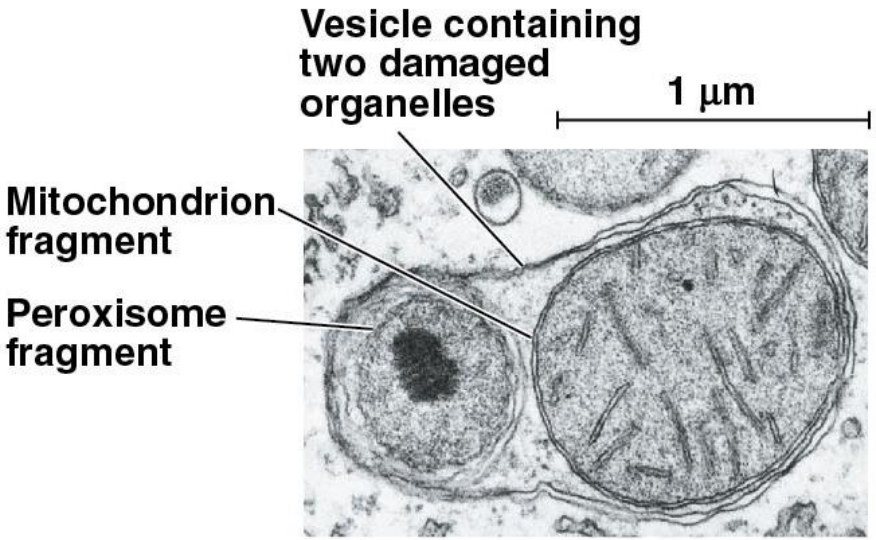
Eukaryotic Cells: Lysosomes

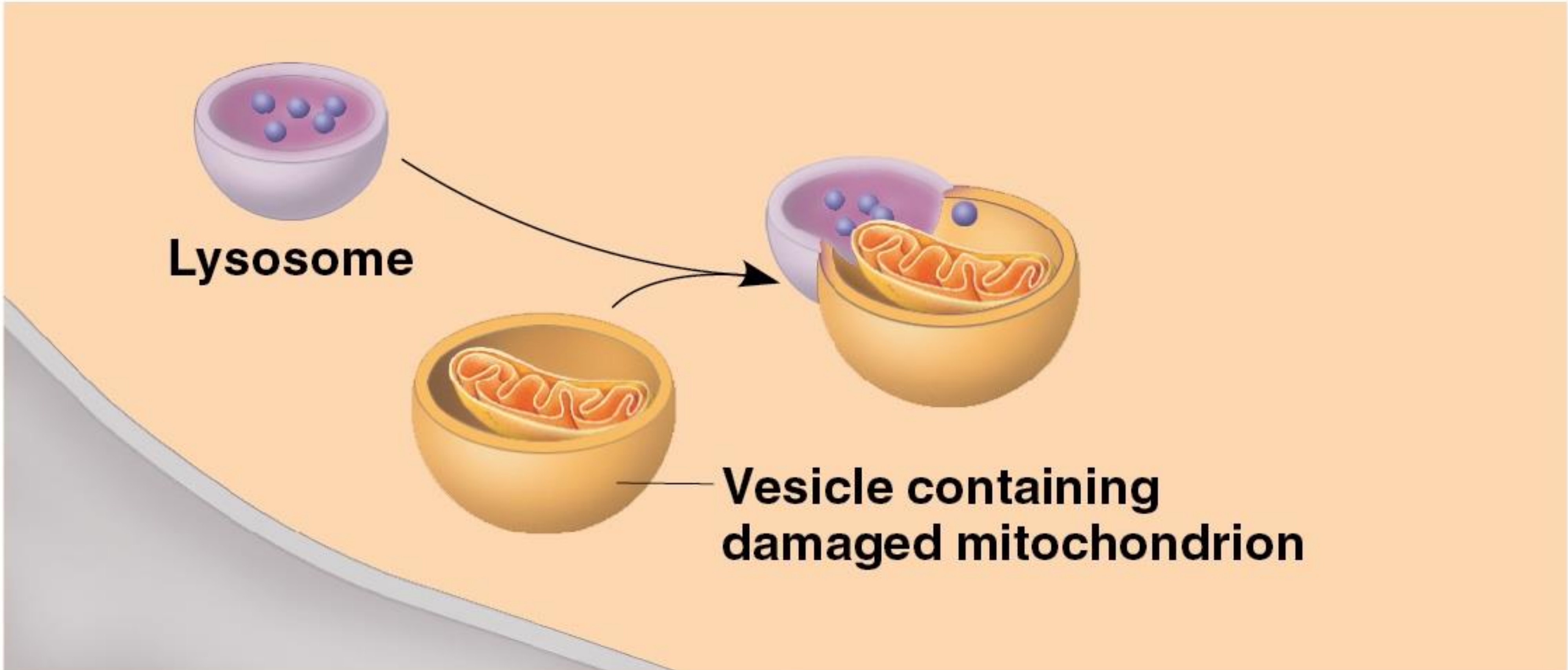
- Autophagy



Eukaryotic Cells: Lysosomes

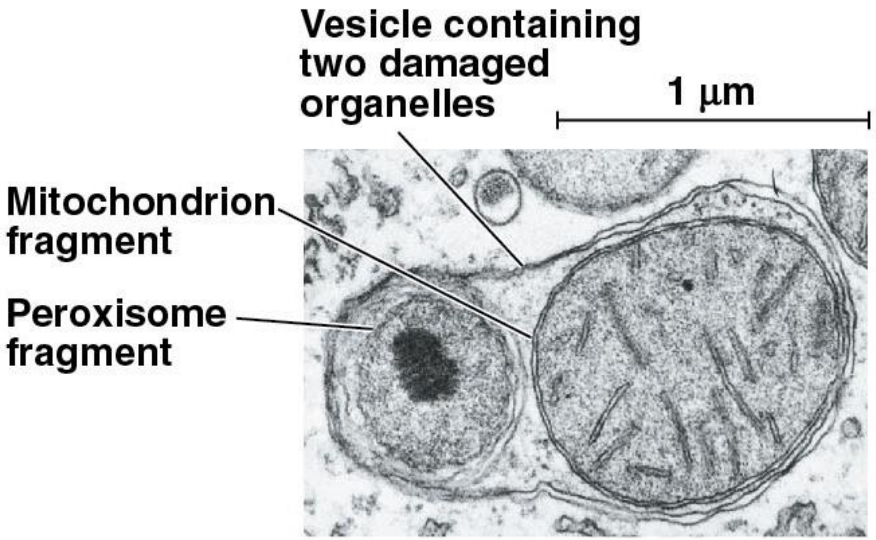
- Autophagy

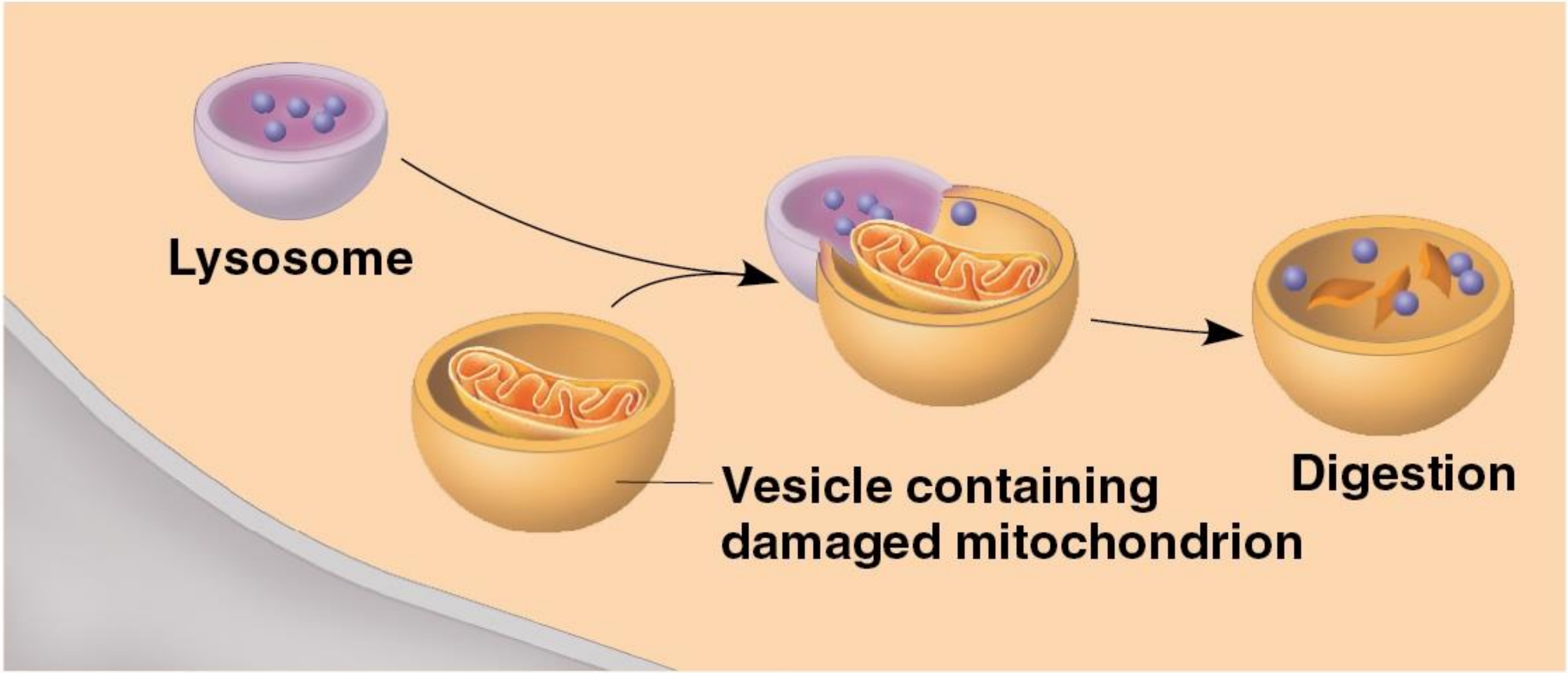




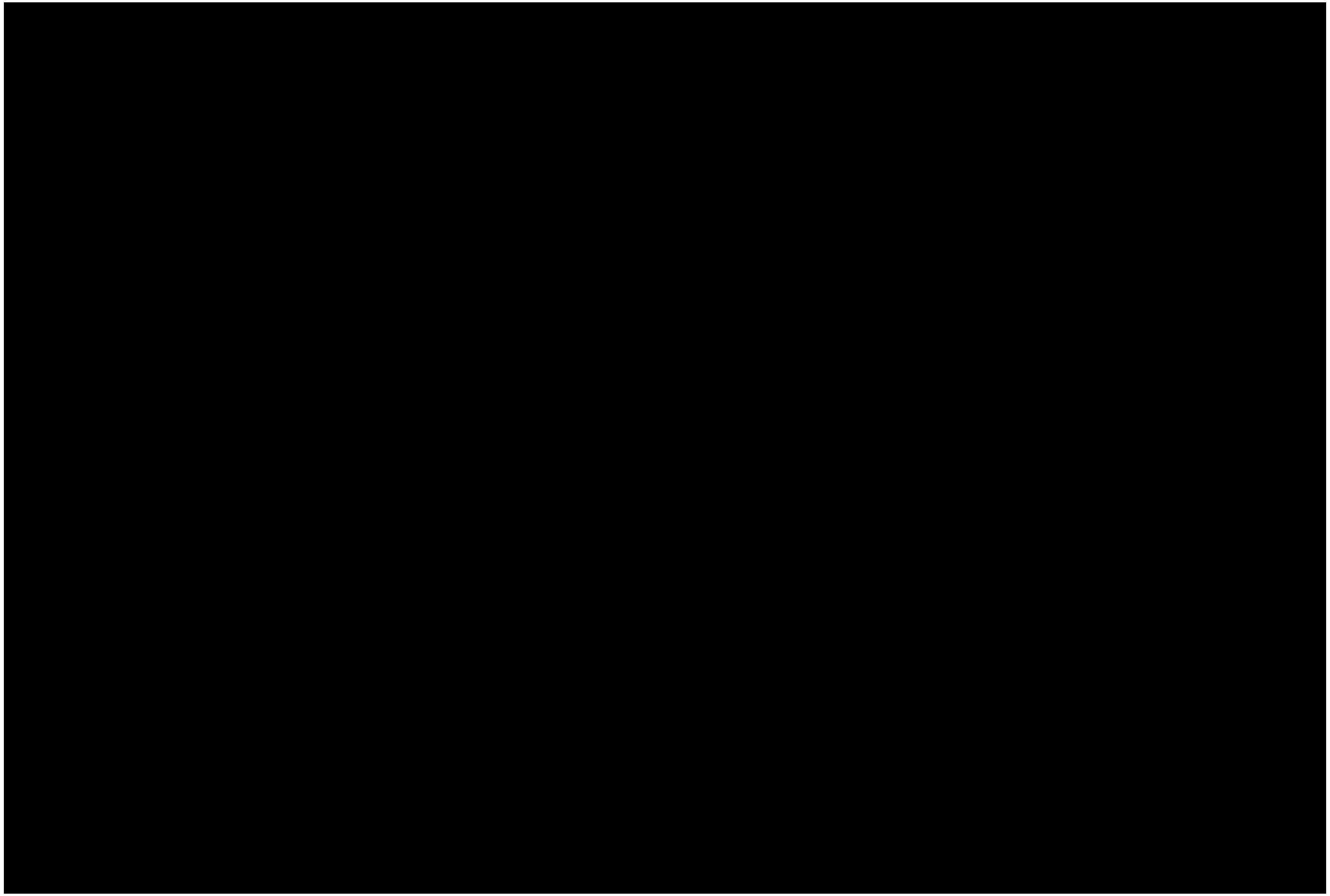
Eukaryotic Cells: Lysosomes

- Autophagy

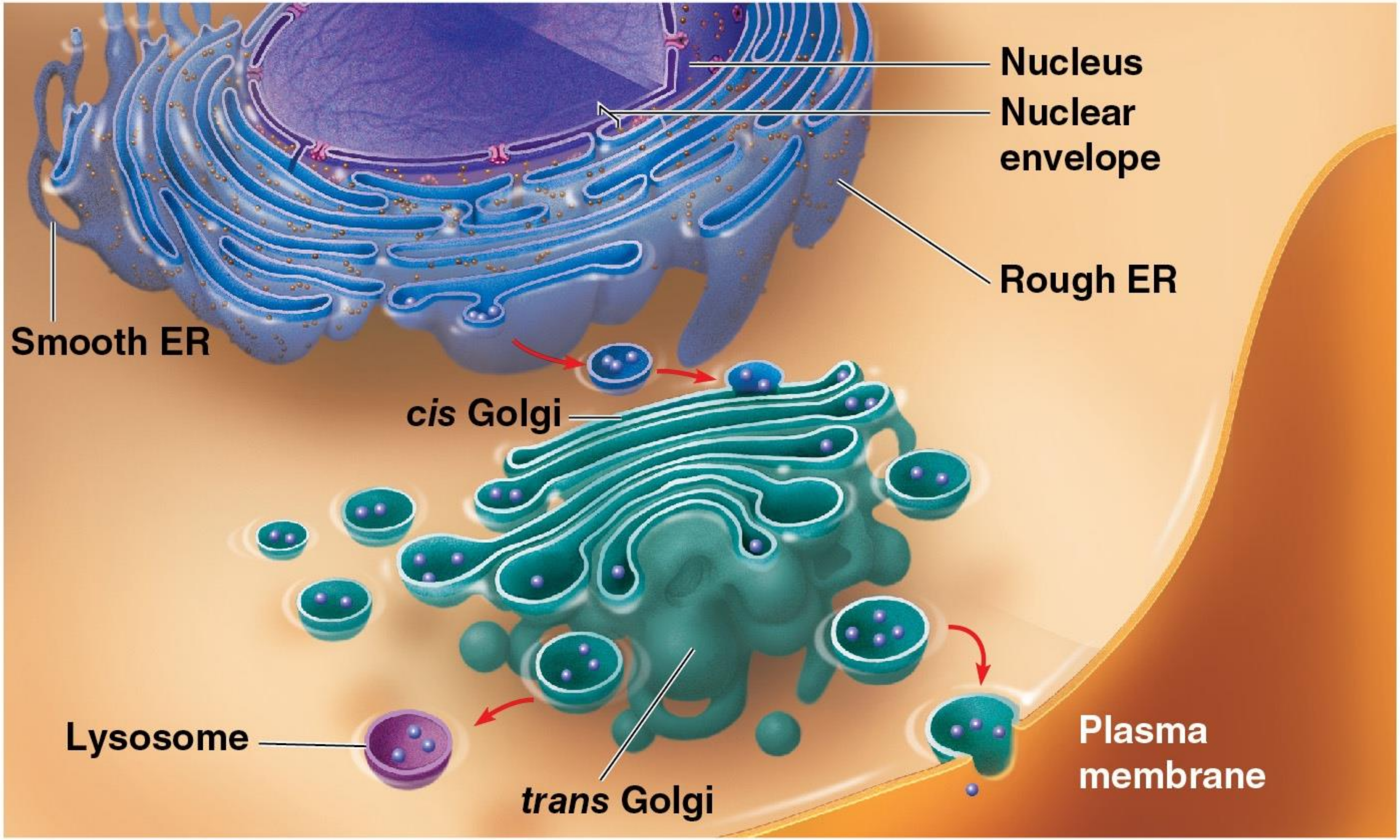




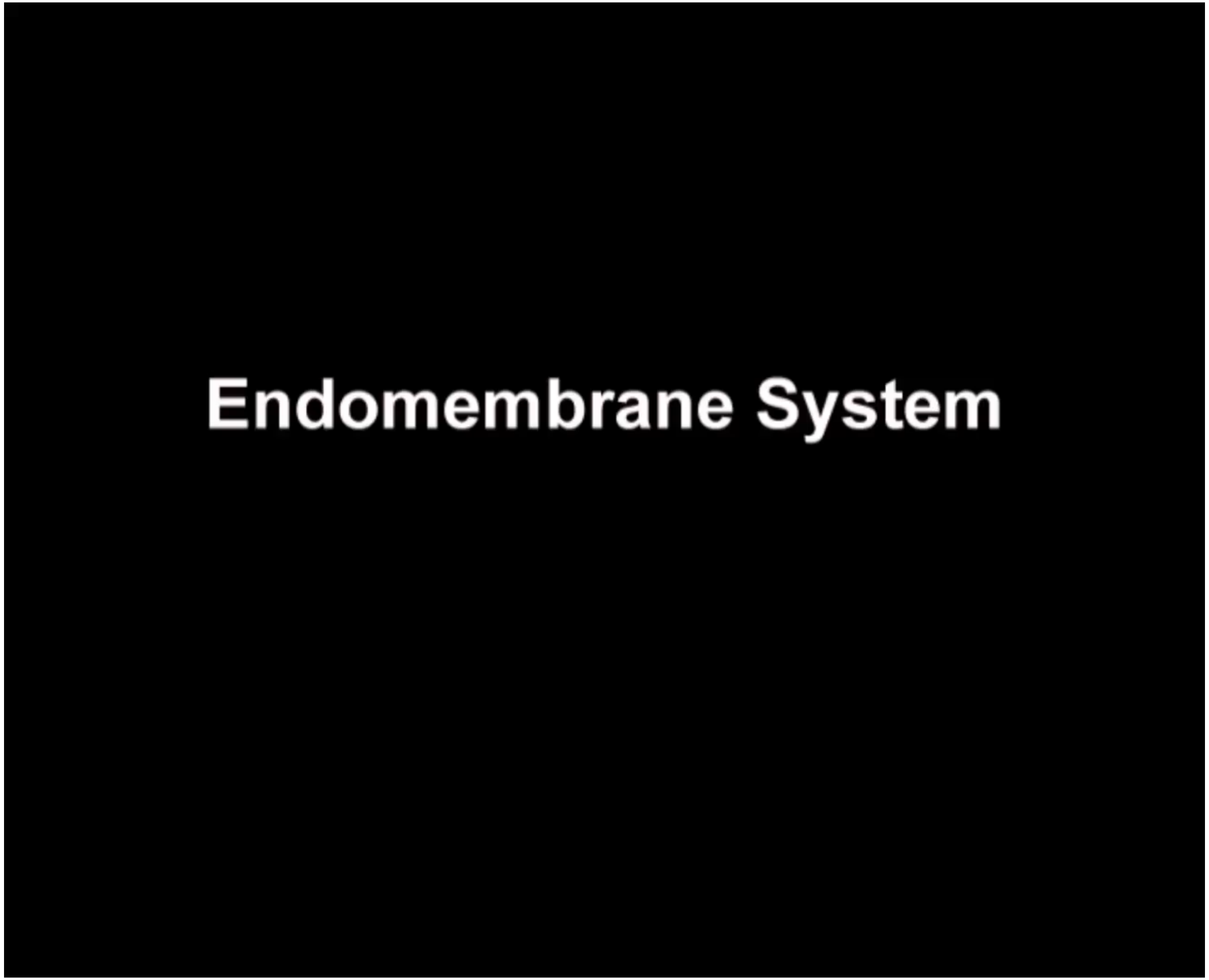
Phagocytosis in Action



The Endomembrane System: *A Review*



Endomembrane System



