Introduction to Bioinformatics

Structure of Cells

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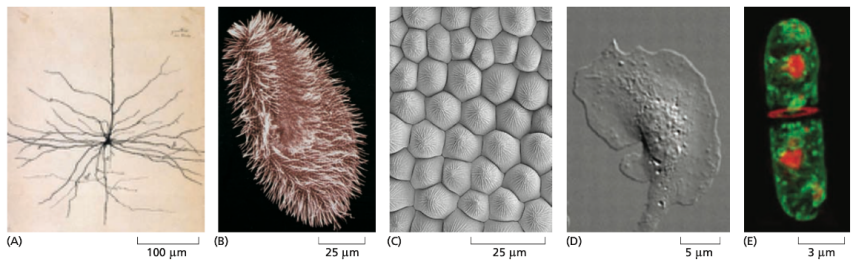
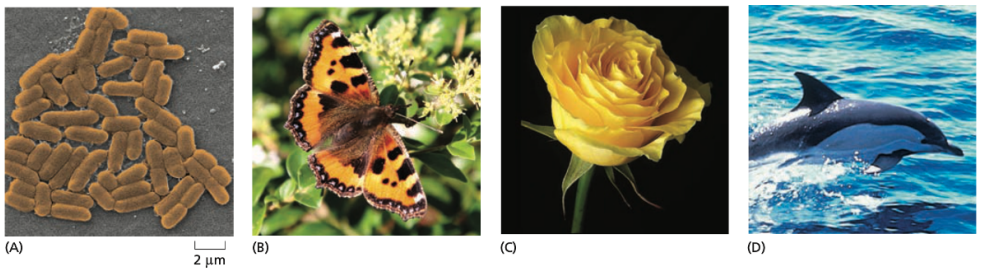
Presentation Overview

Cells: The Fundamental Units of Life

- **What is life?** Petunias, people, and pond scum are living; stones and sand are not.
- **Cell theory:** All living things are built from cells that grow and divide from pre-existing cells.

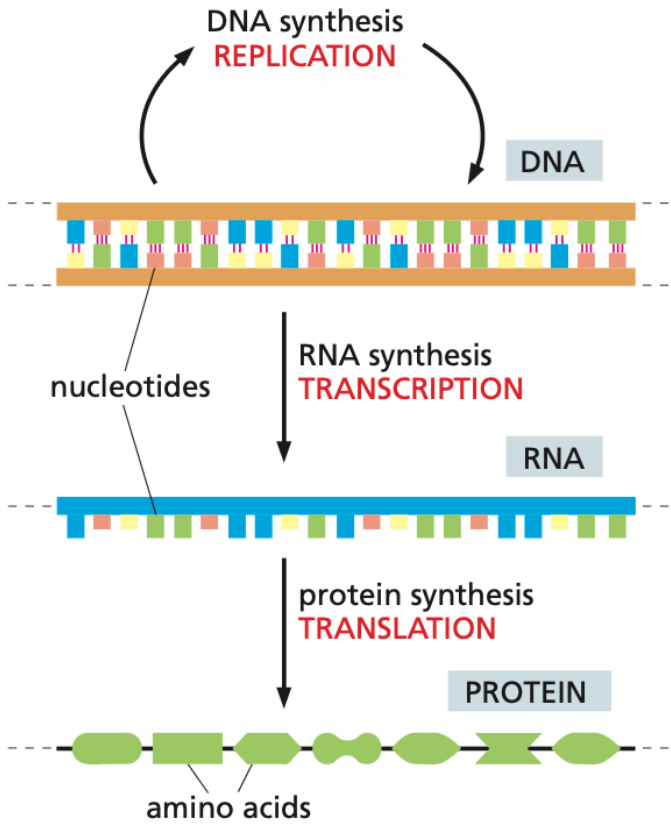


- **Why cells?** They are the basic units of structure and function; communities of specialized cells form tissues and organisms.



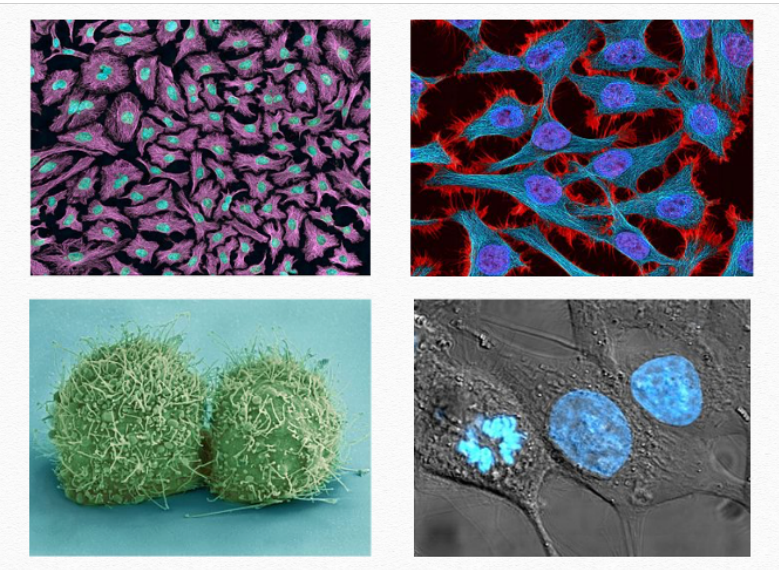
Cells

- Small, membrane-enclosed units with aqueous interior that can grow and divide.
- Sizes: $\sim$1–1000 μm (bacteria $\rightarrow$ frog egg).
- Shapes reflect function: neurons, ciliated protozoa, macrophages, yeasts.
- **Common chemistry:** DNA $\rightarrow$ RNA $\rightarrow$ Protein (central dogma).
- **Autocatalysis:** DNA/RNA store information; proteins catalyze making DNA, RNA, and proteins.



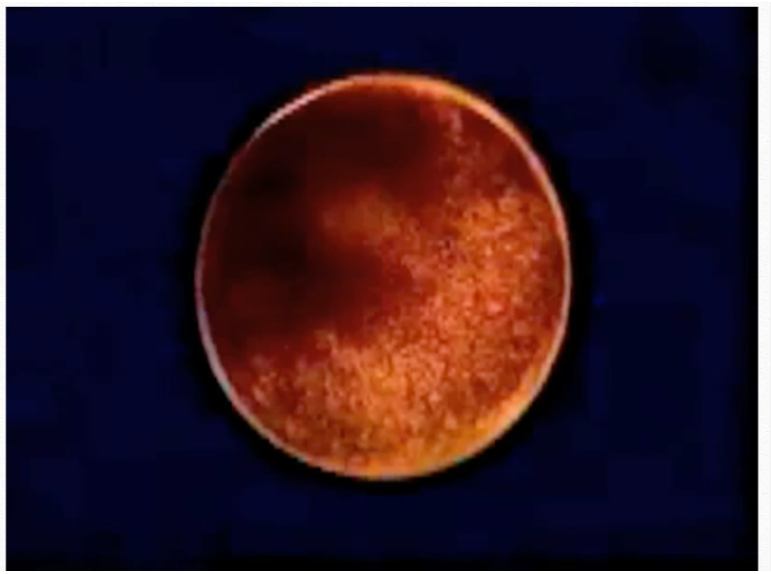
HeLa Cells

- Immortal human epithelial cell line from Henrietta Lacks (1951, cervical cancer).
- First robust human cells in culture; enabled vaccines, virology, cancer biology, drug screens.



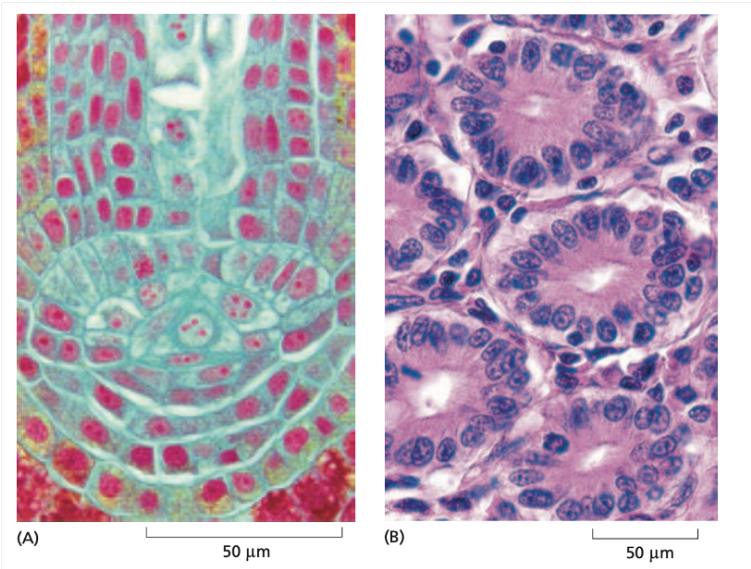
Cells in Embryos

- Same genome, different fates: cells proliferate, migrate, and **differentiate**.
- Cell–cell signals and environment $\rightarrow$ selective gene expression.
- One fertilized egg $\rightarrow$ many specialized cell types (muscle, neuron, skin).



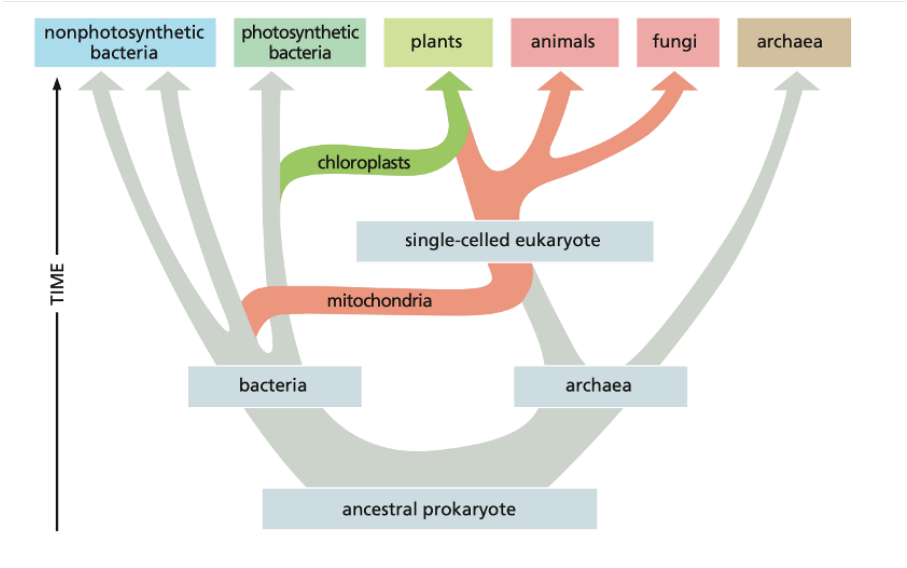
Tissues

- Cooperative groups of specialized cells + extracellular matrix (ECM).
- Examples: epithelial sheets, muscle, connective tissue, nervous tissue, plant epidermis.
- Division of labor enables specialization (contraction, secretion); ECM provides structural and signaling context.



