Lecture Outline: Chemical Fundamentals

I. **Basic Chemistry in Cell Biology**

A. **Chemical Reactions**

1. Involve **reactants** transformed into **products**
2. Essentially a **rearrangement of electrons**
3. Can profoundly affect properties of substances
    a. Example: Sodium (explosively reactive) + Chlorine (poisonous gas) → Sodium Chloride (table salt, essential to life)
4. Involve breaking and forming of **chemical bonds**
5. Example of **emergent properties** (e.g., water from hydrogen and oxygen)

B. **Elements and Compounds**

1. All matter is made of **atoms**
2. **Element**: A substance made up of only one kind of atom
    a. Exhaustively listed on the **periodic table of the elements** (over 100 known)
    b. Defined by the number of **protons** (atomic number)
3. **Compound**: A substance made up of two or more kinds of atoms (e.g., water, sodium chloride)

C. **Composition of Living Organisms**

1. Most abundant elements in the body: **Oxygen, Carbon, Hydrogen, Nitrogen**
2. These are key components of **biological macromolecules** (lipids, polysaccharides, polypeptides, polynucleotides)
3. Elements in living things are generally from the top rows of the periodic table (lighter elements)

D. **Atomic Structure: Subatomic Particles**

1. Atoms are inconceivably tiny structures
2. Composed of three primary **subatomic particles**:

    a. **Protons (p+)**

    (1) Located in the **nucleus** (center of atom)

    (2) **Positively charged** (+1)

    (3) Number of protons determines the **element** (atomic number)

    e. **Neutrons (n)**

    (1) Located in the **nucleus**

    (2) **Electrostatically neutral** (no charge)

    (3) Similar size and mass to protons

    (4) Number of neutrons can vary (zero or more)

    j. **Electrons (e-)**

    (1) Located in the space **around the nucleus** (not in fixed orbits)

    (2) **Negatively charged** (-1)

    (3) Much smaller in size than protons and neutrons, but equal in charge magnitude

3. **Neutral Atom**: Has an equal number of protons and electrons, resulting in no overall charge
4. **Ion**: An atom that has an overall electrical charge

    a. Formed by **gaining or losing electrons** (number of protons remains constant in normal chemistry)

    b. **Anion**: Negatively charged ion (gained electrons)

    c. **Cation**: Positively charged ion (lost electrons)

II. **Electron Behavior and Chemical Bonds**

A. **Electron Energy Levels (Shells)**

1. Space around the nucleus where electrons are found
2. Electrons occupy discrete energy levels (never between levels)

3. Lower energy levels are closer to the nucleus and are more stable
4. Each shell has a maximum electron capacity
5. Shells are subdivided into **subshells**, which are further subdivided into **orbitals**
6. **Orbitals**: Spaces where electrons are found
    a. Can contain at most **two electrons**
    b. Different kinds of orbitals with different shapes:
        (1) **s orbitals**: Spherical; one per shell
        (2) **p orbitals**: Dumbbell-shaped; three per shell (starting from second shell)
7. Electron capacity of shells:
    a. Shell 1: Contains only one 1s orbital, holds a maximum of **2 electrons**
    b. Shell 2: Contains one 2s orbital and three 2p orbitals (4 orbitals total), holds a maximum of **8 electrons** (the "magic number eight")

B. **Atomic Stability and Valence**

1. Atoms achieve high **stability** by having completely filled outer shells or subshells
2. **Noble Gases** (Group 18 elements): Have full outer shells, making them inert (do not react chemically)
3. **Valence Shell**: The outermost electron shell of an atom that contains at least one electron
4. **Valence Electrons**: Electrons located in the valence shell; these are involved in chemical reactions
5. **Valence (of an atom)**: The number of additional electrons an atom needs to fill its valence shell/subshell to achieve stability (like a noble gas)
    a. Fluorine has a valence of 1 (needs 1 more electron)
    b. Hydrogen has a valence of 1 (needs 1 more electron to fill its first shell to 2)

