2. Cellular and Molecular Biology
2.1 Cell Structure

2.2 Transport Across Cell Membranes

2.3 Cellular Metabolism
2.4 DNA Replication

2.5 Cell Division

2.6 Biosynthesis
2.1 Cell Structure
What is a cell?

The smallest and most basic unit of most organisms. Species can be single celled (like *Salmonella* bacteria) or multicellular and complex, like humans.
There are two main types of cells.

**Prokaryotes** (like bacteria) have no nucleus or other membrane-bound organelles. DNA is a single circular chromosome.

**Unicellular organisms**
Eukaryotes (like plants, fungi, and animal cells) have a nucleus as well as other membrane-bound organelles. DNA is arranged into multiple chromosomes. Unicellular and multicellular organisms.
Plant and Animal cells both contain:

- a cell membrane
- a nucleus
- cytoplasm
- cytoplasmic organelles
Animal and Plant cells also contain:

- microvilli
- a cytoskeleton
- ribosomes
- endoplasmic reticulum
- Golgi apparatus
- lysosomes
- mitochondria
Mitochondria – produce energy (cellular respiration)

Ribosomes – site of protein synthesis
Plant cells additionally contain
• a cell wall
• chloroplasts
• a central vacuole
**Cell wall** maintains cell shape.

**Central Vacuole** filled with cell sap that maintains pressure against cell wall.

**Cytoskeleton**
- microtubules
- intermediate filaments
- microfilaments

**Endoplasmic Reticulum**
- smooth
- rough

**Nucleus** contains chromatin, a nuclear envelope, and a nucleolus, as in an animal cell.

**Ribosomes**

**Golgi apparatus**

**Mitochondria**

**Peroxisome**

**Plastid** store pigments

**Chloroplast site of photosynthesis**
The cell membrane separates the cell from its environment, allowing for the interior environment of the cell to be very different from the exterior.
The cell membrane is composed of

- a lipid bilayer
- proteins
- carbohydrates
2.2 Transport Across Cell Membranes
Cell membranes protect the interior of the cell from the exterior.

Transport of molecules across the membrane is possible, and depends upon the size and polarity of the molecule.
Transport across cell membranes has two basic types

- Passive transport
  - Simple diffusion
  - Osmosis
  - Facilitated diffusion
- Active transport
Simple diffusion, with a concentration gradient, small nonpolar molecules
Facilitated diffusion, small polar molecules, like glucose, amino acids
In active transport, molecules move across cell membranes with an expenditure of energy:

- Moving against a concentration gradient
- Requires energy, usually in the form of ATP
2.3 Cellular Metabolism
Nucleus
Nuclear envelope: membrane enclosing the nucleus. Protein-lined pores allow material to move in and out.
Chromatin: DNA plus associated proteins.
Nucleolus: condensed region where ribosomes are formed.

Cytoskeleton
Microtubules: form the mitotic spindle and maintain cell shape.
Centrosome: microtubule-organizing center.
Intermediate filaments: fibrous proteins that hold organelles in place.
Microfilaments: fibrous proteins; form the cellular cortex.

Peroxisome: metabolizes waste

Endoplasmic reticulum
Rough: associated with ribosomes; makes secretory and membrane proteins.
Smooth: makes lipids.

Vacuole

Cytoplasm

Lysosome: digests food and waste materials.
Golgi apparatus: modifies proteins.

Mitochondria: produce energy.
Cell wall maintains cell shape

Endoplasmic Reticulum
- smooth
- rough

Nucleus contains chromatin, a nuclear envelope, and a nucleolus, as in an animal cell

Plasma membrane

Central Vacuole filled with cell sap that maintains pressure against cell wall

Cytoplasm

Cytoskeleton
- microtubules
- intermediate filaments
- microfilaments

Chloroplast site of photosynthesis

Ribosomes

Golgi apparatus

Mitochondria

Plastid store pigments

Peroxisome
Cellular Metabolism encompasses all types of energy transformation in cells

• Photosynthesis
• Respiration
• Growth
• Movement
Metabolic Pathways

**Anabolic:** Small molecules are assembled into large ones. *Energy is required.*

**Catabolic:** Large molecules are broken down into small ones. *Energy is released.*
Adenosine triphosphate, or ATP, is the primary energy currency in biological systems.

- Energy is released by hydrolysis of one of the phosphate groups to form ADP.
- Energy is stored by attaching a new phosphate group to ADP to form ATP.
Photosynthesis takes place in cells with chlorophyll, a green pigment that can absorb light

- Typically in plants
- Two phases
  - Light reaction
  - Dark reaction
Photosynthesis Equation

<table>
<thead>
<tr>
<th>Component</th>
<th>Chemical Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>$6CO_{2}$</td>
</tr>
<tr>
<td>Water</td>
<td>$6H_{2}O$</td>
</tr>
<tr>
<td>Sugar</td>
<td>$C_{6}H_{12}O_{6}$</td>
</tr>
<tr>
<td>Oxygen</td>
<td>$6O_{2}$</td>
</tr>
</tbody>
</table>

Photosynthesis: $6CO_{2} + 6H_{2}O \rightarrow C_{6}H_{12}O_{6} + 6O_{2}$

SUNLIGHT

Oxygen

Sunlight

Sugars made

Carbon dioxide

Water

PHOTOSYNTHESIS
Respiration takes place in all cells

- Glucose is broken down to release energy (glycolysis)
- Two types
  - Anaerobic (no O$_2$)
  - Aerobic (with O$_2$)
Glucose → Glucose-6-phosphate → Fructose-6-phosphate → Fructose-1,6-biphosphate → Dihydroxyacetone phosphate → Glyceraldehyde-3-phosphate
Net outcome of glycolysis (from 1 molecule of glucose)
• 2 molecules of pyruvate
• 4 ATP
• 2 NADH
2.4 DNA Replication
What is DNA?