Kingdoms of Life vs Domains

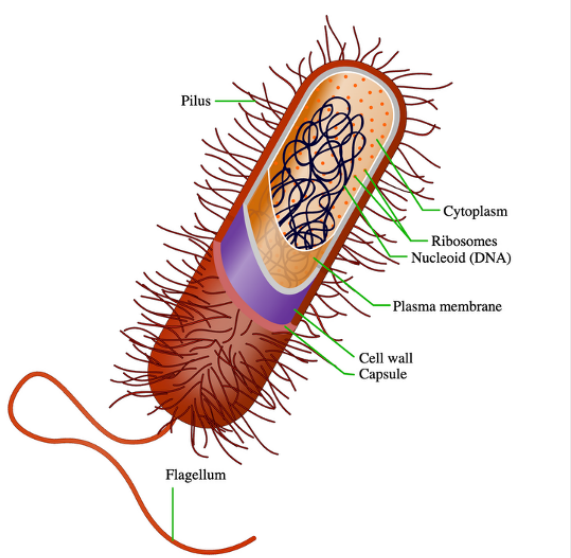
- **Classic Kingdoms (historical):** Animals, Plants, Fungi, Protists, (Monera).
- **Modern view:** Three Domains by molecular phylogeny: **Bacteria, Archaea, Eukarya**.
- Eukarya includes animals, plants, fungi, and protists; Archaea occur in extreme and common habitats.



Prokaryotes

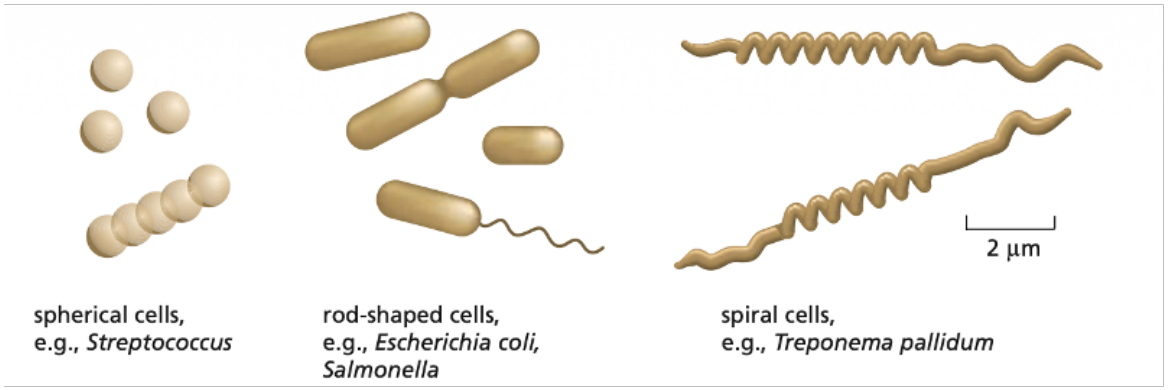
- Cells **without** a nucleus; include **Bacteria** and **Archaea**.
- Small (few μm), fast division (as little as $\sim$20 min), diverse metabolisms.
- Single compartment: cytoplasm + DNA; ribosomes present; no membrane-bound organelles.
- Most are single-celled; some form chains/clusters; chemically the most diverse class of cells.

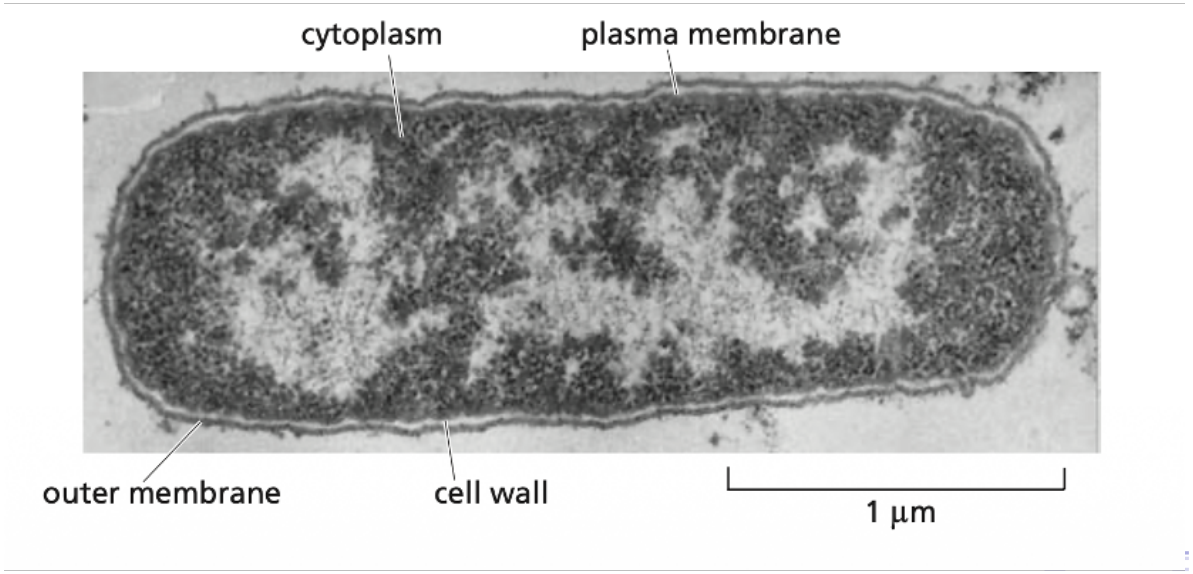
- Some are aerobic, using oxygen to oxidize food molecules. Some are strictly anaerobic and are killed by the slightest exposure to oxygen



Shapes of Bacteria

- **Coccus** (spherical)
- **Bacillus** (rod-shaped)
- **Spirillum/Spirochete** (spiral/corkscrew)

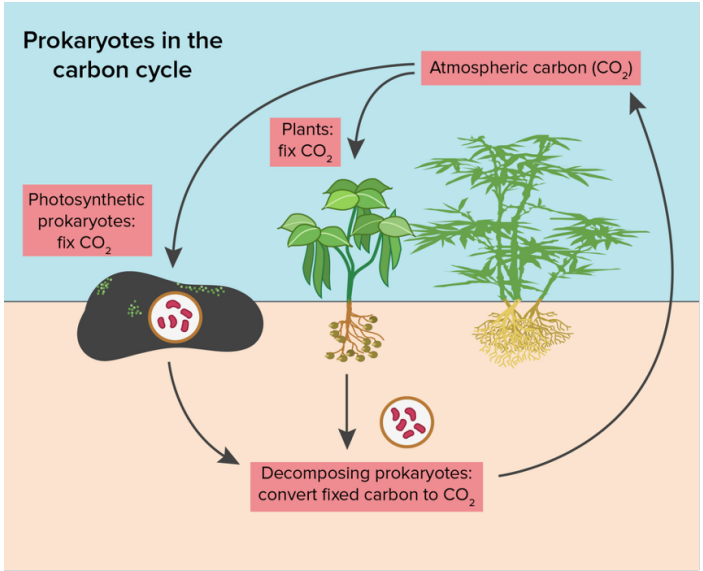




Prokaryotic Metabolism

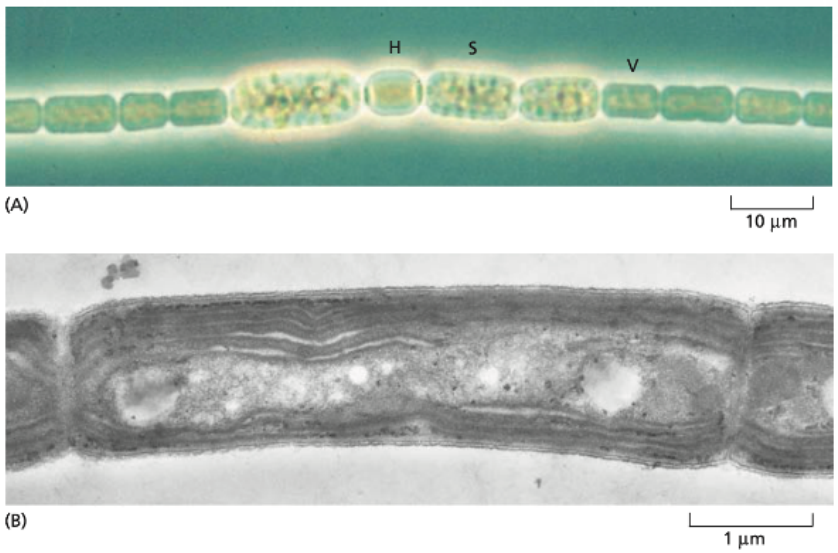
- **Aerobic** vs **anaerobic** (O_2 required vs toxic).
- **Carbon sources:** CO_2 (autotroph) vs organic carbon (heterotroph).
- **Nitrogen:** some fix N_2; others use ammonia, nitrate, etc.

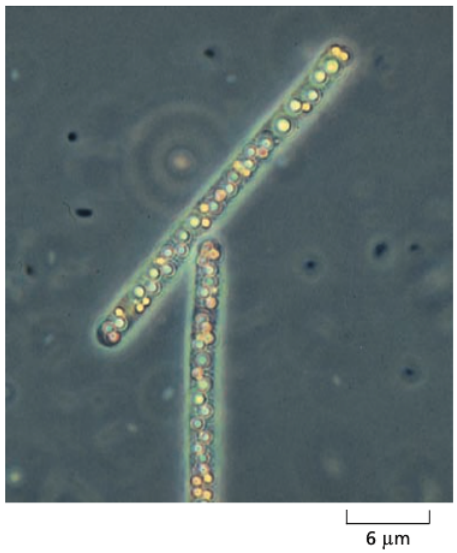
- Specialists: sulfur oxidizers (e.g., *Beggiatoa*), iron oxidizers, methanogens.
- Some prokaryotes can live entirely on inorganic substances (CO_2, N_2, O_2, H, S, P).



Prokaryotic Sources of Energy

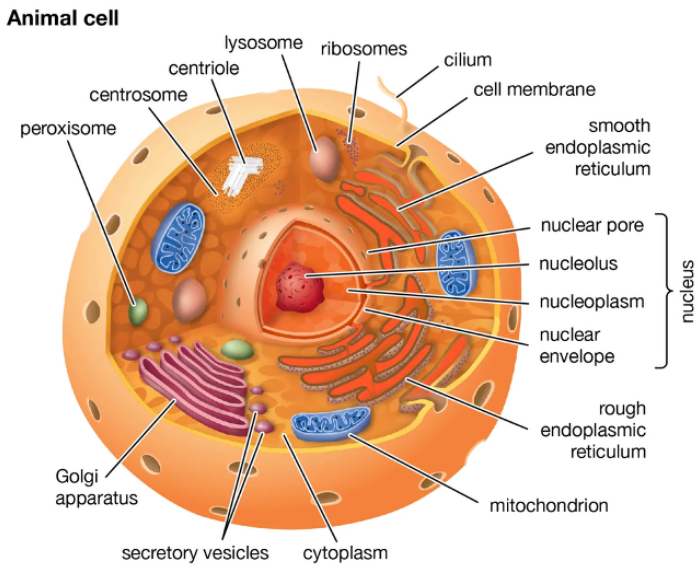
- **Phototrophs:** capture light (photosynthesis), e.g., cyanobacteria.
- **Chemolithotrophs:** energy from inorganic chemicals (H_2S, Fe^{2+}, NH_3).
- **Chemoorganotrophs:** energy from organic molecules (sugars, fats).

