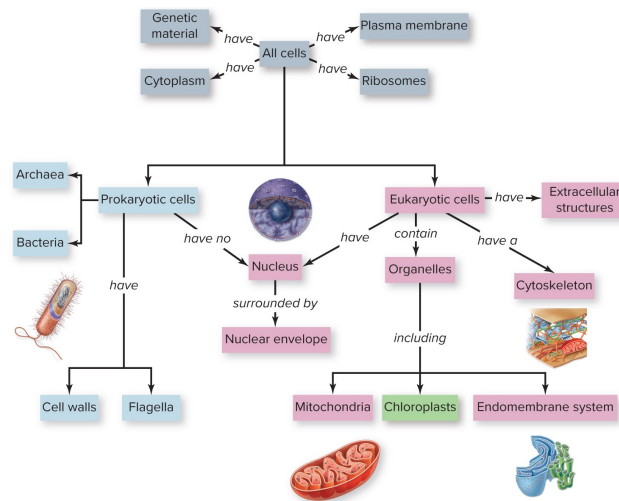


Eukaryotic Cells (Chapter 4.3)

Section 4.3 builds on the comparison between prokaryotic and eukaryotic cells by focusing on the defining structural features that distinguish **eukaryotic cells**. The emphasis in lecture was not simply on naming organelles, but on understanding how compartmentalization allows eukaryotic cells to perform complex, coordinated functions.



Defining Features of Eukaryotic Cells

Eukaryotic cells are characterized by the presence of internal, membrane-bound compartments that divide the cell into specialized regions. These compartments allow different biochemical processes to occur simultaneously without interfering with one another.

Key defining features include:

- A **membrane-bound nucleus**
- An extensive **endomembrane system**
- Numerous specialized **organelles**
- A complex **cytoskeleton**

Unlike prokaryotes, which typically rely on spatial organization within a single cytoplasmic space, eukaryotic cells use membranes to regulate internal environments.

The Nucleus: The Information Center

The nucleus serves as the primary information center of the eukaryotic cell. It houses the cell's genetic material and regulates gene expression.

Key structural features include:

- A **double membrane** called the nuclear envelope
- **Nuclear pores** that control the movement of molecules
- A dense region called the **nucleolus**

DNA within the nucleus is organized into multiple **linear chromosomes** associated with proteins, forming chromatin, which is directly linked to gene expression. This organization allows precise control over which genes are expressed in a given cell type.

The nucleolus is the site where ribosomal RNA (rRNA) is transcribed and ribosomal subunits are assembled before being exported to the cytoplasm.

Ribosomes: A Universal Feature

Although eukaryotic cells are structurally complex, they share essential features with all other cells. One of the most important of these is the presence of **ribosomes**.

Ribosomes:

- Translate messenger RNA into proteins
- Are found in all cells—prokaryotic and eukaryotic
- Can be free in the cytoplasm or bound to the rough ER

The universality of ribosomes underscores the shared evolutionary origin of all life.

Compartmentalization and Cellular Efficiency

The internal organization of eukaryotic cells allows for:

- Separation of incompatible chemical reactions
- Greater efficiency and regulation
- Increased cell size without loss of function

For example, enzymes involved in lipid synthesis are localized to the smooth ER, while enzymes involved in protein modification are concentrated in the Golgi apparatus. This spatial separation improves both speed and accuracy.

The Cytoskeleton as an Internal Framework

Eukaryotic cells possess a well-developed cytoskeleton composed of three major filament types:

- Actin filaments (microfilaments)
- Microtubules
- Intermediate filaments

These fibers provide:

- Structural support
- Organization of organelles
- Pathways for intracellular transport

Motor proteins move along cytoskeletal tracks using ATP. For example, myosin interacts with actin filaments during cell crawling and later becomes especially important in **muscle cells**, where coordinated actin–myosin interactions produce contraction.

