Human Anatomy & Physiology
Chapter 2 (emphasis on pages 47-58)
Chemical Basis Of Life
Matter

- The “stuff” of the universe
- Anything that has mass and occupies space
- Mass vs. Weight (amount of matter vs. force)
- States of Matter
  - Solid – has definite shape and volume
  - Liquid – has definite volume, changeable shape
  - Gas – has changeable shape and volume
Elements – unique substances that cannot be broken down into simpler substances by ordinary chemical means

Each element is composed of Atoms

Physical and Chemical properties of an element’s atoms give the element its unique properties

Atomic symbol – one- or two-letter chemical shorthand for each element
Atomic Structure

- The Nucleus consists of Neutrons and Protons
  - Neutrons – have no charge (Neutral) and a mass of one atomic mass unit (amu)
  - Protons – have a Positive charge and a mass of one amu
- Electrons have a negative charge and 1/2000 the mass of a proton (0 amu)
  - Electrons – are located in regions (Orbitals) around the nucleus
Atomic Structure: Examples of Different Elements

- **Hydrogen (H)**
  - (1p⁺; 0n⁰; 1e⁻)

- **Carbon (C)**
  - (6p⁺; 6n⁰; 6e⁻)

- **Oxygen (O)**
  - (8p⁺; 8n⁰; 8e⁻)

- **Sodium (Na)**
  - (11p⁺; 12n⁰; 11e⁻)

(b) Chemically active elements (valence shell incomplete)

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Examples of Elements

- **Hydrogen**
  - Atomic Number: 1
  - Atomic Mass: 1.00797

- **Carbon**
  - Atomic Number: 6
  - Atomic Mass: 12.01

- **Oxygen**
  - Atomic Number: 8
  - Atomic Mass: 16

- **Nitrogen**
  - Atomic Number: 7
  - Atomic Mass: 14.01

- **Calcium**
  - Atomic Number: 20
  - Atomic Mass: 40.08
# Periodic Table of the Elements

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Major Elements of the Human Body

- Oxygen (O) – major component of organic and inorganic molecules; as a gas, needed for the production of ATP
- Carbon (C) – component of all organic molecules – carbohydrates, lipids, proteins, and nucleic acids
- Hydrogen (H) – component of all organic molecules; as an ion, it influences pH (degree of acidity or alkalinity) of body fluids
- Nitrogen (N) – component of proteins and nucleic acids
Other Elements

Calcium (Ca), Phosphorus (P), Potassium (K), Sulfur (S), Sodium (Na), Chlorine (Cl), Magnesium (Mg), Iodine (I), and Iron (Fe)

Trace Elements

Required in minute amounts, many are found as parts of enzymes: Selenium (Se), Zinc (Zn), Copper (Cu)
Chemical Composition of the Human Body

- Oxygen or O – 65%
- Carbon or C – 18.5%
- Hydrogen or H – 9.5%
- Nitrogen or N – 3.2%
- Calcium or Ca – 1.5%
- Phosphorous or P – 1.0%
Chemical Constituents of Cells

- **Inorganic Molecules** do not contain carbon and hydrogen together, do have other important roles (water, salts, and many acids and bases)

- **Organic Molecules** contain carbon covalently bonded to other atoms, determine structure and function
Chemical Constituents of Cells

- Common Inorganic Compounds:
  - Oxygen
  - Water
  - Carbon Dioxide (CO₂)

- In Blood: \( \text{CO}_2 + \text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{CO}_3 \)