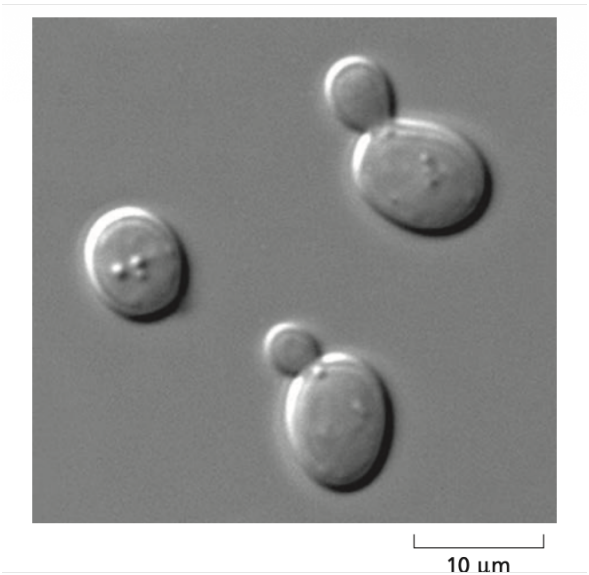




Eukaryotes

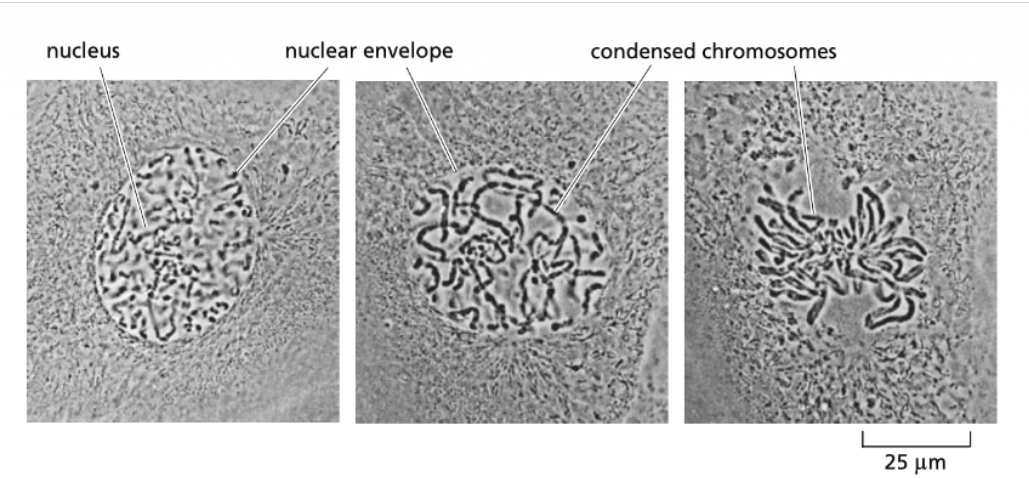
- Cells with a **nucleus** and **membrane-bound organelles**.
- Single-celled (amoebae, yeasts) and multicellular (animals, plants, fungi).
- Typically larger; internal compartmentalization enables complex regulation.

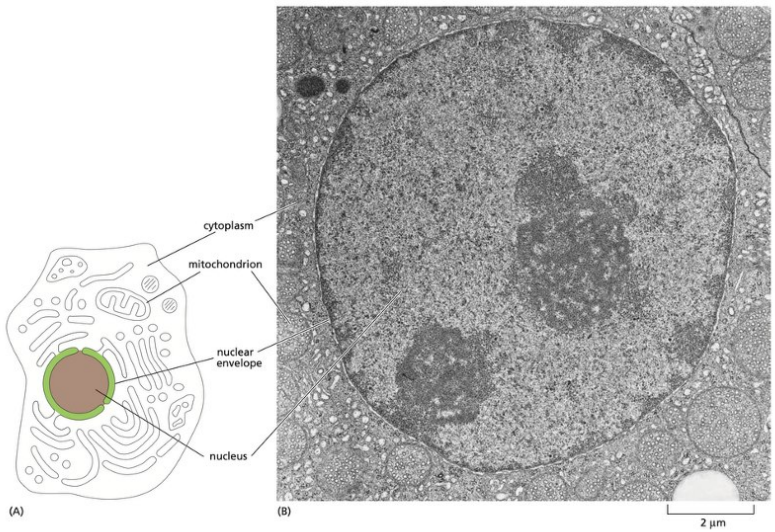




Nucleus: Information Store of the Cell

- **Nuclear envelope:** double membrane; nuclear pores regulate traffic.
- **DNA** packaged into **chromosomes**; condense visibly during division.
- **Nucleolus:** rRNA synthesis and ribosome assembly.





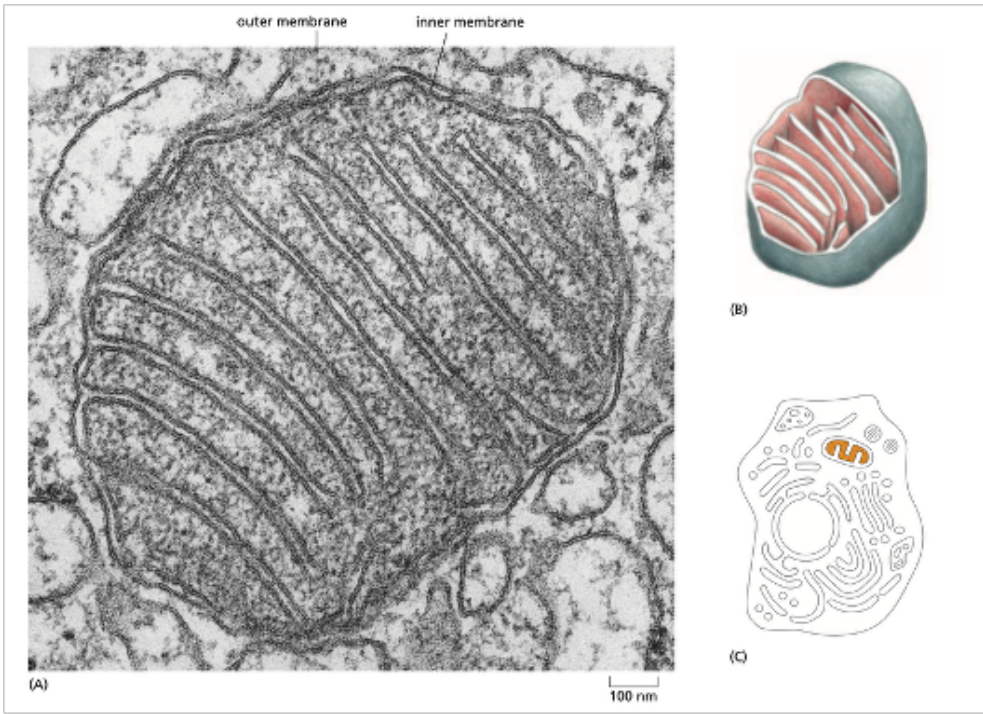
Mitochondria

- Present in essentially all eukaryotic cells; conspicuous in cytoplasm.
- Contain their own DNA and divide by fission.
- Double membrane with folded inner membrane (cristae).

Mitochondria: Function

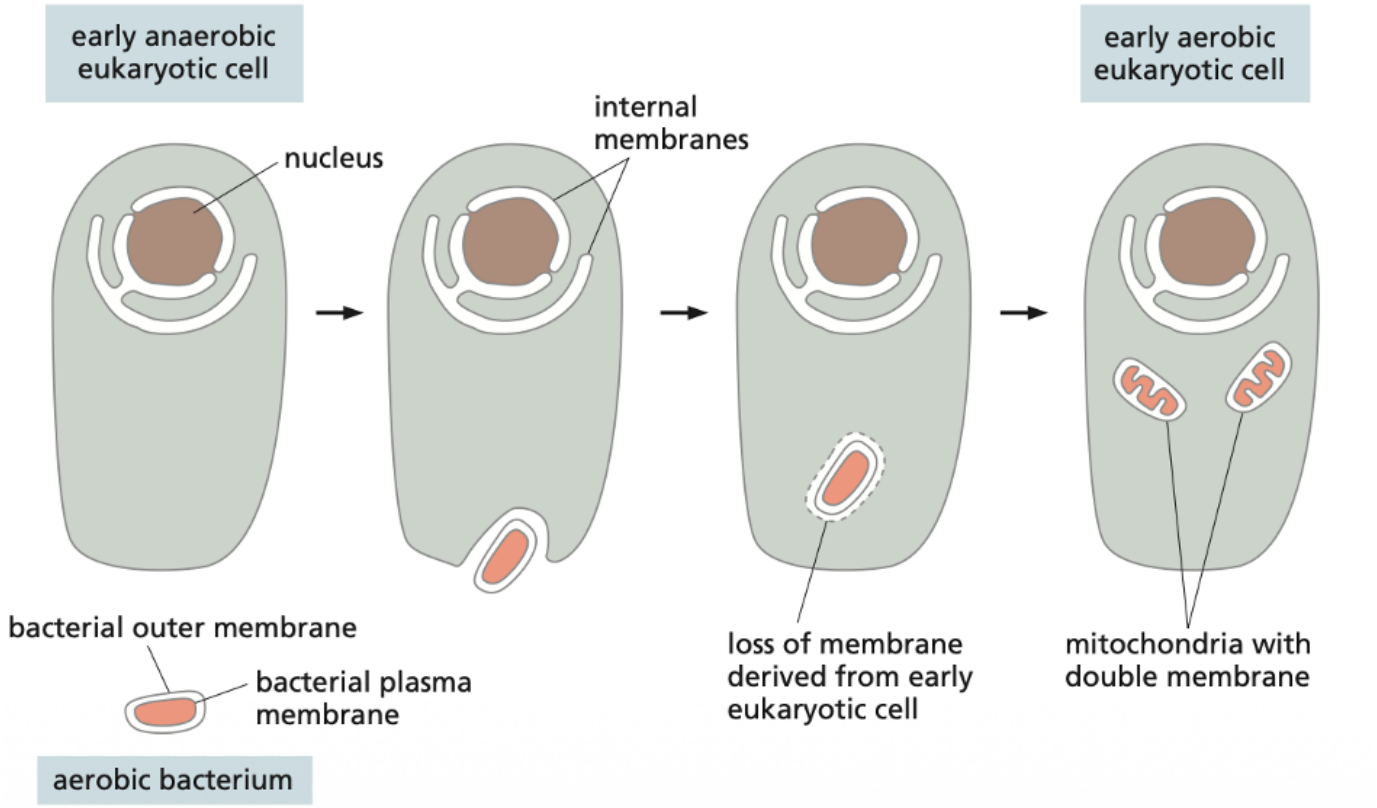
- Generators of chemical energy (ATP) by oxidizing food molecules: **cellular respiration**.
- Consume O_2 and release CO_2; central to energy metabolism.

- Functional discovery via cell fractionation and testing of purified mitochondria.
- Some anaerobic eukaryotes (e.g., *Giardia*) lack typical mitochondria.



Mitochondria: Origin (Endosymbiosis)

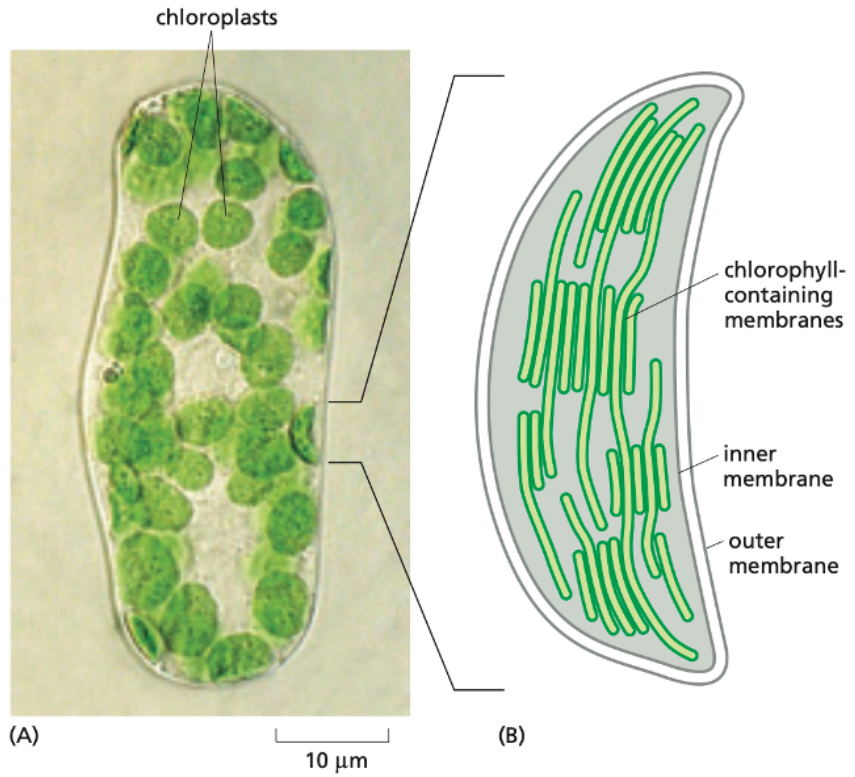
- Derived from engulfed aerobic bacteria $\rightarrow$ symbiosis with early eukaryote.
- Evidence: double membrane, bacterial-like ribosomes, circular DNA, division by fission.