The Endomembrane System (Chapter 4.4)

Section 4.4 introduces the **endomembrane system**, a network of membranes that divides the cytoplasm of eukaryotic cells into functional compartments. The central idea emphasized in lecture is that compartmentalization allows the cell to carry out complex chemical processes efficiently and in a regulated manner.

Overview of the Endomembrane System

The endomembrane system includes membranes that are either physically connected or exchange materials through vesicles. Together, these structures coordinate the synthesis, modification, transport, and degradation of macromolecules.

Major components include:

- Nuclear envelope
- Endoplasmic reticulum (rough and smooth)
- Golgi apparatus
- Lysosomes
- Transport vesicles
- Vacuoles (in plants and some protists)

Rough Endoplasmic Reticulum (RER)

The rough ER is distinguished by ribosomes attached to its cytoplasmic surface. These ribosomes synthesize:

- Proteins destined for secretion
- Proteins inserted into membranes
- Proteins targeted to specific organelles

As proteins are synthesized, they enter the lumen of the RER, where they may begin folding and undergo early chemical modification.

Smooth Endoplasmic Reticulum (SER)

The smooth endoplasmic reticulum lacks bound ribosomes and contains embedded enzymes that support several key cellular functions:

- Synthesis of lipids, phospholipids, and steroid hormones
- Carbohydrate metabolism
- Detoxification of drugs and poisons, especially in liver cells
- Storage and regulated release of calcium ions (Ca^{2+})

In muscle cells, specialized smooth ER (the sarcoplasmic reticulum) plays a critical role in contraction by releasing and reabsorbing Ca^{2+} ions, illustrating how the same organelle can be functionally specialized in different cell types.

Golgi Apparatus

The Golgi apparatus functions as the cell's central processing, sorting, and distribution center for proteins and lipids received from the endoplasmic reticulum.

Its roles include:

- Chemical modification of proteins
- Sorting macromolecules by their cellular destination
- Packaging materials into transport vesicles

- Contributing to the synthesis and renewal of cellular membranes

The Golgi apparatus has a distinct polarity: the *cis* face receives vesicles from the ER, while the *trans* face directs vesicles to specific destinations, such as the plasma membrane, lysosomes, or secretion outside the cell.

Lysosomes

Lysosomes are membrane-bound organelles that originate from the Golgi apparatus and contain digestive enzymes.

These enzymes:

- Break down macromolecules such as proteins, nucleic acids, lipids, and carbohydrates
- Recycle components of old or damaged organelles
- Function optimally at an acidic pH

By isolating these enzymes within membranes, the cell prevents accidental damage to other cellular structures. Uncontrolled release of lysosomal enzymes could damage or destroy the cell.

Vacuoles

Vacuoles are most prominent in plant cells, where a large central vacuole may occupy most of the cell's volume.

Functions include:

- Storage of water, ions, and metabolites
- Regulation of internal pressure (turgor)
- Contribution to cell growth

The vacuolar membrane, called the **tonoplast**, contains channels that regulate the movement of water and solutes, helping maintain cellular tonicity and osmotic balance. Some fungi and protists also use vacuoles for water balance.

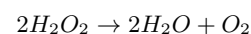
Lipid Droplets and Microbodies

Lipid droplets store neutral lipids and consist of lipid cores surrounded by a phospholipid monolayer. These structures provide an efficient way to store energy-rich molecules.

Microbodies are a diverse group of organelles that include **peroxisomes**. Peroxisomes contain enzymes that:

- Oxidize fatty acids
- Participate in detoxification reactions
- Utilize peroxide in metabolic reactions