DeoxyriboNucleic Acid

A biopolymer that encodes all of the information needed to form a specific organism and produce proteins for functioning.

A gene is a portion of DNA that encodes a specific protein.
2’-DeoxyriboNucleic Acid
Since DNA codes for genes, which contain the blueprint for an organism, it's important to be able to make copies of this blueprint for each cell. The end result of DNA replication is two pieces of double stranded DNA identical to the parent DNA.
In transcription, an RNA (ribonucleic acid) copy of the DNA is made.

What does it mean to transcribe something?
In translation, the information contained in the RNA copy of the DNA is used to guide the creation of proteins.

What does it mean to translate something?
Growing peptide chain

Amino acid

Ribosome large subunit

tRNA

mRNA

Ribosome small subunit
DNA
replication

RNA
transcription

Protein
translation
2.5 Cell Division
Cell division is the process of cellular reproduction, where a copy of the cells “blueprint” needs to be made and passed on
<table>
<thead>
<tr>
<th>DNA double helix</th>
<th>DNA wrapped around histone</th>
<th>Nucleosomes coiled into a chromatin fiber</th>
<th>Further condensation of chromatin</th>
<th>Duplicated chromosome</th>
</tr>
</thead>
</table>

- **centromere**
- **homologs**
- **chromatids**
Mitosis

A sequence of events that ends with cell division and the creation of two daughter cells from a single parent cell.
4 Phases of Mitosis

• Prophase
• Metaphase
• Anaphase
• Telophase
<table>
<thead>
<tr>
<th>Prophase</th>
<th>Prometaphase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromosomes condense and</td>
<td>Chromosomes continue to condense</td>
</tr>
<tr>
<td>become visible</td>
<td></td>
</tr>
<tr>
<td>Spindle fibers</td>
<td>Kinetochore appear at the centromeres</td>
</tr>
<tr>
<td>emerge from the centrosomes</td>
<td></td>
</tr>
<tr>
<td>Nuclear envelope breaks</td>
<td>Mitotic spindle microtubules attach to</td>
</tr>
<tr>
<td>down</td>
<td>kinetochores</td>
</tr>
<tr>
<td>Nucleolus disappears</td>
<td>Centrosomes move toward opposite poles</td>
</tr>
</tbody>
</table>

[Diagram showing a cell in prophase and a cell in prometaphase]
<table>
<thead>
<tr>
<th>Metaphase</th>
<th>Anaphase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitotic spindle is fully developed, centrosomes are at opposite poles of the cell</td>
<td>Cohesin proteins binding the sister chromatids together break down</td>
</tr>
<tr>
<td>Chromosomes are lined up at the metaphase plate</td>
<td>Sister chromatids (now called chromosomes) are pulled toward opposite poles</td>
</tr>
<tr>
<td>Each sister chromatid is attached to a spindle fiber originating from opposite poles</td>
<td>Non-kinetochore spindle fibers lengthen, elongating the cell</td>
</tr>
<tr>
<td>Telophase</td>
<td>Cytokinesis</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Chromosomes arrive at opposite poles and begin to decondense</td>
<td>Animal cells: a cleavage furrow separates the daughter cells</td>
</tr>
<tr>
<td>Nuclear envelope material surrounds each set of chromosomes</td>
<td>Plant cells: a cell plate separates the daughter cells</td>
</tr>
<tr>
<td>The mitotic spindle breaks down</td>
<td></td>
</tr>
</tbody>
</table>
Meiosis is a type of cell division that takes place in eukaryotes.

It reduces the chromosome number by half, resulting in 4 daughter cells (gametes) that are all genetically distinct from the parent cell as part of reproduction.
<table>
<thead>
<tr>
<th>Stage</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTERPHASE</td>
<td></td>
</tr>
<tr>
<td>S phase</td>
<td>Nuclear envelope</td>
</tr>
<tr>
<td></td>
<td>Centrosomes (with centriole pairs)</td>
</tr>
<tr>
<td></td>
<td>Chromatin</td>
</tr>
</tbody>
</table>
MEIOSIS II

Prophase II

Prometaphase II

Metaphase II

Anaphase II

Telophase II and Cytokinesis

Haploid daughter cells

Sister chromatids separate
2.6 Biosynthesis
Biosynthesis is the process of making chemical compounds, like proteins and DNA, by living things. Through anabolic processes, small molecules and building blocks can get built up into larger functional systems.
Enzymes are made primarily of protein and act as catalysts to help reactions take place in biological systems by lowering the activation energy, and therefore increasing the rate of reaction.
Substrate entering active site of enzyme
Enzyme/substrate complex
Enzyme/products complex
Products leaving active site of enzyme

Enzyme changes shape slightly as substrate binds.