- In Lungs: \( \text{H}_2\text{CO}_3 \rightarrow \text{H}_2\text{O} + \text{CO}_2 \)
<table>
<thead>
<tr>
<th>Substance</th>
<th>Symbol or Formula</th>
<th>Functions</th>
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<tbody>
<tr>
<td><strong>I. Inorganic Molecules</strong></td>
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<tr>
<td>Water</td>
<td>H₂O</td>
<td>Major component of body fluids (chapter 21, p. 808); medium in which most biochemical reactions occur; transports various chemical substances (chapter 14, p. 523); helps regulate body temperature (chapter 6, p. 170)</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O₂</td>
<td>Used in release of energy from glucose molecules (chapter 4, p. 111)</td>
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<tr>
<td>Carbon dioxide</td>
<td>CO₂</td>
<td>Waste product that results from metabolism (chapter 4, p. 111); reacts with water to form carbonic acid (chapter 19, p. 762)</td>
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<td><strong>II. Inorganic Ions</strong></td>
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<td>Bicarbonate ions</td>
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<td>Help maintain acid-base balance (chapter 21, p. 819)</td>
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<td>Calcium ions</td>
<td>Ca²⁺</td>
<td>Necessary for bone development (chapter 7, p. 190); muscle contraction (chapter 9, p. 284) and blood clotting (chapter 14, fig. 14.19)</td>
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<tr>
<td>Carbonate ions</td>
<td>CO₃⁻²</td>
<td>Component of bone tissue (chapter 7, p. 194)</td>
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<td>Chloride ions</td>
<td>Cl⁻</td>
<td>Help maintain water balance (chapter 21, p. 810)</td>
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<td>Hydrogen ions</td>
<td>H⁺</td>
<td>pH of the internal environment (chapters 19, p. 754, and 21, p. 817)</td>
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<td>Magnesium ions</td>
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<td>Component of bone tissue (chapter 7, p. 194); required for certain metabolic processes (chapter 18, p. 715)</td>
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<td>Phosphate ions</td>
<td>PO₄⁻³</td>
<td>Required for synthesis of ATP, nucleic acids, and other vital substances (chapter 4, p. 108); component of bone tissue (chapter 7, p. 194); help maintain polarization of cell membranes (chapter 10, p. 350)</td>
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<td>Potassium ions</td>
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<td>Required for polarization of cell membranes (chapter 10, p. 350)</td>
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<td>Na⁺</td>
<td>Required for polarization of cell membranes (chapter 10, p. 350); help maintain water balance (chapter 21, p. 810)</td>
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<td>Sulfate ions</td>
<td>SO₄⁻²</td>
<td>Help maintain polarization of cell membranes (chapter 10, p. 350) and acid-base balance (chapter 21, p. 817)</td>
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</table>
Carbon (C) has 4 electrons in its outer shell. Because 8 electrons are needed to fill its valence shell, it can form strong, stable covalent bonds with 4 other atoms (usually H, O, N, S, P, or another C).
Carbon can bind to itself, which allows the formation of different carbon-based molecules with unique structures.

Carbon atoms can form...

- long chains,
- branches,
- and ring structures.
Adjacent carbon atoms can also form Double and Triple bonds.

- Carbon-carbon **single** bond
- Carbon-carbon **double** bond
- Carbon-carbon **triple** bond
## Organic Molecules – Monomers and Polymers

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<tr>
<th>Class</th>
<th>Monomer (subunit)</th>
<th>Polymer</th>
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<tr>
<td>Carbohydrates</td>
<td>Sugar</td>
<td>Polysaccharides</td>
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<tr>
<td>Lipids</td>
<td>Fatty Acids</td>
<td>Lipids, Phospholipids</td>
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<tr>
<td>Proteins</td>
<td>Amino Acids</td>
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<tr>
<td>Nucleic Acids</td>
<td>Nucleotides</td>
<td>(DNA, RNA)</td>
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### Subunits
- Sugars
- Fatty Acids
- Amino Acids
- Nucleotides

### Large Molecules
- Polysaccharides
- Fats/Lipids/Membranes
- Proteins
- Nucleic Acids
Chemical Constituents of Cells

Common Organic Substances:

- Carbohydrates – monosaccharides, disaccharides, & polysaccharides
- Lipids – saturated & unsaturated fats
- Proteins – enzymes, antibodies, structural protein (e.g. collagen)
- Nucleic Acids - nucleotides & polynucleotides
The chemical properties of the different classes depend on the presence of specific functional groups. The larger molecules in each class are formed by joining one or more subunit molecules together.
Organic Molecules – Four Classes

Carbohydrates

Lipids

Proteins

Nucleic Acids
Carbohydrates

- Contain carbon, hydrogen, and oxygen, generally the hydrogen to carbon ratio is 2:1 (same as water) carbohydrate – “hydrated carbon”
- Classified as:
  - Monosaccharide – “one sugar” - exist as straight chains or rings
  - Disaccharide – “two sugars”
  - Polysaccharide – “many sugars”
Carbohydrates

Monosaccharides - simple sugars, single chain or single ring structures
Most important in the body are the pentose and hexose sugars

Glucose, fructose, and galactose are isomers, they have the same formula \((C_6H_{12}O_6)\), but the atoms are arranged differently
Carbohydrates

Disaccharides - double sugars – two monosaccharides joined by *dehydration synthesis* (loss of water molecule)

Must be broken down by *hydrolysis* to simple sugar units for absorption from digestive tract into blood stream
Carbohydrates