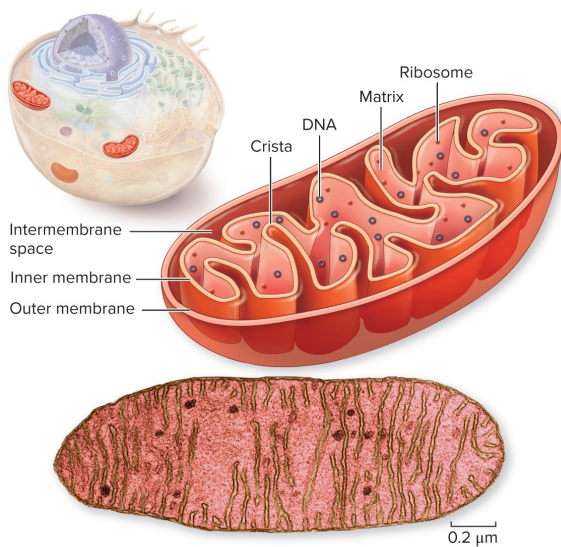
Peroxisomes contain the enzyme catalase, which decomposes hydrogen peroxide according to the reaction:



Mitochondria and Chloroplasts (Chapter 4.5)

Section 4.5 focuses on the organelles responsible for cellular energy transformations: **mitochondria** and **chloroplasts**. Emphasis is placed on how their structure reflects their function and how multiple lines of evidence support their evolutionary origin through endosymbiosis.

Mitochondria: Cellular Powerhouses



Mitochondria are the primary sites of ATP production in eukaryotic cells. Most cellular ATP is generated through metabolic reactions that occur within this organelle.

Key structural features include:

- A **double membrane**
- A smooth outer membrane
- A highly folded inner membrane forming **cristae**
- An internal fluid-filled space called the **matrix**
- A compartment between membranes called the **intermembrane space**

The extensive folding of the inner membrane increases surface area, allowing more proteins involved in energy metabolism to be embedded in the membrane.

Mitochondrial Function

Proteins located on the inner membrane and within the matrix carry out the reactions that lead to ATP synthesis. These reactions involve the controlled transfer of energy through metabolic pathways rather than direct combustion of fuels.

Because ATP is required for nearly all cellular processes, mitochondria are essential for the survival of most eukaryotic cells.

Mitochondria are not synthesized *de novo*. Instead, they divide independently within the cell, and their numbers increase prior to cell division. Most proteins required for mitochondrial structure and division are encoded by genes in the nucleus.

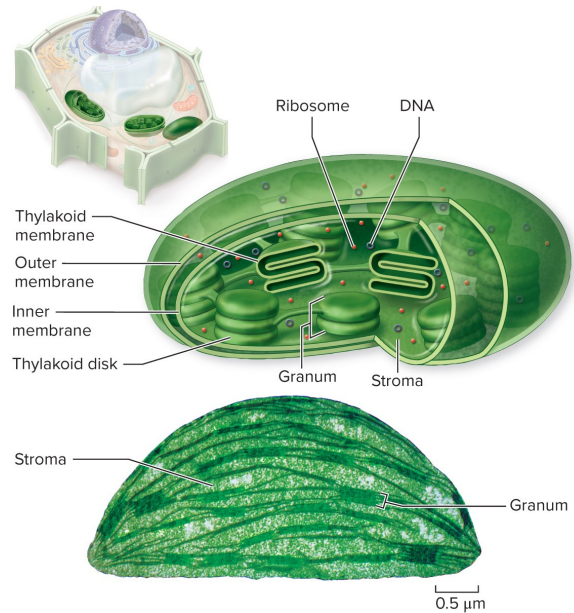
Chloroplasts: Energy Conversion via Light

Chloroplasts are found in plants and some protists and are responsible for capturing light energy and converting it into chemical energy.

Structural features include:

- A **double outer membrane**
- An internal system of flattened membranes called **thylakoids**
- Stacks of thylakoids known as **grana**
- An internal fluid-filled space called the **stroma**

Light-dependent reactions occur on the thylakoid membranes, while the synthesis of sugars occurs in the stroma.



Functional Parallels Between Organelles

Despite their different roles, mitochondria and chloroplasts share several important characteristics:

- Both generate ATP
- Both contain their own DNA
- Both divide independently within the cell

These shared features suggest a common evolutionary origin.

Endosymbiotic Theory

The endosymbiotic theory proposes that mitochondria and chloroplasts originated as free-living prokaryotic cells that were engulfed by an ancestral host cell.