Chloroplasts: Function

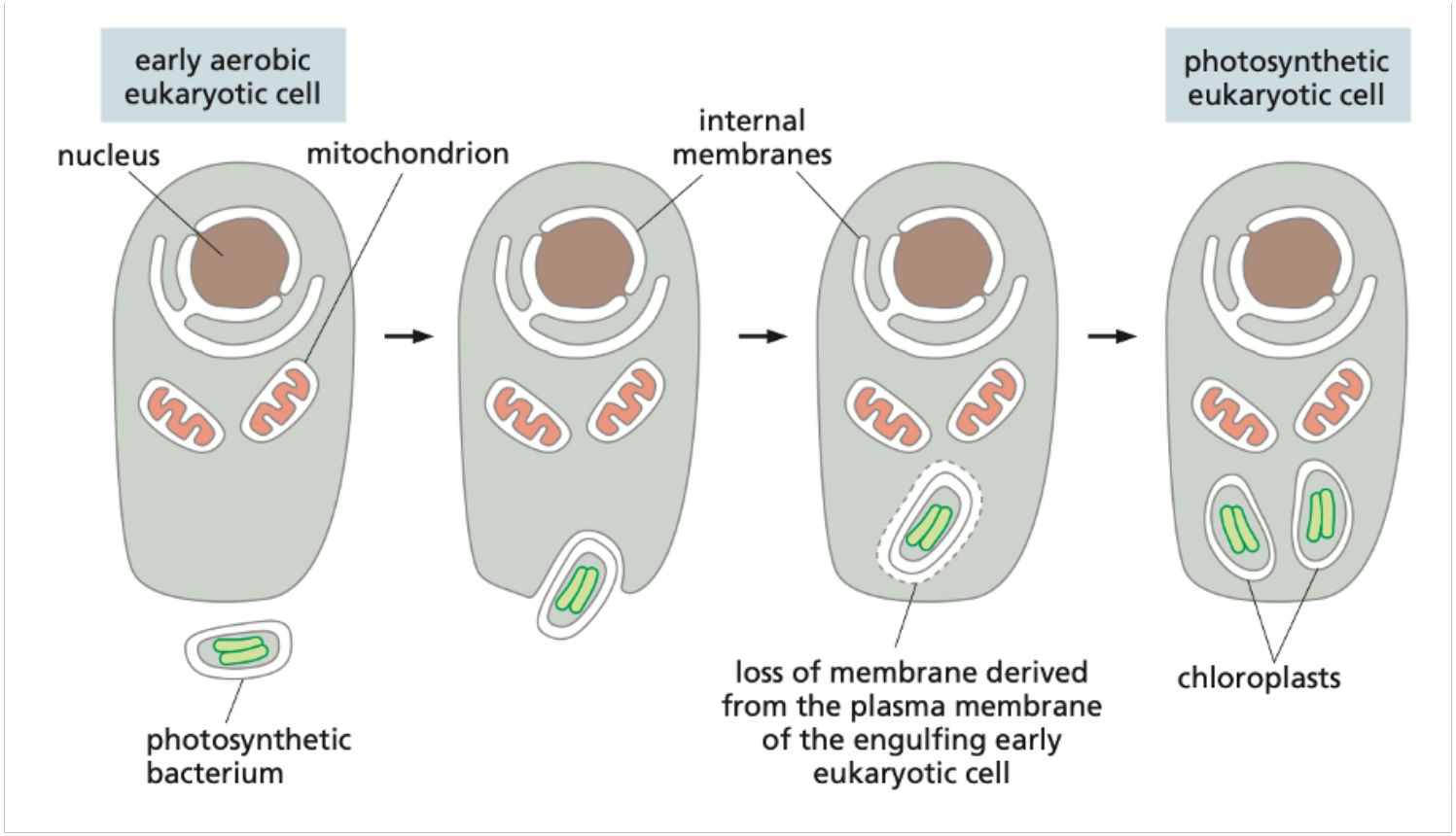
- **Photosynthesis:** light $\rightarrow$ chemical energy; fixes CO_2 into sugars; releases O_2.
- Internal thylakoid membranes with chlorophyll.

- Plant cells oxidize sugars in mitochondria to make ATP as needed.
- Large, green organelles in plants and algae.



Chloroplasts: Origin (Endosymbiosis)

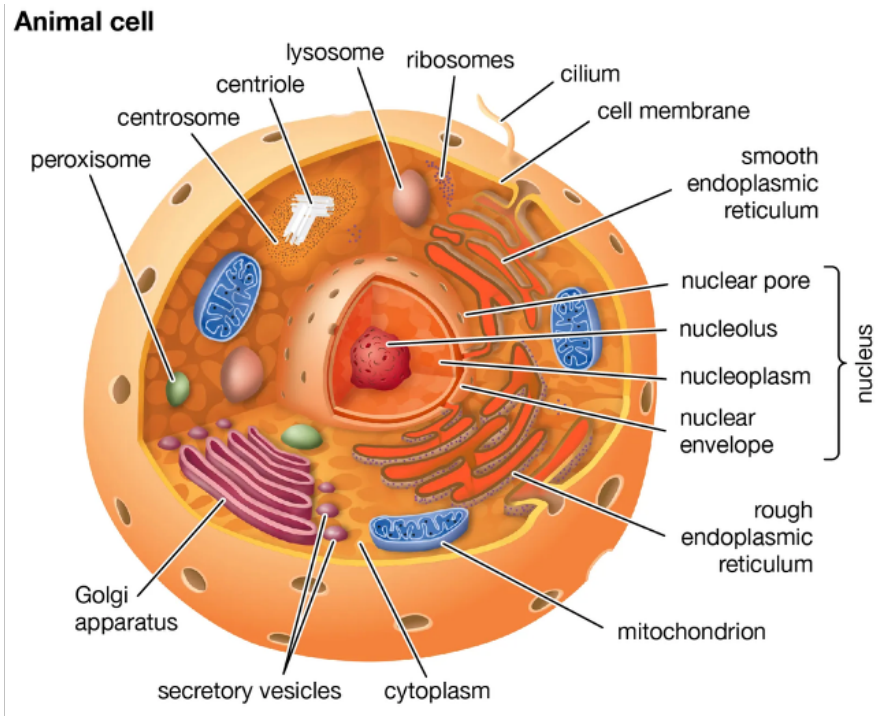
- From engulfed photosynthetic bacteria (cyanobacteria-like).
- Own DNA, bacterial ribosomes; divide by fission; double membrane.



Other Organelles

- **Endoplasmic Reticulum (ER):** lipid/protein synthesis (RER with ribosomes; SER without).
- **Golgi apparatus:** processing, modification, and sorting.
- **Lysosomes:** intracellular digestion and recycling.

- **Peroxisomes:** detox reactions using H_2O_2.
- **Endosomes:** sorting centers after endocytosis.
- **Cytosol:** concentrated aqueous gel for metabolism and protein synthesis.



Endoplasmic Reticulum (ER)

- Network of **interconnected membrane-bound sacs and tubules**.
- Synthesizes **lipids** and **membrane proteins**.
- **Rough ER** has ribosomes attached $\rightarrow$ primary site of **protein synthesis**.
- Continuous with the **nuclear envelope**, allowing direct transport of proteins into the ER.
- Key for maintaining cell structure and intracellular transport.

Endoplasmic Reticulum Image

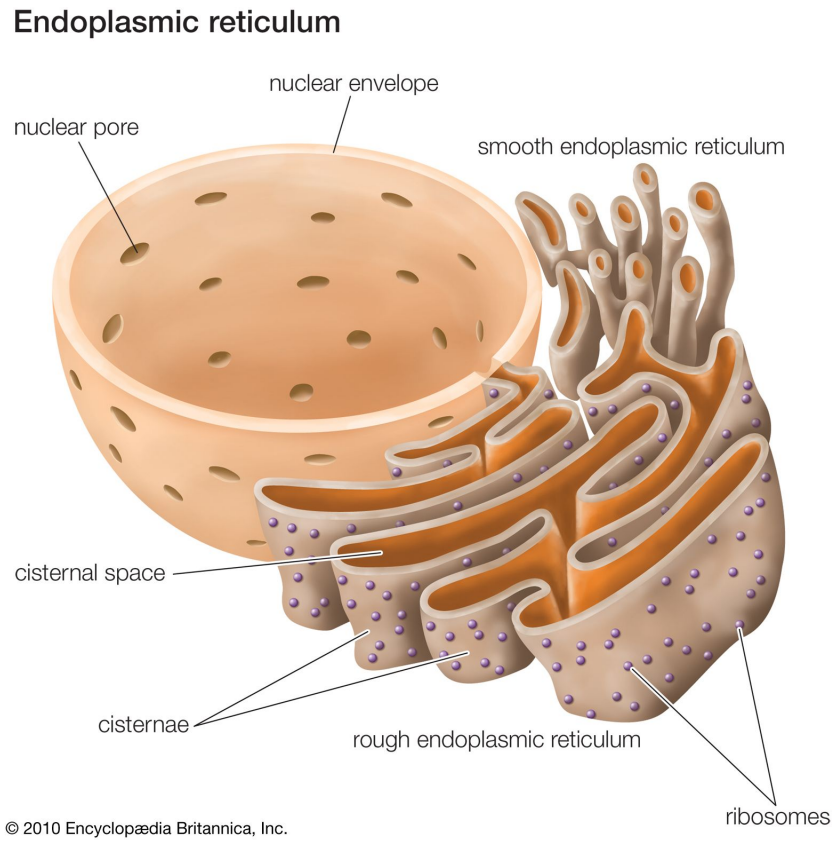


Figure: Rough and smooth ER network. Ribosome-studded areas are rough ER. Source: Britannica

Golgi Apparatus

- Composed of **stacked, flattened membrane sacs**.
- Receives proteins and lipids from the ER for further modification.
- Performs chemical modifications: **glycosylation, phosphorylation, sulfation**.
- Sorts and packages molecules into vesicles for transport to other organelles or the plasma membrane.
- Essential for secretion and membrane composition regulation.

