Chapters 3 & 4: Cellular Form and Function
Genetics and Cellular Function

**KEY CONCEPT**

- Cells: basic structural and functional units of life
  - respond to their environment
  - maintain homeostasis at the cellular level
  - modify structure and function over time
  - perform all life functions

**Sex & Somatic Cells**

- Sex cells (germ cells):
  - reproductive cells
  - male sperm
  - female oocytes (eggs)
- Somatic cells (*soma* = body):
  - all body cells except sex cells
Functions of Cell (Plasma) Membrane

- **Physical isolation:**
  - barrier
- **Regulates exchange with environment:**
  - ions and nutrients enter
  - waste and cellular products released
- **Monitors the environment:**
  - extracellular fluid composition
  - chemical signals
- **Structural support:**
  - anchors cells and tissues
Phospholipid Bilayer

- Double layer of phospholipid molecules:
  - hydrophilic heads — toward watery environment, both sides
  - hydrophobic fatty-acid tails — inside membrane
  - barrier to ions and water soluble compounds

Membrane Proteins

- Integral proteins:
  - within the membrane
- Peripheral proteins:
  - inner or outer surface of the membrane

6 Functions of Membrane Proteins (1 of 2)

1. Anchoring proteins (stabilizers):
   - attach to inside or outside structures
2. Recognition proteins (identifiers):
   - label cells normal or abnormal
3. Enzymes:
   - catalyze reactions

6 Functions of Membrane Proteins (2 of 2)

4. Receptor proteins:
   - bind and respond to ligands (ions, hormones)
5. Carrier proteins:
   - transport specific solutes through membrane
6. Channels:
   - regulate water flow and solutes through membrane
Membrane Carbohydrates

- Proteoglycans, glycoproteins, and glycolipids:
  - extend outside cell membrane
  - lubrication and protection
  - anchoring and locomotion
  - specificity in binding (receptors)
  - recognition (immune response)

Cytoplasm

- All materials inside the cell and outside the nucleus:
  - cytosol (fluid):
    - dissolved materials:
      - nutrients, ions, proteins, and waste products
  - organelles:
    - structures with specific functions

Types of Organelles

- Nonmembranous organelles:
  - direct contact with cytosol
- Membranous organelles:
  - covered with membrane
  - isolated from cytosol

Nonmembranous Organelles

- 6 types of nonmembranous organelles:
  - cytoskeleton
  - microvilli
  - centrioles
  - cilia
  - ribosomes
  - proteasomes
The Cytoskeleton

- Structural proteins for shape and strength

Intermediate Filaments

- Mid-sized between microfilaments and thick filaments:
  - durable (collagen)
  - strengthen cell and maintain shape
  - stabilize organelles
  - stabilize cell position

Microfilaments

- Thin filaments composed of the protein actin:
  - provide mechanical strength
  - Pairs with thick filaments of myosin for muscle movement

Intermediate Filaments

- Large, hollow tubes of tubulin protein:
  - attach to centrosome
  - strengthen cell and anchor organelles
  - change cell shape
  - move vesicles within cell (kinesin and dynein)
  - form spindle apparatus
Microvilli
- Increase surface area for absorption
- Attach to cytoskeleton

Centrioles in the Centrosome
- Centrioles form spindle apparatus during cell division
- Centrosome: cytoplasm surrounding centriole

Cilia Power
- Cilia move fluids across the cell surface

Ribosomes
- Build polypeptides in protein synthesis
- Two types:
  - free ribosomes in cytoplasm:
    - proteins for cell
  - fixed ribosomes attached to ER:
    - proteins for secretion
Proteasomes

- Contain enzymes (proteases)
- Disassemble damaged proteins for recycling

Membranous Organelles

- 5 types of *membranous* organelles:
  - endoplasmic reticulum (ER)
  - Golgi apparatus
  - lysosomes
  - peroxisomes
  - mitochondria

Endoplasmic Reticulum (ER)

- Smooth Endoplasmic Reticulum (SER)
  - No ribosomes attached
  - Synthesizes lipids and carbohydrates:
    - phospholipids and cholesterol (membranes)
    - steroid hormones (reproductive system)
    - glycerides (storage in liver and fat cells)
    - glycogen (storage in muscles)
Rough Endoplasmic Reticulum (RER)

- Surface covered with ribosomes:
  - active in protein and glycoprotein synthesis
  - folds polypeptides
  - encloses products in transport vesicles

Golgi Apparatus

Transport Vesicles

- Carry materials to and from Golgi apparatus

Lysosomes

- Powerful enzyme-containing vesicles:
  - lyso = dissolve, soma = body

Activation of lysosomes occurs when:

1. Primary lysosome fuses with the membrane of another organelle, such as a mitochondrion
2. Primary lysosome fuses with an endosome containing fluid or solid materials from outside the cell
3. The lysosomal membrane breaks down during autolysis following injury to, or death of, the cell
Lysosome Functions

- Clean up inside cells:
  - break down large molecules
  - attack bacteria
  - recycle damaged organelles
  - eject wastes by exocytosis

Peroxisomes

- Are enzyme-containing vesicles:
  - break down fatty acids, organic compounds
  - produce hydrogen peroxide ($H_2O_2$)
  - replicate by division

Mitochondrion Structure

- Smooth outer membrane and folded inner membrane (cristae)
- Matrix: fluid around cristae

Mitochondrial Function

- Aerobic metabolism (cellular respiration):
  - mitochondria use oxygen to break down food and produce ATP (energy for life activities)
The Nucleus
- Is the cell’s control center

Structure of the Nucleus
- Nucleus: - largest organelle
- Nuclear envelope: - double membrane around the nucleus
- Nuclear pores: - transport

Within the Nucleus
- DNA: - all information to build and run organisms
- Nucleoplasm: - fluid containing ions, enzymes, nucleotides, and some RNA
- Nuclear matrix: - support filaments
- Nucleolus: - Synthesize rRNA and ribosomal subunits

Organization of DNA
Organization of DNA

- **Nucleosomes:**
  - DNA coiled around histones
- **Chromatin:**
  - loosely coiled DNA (cells not dividing)
- **Chromosomes:**
  - tightly coiled DNA (cells dividing)

DNA and Genes

- **DNA:**
  - instructions for every protein in the body
- **Gene:**
  - DNA instructions for 1 protein

Genetic Code

- The chemical language of DNA instructions:
  - sequence of bases (A, T, C, G)
  - triplet code:
    - 3 bases = 1 amino acid

RNA & Protein Synthesis

- **Transcription:**
  - copies instructions from DNA to mRNA (in nucleus)
- **Translation:**
  - ribosome reads code from mRNA (in cytoplasm)
  - assembles amino acids into polypeptide chain
mRNA Synthesis

- Gene activation
- Transcription by RNA polymerase
- RNA processing

Codons

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<th>tRNA Anticodon</th>
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Translation (1 of 6)

- mRNA moves:
  - from the nucleus
  - through a nuclear pore

Translation (2 of 6)

- mRNA moves:
  - to a ribosome in cytoplasm
  - surrounded by amino acids
Translation (3 of 6)

- mRNA binds to ribosomal subunits
- tRNA delivers amino acids to mRNA

Translation (4 of 6)

- tRNA anticodon binds to mRNA codon
- 1 mRNA codon translates to 1 amino acid

Translation (5 of 6)

- Enzymes join amino acids with peptide bonds
- Polypeptide chain has specific sequence of amino acids

Translation (6 of 6)

- At stop codon, components separate

Protein Synthesis: Sequence of Amino Acids in the Newly Synthesized Polypeptide
KEY CONCEPT

• Mutation is a change in the nucleotide sequence of a gene:
  - can change gene function

• Causes:
  - exposure to chemicals
  - exposure to radiation
  - mistakes during DNA replication

Overcoming the Cell Barrier

• The cell membrane is a barrier, but:
  - nutrients must get in
  - products and wastes must get out

• How do things get in and out of cells?

Selective Permeability

• Cell membrane is selectively permeable:
  - allows some materials to move freely
  - restricts other materials

Restricted Materials

• Selective permeability restricts materials based on:
  - size
  - electrical charge
  - molecular shape
  - lipid solubility

Membrane Transport:
Fat- and Water-Soluble Molecules
Transport

Transport through a cell membrane can be:
- active (requiring energy and ATP)
- passive (no energy required)

3 Categories of Transport

- Diffusion (passive)
- Carrier-mediated transport (passive or active)
- Vesicular transport (active)

Solutions

- All molecules are constantly in motion
- Molecules in solution move randomly
- Random motion causes mixing

Concentration Gradient

- Concentration is the amount of solute in a solvent
- Concentration gradient:
  - more solute in 1 part of a solvent than another
- Diffusion:
  - molecules mix randomly
  - solute spreads through solvent
  - eliminates concentration gradient
Factors Affecting Diffusion Rates

- *Distance* the particle has to move
- *Molecule size*:
  - smaller is faster
- *Temperature*:
  - more heat, faster motion
- *Gradient size*:
  - the difference between high and low concentration
- *Electrical forces*:
  - opposites attract, like charges repel

Diffusion and the Cell Membrane

- Diffusion can be *simple* or *channel-mediated*

Simple Diffusion

- Materials which diffuse through cell membrane:
  - lipid-soluble compounds (alcohols, fatty acids, and steroids)
  - dissolved gases (oxygen and carbon dioxide)