Eukaryotic Cells: Mitochondria and Chloroplast

- *Mitochondria and chloroplasts change energy from one form to another*

- **Mitochondria** are the sites of **cellular respiration**, a metabolic process that uses **oxygen** to generate **ATP**

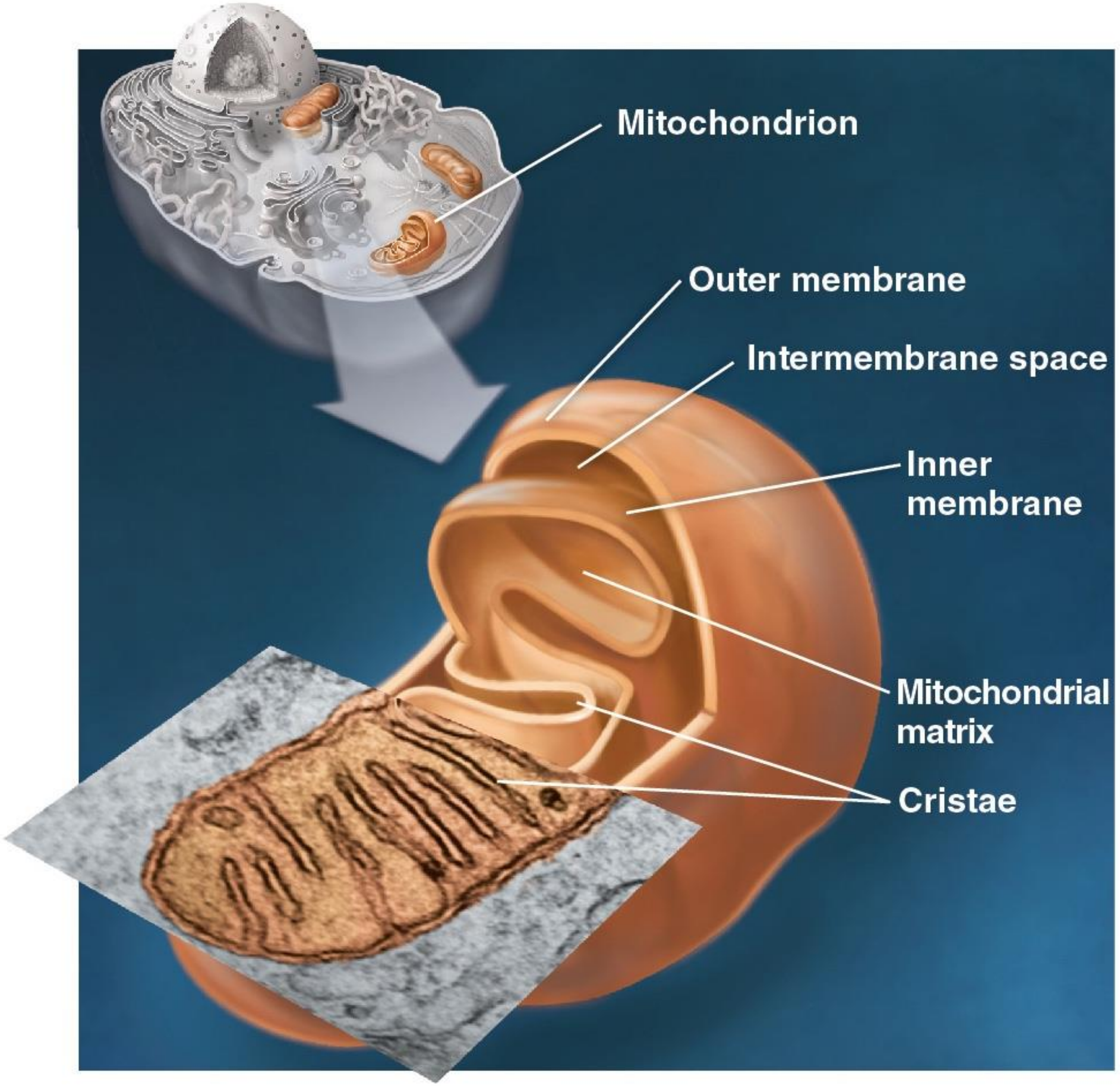
- **Chloroplasts**, found in plants and algae, are the sites of **photosynthesis**

Mitochondria: Chemical Energy Conversion

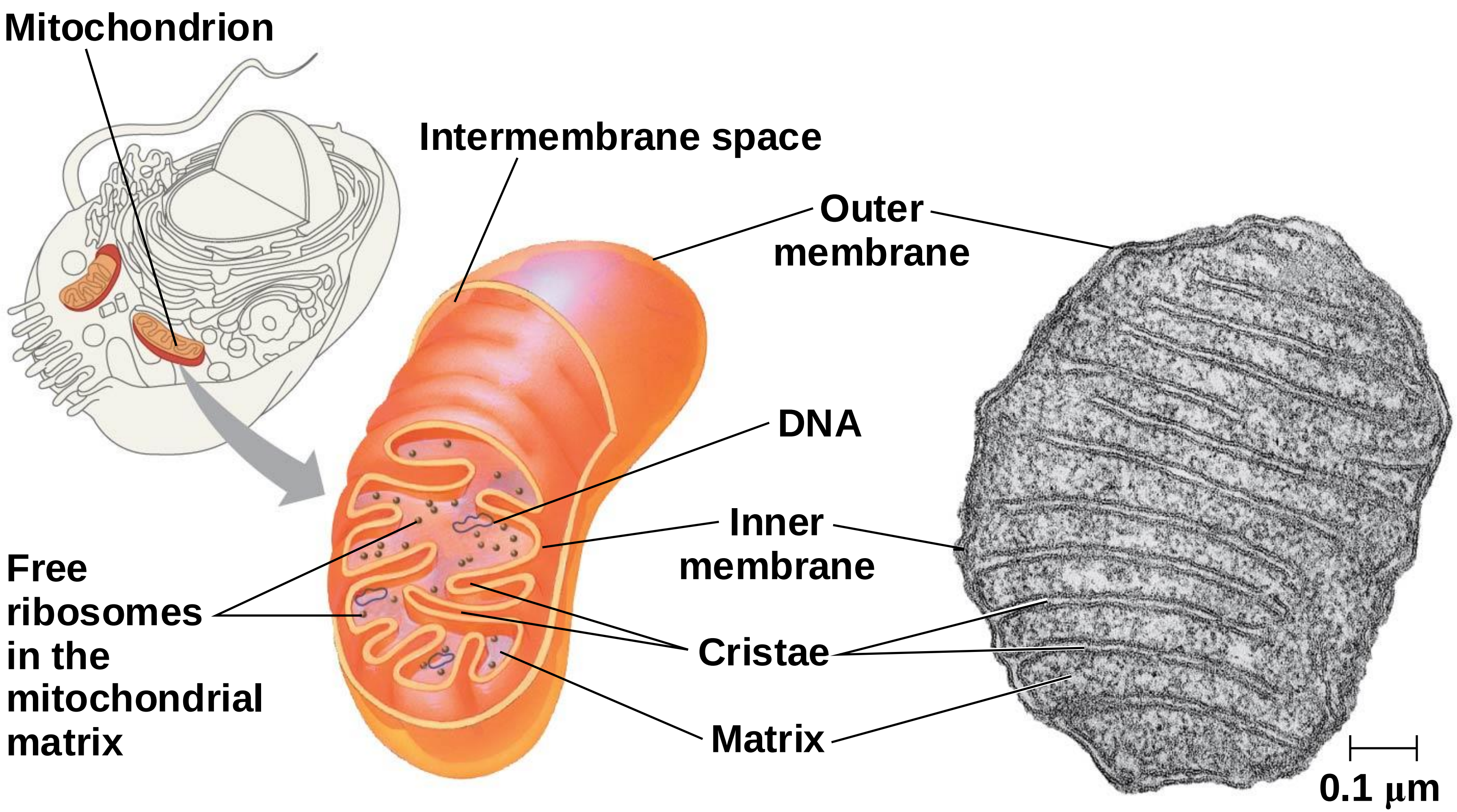
- **Mitochondria** are organelles that carry out cellular respiration in nearly all eukaryotic cells