Polysaccharides - polymers of simple sugars

(Polymer – long, chain-like molecule)
Carbohydrates – Types of Polysaccharides

**Starch** - straight chain of glucose molecules, few side branches. Energy storage for plant cells.

**Glycogen** - highly branched polymer of glucose, storage carbohydrate of animals.

**Cellulose** - chain of glucose molecules, structural carbohydrate, primary constituent of plant cell walls.

**Chitin** - polymer of glucose with amino acids attached, primary constituent of exoskeleton.
Organic Molecules – Four Classes

Carbohydrates

Lipids

Proteins

Nucleic Acids
Lipids

- Four Types of Lipids
  - Neutral Fats or Triglycerides
  - Phospholipids
  - Steroids
  - Other Lipoid substances – eicosanoids, lipoproteins
Lipids

- Lipids are insoluble in water but are soluble in other lipids and in organic solvents (alcohol, ether) or detergents.
- Most of the structure of lipids is non-polar, formed almost exclusively of carbon and hydrogen atoms.
- Contain C, H, and O, but the proportion of oxygen in lipids is less than in carbohydrates.
Neutral Fats (Triglycerides or Triacylglycerols)

Glycerol and 3 fatty acids. (Fats & oils)
Neutral Fats (Triglycerides or Triacylglycerols)

Commonly known as fats when solid or oils when liquid

Composed of three fatty acids (hydrocarbon chains) bonded to a glycerol (sugar alcohol) molecule

(a) Formation of a triglyceride
Neutral Fats (Triglycerides or Triacylglycerols)

**Nutrition Facts**

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* Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs.

**Total Fat = 5 grams**

**Saturated Fat = 1 gram**

**What is the rest of the fat?**

**Unsaturated**

- Monounsaturated
- Polyunsaturated

**Hydrogenated**

- Cis and Trans fats
Neutral Fats (Triglycerides or Triacylglycerols)

- Saturated Fats Align Solid
  - Tight Fit
  - As Hard As Butter

- Polyunsaturated Fats Are Fluid
  - Loose Fit
  - Liquid Oil

Cis-Fat
- Add Hydrogen (Hydrogenation)
- Straight and Solid

Trans-Fat
Lipids – Phospholipids

Glycerol, 2 fatty acids, 1 phosphate (Cell Membranes)
Phospholipids – modified triglycerides with two fatty acid groups and a phosphorus group- main component of cell membranes
Cholesterol is a constituent of the animal cell membrane and a precursor of other steroids.

Steroids are fat-soluble with a tetracyclic (four fused carbon rings) base structure.

Cholesterol is a constituent of the animal cell membrane and a precursor of other steroids.
Representative Lipids Found in the Body

- Neutral fats – found in subcutaneous tissue and around organs
- Phospholipids – chief component of cell membranes
- Steroids – cholesterol, bile salts, vitamin D, sex hormones, and adrenal cortical hormones
- Fat-soluble vitamins – vitamins A, E, and K
- Lipoproteins (HDL, LDL) – combinations of fat and protein that transport fatty acids and cholesterol in the bloodstream
Importance of Lipids

Long-term Energy storage -
highest caloric values per weight

Chemical messengers –
steroid hormones (testosterone & estrogen)

Cell membranes –
phospholipids, cholesterol
Organic Molecules – Four Classes

Carbohydrates

Lipids

Proteins

Nucleic Acids
Proteins

Protein is the basic structural material of the body
– 10 to 30% of cell mass

Many other vital functions – enzymes, hemoglobin, contractile proteins, collagen, even proteins that help and protect other proteins

Most are macromolecules, large (100 to 10,000 a.a.), complex molecules composed of combinations of 20 types of amino acids bound together with peptide bonds
Proteins

- structural material
- energy source
- hormones
- receptors
- enzymes
- antibodies
- building blocks are amino acids

Note: amino acids held together with peptide bonds
20 types of building blocks for protein molecules
Each amino acid contains an amine group, a carboxyl group (COOH), and a functional (R) group

Differences in the R group make each amino acid chemically unique
Proteins are polymers – **polypeptides** – of amino acids held together by *Peptide* bonds with the amine end of one amino acid linked to the carboxyl end of the next amino acid. The order or *sequence* of the amino acids determine the function of the protein.
Structural Levels of Proteins

- Primary
- Secondary
- Tertiary
- Quaternary
Primary – linear sequence of amino acids composing the polypeptide chain (strand of amino acid “beads”)
Structural Levels of Proteins

Secondary – alpha helix or beta pleated sheets

Both stabilized by hydrogen bonds
Hydrogen Bonds in Water
Hydrogen Bonds in Protein

Intramolecular hydrogen bonds
Hydrogen bonding as well as covalent bonding between atoms in different parts of a polypeptide cause a tertiary structure. It is the tertiary structure that gives a protein its shape and thus determines its function.
Although some proteins are just polypeptide chains, others have several polypeptide chains and are connected in a fourth level (quaternary).