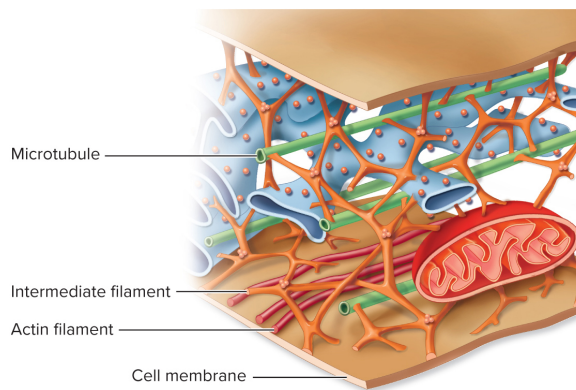
Evidence supporting this theory includes:

- The presence of double membranes
- Circular DNA similar to bacterial chromosomes
- Independent replication within the cell

Over time, these engulfed cells formed stable, mutually beneficial relationships with their hosts and became permanent organelles. Without these organelles, the energetic demands of complex life would not be sustainable.

The Cytoskeleton (Chapter 4.6)

Section 4.6 introduces the **cytoskeleton**, a dynamic network of protein fibers that provides structural support, organizes the cell interior, and enables movement of both cells and intracellular components. Emphasis is placed on the cytoskeleton as an active, adaptable system rather than static scaffolding.



Overview of the Cytoskeleton

The cytoskeleton is composed of crisscrossing protein fibers that:

- Maintain cell shape
- Anchor and organize organelles
- Enable intracellular transport
- Drive cell movement and division

Eukaryotic cells possess three major types of cytoskeletal filaments, each with distinct structures and functions.

Microfilaments (Actin Filaments)

Microfilaments are long, thin fibers composed of the protein **actin**. They are especially important in cell shape and movement.

Functions include:

- Cell crawling and migration
- Formation of the cell cortex beneath the plasma membrane
- Muscle contraction when interacting with myosin

During cell crawling, actin polymerization pushes the plasma membrane forward, while myosin contracts actin filaments to pull the cell body toward the leading edge. This same actin–myosin interaction is later adapted in muscle cells to produce contraction.

Microtubules

Microtubules are hollow cylinders composed of tubulin proteins. They are the largest and most rigid cytoskeletal elements and serve as structural tracks within the cell.

Key roles include:

- Transport of vesicles and organelles
- Formation of the mitotic spindle during cell division
- Structural support for cilia and flagella

Microtubules originate from organizing centers such as the centrosome and extend outward through the cytoplasm.

Intermediate Filaments

Intermediate filaments are composed of various fibrous proteins, including keratin and vimentin. Their primary role is mechanical strength rather than movement.

Functions include:

- Resistance to mechanical stress
- Maintenance of cell integrity
- Stabilization of cell shape over time

Unlike microfilaments and microtubules, intermediate filaments are relatively stable and less dynamic.

Molecular Motors and Intracellular Transport

The cytoskeleton functions as a system of tracks for motor proteins that move materials within the cell.

Important motor proteins include:

- **Kinesin**, which typically transports cargo along microtubules toward the cell periphery
- **Dynein**, which generally moves cargo toward the cell center
- **Myosin**, which moves along actin filaments

These motor proteins use energy from ATP hydrolysis to transport vesicles, organelles, and other cargo, functioning analogously to trains moving along rails.

Centrosomes and Cell Division

Centrosomes act as microtubule-organizing centers in animal cells and typically contain a pair of centrioles. They play a critical role during cell division by helping assemble the mitotic spindle that separates chromosomes into daughter cells.

Functional Significance of the Cytoskeleton

The cytoskeleton allows cells to:

- Change shape in response to signals
- Move toward or away from stimuli
- Organize internal components efficiently
- Divide accurately during reproduction

Because these functions are essential for life, defects in cytoskeletal components often lead to serious cellular and organismal dysfunction.