- Mitochondria have two internal compartments.
  1. The intermembrane space is the narrow region between the inner and outer membranes

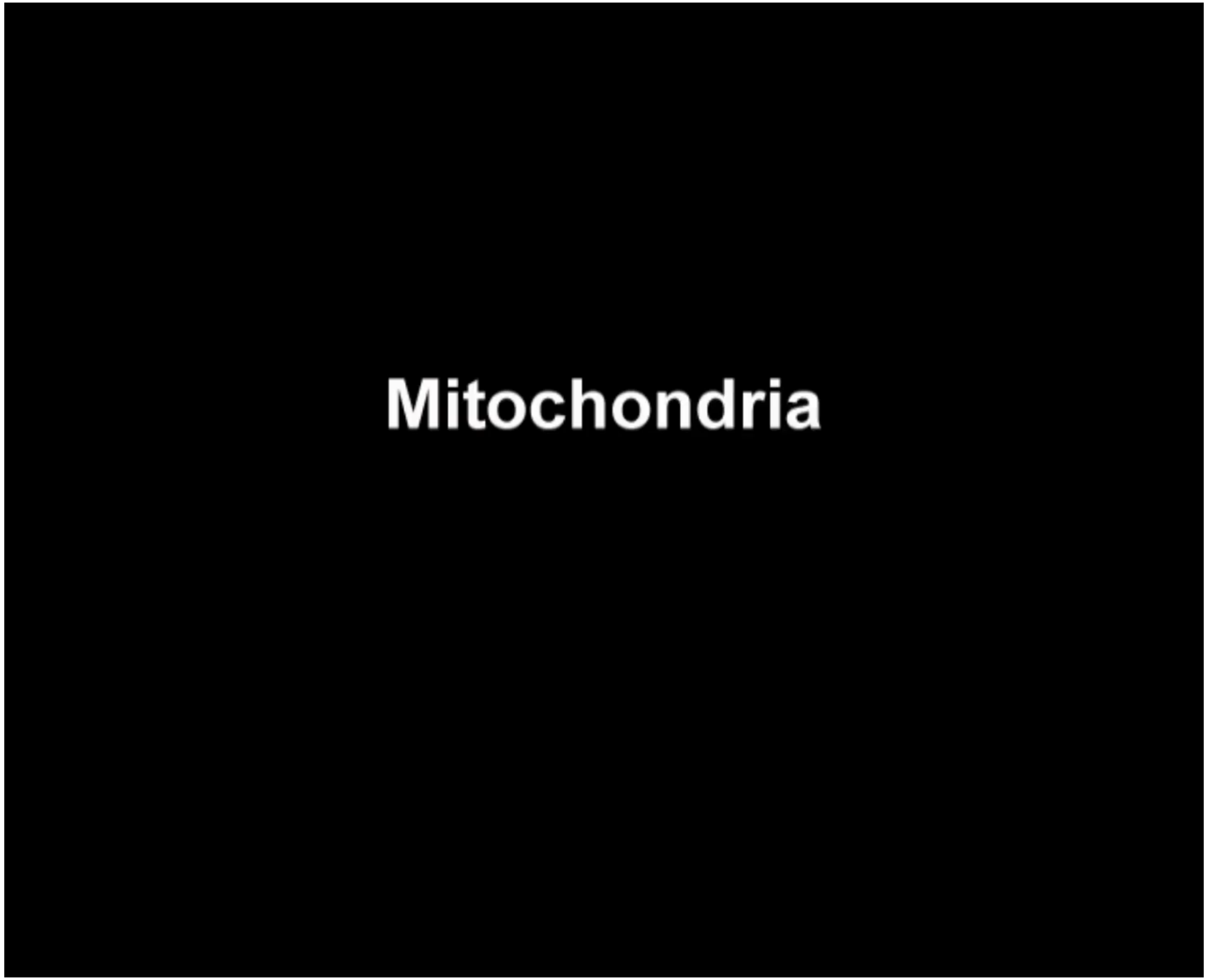
  2. The **mitochondrial matrix** contains the mitochondrial DNA, ribosomes, and many enzymes that catalyze some of the reactions of cellular respiration



Mitochondria: Chemical Energy Conversion



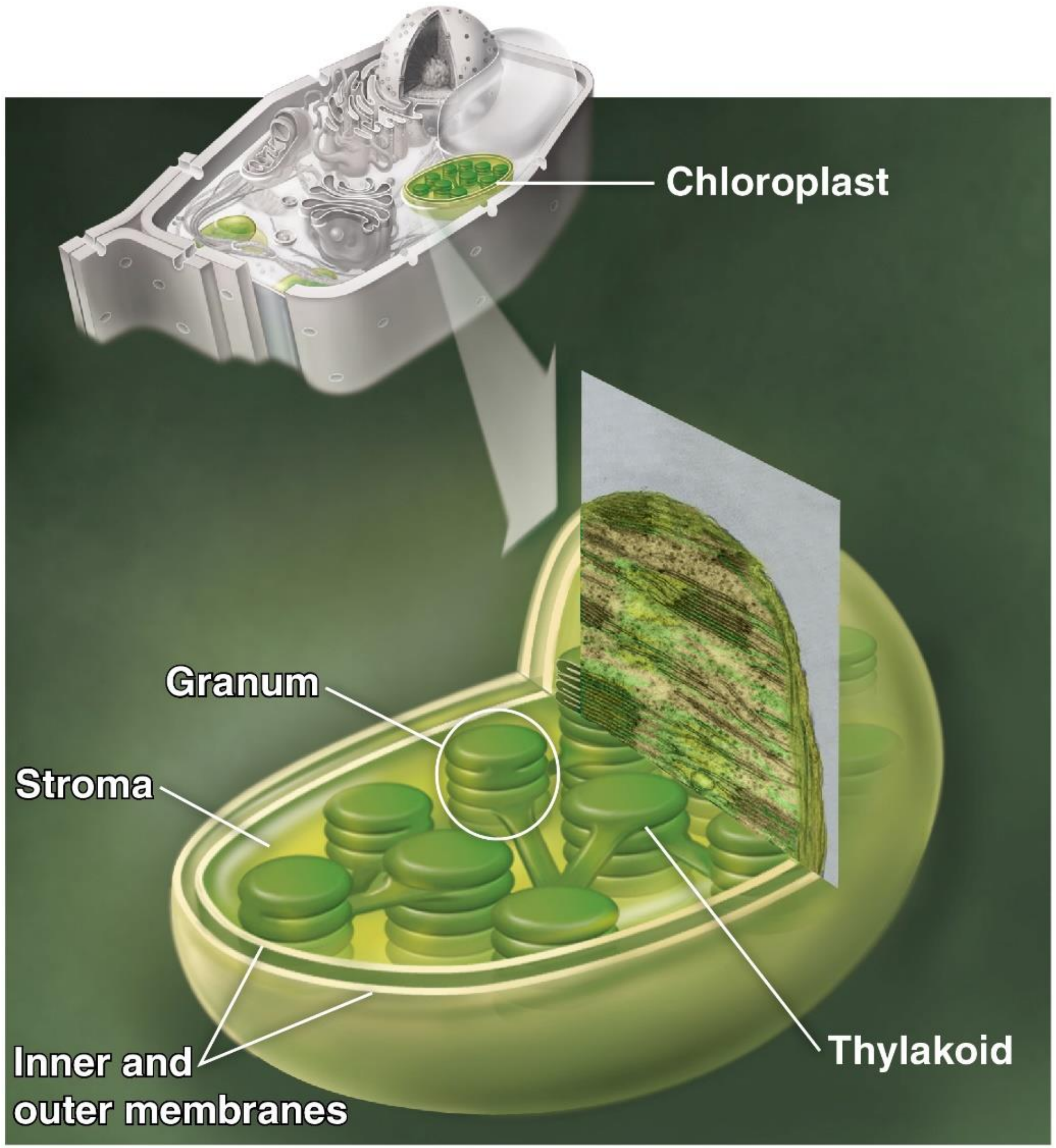
Animation: Mitochondria



Chloroplasts: Convert Solar Energy to Chemical Energy

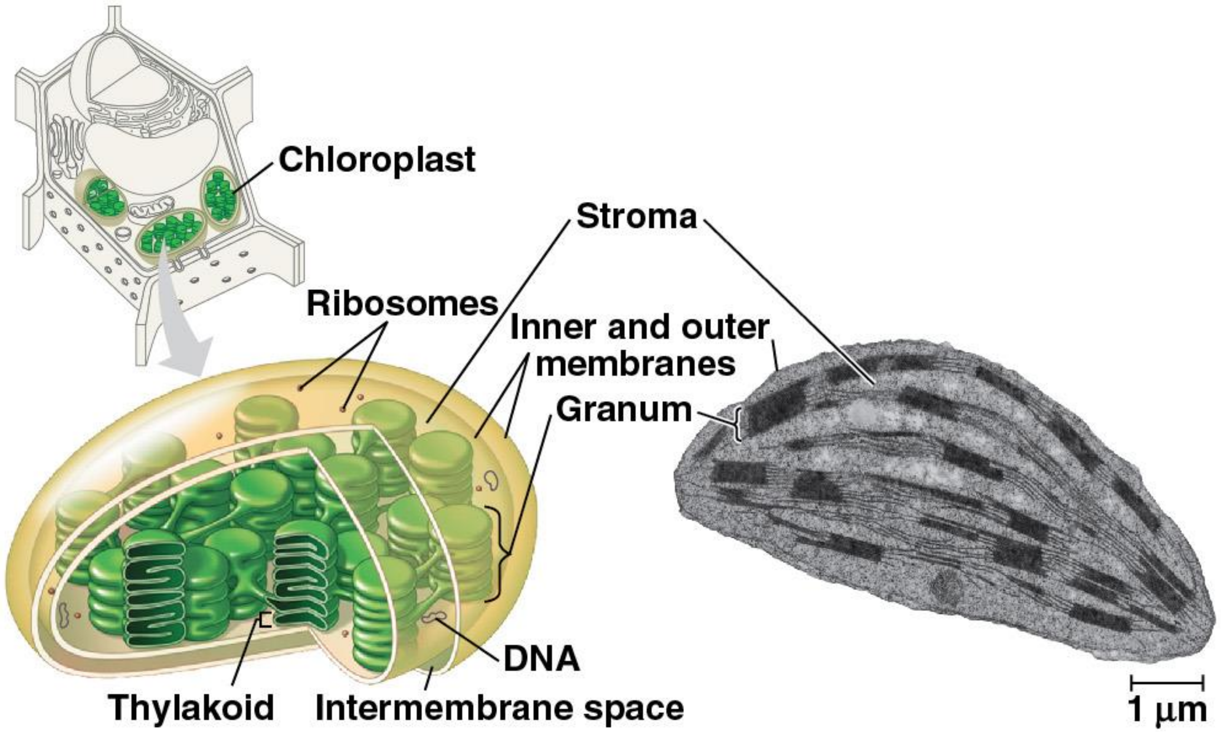
- Photosynthesis is the conversion of light energy from the sun to the chemical energy of sugar molecules

- **Chloroplasts** are the photosynthesizing organelles of plants and algae

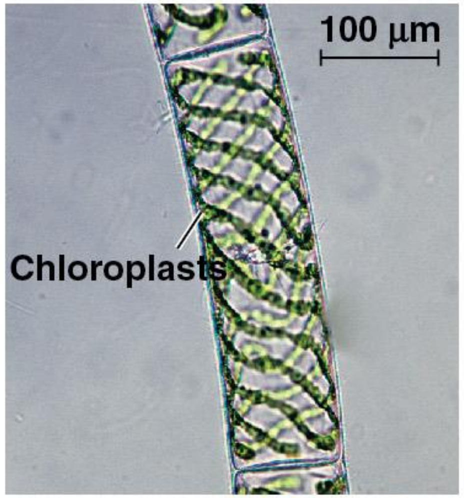


Chloroplasts: Convert Solar Energy to Chemical Energy

- Chloroplast structure includes
  - **Thylakoids**, membranous sacs (stacked to form a **granum)** – sites of photosynthesis
  - **Stroma**, the internal fluid



