Biochemistry

- Biochemistry is the study of chemical composition and chemical rxns. of living matter

- Organic compounds
  - Contain carbon, are covalently bonded, and are often large

- Inorganic compounds
  - Do not contain carbon
  - Water, salts, and many acids and bases
Properties of Water

- High heat capacity – absorbs and releases large amounts of heat before changing temperature. Important for temperature homeostasis

- High heat of vaporization – cooling effect due to heat absorption by water to break H-bonds upon vaporization
Properties of Water

- Polar solvent properties – water is the universal solvent. Water’s – ends orient toward the solute’s + end(s) and dissociate the solute.

- Forms hydration layers around large charged molecules (e.g. proteins) forming “biological colloids” e.g. cerebrospinal fluid and blood.

- Water serves as the body’s major transport medium (e.g. blood plasma, urine, sweat, mucus)
Properties of Water

- Reactivity – Water is a reactant in rxns. E.g. hydrolysis (splitting of water) and dehydration synthesis (bond formation by the removal of water) reactions

- Cushioning – Water protects body against physical trauma. E.g. cerebrospinal fluid cushions the brain
Salts

- Inorganic compounds
- Contain cations other than H\(^+\) and anions other than OH\(^-\)
- Are electrolytes; they conduct electrical currents
- Dissociate in water into their components
Acids and Bases

- Acids release $\text{H}^+$ and are therefore proton donors
  \[ \text{HCl} \rightarrow \text{H}^+ + \text{Cl}^- \]
- Bases release $\text{OH}^-$ and are proton acceptors
  \[ \text{NaOH} \rightarrow \text{Na}^+ + \text{OH}^- \]
Acid-Base Concentration (pH)

- Acidic solutions have higher H\(^+\) concentration (denoted as [H\(^+\)]) and therefore a lower pH
- Alkaline solutions have lower H\(^+\) concentration and therefore a higher pH
- Neutral solutions have equal H\(^+\) and OH\(^-\) concentrations
Acid-Base Concentration (pH)

- **Acidic:** pH 0–6.99
- **Basic:** pH 7.01–14
- **Neutral:** pH 7.00

pH scale is based on the [H+] in a solution
Expressed as moles/L or M

pH = -log [H+] in moles/L

pH 7; [H+] = 10^{-7}M

pH = pondus Hydrogenii (latin)
potential of hydrogen

Actually pH is shorthand for its mathematical approximation p = -log10 & H = [H+]

Figure 2.13
Buffers

- Living cells are extremely sensitive to pH
- Kidney & lungs regulate the homeostasis of pH
- Buffers resist abrupt and large swings in the pH of body fluids
- Accomplished by releasing H$^+$ ions when the pH begins to rise and by binding (accepting) H$^+$ ions when the pH begins to drop

InterActive Physiology$^\text{®}$: Fluid, Electrolyte, and Acid/Base Balance: Acid/Base Homeostasis
Buffers

- **Strong Acids**: acids that dissociate completely and irreversibly in water. Can dramatically change the pH of a solution, e.g. HCl

- **Weak Acids**: acids that do not dissociate completely, e.g. acetic acid (vinegar)

- **Strong base**: dissociate easily in water

- **Weak base**: do not dissociate easily in water
Buffers

- Carbonic acid-bicarbonate buffer system
  - Carbonic acid dissociates, reversibly releasing bicarbonate ions and protons
  - The chemical equilibrium between carbonic acid and bicarbonate resists pH changes in the blood

response to increase in pH

\[ H_2CO_3 \rightleftharpoons HCO_3^- + H^+ \]

response to decrease in pH
Organic Compounds

- Molecules unique to living systems contain carbon and hence are organic compounds

- Usually very large w/ small functional groups that interact w/ other molecules

- Include:
  - Carbohydrates
  - Lipids
  - Proteins
  - Nucleic Acids
Carbohydrates

- Contain carbon, hydrogen, and oxygen
- Their major function is to supply a source of cellular food
- Examples:
  - Monosaccharides or simple sugars (hexose/pentose single ring)

![Monosaccharides](Figure 2.14a)
Carbohydrates

- Disaccharides or double sugars (2 rings)

Too large to pass thru cell membranes. Must be digested to be absorbed

(b) Disaccharides

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Figure 2.14b
Carbohydrates

- Polysaccharides or polymers of simple sugars
- Large and insoluble. Good for storage
- Ready Source of cellular fuel
- Glycogen $\rightarrow$ Glucose $\rightarrow$ ATP $\rightarrow$ ADP
Lipids

- Contain C, H, and O, but the proportion of oxygen in lipids is less than in carbohydrates

- Examples:
  - Neutral fats or triglycerides
  - Phospholipids
  - Steroids
  - Eicosanoids
Neutral Fats (Triglycerides)

- Composed of three fatty acids bonded to a glycerol molecule

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

- Formed by dehydration synthesis

- Glycerol is common in all triglycerides, but the length of the fatty acid chains varies.