Extracellular Structures and Cell Movement (Chapter 4.7)

Section 4.7 examines how cells move and interact with their surroundings. The lecture emphasized that cellular movement can be driven by internal cytoskeletal forces or by external structures, and that animal cells are embedded within an extracellular matrix that actively influences cell behavior.

Modes of Cellular Movement

Cells move using different strategies depending on cell type and environment. Two major categories of movement were emphasized:

- **Cell crawling**, driven by internal cytoskeletal proteins
- **Surface appendages**, such as cilia or flagella

These mechanisms rely on different molecular systems but share the common goal of repositioning cells or moving fluids.

Cell Crawling

Cell crawling occurs when actin filaments polymerize beneath the plasma membrane, pushing it forward. At the same time, myosin motors pull the cell body in the same direction.

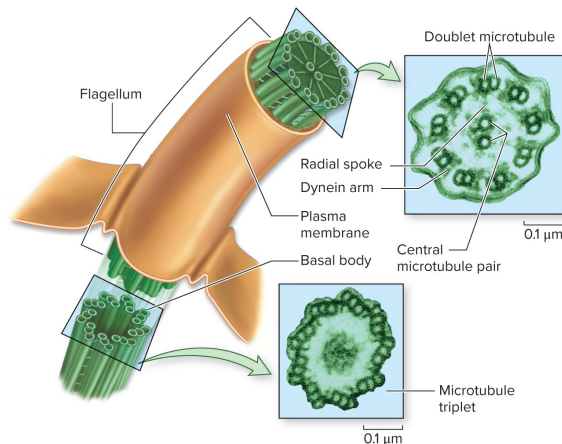
This process is especially important during:

- Development
- Wound healing
- Immune cell movement

The actin-myosin interaction used in cell crawling is also adapted for muscle contraction, where highly ordered arrays of these proteins generate force at the tissue level.

Cilia and Flagella in Eukaryotic Cells

Eukaryotic cilia and flagella are external structures used for movement or fluid transport. They share a characteristic internal arrangement of microtubules known as the **9 + 2 structure**.



Key features include:

- Bundles of microtubules surrounded by membrane
- Whip-like, undulating motion
- A basal body that anchors the structure to the cell

Cilia are typically short and numerous, while flagella are longer and fewer in number.

Prokaryotic Flagella

Prokaryotic flagella differ fundamentally from eukaryotic flagella in both structure and energy source. Bacterial flagella rotate like propellers and are powered by proton gradients across the plasma membrane.

Archaeal motility structures, called *archaella*, resemble bacterial flagella in appearance but are powered by ATP hydrolysis. These similarities reflect **convergent evolution** rather than shared ancestry.

Plant Cell Walls

Plant cells possess rigid cell walls composed primarily of cellulose fibers. These walls:

- Provide protection and mechanical support
- Maintain cell shape
- Resist osmotic pressure

Adjacent plant cells are held together by the middle lamella, contributing to tissue integrity.

Extracellular Matrix (ECM) in Animal Cells

Animal cells do not have cell walls. Instead, they secrete a complex network of glycoproteins known as the **extracellular matrix** (ECM).

Major components include:

- Collagen
- Elastin
- Fibronectin
- Proteoglycans

The ECM provides structural support, strength, and elasticity to tissues.

Integrins and Cell-ECM Interactions

Integrins are transmembrane proteins that link the ECM to the cytoskeleton. Through these connections, integrins allow the ECM to influence cell behavior.

Integrin signaling can:

- Alter gene expression
- Influence cell migration
- Coordinate mechanical and chemical signals

In this way, the ECM is not merely structural but plays an active role in regulating cellular function.

Functional Significance

Extracellular structures and movement systems allow cells to:

- Respond dynamically to their environment
- Coordinate behavior within tissues
- Maintain tissue structure under mechanical stress

These systems are essential for multicellular organization and function.

Cell-to-Cell Interactions (Chapter 4.8)

Section 4.8 explains how individual cells become organized into tissues and coordinate their behavior. Emphasis is placed on the role of surface proteins, junctions, and communication systems that allow cells to recognize one another, adhere together, and exchange information.