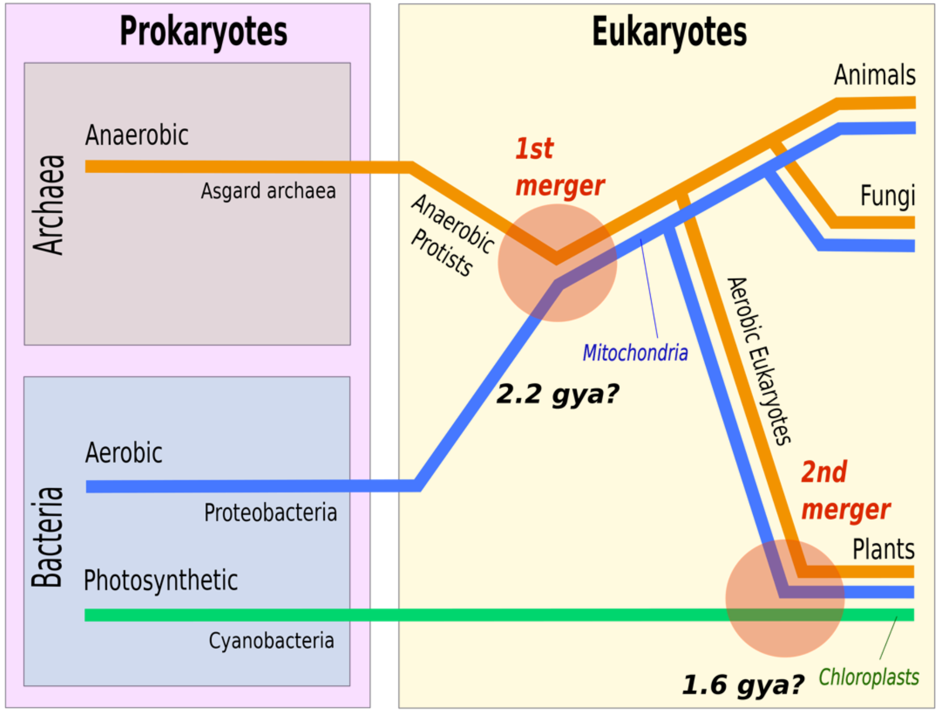
(a) Diagram and TEM of chloroplast



(b) Chloroplasts in an algal cell

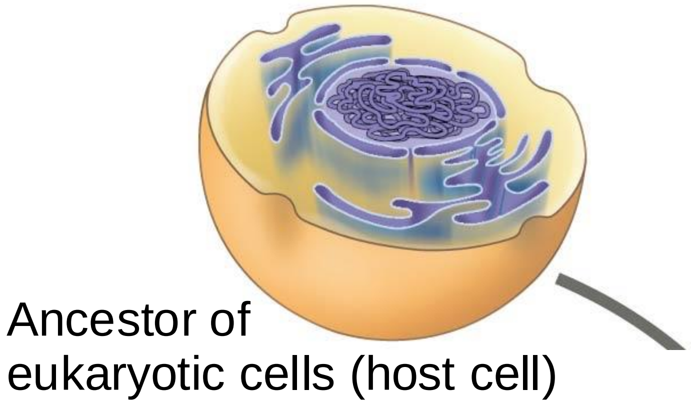
The Evolutionary Origins of Mitochondria and Chloroplasts

- Mitochondria and chloroplasts have similarities with bacteria
- These similarities led to the **endosymbiont theory**
- It suggests that an early ancestor of eukaryotes engulfed an oxygen-using non-photosynthetic prokaryotic cell



The Evolutionary Origins of Mitochondria and Chloroplasts

- The engulfed cell formed a relationship with the host cell, becoming an endosymbiont
- The endosymbionts evolved into mitochondria
- At least one of these cells may have then taken up a photosynthetic prokaryote, which evolved into a chloroplast
- Similarities between mitochondria and chloroplasts that support this theory:
  - Enveloped by a double membrane
  - Contain free ribosomes and circular DNA molecules
  - Grow and reproduce somewhat independently in cells



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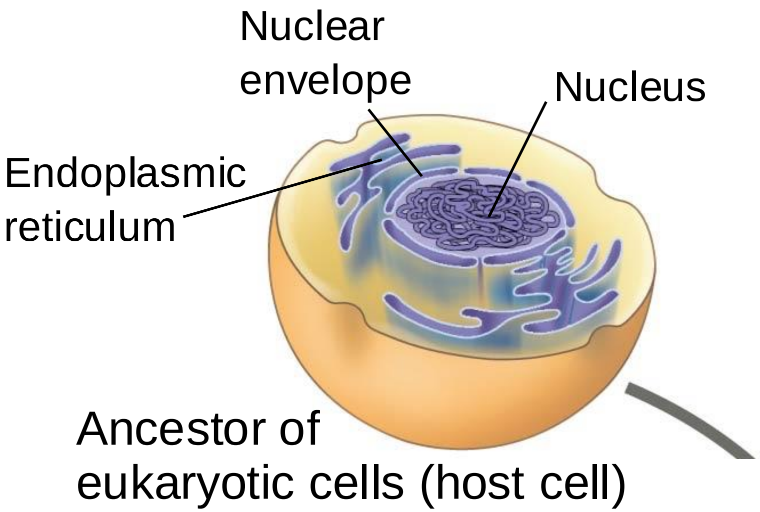

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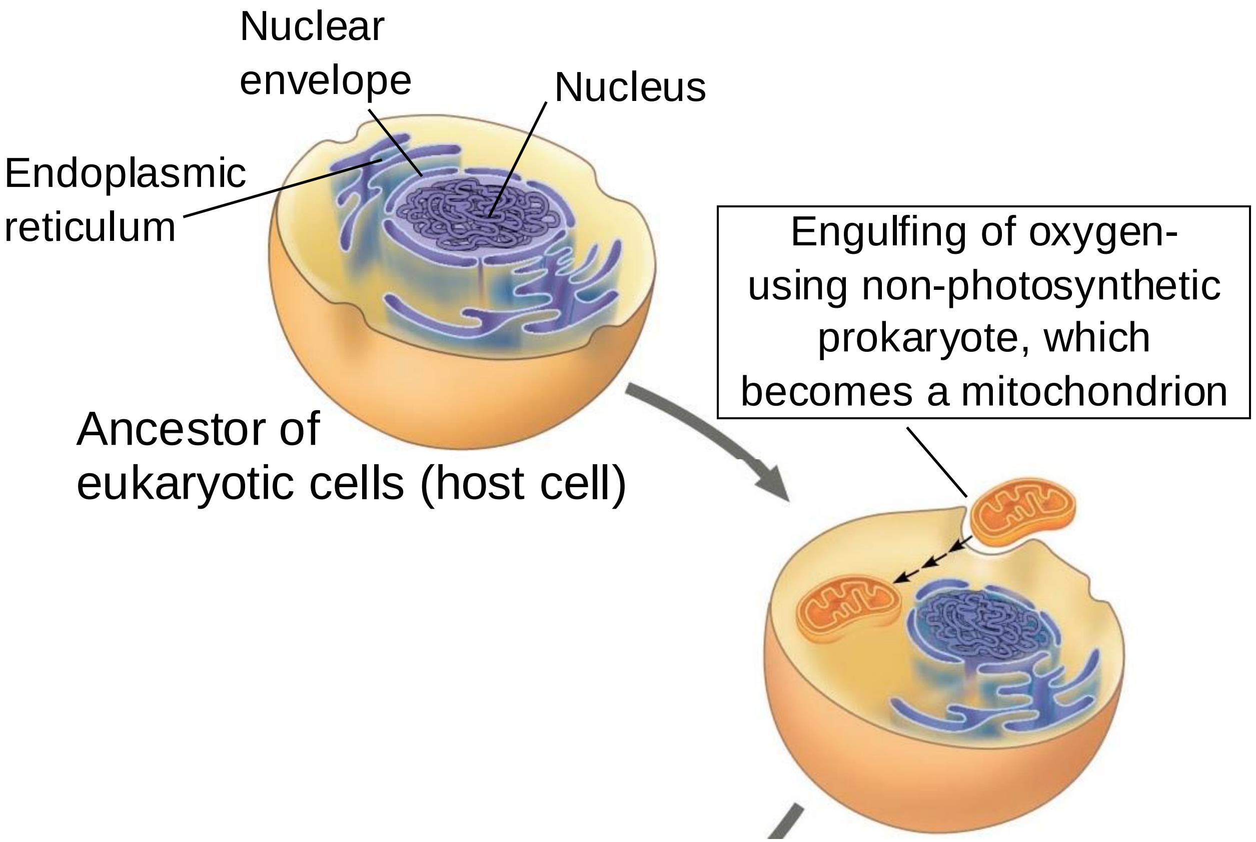

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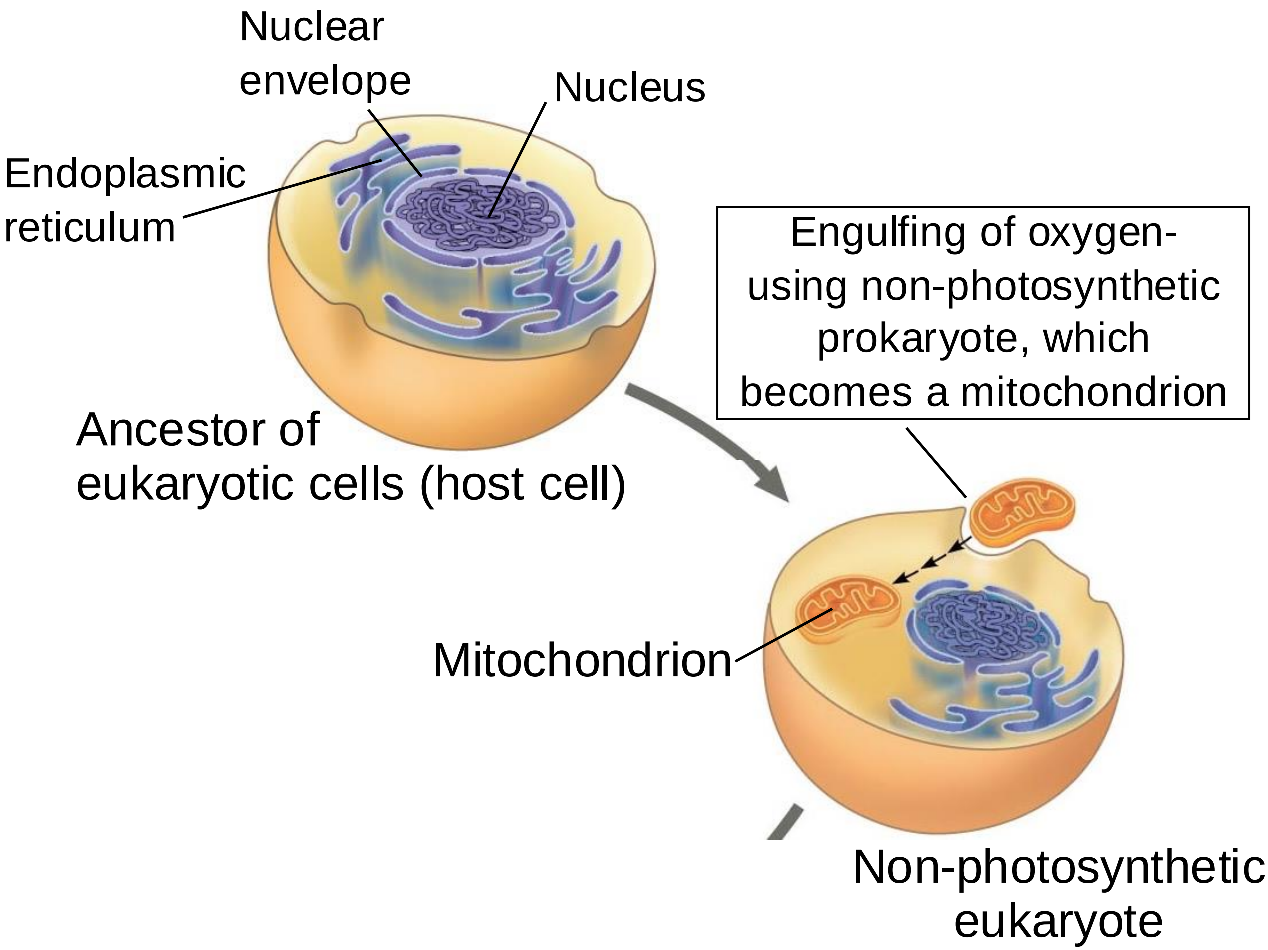

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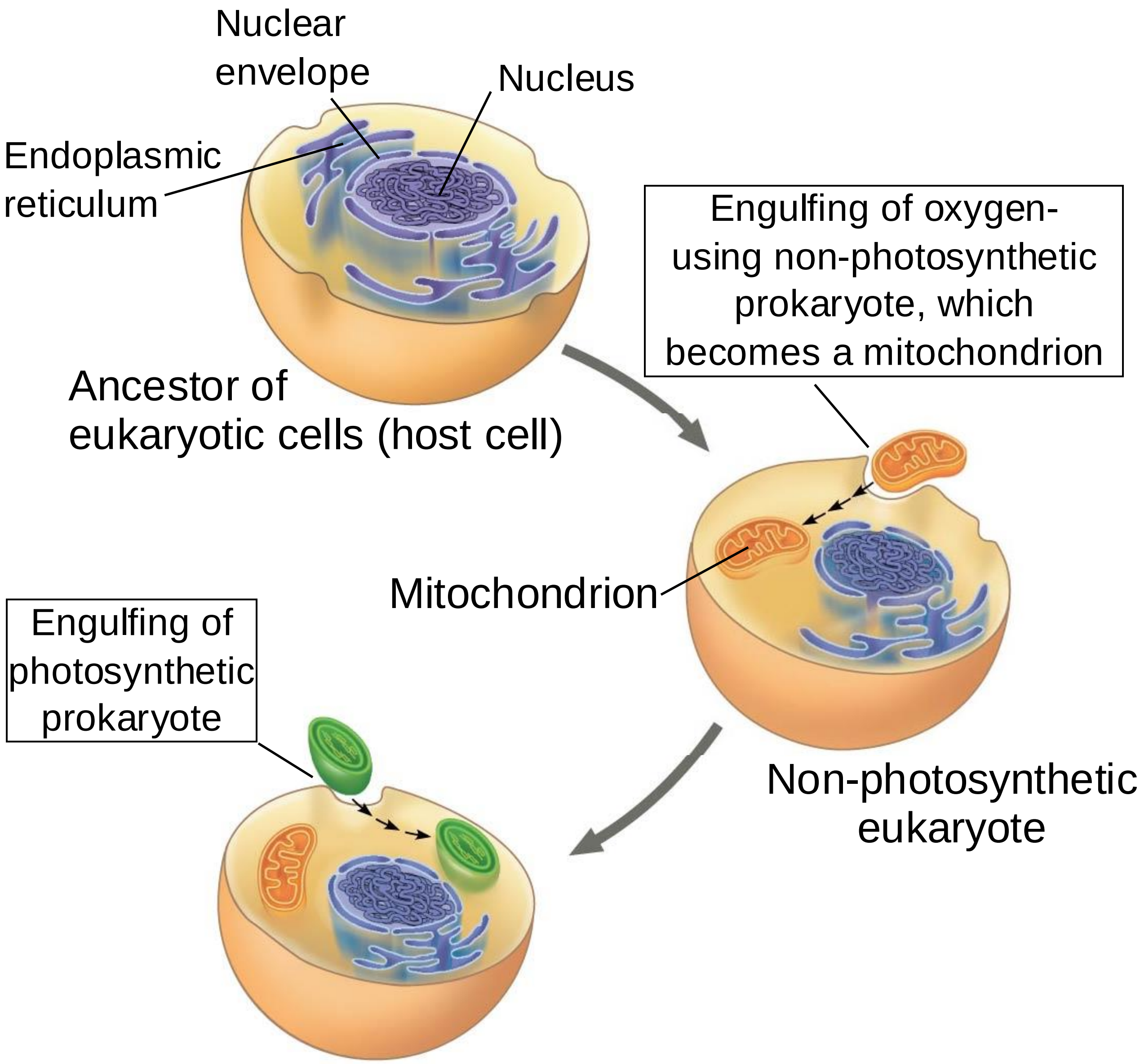