- Provide the body with the most efficient and compact form of stored energy and yields large amounts of energy

- Located as subcutaneous fat layer

- Insulates the body
Other Lipids

- Saturate fats: fatty acid chains w/ single covalent bonds

- Unsaturated fats: fatty acid chains w/ one or more double bonds causing the chain to kink thus reducing the packing ability

- Trans Fats: oils solidified by the addition of Hydrogen atoms at the site of double bonds
Other Lipids

- Phospholipids – modified triglycerides with two fatty acid groups and a phosphorus group

![Diagram of Phospholipid Molecule]

(b) Phospholipid molecule (phosphatidylcholine)

Used in cell membranes and lipid bilayers

Figure 2.15b
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
Amino Acids

- Building blocks of protein, containing an amino group and a carboxyl group
- Amino group $\text{NH}_2$
- Carboxyl groups $\text{COOH}$
Amino Acids

(a) Generalized structure of all amino acids

(b) Glycine (the simplest amino acid)

(c) Aspartic acid (an acidic amino acid)
Protein

- Macromolecules composed of combinations of 20 types of amino acids bound together with peptide bonds
Protein

- Macromolecules composed of combinations of 20 types of amino acids bound together with peptide bonds
Structural Levels of Proteins

- Primary – amino acid sequence
- Secondary – twist / bend of linear sequence, e.g. alpha helices or beta pleated sheets
Structural Levels of Proteins

- Tertiary – superimposed folding of secondary structures

- Quaternary – when 2 or more polypeptide chains are linked together in a specific manner

- The overall structure is dictated by the a.a. sequence found in the primary structure (linear sequence of a.a.)
Structural Levels of Proteins

(a) Primary structure (polypeptide strand)

(c) Secondary structure (β-pleated sheet)
Structural Levels of Proteins

(b) Secondary structure
(α-helix)

(d) Tertiary structure

(e) Quaternary structure
(hemoglobin molecule)

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Figure 2.18b,d,e
Fibrous and Globular Proteins

- Fibrous proteins
  - Extended and strand-like proteins
  - Examples: keratin, elastin, collagen, and certain contractile fibers
Fibrous and Globular Proteins

- Globular proteins
  - Compact, spherical proteins with tertiary and quaternary structures
  - Examples: antibodies, hormones, and enzymes
Protein Denaturation

- Reversible unfolding of proteins due to drops in pH and/or increased temperature

Figure 2.19a
Protein Denaturation

- Irreversibly denatured proteins cannot refold and are formed by extreme pH or temperature changes.
Protein Denaturation

- However, denaturation is often reversible
- When denatured, the protein’s active site is removed leaving the protein unable to function
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
Characteristics of Enzymes

- Most are globular proteins that act as biological catalysts
- Accelerate the rate of biological rxns without themselves being altered in any way
- Holoenzymes consist of an apoenzyme (protein) and a cofactor (usually an ion)
- Enzymes are chemically specific
Characteristics of Enzymes

- Frequently named for the type of reaction they catalyze
- Enzyme names usually end in -ase
- Lower activation energy
Characteristics of Enzymes

(a) Noncatalyzed reaction
(b) Enzyme-catalyzed reaction

Activation energy
Energy released by reaction

Energy
Mechanism of Enzyme Action

- Enzyme binds with substrate
- Product is formed at a lower activation energy
- Product is released
Figure 2.21

Active site

Amino acids

Enzyme (E)

Substrates (S)

Enzyme-substrate complex (E-S)

Internal rearrangements leading to catalysis

Free enzyme (E)

H₂O

Peptide bond

Dipeptide product (P)
Nucleic Acids

- Composed of carbon, oxygen, hydrogen, nitrogen, and phosphorus
- Their structural unit, the nucleotide, is composed of N-containing base, a pentose sugar, and a phosphate group
Nucleic Acids

- Five nitrogen bases contribute to nucleotide structure – adenine (A), guanine (G), cytosine (C), thymine (T), and uracil (U)

- Two major classes – DNA and RNA
Deoxyribonucleic Acid (DNA)

- Double-stranded helical molecule found in the nucleus of the cell
- Replicates itself before the cell divides, ensuring genetic continuity
- Provides instructions for protein synthesis
Structure of DNA

Figure 2.22a

Purine: A & G
Pyrimidine: U, C, T
Central Dogma

- DNA → RNA → Protein

“The Central Dogma of Molecular Biology”, Francis Crick.

DNA. Genetic material located in nucleus

RNA. Outside the nucleus. RNA transfers genetic information out of nucleus and is used as the scaffold to build proteins.
Structure of DNA

Key:
- Thymine (T)
- Adenine (A)
- Cytosine (C)
- Guanine (G)
- Deoxyribose sugar
- Phosphate
- Hydrogen bond

Figure 2.22b
Ribonucleic Acid (RNA)

- Single-stranded molecule found in both the nucleus and the cytoplasm of a cell
- Uses the nitrogenous base uracil instead of thymine
- Several varieties of RNA: messenger RNA, transfer RNA, ribosomal RNA, micro RNA, sRNA, RNAi
Adenosine Triphosphate (ATP)

- Source of immediately usable energy for the cell
- Adenine-containing RNA nucleotide with three phosphate groups
Adenosine Triphosphate (ATP)

Adenosine

Adenosine monophosphate (AMP)

Adenosine diphosphate (ADP)

Adenosine triphosphate (ATP)
Figure 2.24

(a) Transport work

(b) Mechanical work

(c) Chemical work