Channel-Mediated Diffusion

- Materials which pass through transmembrane proteins (channels):
  - are water soluble compounds
  - are ions
Osmosis

- Osmosis is the diffusion of water across the cell membrane

How Osmosis Works

- More solute molecules, lower concentration of water molecules
- Membrane must be freely permeable to water, selectively permeable to solutes
- Water molecules diffuse across membrane toward solution with more solutes
- Volume increases on the side with more solutes

Tonicity

- The osmotic effect of a solute on a cell:
  - Isotonic means solution does not cause osmotic flow of water into or out of cell

Cells and Hypotonic Solutions

- A cell in a hypotonic solution:
  - gains water
  - ruptures (hemolysis of red blood cells)
Cells and Hypertonic Solutions

- A cell in a hypertonic solution:
  - loses water
  - shrinks (crenation of red blood cells)

Carrier-Mediated Transport

- Carrier-mediated transport of ions and organic substrates:
  - facilitated diffusion
  - active transport

Facilitated Diffusion

- Passive
- Carrier mediated

How Facilitated Diffusion Works

- Carrier proteins transport molecules too large to fit through channel proteins (glucose, amino acids):
  - molecule binds to receptor site on carrier protein
  - protein changes shape, molecules pass through
  - receptor site is specific to certain molecules
Active Transport

- Active transport proteins:
  - move substrates against concentration gradient
  - require energy, such as ATP
  - ion pumps move ions (Na\(^+\), K\(^+\), Ca\(^+\), Mg\(^{2+}\))
  - exchange pump countertransports 2 ions at the same time

Secondary Active Transport

- Na\(^+\) concentration gradient drives glucose transport
- ATP energy pumps Na\(^+\) back out

Transport Vesicles

- Also called *bulk transport*
- Vesicles:
  - endocytosis (endo = into)
  - active transport using ATP:
    - receptor-mediated
    - pinocytosis
    - phagocytosis
  - exocytosis (exo = out of)
Receptor-Mediated Endocytosis

- Pinocytosis (cell drinking)
- Endosomes “drink” extracellular fluid

Pinocytosis

Exocytosis

- Is the reverse of endocytosis
- Ejects secretory products and wastes
3 Stages of Cell Division

- **Body (somatic) cells divide in 3 stages:**
  - Interphase: DNA replication duplicates genetic material exactly
  - Mitosis divides genetic material equally
  - Cytokinesis divides cytoplasm and organelles into 2 daughter cells

### Interphase

- The nondividing period:
  - **G₀ phase**—specialized cell functions only
  - **G₁ phase**—cell growth, organelle duplication, protein synthesis
  - **S phase**—DNA replication and histone synthesis
  - **G₂ phase**—finishes protein synthesis and centriole replication

### DNA Replication

- DNA strands unwind
- DNA polymerase attaches complementary nucleotides
Mitosis

- Mitosis divides duplicated DNA into 2 sets of chromosomes:
  - DNA coils tightly into chromatids
  - chromatids connect at a centromere
  - protein complex around centromere is kinetochore

Stage 1: Prophase

- Nucleoli disappear
- Centriole pairs move to cell poles
- Microtubules (spindle fibers) extend between centriole pairs
- Nuclear envelope disappears
- Spindle fibers attach to kinetochore

Stage 2: Metaphase

- Chromosomes align in a central plane (metaphase plate)
Stage 3: Anaphase

- Microtubules pull chromosomes apart
- Daughter chromosomes groups near centrioles

Stage 4: Telophase

- Nuclear membranes reform
- Chromosomes uncoil
- Nucleoli reappear
- Cell has 2 complete nuclei

Stage 4: Cytokinesis

- Cleavage furrow around metaphase plate
- Membrane closes, producing daughter cells

What regulates cell division?

- Muscle cells, neurons rarely divide
- Exposed cells (skin and digestive tract) live only days or hours
Cancer

Cell Division and Tumors

• Tumor (neoplasm):
  - enlarged mass of cells
  - abnormal cell growth and division
• Benign tumor:
  - contained
  - not life threatening
• Malignant tumor:
  - spread into surrounding tissues (invasion)
  - start new tumors (metastasis)

Cancer and Genes

• Oncogenes:
  - mutated genes that cause cancer
• Tumor suppressor genes:
  - normally control cell growth until mutated

Cell Differentiation

• All body cells, except sex cells, contain the same 46 chromosomes
• Cells specialize or differentiate to form tissues (e.g., liver cells, fat cells, neurons)
• What makes cells different?
• Differentiation depends on which genes are active and which are inactive