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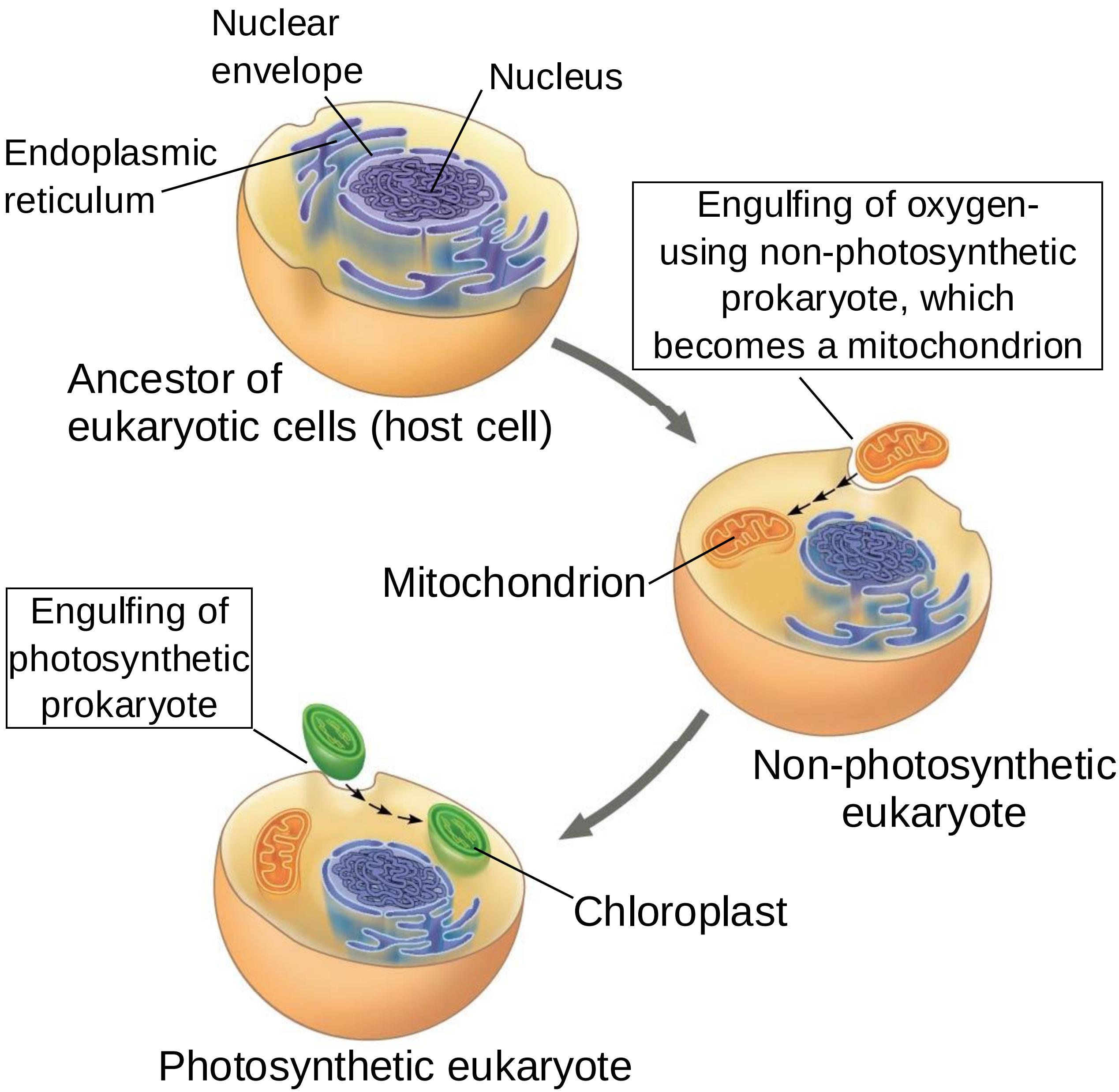
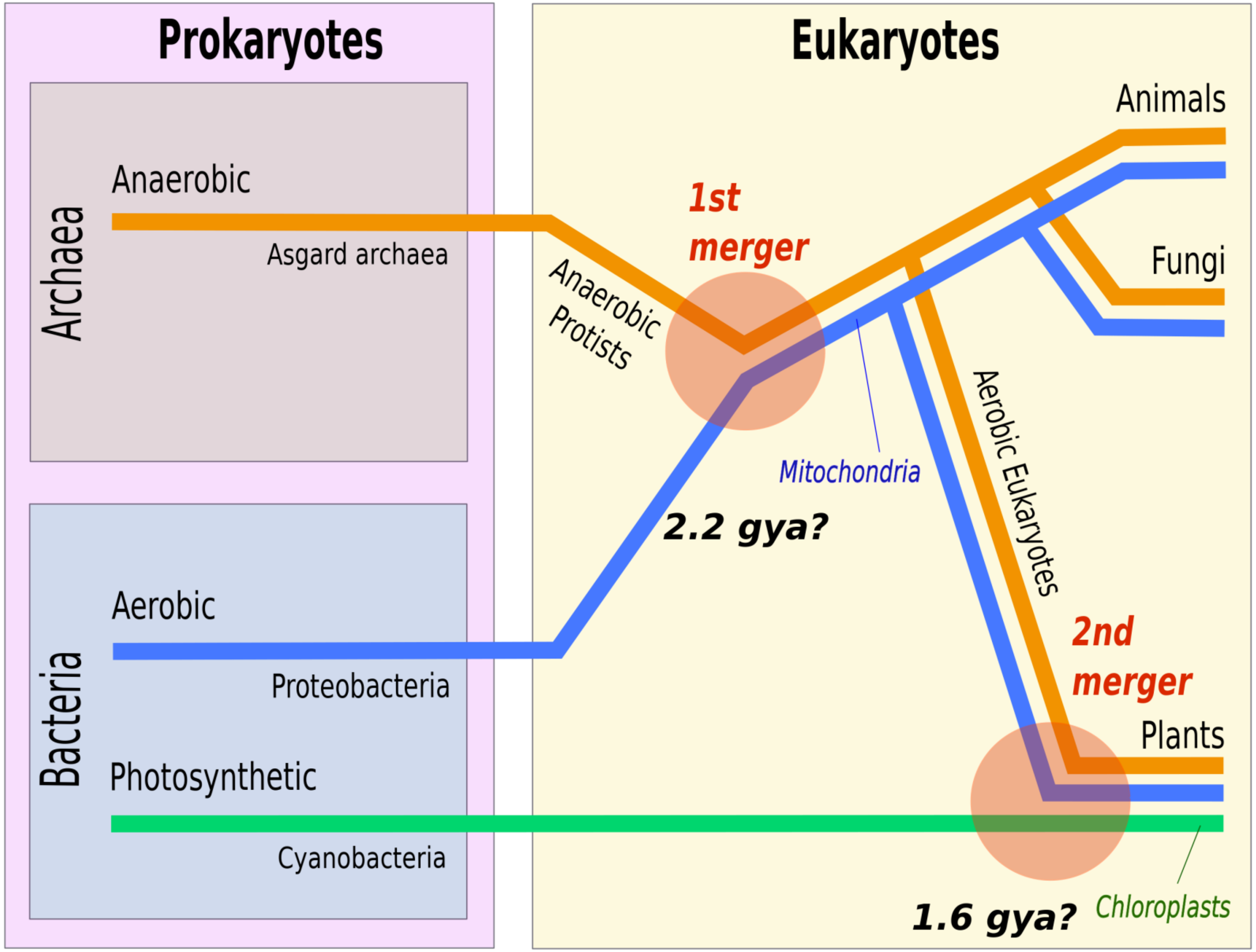
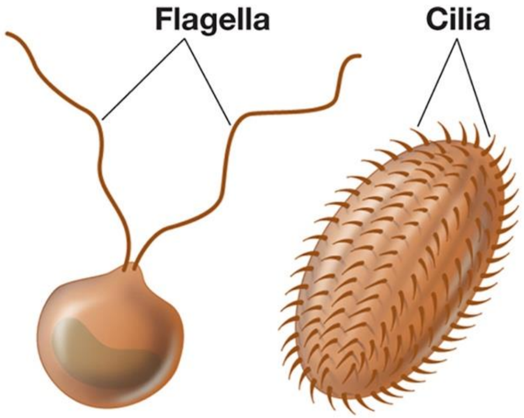


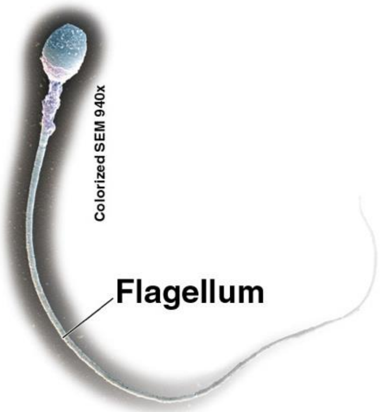


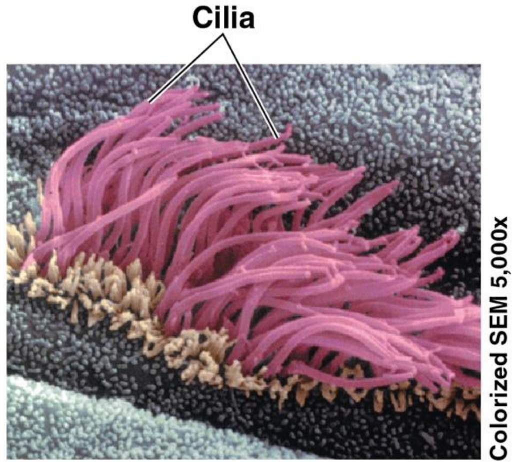
Prokaryotes
Eukaryotes
Archaea
Anaerobic
Asgard archaea
Bacteria
Aerobic
Proteobacteria
Photosynthetic
Cyanobacteria
1st merger
Anaerobic Protists
Mitochondria
2.2 gya?
Animals
Fungi
Aerobic Eukaryotes
2nd merger
Plants
1.6 gya?
Chloroplasts

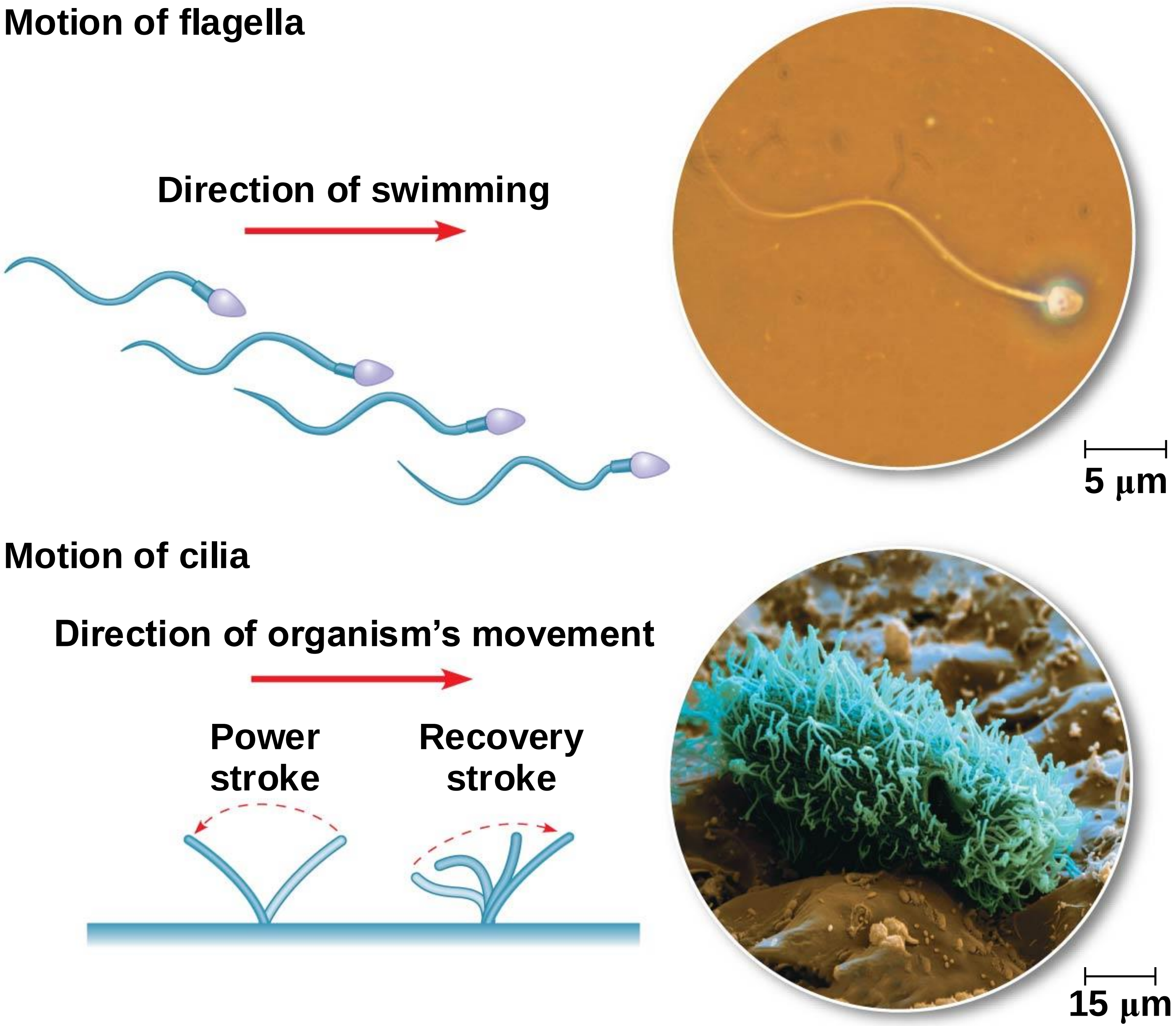
Flagella and Cilia

- Eukaryotic **cilia** and flagella are locomotor appendages made of microtubules.
- Flagella, longer than cilia, propel a cell by an undulating, whiplike motion.
- Cilia work more like the coordinated oars of a rowing team.
- Many unicellular eukaryotes are propelled through water by cilia or flagella