Golgi Apparatus Image

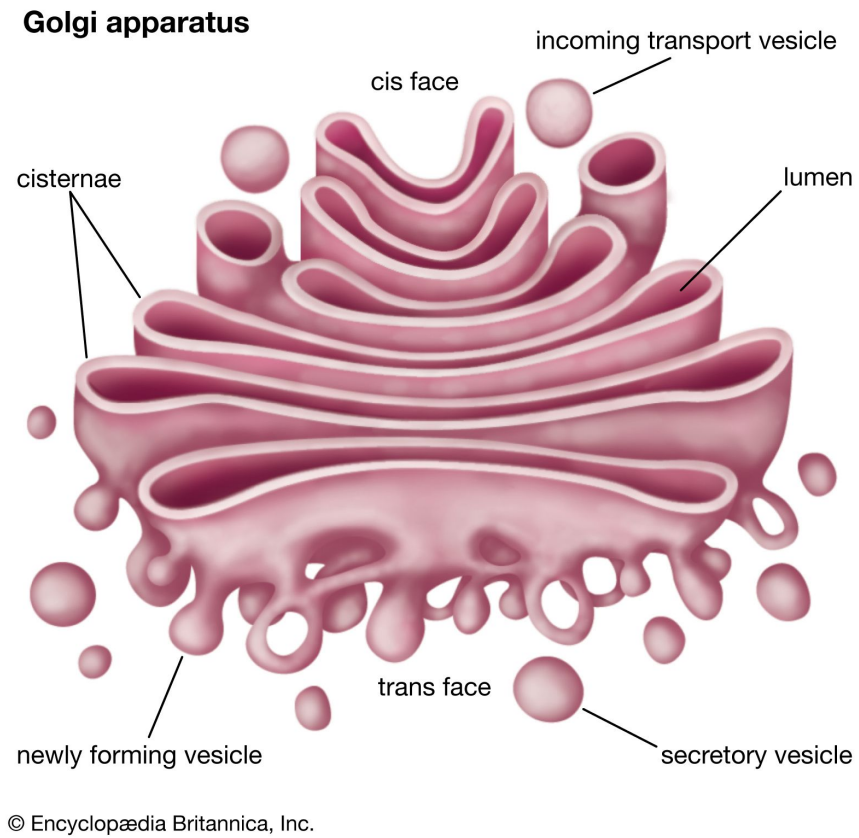


Figure: Golgi apparatus; site of protein modification and vesicle packaging. Source: Britannica

Lysosomes

- Small, membrane-bound organelles containing **digestive enzymes**.
- Break down macromolecules and recycle cell components.
- Formed from **endosomes** after endocytosis.
- Protect the cell by safely digesting waste and foreign material.
- Critical for autophagy, immune response, and nutrient recycling.

Lysosome Image

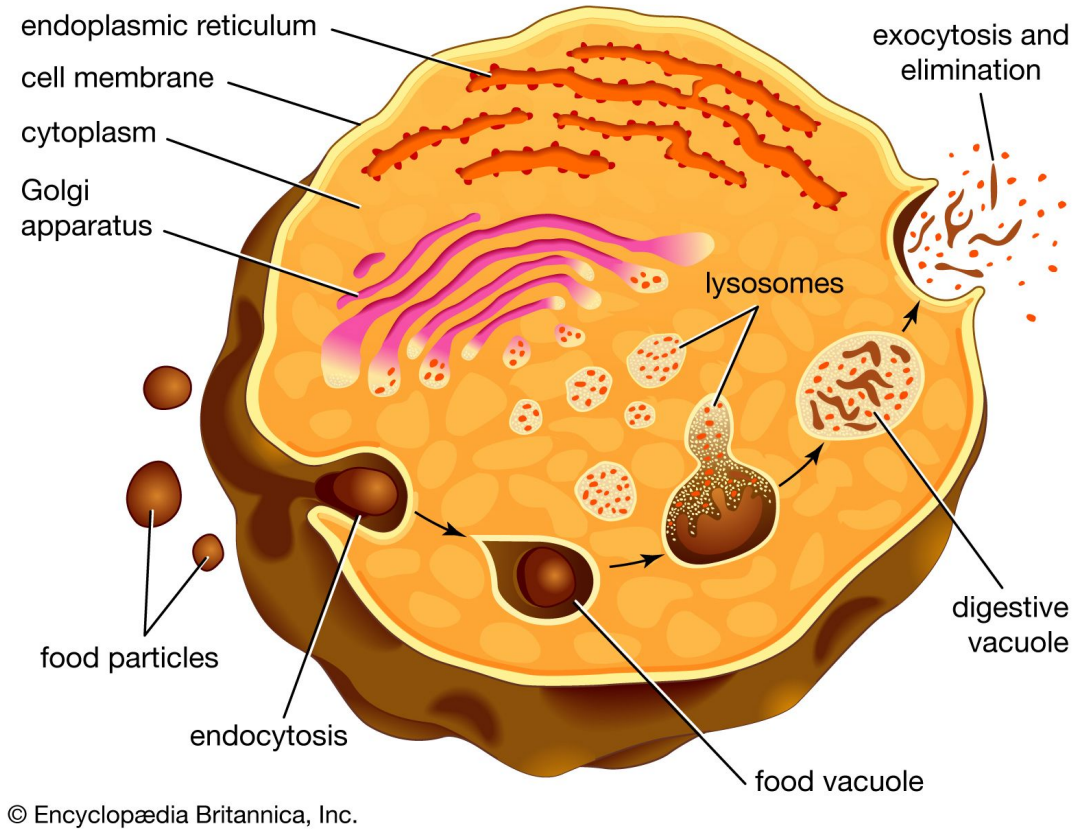


Figure: Lysosomes digest internalized material. Source: Britannica

Peroxisomes

- Membrane-enclosed vesicles containing **oxidative enzymes**.
- Metabolize hydrogen peroxide and other reactive oxygen species.
- Detoxify harmful molecules and protect the cell from oxidative damage.
- Important in lipid metabolism and liver function.

Peroxisome Image

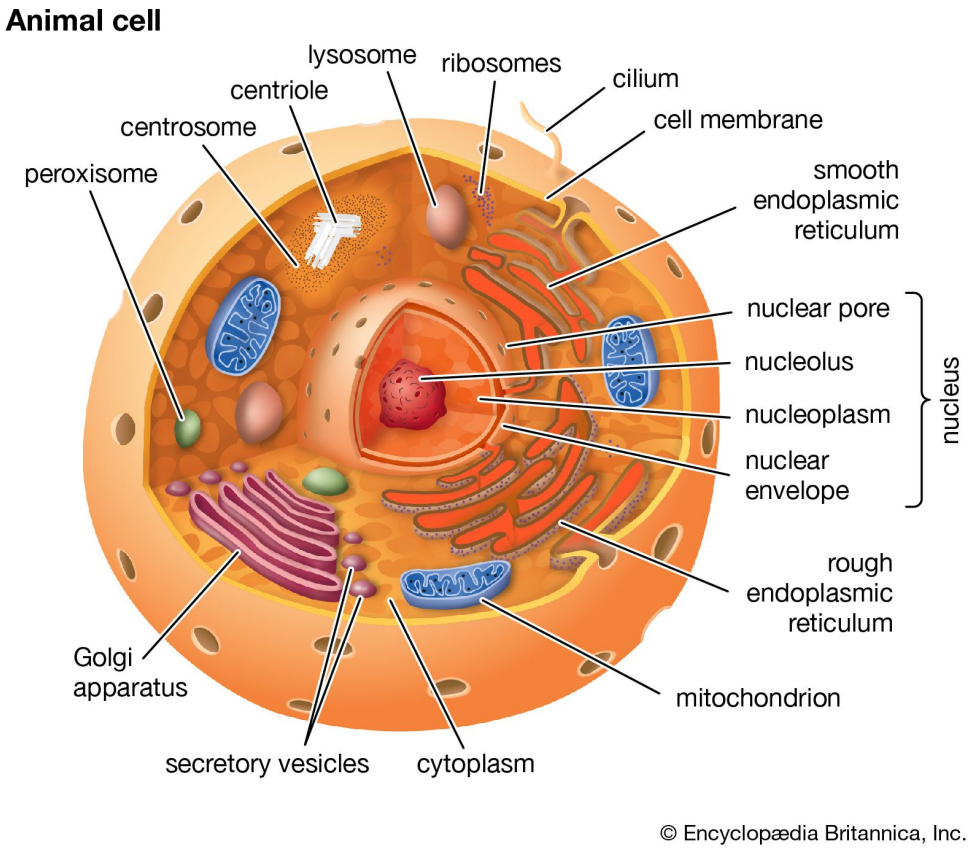


Figure: Peroxisome containing oxidative enzymes. Source: Britannica

Vesicles

- Small, membrane-bound sacs that transport cargo between organelles or to the cell surface.
- Can form from budding of ER or Golgi and fuse with other membranes.
- Analogy: **tiny transport vehicles** for proteins and molecules.
- Crucial for cellular logistics and secretion.

Vesicle Image

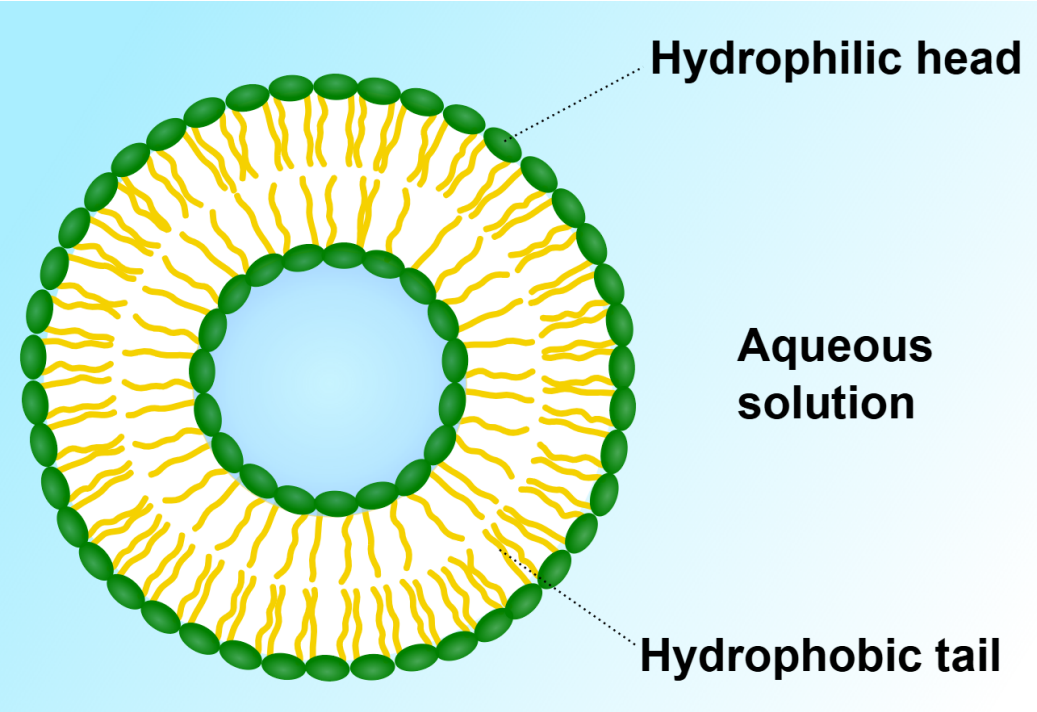


Figure: Vesicle structure. Source: Wikipedia

Endocytosis

- Plasma membrane folds inward to form vesicles.
- Enables cells to engulf large particles, fluids, or even other cells.
- Important in nutrient uptake, immune defense, and signaling.