(d) Quaternary structure—Two or more polypeptide chains may be connected to form a single protein molecule.
Structural Levels of Proteins

Quaternary – polypeptide chains linked together in a specific manner
Fibrous and Globular Proteins

- **Fibrous proteins (structural proteins)**
  - Extended and strandlike proteins
  - Insoluble in water and very stable
  - Examples: keratin, elastin, collagen, and contractile fibers (actin and myosin)

- **Globular proteins (functional proteins)**
  - Compact, spherical proteins
  - Insoluble in water and chemically active
  - Examples: antibodies, hormones, and enzymes
Characteristics of Enzymes

- Most are globular proteins that act as biological catalysts
- Enzymes are chemically specific
- Frequently named for the type of reaction they catalyze
- Enzyme names usually end in –ase (e.g., amylase, protease, nuclease, triose phosphate isomerase, hexokinase)
- Lower activation energy
Characteristics of Enzymes

(a) Noncatalyzed reaction

(b) Enzyme-catalyzed reaction
Mechanism of Enzyme Action

- Enzyme binds substrate(s) at active site
- Product is formed at a lower activation energy
- Product is released
Protein Denaturation

The activity of a protein depends on its three-dimensional structure.

Intramolecular bonds, especially hydrogen bonds, maintain the structure.

Hydrogen bonds may break when the pH drops or the temperature rises above normal.
A protein is *denatured* when it unfolds and loses its three-dimensional shape (conformation).

Depending upon the severity of the change, Denaturation may be irreversible.
Molecular Chaperones (Chaperonins)

- Help other proteins to achieve their functional three-dimensional shape
- Maintain folding integrity
- Assist in translocation of proteins across membranes
- Promote the breakdown of damaged or denatured proteins

heat shock proteins (hsp), stress proteins
Organic Molecules – Four Classes

Carbohydrates

Lipids

Proteins

Nucleic Acids
Nucleic Acids – polymers of Nucleotides

- Composed of carbon, oxygen, hydrogen, nitrogen, and phosphorus
- Nucleotides are composed of N-containing base, a pentose sugar, and a phosphate group
- Five nitrogen bases – adenine (A), guanine (G), cytosine (C), thymine (T), and uracil (U)
- Two major classes – DNA and RNA
Nucleic Acids – polymers of Nucleotides

- Nucleotides are composed of N-containing base, a pentose sugar, and a phosphate group
- Five nitrogen bases – adenine (A), guanine (G), cytosine (C), thymine (T), and uracil (U)

Adenine and Guanine
Purines – 2-ring structure

Cytosine, Thymine, Uracil
Pyrimidines – 1-ring structure
Structure of DNA

Nucleotides are linked by hydrogen bonds between their complementary bases

A always bonds to T
G always bonds to C
Structure of DNA

A coiled, double-stranded polymer of nucleotides
The molecule is referred to as a double helix

Alternating sugar and phosphate?
Joined bases?
Deoxyribonucleic Acid (DNA)

- Double-stranded helical molecule found in the nucleus of the cell (also in mitochondria)
- Replicates itself before the cell divides, ensuring genetic continuity - it is the genetic material inherited from parents – it is the genetic code
- Provides instructions for protein synthesis

DNA → RNA → Protein Synthesis → Proteins and Enzymes → Structure and Metabolism
Ribonucleic Acid (RNA)

- Single-stranded molecule found in both the nucleus and the cytoplasm of a cell
- Sugar is Ribose instead of Deoxyribose
- Uses the nitrogenous base **Uracil** instead of Thymine
- Three varieties of RNA: messenger RNA, transfer RNA, and ribosomal RNA
Adenosine Triphosphate (ATP)

- Adenine-containing RNA nucleoside with three phosphate groups
- Source of immediately usable energy for the cell

Although glucose is the main cellular fuel, the chemical energy contained in its bonds is not directly used, but the energy released during glucose catabolism is coupled to the synthesis of ATP.
From Molecules to Cells

- From nonliving chemicals to an organized ensemble that possesses the characteristics of life.
- Fundamental unit of life is the cell.
- Humans are multicellular organisms
- An adult human is composed of about 75 trillion cells.
red blood cell

white blood cell

human egg cell

Smooth muscle cell

SCALE: $1000 \mu m = 1 \text{ mm}$
Nerve cell – transmits impulses

Epithelial cells – form protective layers

Muscle cells - contraction