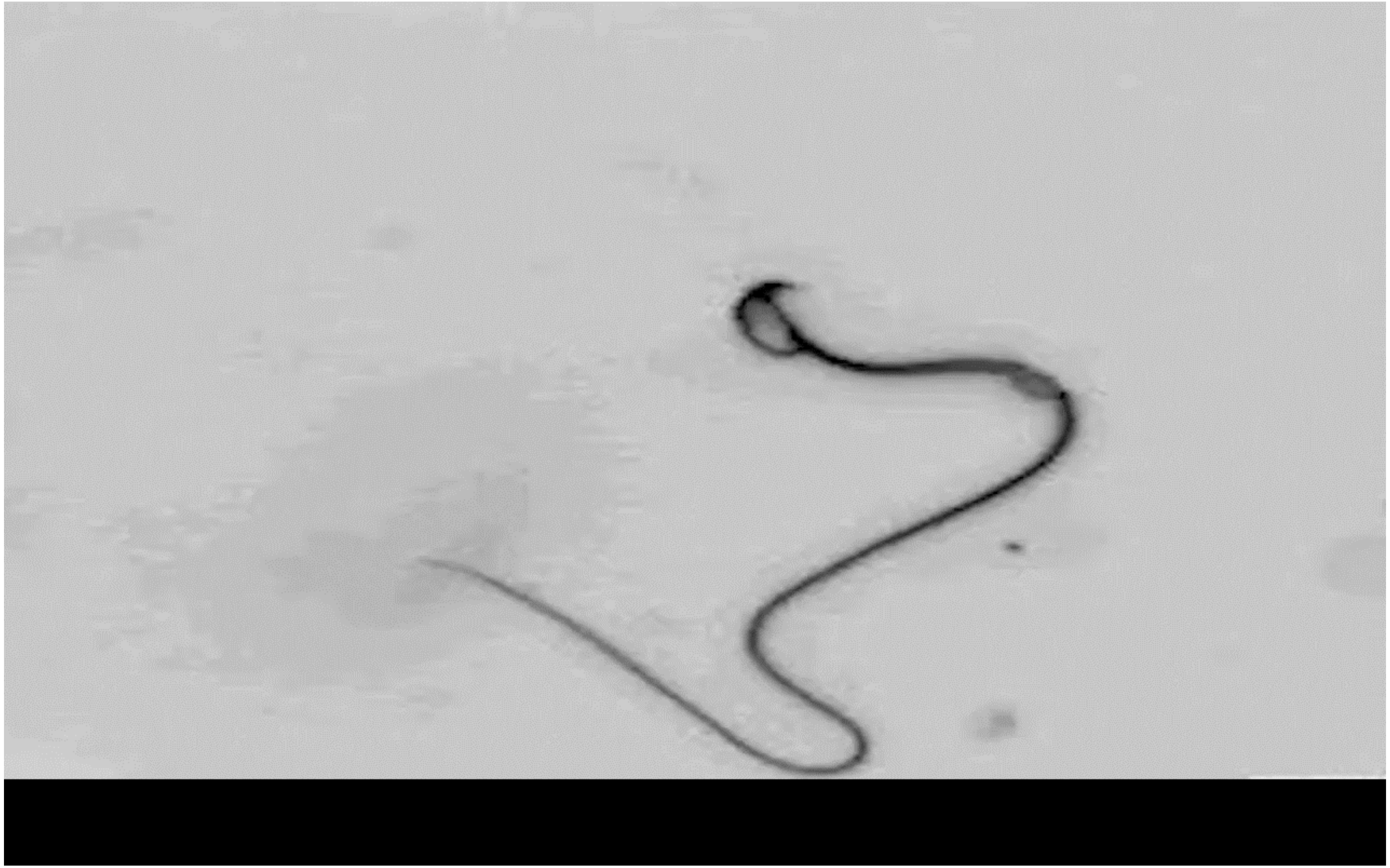




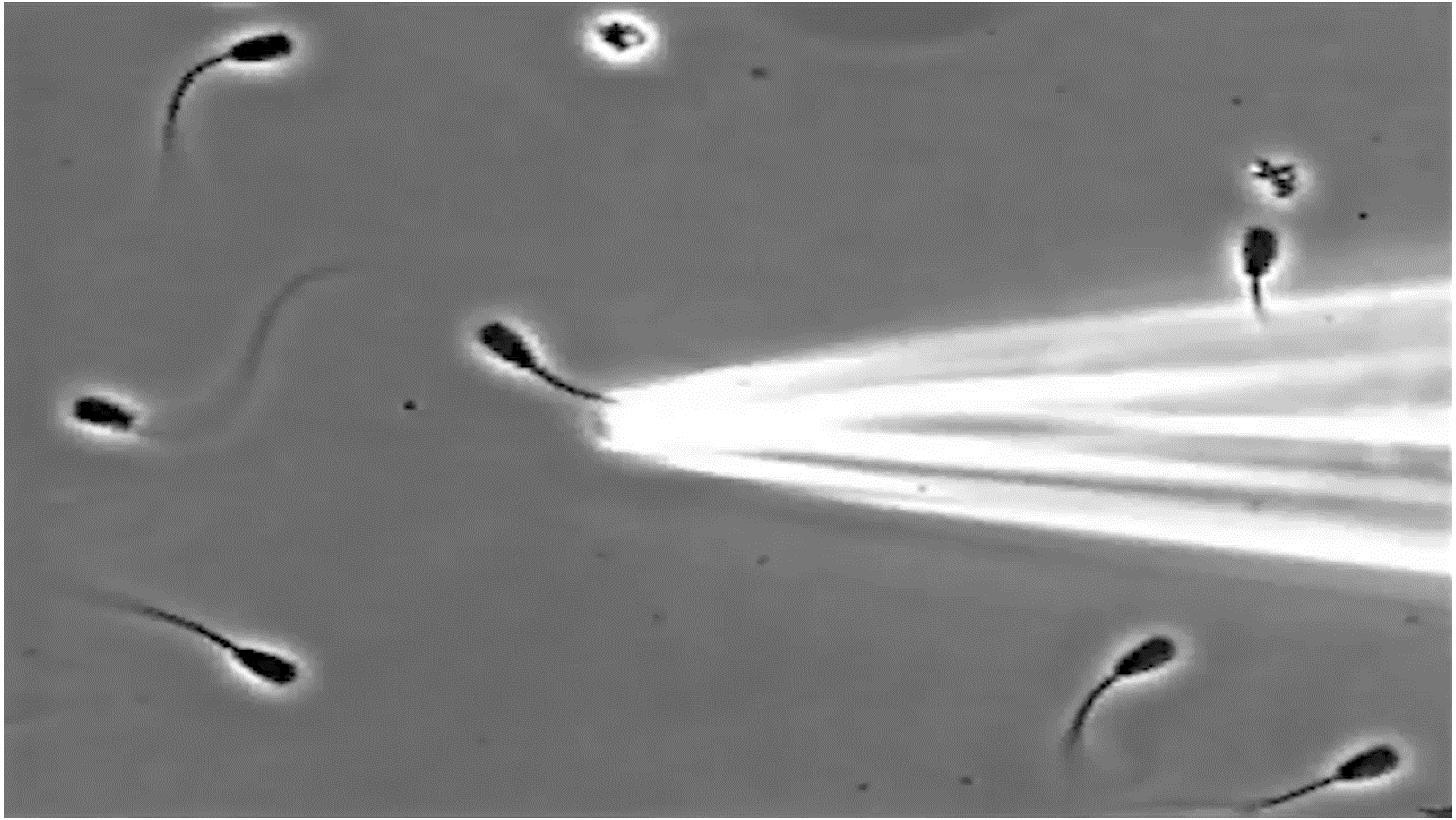



Motion of flagella
Direction of swimming
5 µm
Motion of cilia
Direction of organism’s movement
Power stroke
Recovery stroke
15 µm

Flagellum Beating with ATP



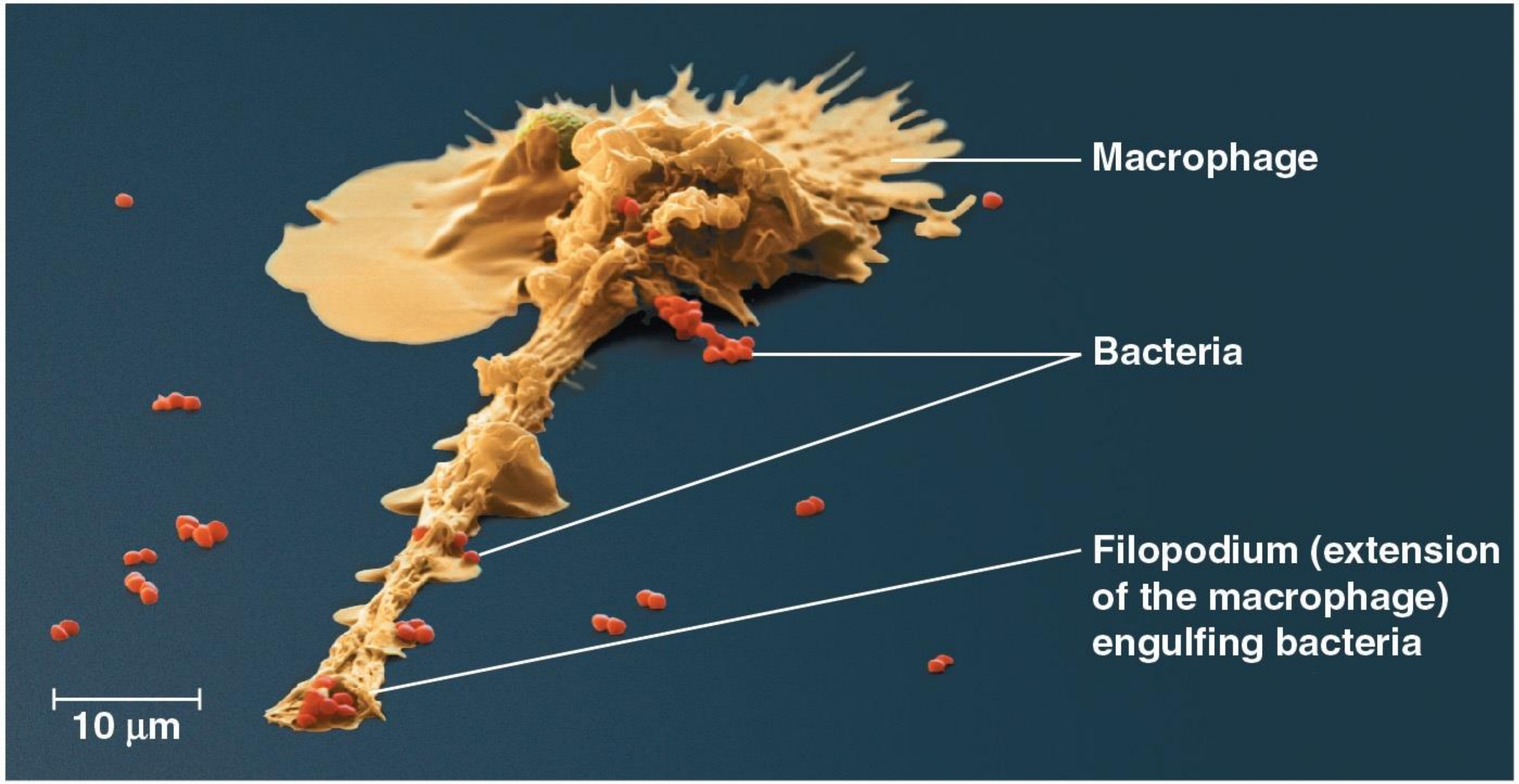
Motion of Isolated Flagellum



Paramecium Cilia

A cell is greater than the sum of its parts

- None of the cell's components work alone
- For example, a macrophage's ability to destroy bacteria involves the whole cell, coordinating components such as the cytoskeleton, lysosomes, and plasma membrane