Endocytosis Image

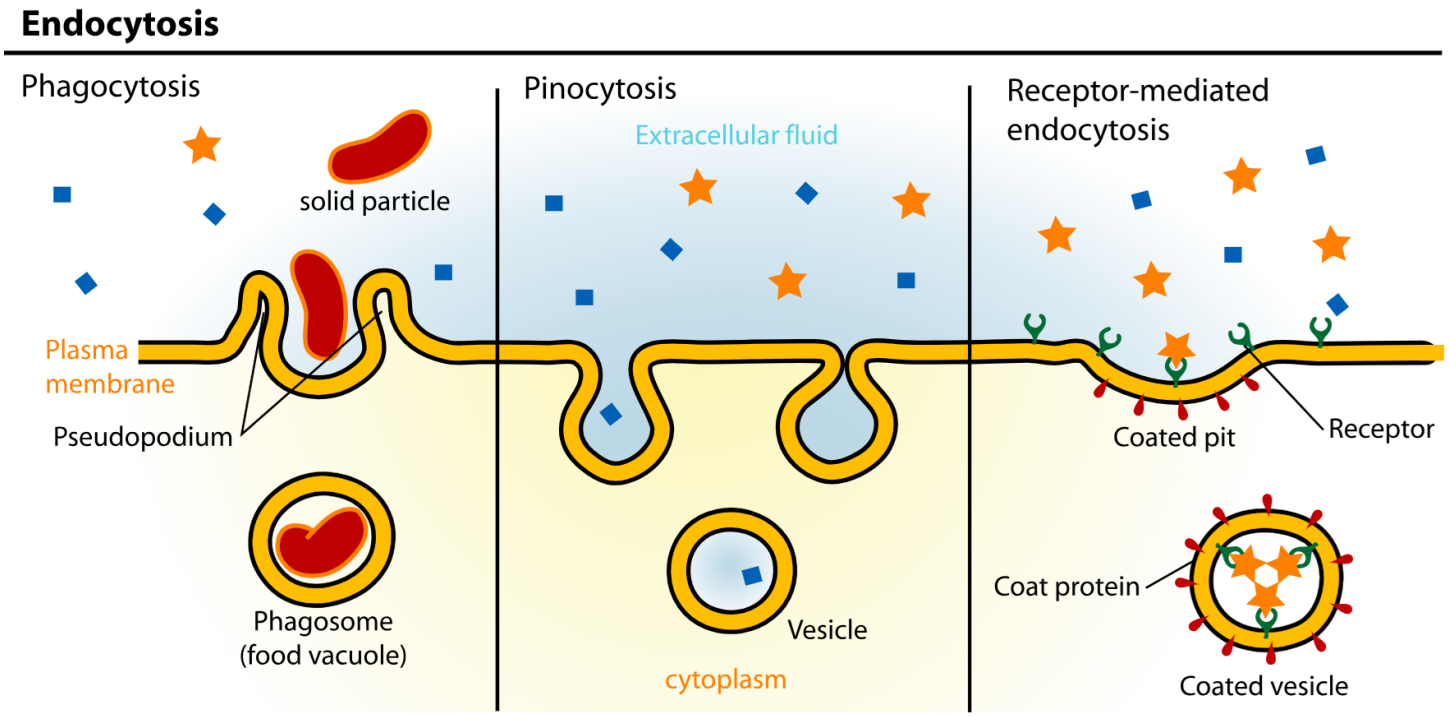


Figure: Types of endocytosis. Source: Wikipedia

Exocytosis

- Vesicles fuse with the plasma membrane to release contents outside the cell.
- Secretes hormones, neurotransmitters, enzymes, and signaling molecules.
- Balances membrane composition and supports intercellular communication.

Exocytosis Image

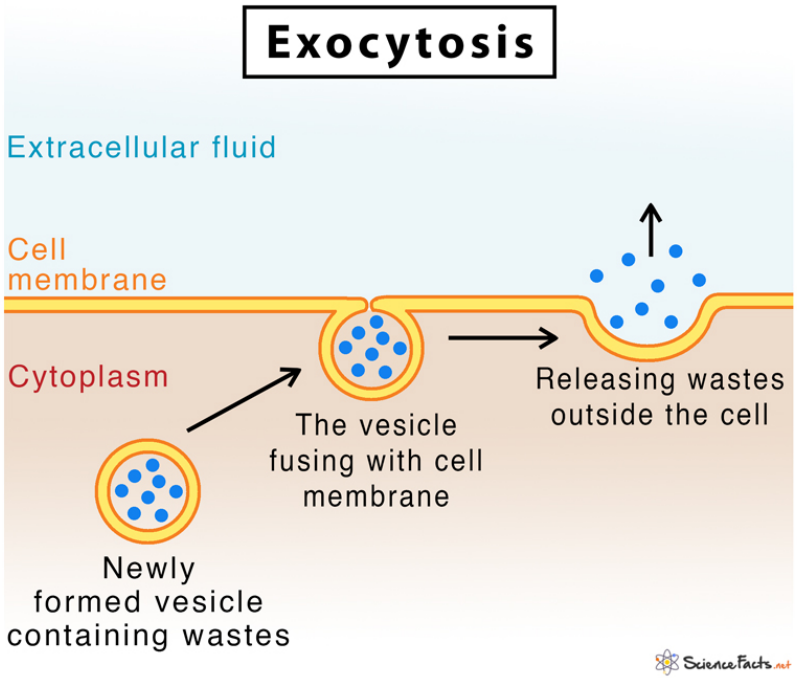


Figure: Exocytosis process. Source: ScienceFacts

Cytosol

- Fluid portion of the cytoplasm where organelles are suspended.
- Contains ions, small molecules, and macromolecules.
- Site for many **metabolic pathways**, such as glycolysis and protein synthesis.
- Supports intracellular transport and acts as a medium for signaling molecules.

Cytosol Image

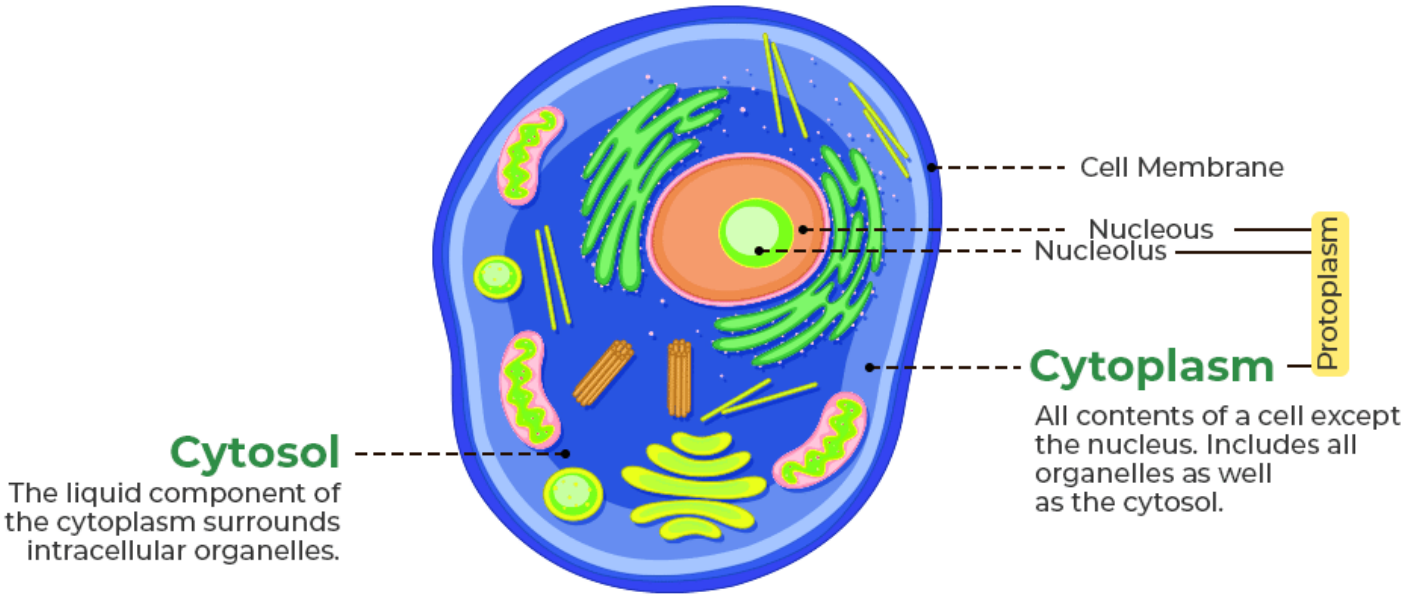


Figure: Cytosol surrounds organelles and facilitates biochemical reactions. Source: GeeksforGeeks

Ribosomes

- Molecular machines responsible for **protein synthesis**.
- Found **free in cytosol** or **bound to rough ER**.
- Translate mRNA sequences into polypeptide chains.
- Fundamental for cell growth, division, and enzyme production.

Ribosome Images

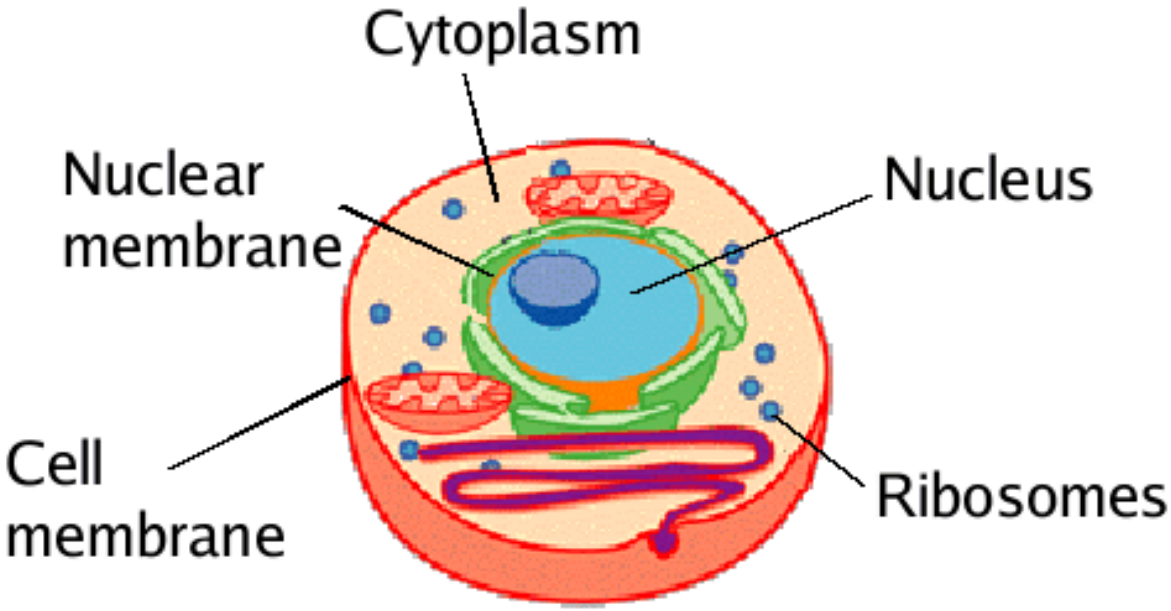


Figure: Ribosome during protein synthesis. Source: News-Medical

Cytoskeleton Overview

- Network of **protein filaments**: actin filaments, microtubules, and intermediate filaments.
- Provides **mechanical support, maintains cell shape, and organizes internal structures**.
- Drives **cell movement, division, and intracellular transport**.