Cell Identity and Surface Proteins

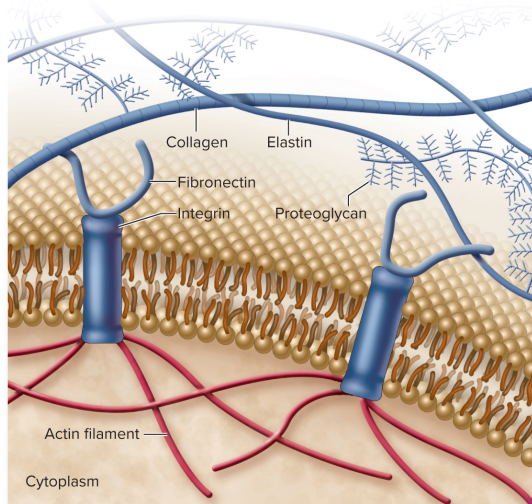
Cells in multicellular organisms must identify themselves as belonging to a specific tissue or organism. This identity is established through proteins and glycolipids embedded in the plasma membrane.

Many cell-surface markers are **glycolipids**, which consist of lipids with carbohydrate chains projecting outward from the membrane. These markers allow cells to recognize neighboring cells and respond appropriately.

In humans, glycolipid surface markers are responsible for the **A, B, and O blood types**.

Self vs. Nonself Recognition

A critical function of cell-surface markers is distinguishing **self** from **non-self**. In vertebrates, this role is carried out by proteins encoded by the **major histocompatibility complex (MHC)**.



MHC proteins allow immune cells to recognize foreign or abnormal cells, a process essential for defense against pathogens and cancer.

Cell Junctions and Tissue Formation

Multicellularity required the evolution of proteins that physically connect cells. These connections allow tissues to maintain structure, coordinate function, and communicate effectively.

Cell junctions can be grouped into **three major functional classes**: adhesive junctions, barrier junctions, and communicating junctions.

1. Adhesive Junctions

Adhesive junctions mechanically attach cells to one another or to the extracellular matrix.

Major types include:

- **Adherens junctions**, which use cadherins linked to actin filaments

- **Desmosomes**, cadherin-based junctions that connect cells via intermediate filaments and provide strong mechanical attachment
- **Hemidesmosomes and focal adhesions**, which anchor cells to the extracellular matrix through integrins

Adhesive junctions are especially important in tissues subjected to mechanical stress, such as skin, muscle, and connective tissue.

2. Barrier (Occluding) Junctions

Barrier junctions form seals between adjacent cells, preventing substances from passing freely between them.

In vertebrates, these junctions are called **tight junctions** and contain proteins known as **claudins**. Tight junctions:

- Create continuous sheets of cells
- Separate internal and external environments
- Maintain polarity in epithelial tissues

In invertebrates, a functionally similar barrier is formed by **septate junctions**.

An example discussed in lecture was the lining of the digestive tract, where tight junctions force nutrients to pass *through* cells rather than between them.

3. Communicating Junctions

Communicating junctions allow direct exchange of small molecules and ions between neighboring cells.

In animals, these junctions are called **gap junctions**. They form channels that link adjacent cells and allow rapid diffusion of ions and small solutes.

In plants, communicating junctions are called **plasmodesmata**. These channels pass through the cell wall and connect the cytoplasm of neighboring cells.

Functional Importance of Cell Communication

Communicating junctions allow tissues to:

- Coordinate electrical activity (e.g., heart muscle)
- Share nutrients and signaling molecules
- Maintain synchronized cellular responses

The ability to regulate the opening and closing of these channels provides an additional level of control.

Evolutionary Perspective

Although multicellularity **evolved independently in different lineages**, the molecular mechanisms used for cell adhesion and communication are ancient and highly conserved.

This conservation highlights the central role of cell-cell interactions in the evolution of complex multicellular life.