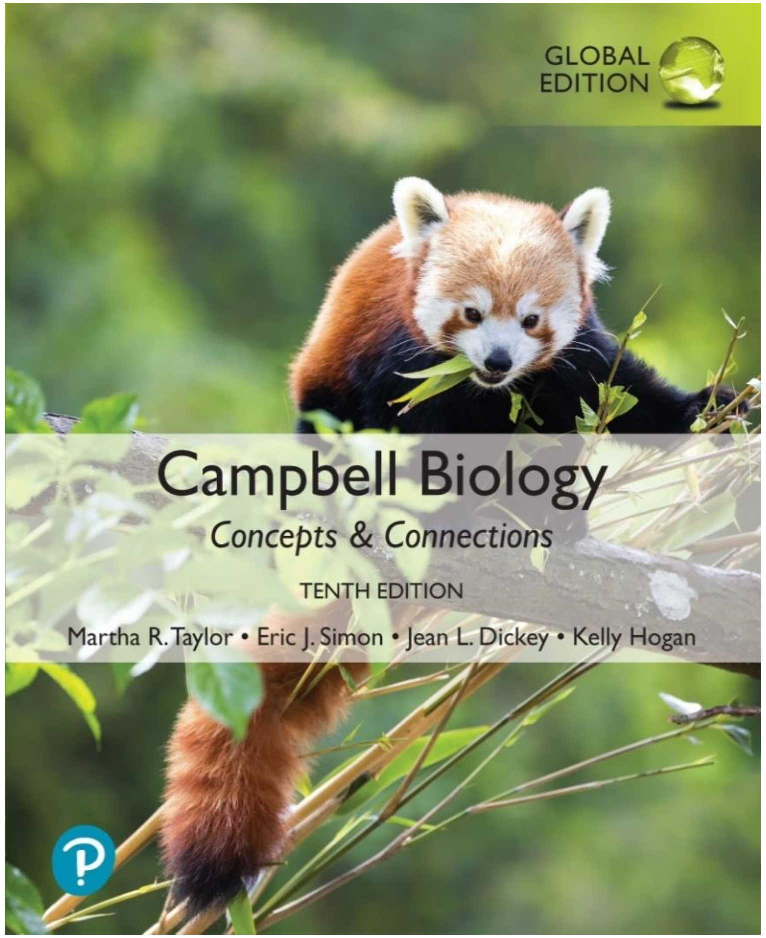


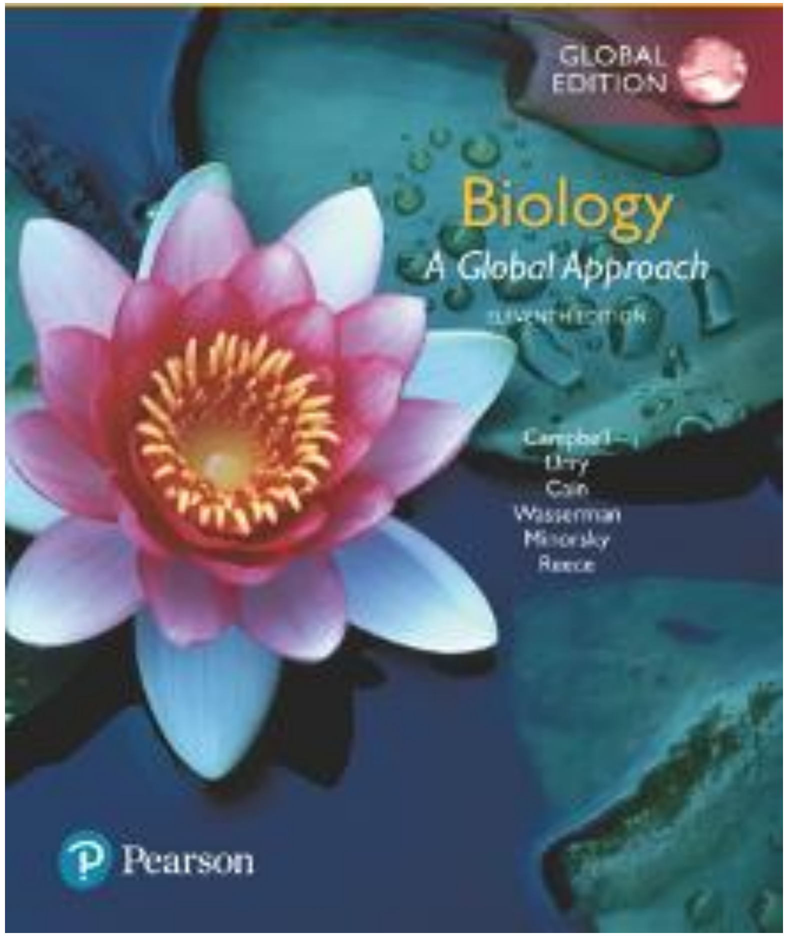
Cell Walls of Plants

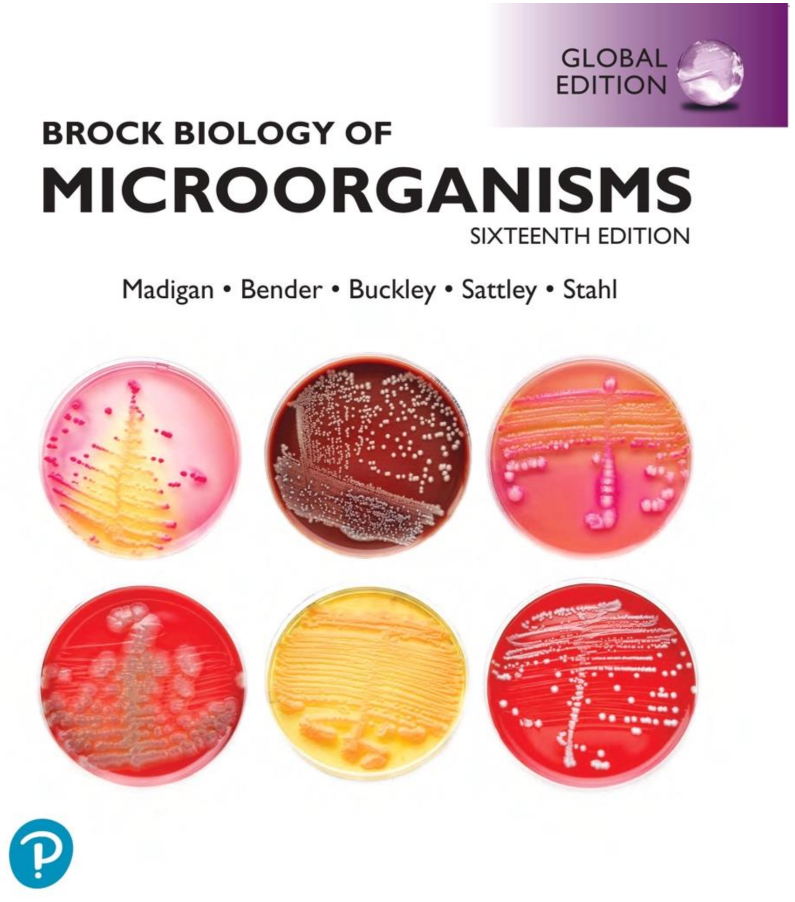
Cell Walls Enclose and Support Plant Cells

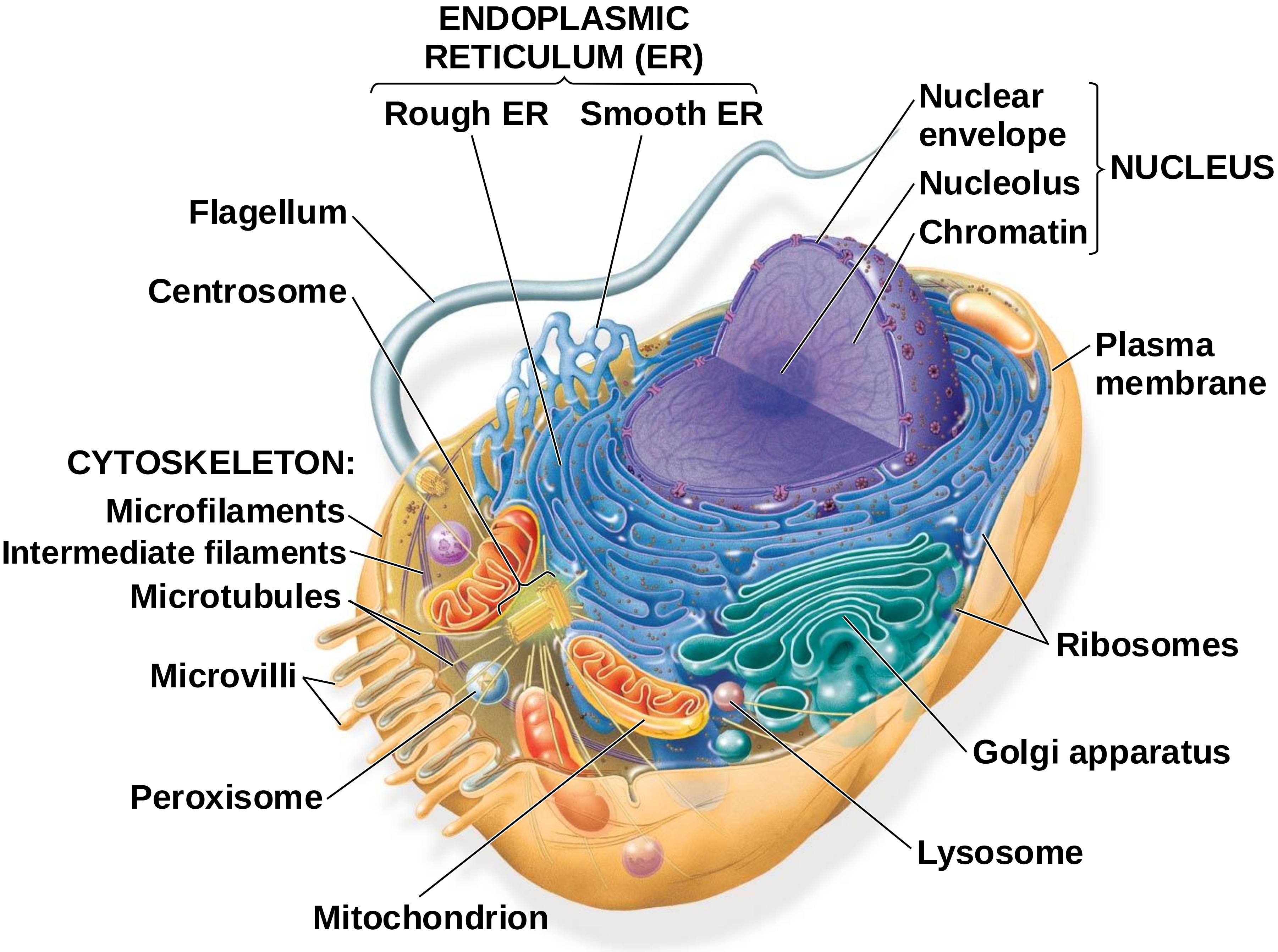
- The **cell wall** is an extracellular structure that distinguishes plant cells from animal cells
- Prokaryotes, fungi, and some protists also have cell walls
- The cell wall protects the plant cell, maintains its shape, and prevents excessive uptake of water
- Plant cell walls are made of cellulose fibers embedded in other polysaccharides and protein

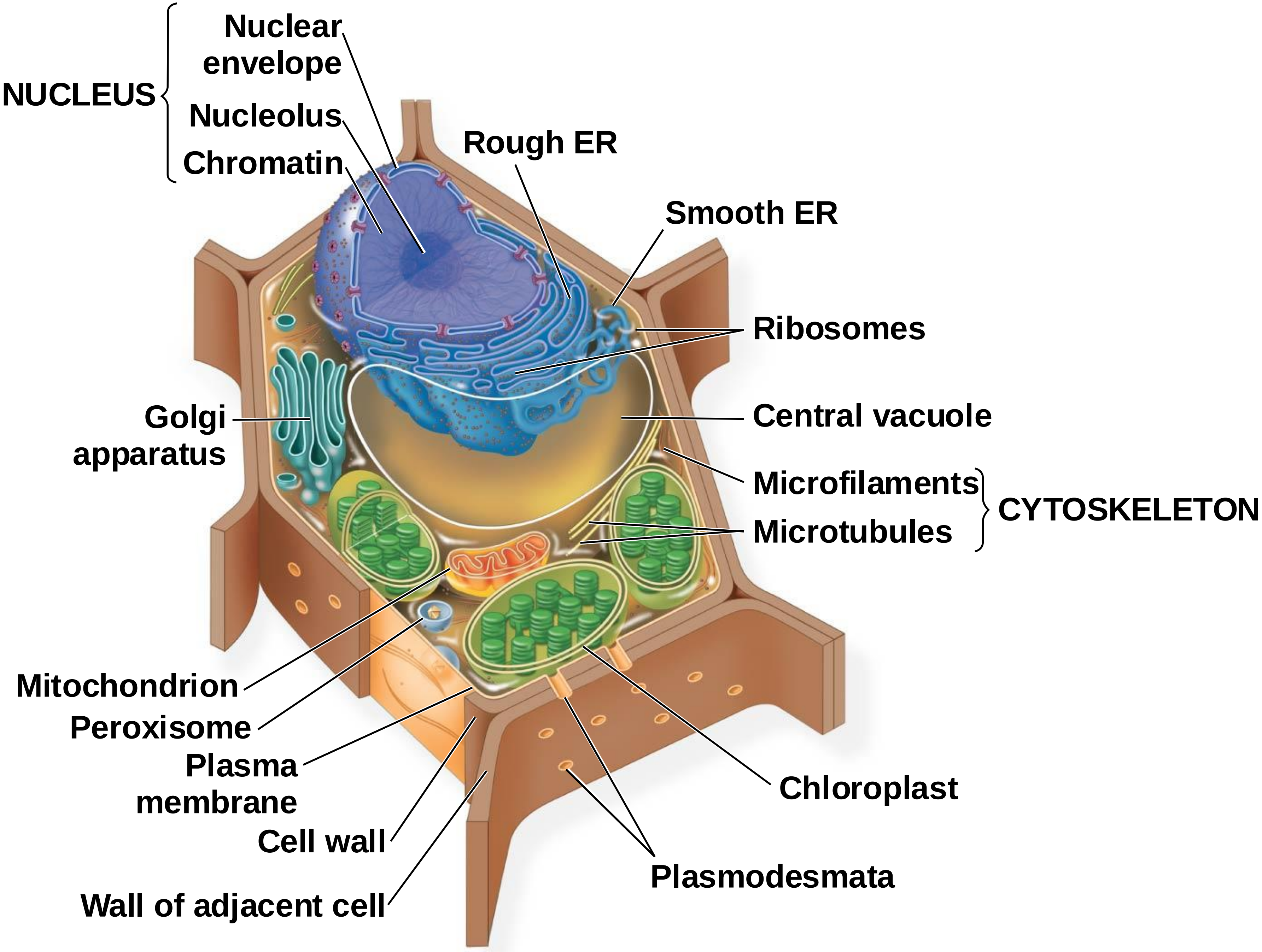
Sources:


GLOBAL EDITION
Campbell Biology
Concepts & Connections
TENTH EDITION
Martha R. Taylor • Eric J. Simon • Jean L. Dickey • Kelly Hogan