Cytoskeleton Image

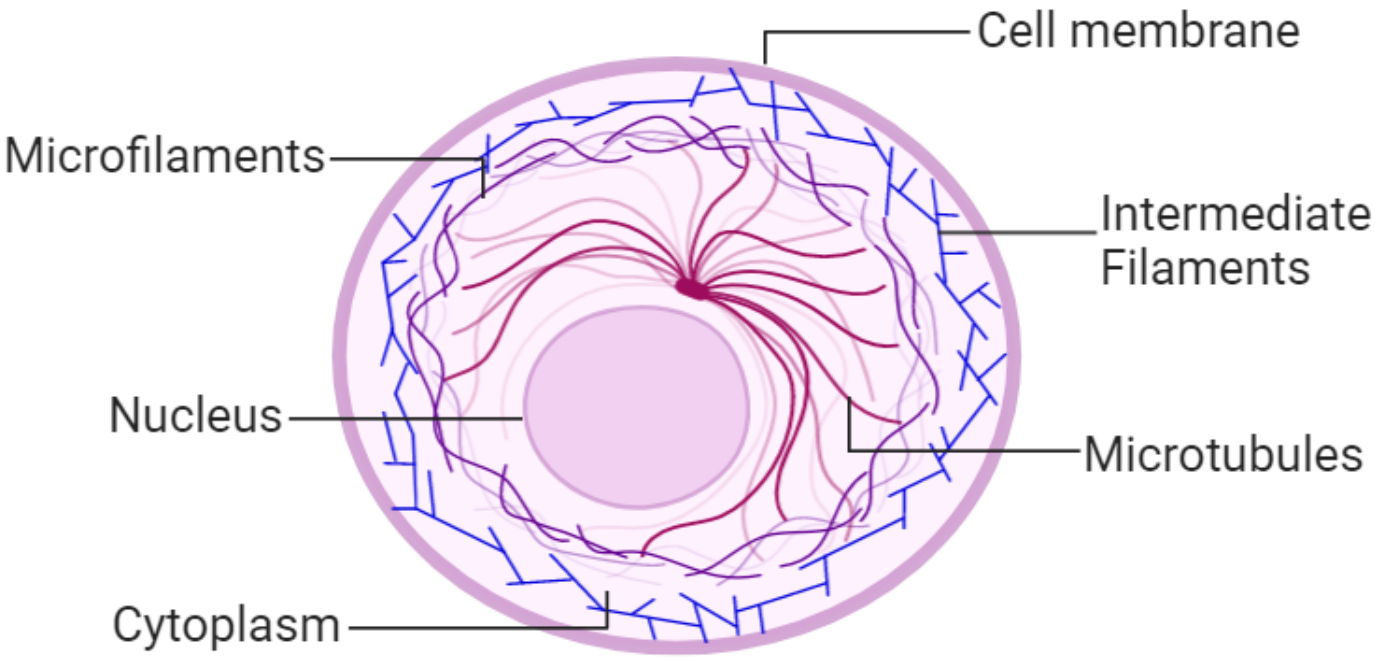


Figure: Cytoskeleton network maintaining structure and transport.
Source: Ahmad Coaching

Actin Filaments and Microtubules

- **Actin filaments:** thin, flexible fibers; generate contractile forces; abundant in cell cortex and muscle.
- **Microtubules:** thick, hollow tubes; organize organelles and guide chromosome movement during division.
- **Intermediate filaments:** provide tensile strength and maintain nuclear positioning.

Actin and Microtubule Images

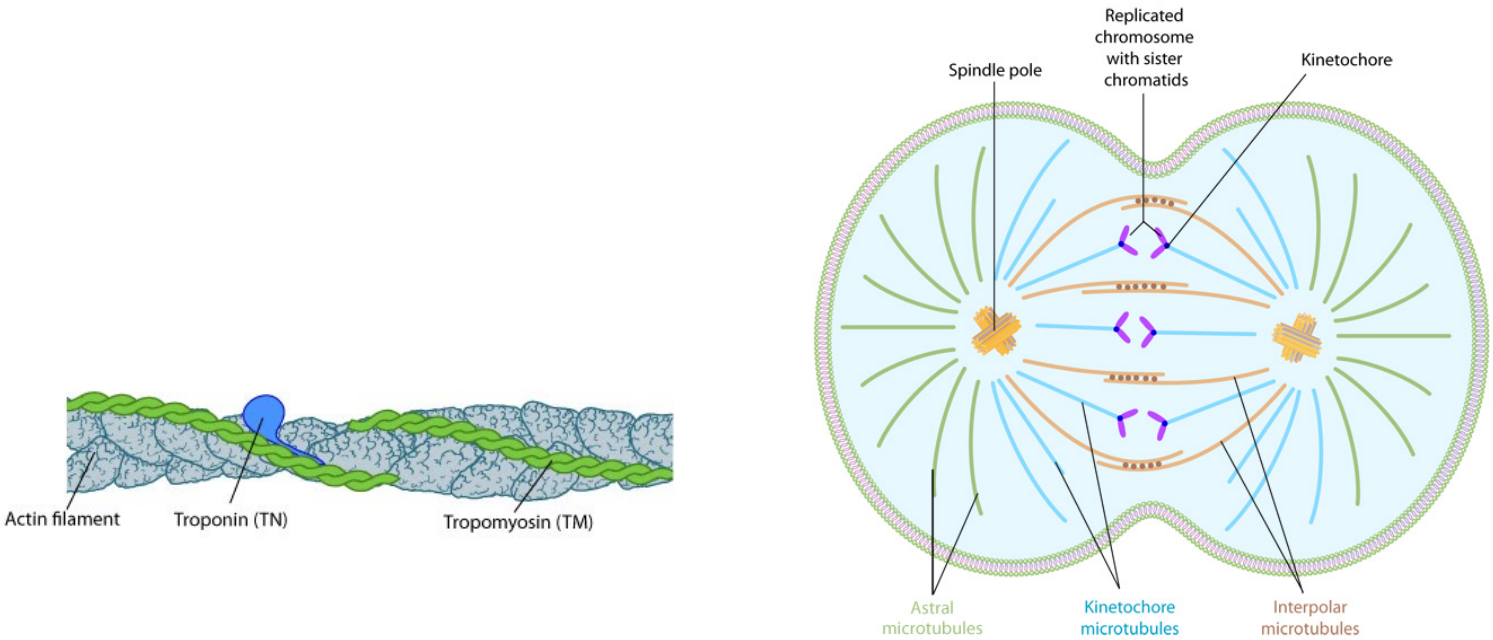


Figure: Actin filaments (left) and microtubules (right). Sources: MBI NUS, Nature

Observing Cells

- **Light microscopy:** allows visualization of large organelles ($>$ 200 nm).
- **Electron microscopy:** provides detailed ultrastructure at nanometer scale.
- **Fluorescence microscopy:** highlights specific organelles or molecules using dyes or tags.
- Techniques complement each other to study structure and function in cells.

Cells Under Microscope

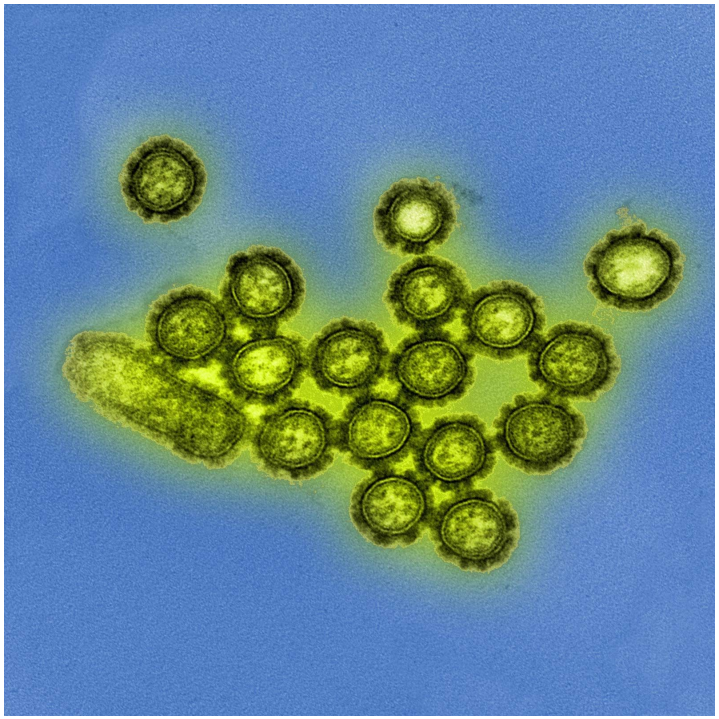


Figure: Surface proteins of virus particles and cells. Source: Britannica

Cell Membrane Thickness

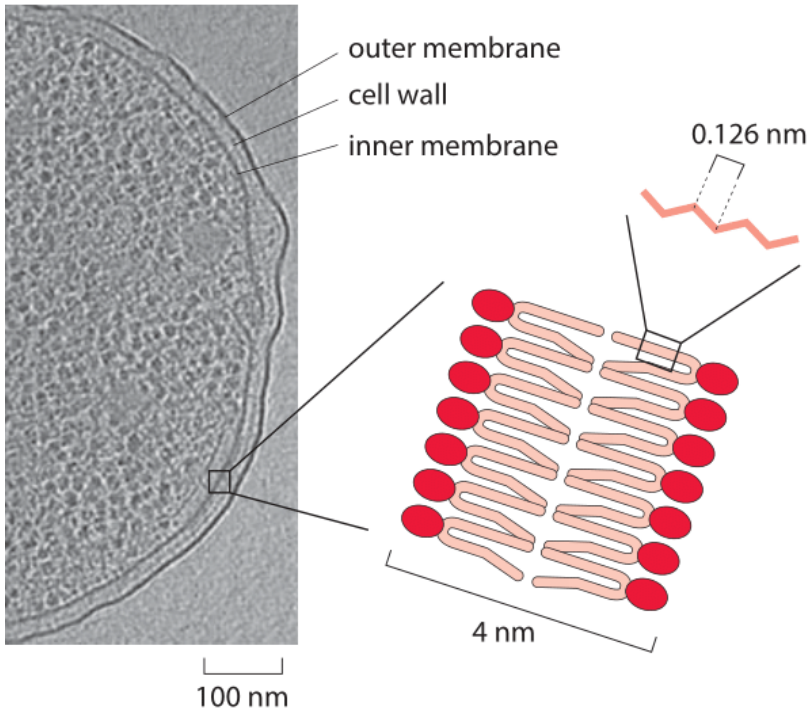


Figure: Cell membrane thickness (5–10 nm). Source: BioNumbers

Signs of Life in Cells

- Cells exhibit internal motion: particles, vesicles, organelles move around.
- Cells change shape, grow, divide — these dynamics signal life.
- Without staining, many organelles are transparent and difficult to see.
- To observe them, we use contrast-enhancing techniques and specialized microscopy.

Light Microscopy

- Uses visible light passed through or reflected from specimens.
- Typically can resolve structures down to 200 nm.
- Useful for observing whole cells, larger organelles, live cells.
- Often combined with dyes or stains to highlight structures.

Confocal Microscopy

- A laser scans a focused point and rejects out-of-focus light via pinholes.
- Produces sharper optical “slices” through cells (optical sectioning).
- Can reconstruct 3D images from stacked slices.

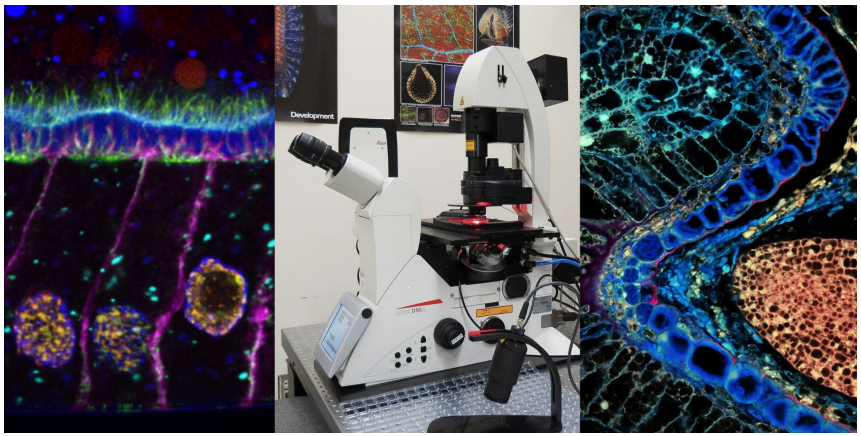


Figure: Confocal microscopy image (optical section of a cell). Source: Illinois State Univ.