C. **Types of Chemical Bonds**

1. **Ionic Bonds**
    a. Form between a **metal** and a **non-metal**
    b. Involve the **transfer of electrons** from the metal (forming a cation) to the non-metal (forming an anion)
    c. Oppositely charged ions attract each other electrostatically
    d. Weakest type of chemical bond
    e. Form **ionic compounds**, also called **salts** (e.g., sodium chloride)
    f. Ionic compounds form crystal lattices; not referred to as "molecules"
    g. Smallest piece of an ionic compound is a **formula unit**
2. **Covalent Bonds**
    a. Form between two **non-metals** (e.g., hydrogen, oxygen, nitrogen, carbon)
    b. Involve the **sharing of valence electrons** between atoms
    c. Much stronger than ionic bonds
    d. Form discrete **molecules** (e.g., H2O, O2)
    e. Each covalent bond consists of a pair of shared electrons
    f. Types of covalent bonds:
        (1) **Single Covalent Bond**: One shared pair of electrons
        (2) **Double Covalent Bond**: Two shared pairs of electrons (stronger than single)
        (3) **Triple Covalent Bond**: Three shared pairs of electrons (strongest covalent bond)
    j. Valence of an atom can be seen as the number of covalent bonds it will form
3. **Carbon's Special Role in Organic Chemistry**
    a. Carbon exhibits **tetravalence** (valence of four), meaning it always forms four bonds
    b. High versatility in bonding, allowing for a limitless number of organic compounds
    c. Smallest, simplest atom with tetravalence, making it the basis of

carbon-based life

D. **Polarity of Covalent Bonds and Molecules**

1. **Electronegativity**: An atom's "greediness" or attraction for shared electrons
    a. Increases across the periodic table from lower left to upper right (excluding noble gases)
    b. Oxygen has high electronegativity
2. **Non-polar Covalent Bond**: Equal or near-equal sharing of electrons
    a. Occurs between atoms with similar electronegativities (e.g., C-H bonds, O-O bonds in O2)
    b. Results in no significant partial charges
3. **Polar Covalent Bond**: Unequal sharing of electrons
    a. Electrons spend more time around the more electronegative atom, creating a slight negative charge (δ-)
    b. The other atom develops a slight positive charge (δ+)
    c. Example: O-H bonds in water (Oxygen is more electronegative than Hydrogen)
4. **Polar Molecule**: An overall molecule with a net separation of partial charges due to polar bonds and molecular shape (e.g., water)
    a. Water's polarity is crucial for life (e.g., its properties as a solvent)
    b. Water's bent shape (due to electron pair repulsion) contributes to its polarity

E. **Hydrogen Bonds**

1. Weak attractions between **polar molecules** (e.g., water and ammonia)
2. Occur between the slightly positive part of one molecule and the slightly negative part of another
3. **Not classified as chemical bonds** (less permanent, do not form new substances)
4. Responsible for properties like water's solubility for salts

III. **Chemical Signals and Cellular Responses**

A. **Signal Molecules (Chemical Signals)**

1. Particles that cause specific events to occur within an organism or cell
2. Function based on their unique **three-dimensional shape**
3. Must bind to a complementary-shaped **receptor protein** to elicit an effect

B. **Receptors**

1. Proteins that can adopt a limitless number of shapes, allowing for high specificity to signals
2. Often membrane-bound, extending across the cell membrane

C. **Types of Signals**

1. **Endogenous Signals**: Produced naturally within the organism (e.g., endorphin, hormones like oxytocin)
2. **Exogenous Signals (Drugs)**: Originate outside the organism (e.g., morphine)
3. Exogenous drugs can mimic endogenous signals if their "business end" (the part that binds to the receptor) has a similar shape

D. **Mechanism of Signal Transduction**

1. When a signal molecule binds to its receptor, the receptor undergoes a **conformational change** (change in shape)
2. This shape change in the receptor's internal part triggers subsequent events inside the cell, even if the signal molecule itself does not enter the cell

E. **Ligands**

1. General term for any molecule or particle that **binds to a protein**
2. Examples include:
    a. Signal molecules binding to receptor proteins
    b. Substrates binding to enzyme proteins
3. Binding of a ligand to a protein generally results in a **conformational change** in the protein