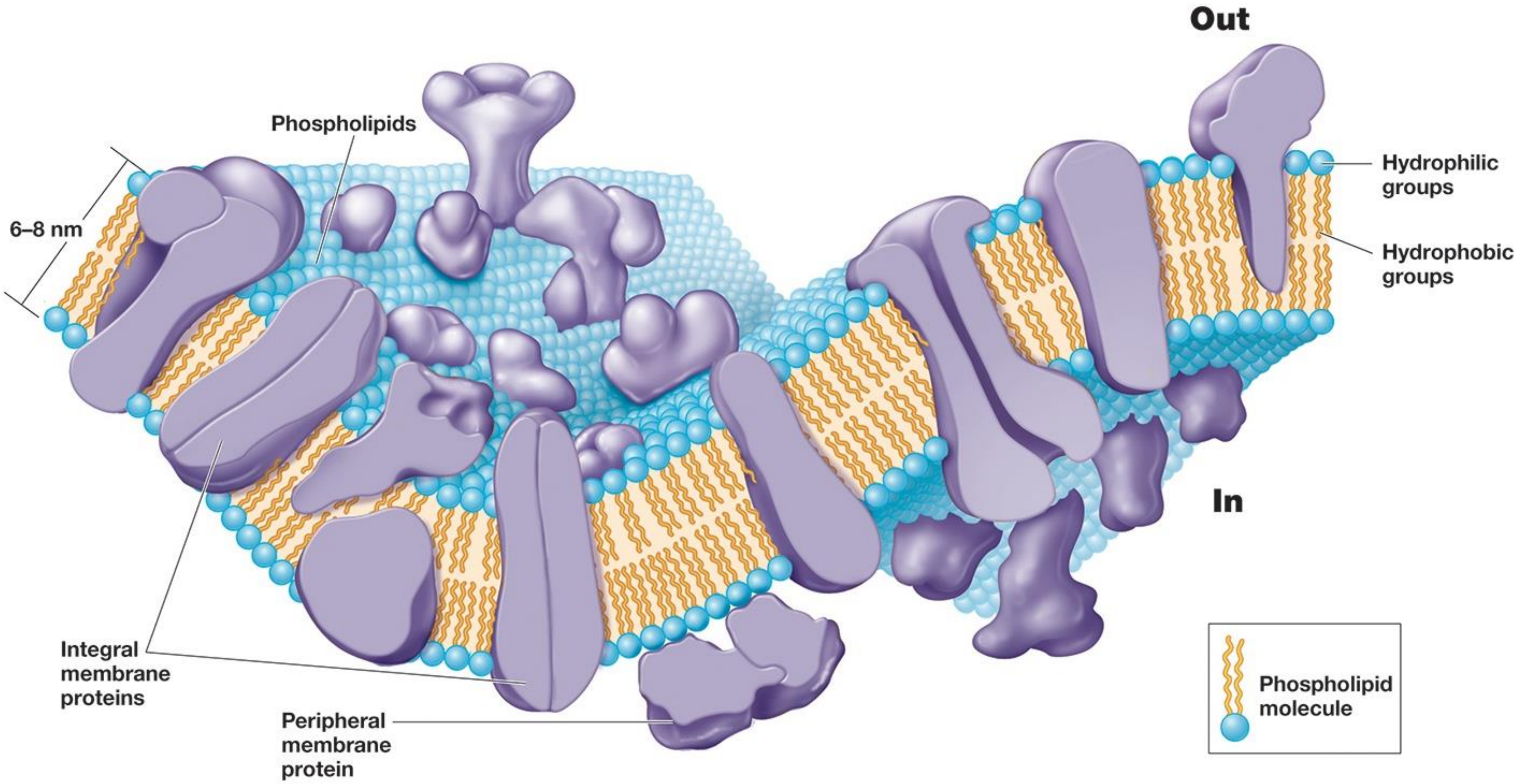

GLOBAL EDITION
Biology
A Global Approach
Cain
Wasserman
Minorsky
Reece
Pearson

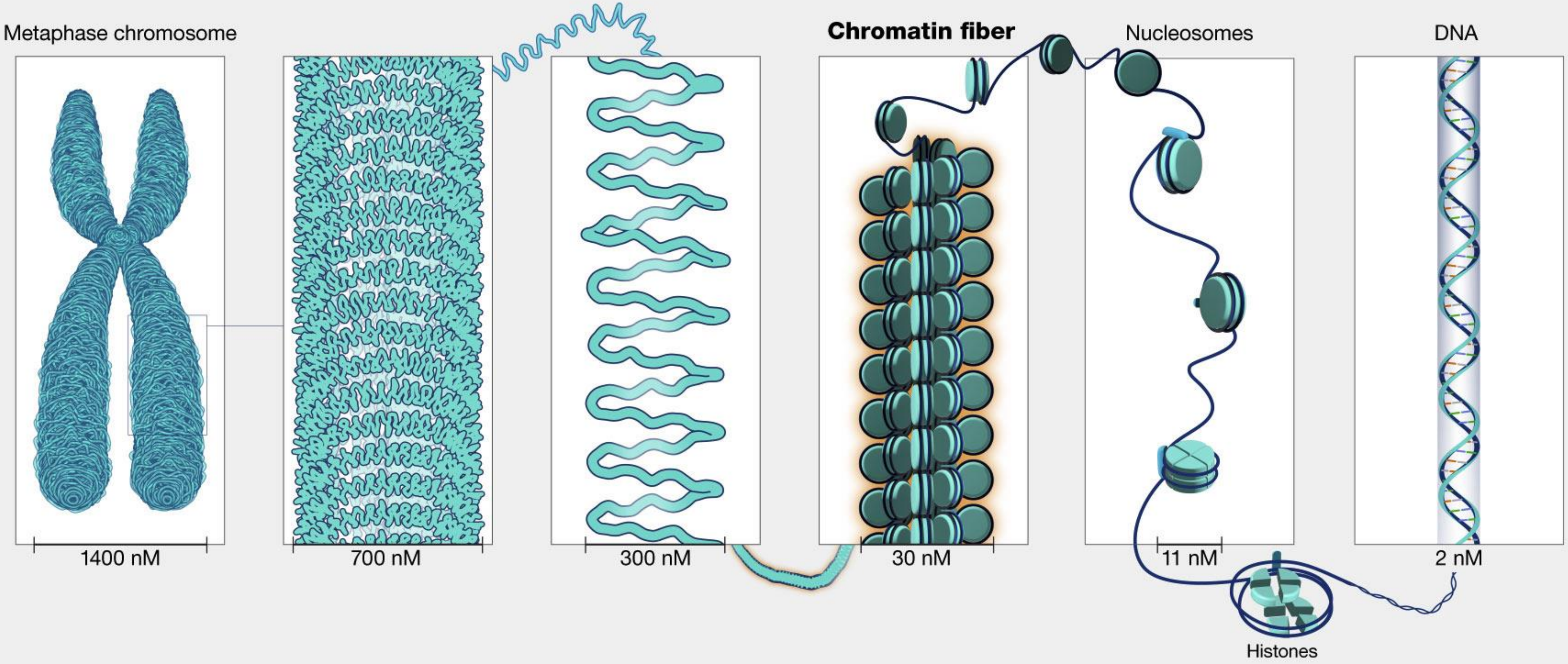

GLOBAL EDITION
BROCK BIOLOGY OF
MICROORGANISMS
SIXTEENTH EDITION
Madigan • Bender • Buckley • Sattley • Stahl


ENDOPLASMIC RETICULUM (ER)
Rough ER
Smooth ER
Nuclear envelope
Nucleolus
Chromatin
NUCLEUS
Flagellum
Centrosome
Plasma membrane
CYTOSKELETON:
Microfilaments
Intermediate filaments
Microtubules
Microvilli
Ribosomes
Golgi apparatus
Peroxisome
Lysosome
Mitochondrion


NUCLEUS
Nuclear envelope
Nucleolus
Chromatin
Rough ER
Smooth ER
Ribosomes
Golgi apparatus
Central vacuole
Microfilaments
Microtubules
CYTOSKELETON
Mitochondrion
Peroxisome
Plasma membrane
Cell wall
Wall of adjacent cell
Chloroplast
Plasmodesmata

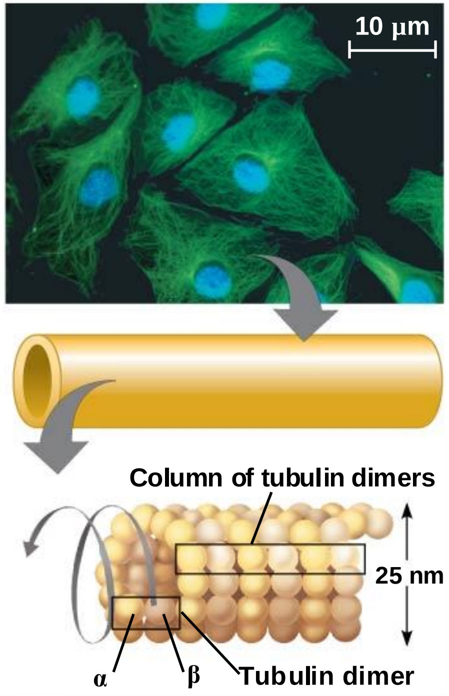
Plasma Membrane

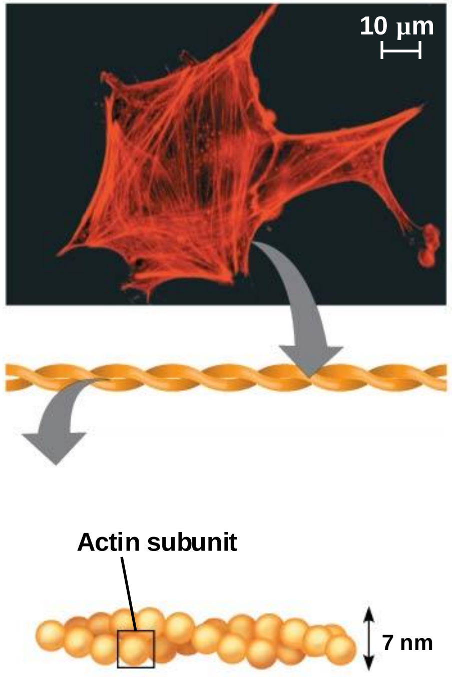


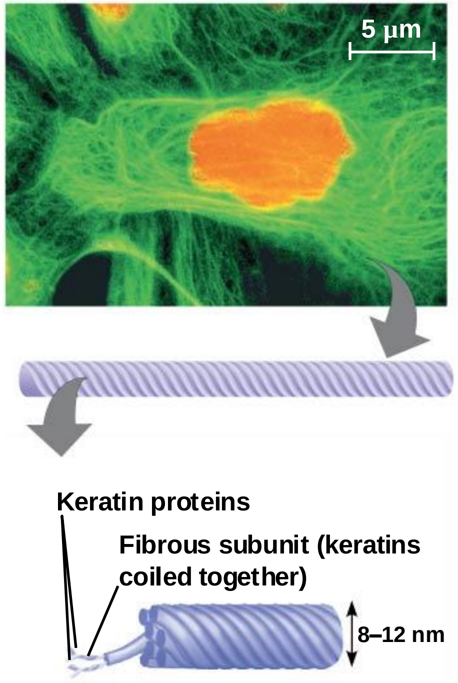

Metaphase chromosome
Chromatin fiber
Nucleosomes
DNA
1400 nM
700 nM
300 nM
30 nM
11 nM
2 nM
Histones

Property	Microtubules (Tubulin Polymers)	Microfilaments (Actin Filaments)	Intermediate Filaments
Structure	Hollow tubes	Two intertwined strands of actin	Fibrous proteins coiled into cables
Diameter	25 nm with 15-nm lumen	7 nm	8–12 nm
Protein subunits	Tubulin, a dimer consisting of α-tubulin and β-tubulin	Actin	One of several different proteins (such as keratins)
Main functions	Maintenance of cell shape (compression-resisting “girder”); cell motility (as in cilia or flagella); chromosome movements in cell division; organelle movements	Maintenance of cell shape (tension-bearing elements); changes in cell shape; muscle contraction; cytoplasmic streaming in plant cells; cell motility (as in amoeboid movement); division of animal cells	Maintenance of cell shape (tension-bearing elements); anchorage of nucleus and certain other organelles; formation of nuclear lamina

Fluorescence micrographs of fibroblasts. Fibroblasts are a favorite cell type for cell biology studies because they spread out flat and their internal structures are easy to see. In each, the structure of interest has been tagged with fluorescent molecules. The DNA in the nucleus has also been tagged in the first micrograph (blue) and third micrograph (orange).





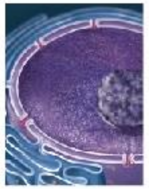
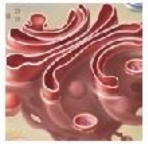


The Cell's Internal Skeleton Helps Organize Its Structure and Activities

Which component of the cytoskeleton is most important in

a. holding the nucleus in place within an animal cell — intermediate filaments
b. guiding transport vesicles from the Golgi to the plasma membrane — microtubules
c. contracting muscle cells — microfilaments

TABLE 4.22 Eukaryotic Cell Structures and Their Functions

Structure	Function
1. Genetic Control	
Nucleus 	DNA replication, RNA synthesis; assembly of ribosomal subunits (in nucleolus)
Ribosomes	Polypeptide (protein) synthesis
2. Manufacturing, Distribution, and Breakdown	
Rough ER	Synthesis of membrane lipids and proteins, secretory proteins, and hydrolytic enzymes; formation of transport vesicles
Smooth ER	Lipid synthesis; detoxification in liver cells; calcium ion storage in muscle cells
Golgi apparatus 	Modification and sorting of ER products; formation of lysosomes and transport vesicles
Lysosomes (in animal cells and some protists)	Digestion of ingested food or bacteria and recycling of a cell's damaged organelles and macromolecules
Vacuoles	Digestion (food vacuole); water balance (contractile vacuole); storage of chemicals and cell enlargement (central vacuole in plant cells)
Peroxisomes (not part of endomembrane system)	Diverse metabolic processes, with breakdown of toxic hydrogen peroxide by-product
3. Energy Processing	
Mitochondria 	Cellular respiration: conversion of chemical energy in food to chemical energy of ATP
Chloroplasts (in plants and algae)	Photosynthesis: conversion of light energy to chemical energy of sugars
4. Structural Support, Movement, and Communication Between Cells	
Cytoskeleton (microfilaments, intermediate filaments, and microtubules) 	Maintenance of cell shape; anchorage for organelles; movement of organelles within cells; cell movement (crawling, muscle contraction, bending of cilia and flagella)
Plasma membrane	Regulate traffic in and out of cell
Extracellular matrix (in animals)	Support; regulation of cellular activities
Cell junctions 	Communication between cells; binding of cells in tissues
Cell walls (in plants)	Support and protection; binding of cells in tissues

How does the internal organization of eukaryotic cells allow them to perform the functions of life?