Transmission Electron Microscopy (TEM)

- TEM passes an electron beam through an ultra-thin section of the specimen.
- Reveals detailed **internal ultrastructure**: membranes, organelles, macromolecular complexes.
- Resolution is extremely high (on the order of nanometers), far beyond light microscopes.
- Requires specimen preparation (sectioning, staining with heavy metals) and vacuum environment.

TEM Image

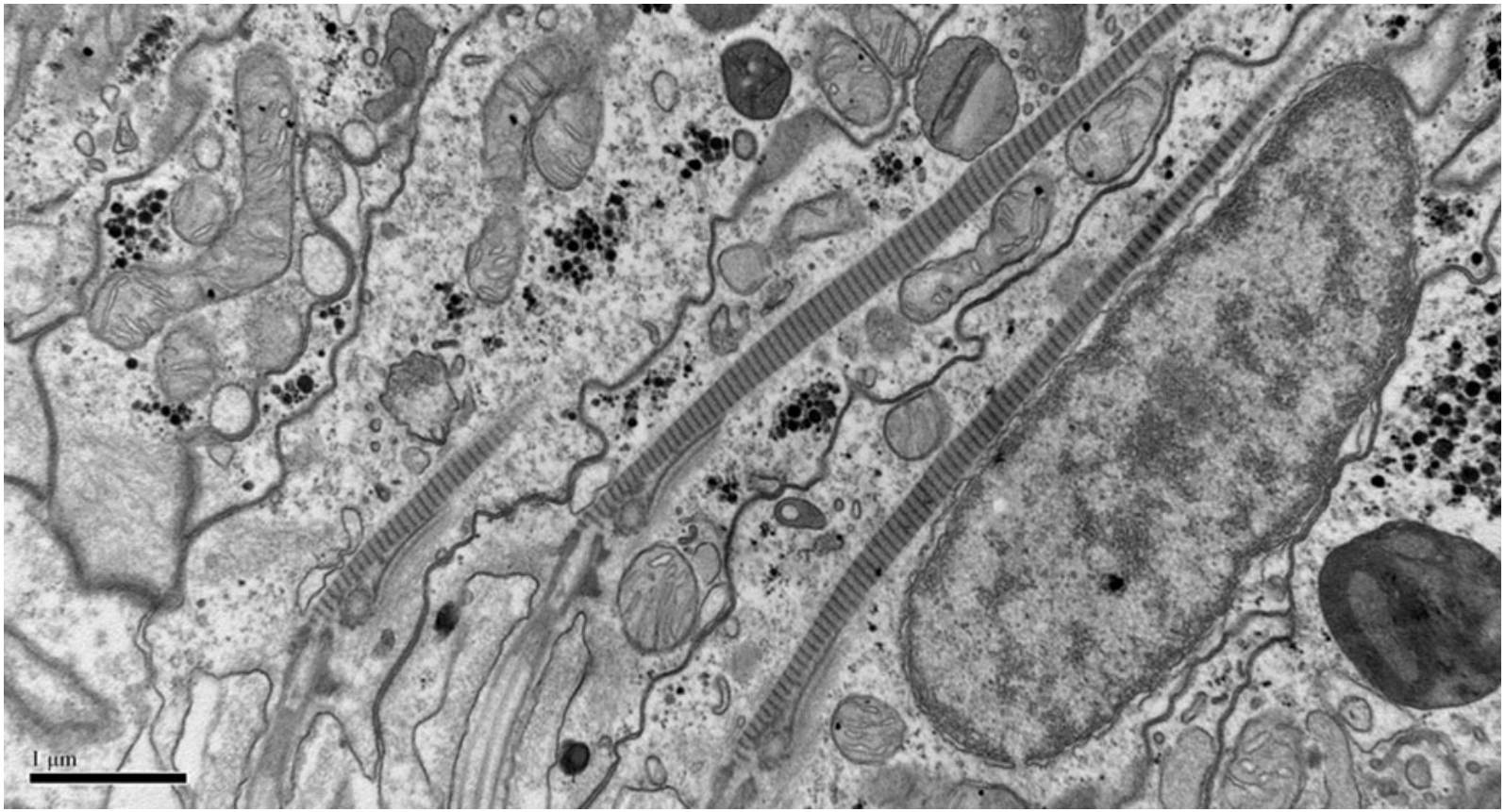


Figure: TEM micrograph showing internal cellular structure (e.g. organelle membranes). Source: University of Exeter Bioimaging TEM

Scanning Electron Microscopy (SEM)

- SEM scans a focused electron beam over the specimen's surface.
- Creates a 3D-like image of surface topography and external morphology.
- Lower resolution for internal details but excellent for surface structures (microvilli, cilia, cell edges).
- Specimens often must be coated in a conductive material (e.g. gold) and placed in vacuum.

SEM Image

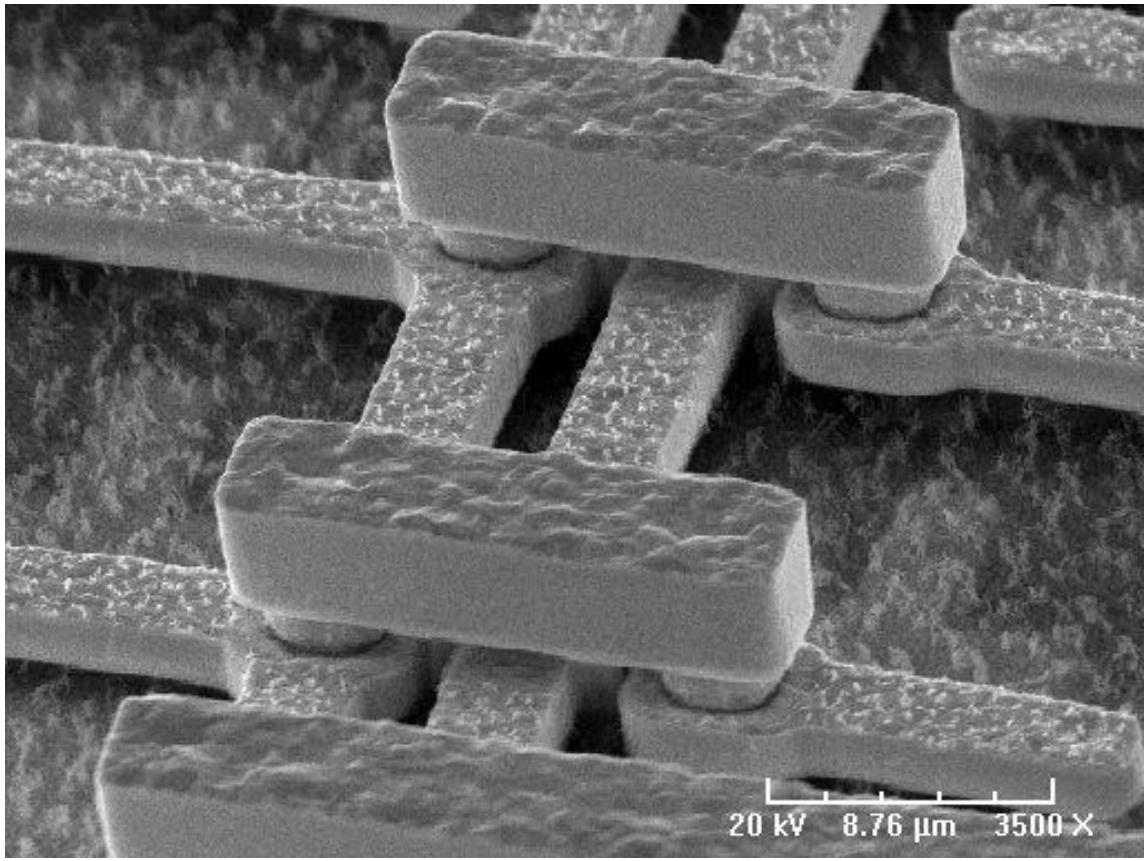
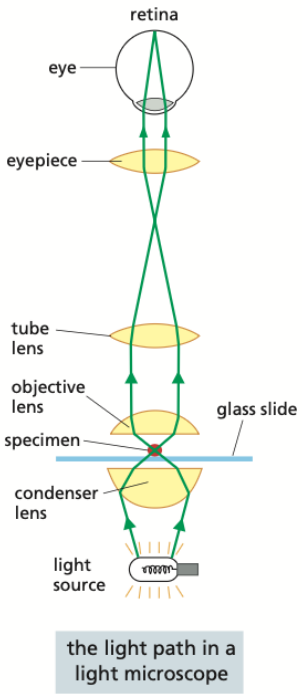


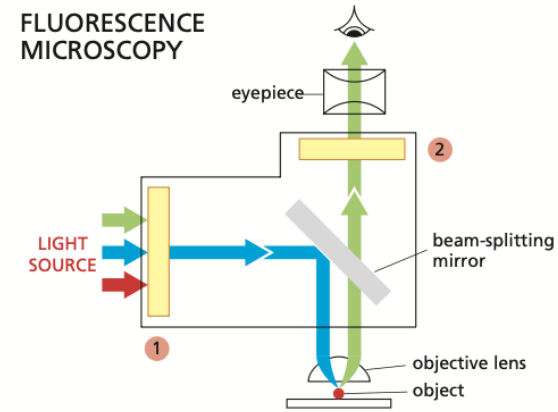
Figure: SEM image of cell surface morphology. Source: ORSlabs SEM

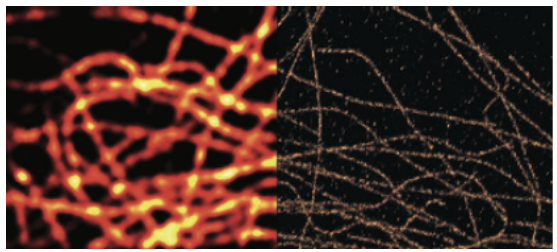
Observing Cells: Microscopy (Brief)

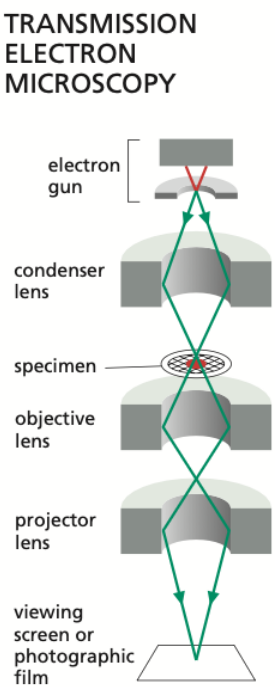
- **Light microscopy:** brightfield + stains; phase/DIC for live cells.
- **Fluorescence/confocal:** specific labeling; optical sections; 3D.
- **Super-resolution:** ∼20 nm resolution.
- **Electron microscopy:** TEM (internal details), SEM (surface).

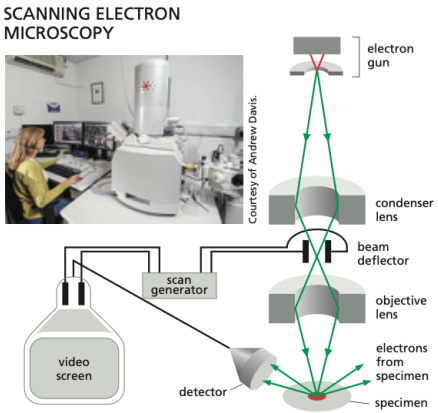


the light path in a light microscope









The End

Questions? Comments?