Chapter 15

The Chemistry of Life
• **Chiral objects** cannot be superimposed on their mirror images
• **Achiral objects** are superimposable on their mirror images
• **Enantiomers (optical isomers):** A chiral molecule and its non-superimposable mirror-image molecule
• Simplest case: tetrahedral C atom bonded to 4 different atoms/groups of atoms. C atom is asymmetric and said to be a stereogenic center (from the Greek stereo, meaning “handed,” and genesis, meaning “source”).
Enantiomers are mirror-image molecules that have all the same groups attached but are arranged differently in space.

Enantiomers of a chiral compound have the same
- Melting point
- Boiling point
- Density
- Other identical physical and chemical properties.

How they differ:
- Rotate a beam of plane-polarized light in opposite directions; chiral molecules are optically active.
- Interact differently with other chiral molecules.
Naming Enantiomers

Same naming system still used for amino acids (natural are l-amino acids) and sugars (natural are d-sugars).

Historically, enantiomers named after similarity to enantiomers of glyceraldehyde, which rotated the plane of plane-polarized light clockwise fashion (d; dextrorotatory) or counterclockwise (l; levorotatory).

Modern naming based on configuration, a description of the specific arrangement of atoms in a chemical compound.

\[ R \text{ configuration} \]

\[ S \text{ configuration} \]
Stereoisomers

Enzymes
• Catalysts for biochemical reactions
• Made from L-amino acids → chiral proteins
• Have binding preference for one enantiomer
Because of chirality of sugars, proteins, and DNA, the human body highly sensitive to enantiomers

Laboratory synthesis of a chiral compound normally gives a mixture of equal amounts of the enantiomers, a racemic mixture.
e.g. drug thalidomide
• One enantiomer was useful for treating morning sickness
• Other enantiomer was a teratogen, a chemical or factor that causes malformation of an embryo
Test Your Knowledge

For each of the following molecules, decide whether the underlined carbon atom is or is not a stereogenic center:

(a) CH₂Cl₂
(b) H₂N-CH(CH₃)-COOH
(c) Cl-CH(OH)-CH₂Cl.

SOLUTION
To be a stereogenic center, an atom must be bonded to 4 different groups.
In (a) the underlined C atom is bonded to two H atoms and two Cl atoms, and is not a stereogenic center.
In (b) & (c) the underlined C atoms are bonded to 4 different groups and are stereogenic centers.
Biological macromolecules

• Also made of various ‘monomer’ units.
• Synthesized in cells and various organisms, including plants and animals.
• Three classes we will examine:
  • 1. Polysaccharides -- for energy storage
  • 2. Proteins -- for carrying out reaction functions in cells and to give cells structure
  • 3. DNA/RNA -- carry instructions to make proteins
• Note: are solubilized in water by same
Carbohydrates: Sugar, Starch, and Fiber

• Carbohydrates are the primary molecules responsible for short-term energy storage in living organisms.
• Carbohydrates form the main structural components of plants.
• Carbohydrates often have the general formula \((\text{CH}_2\text{O})_n\). \((i.e. \ C \ plus \ H_2O)\)
• Structurally, carbohydrates are aldehydes or ketones containing multiple –OH groups. They
Carbohydrates = carbon hydrates, \( C_x(H_2O)_y \)

C, O, H arranged as 3 functional groups:
- Alcohols (ROH)
- Ketones (RCOR’)
- Aldehydes (RCHO)

Categories:
- Monosaccharides
- Disaccharides
- Polysaccharides

saccharum = sugar
mono = one
di = two
poly = many
15-2a Monosaccharides

Monosaccharides have a 5 or 6-membered ring called hexoses, with molecular formula of $\text{C}_6\text{H}_{12}\text{O}_6$.

- **Glucose**
  - Found in fruit, blood, and living cells
  - Given by IV

- **Galactose**
  - Stereoisomer of glucose

- **Fructose**
  - Fruit sugar

**Examples:**
- D-Glucose
- D-Galactose
- D-Fructose

**Molecular Formulas:**
- $\text{C}_6\text{H}_{12}\text{O}_6$
D-Galactose and D-Glucose are Stereoisomers

Stereoisomers: same formula, same connections, different 3D arrangement (note 6-atom vs 5-atom rings in two molecules above), rings are not planar, the ‘zig-zag’ up and down.
Glucose ($C_6H_{12}O_6$), Fructose ($C_6H_{12}O_6$), and Galactose ($C_6H_{12}O_6$) are isomers

- Glucose is an aldehyde (it contains the $-CHO$ group) with $-OH$ groups on most of the carbon atoms.
- The many $-OH$ groups make glucose soluble in water and blood. These groups form hydrogen bonds to water molecules.
- Glucose is easily transported in the bloodstream and is soluble within the aqueous interior of a cell. Where enzymes “chop” it up to produce energy for the organism.
- Glucose is a key energy source for all cells, especially in the brain and heart.
Glucose is an example of a monosaccharide, a carbohydrate that cannot be broken down into simpler carbohydrates. Monosaccharides such as glucose rearrange in aqueous solution to form ring structures.
Monosaccharides can link together to form polysaccharides, long, chainlike molecules composed of many monosaccharide units. Polysaccharides are a type of polymer—chemical compounds composed of repeating structural units in a long chain.
Carbohydrates: Sugar, Starch, and Fiber

- Monosaccharides and disaccharides are **simple sugars** or **simple carbohydrates**.
- Polysaccharides are **complex carbohydrates** (many monomers in one molecule).
- Some common polysaccharides include **starch** and **cellulose**, both of which are composed of repeating glucose units.
- A third kind of polysaccharide is **glycogen**. Glycogen has a structure similar to starch, but the chain is **highly branched**. In animals, excess glucose in the blood is stored as glycogen until it is needed. A large but easily broken down energy storage
Practice—Which of the Following Molecules Are Carbohydrates?
Practice—Which of the Following Molecules Are Carbohydrates?, Continued

Carbohydrates have multiple OH groups and either C=O or two Os attached to the same C.

No -OH
Disaccharides: results from two monosaccharides reacting with the elimination of water (condensation – like polymerization in Ch. 14!)

General formula: $\text{C}_{12}\text{H}_{22}\text{O}_{11}$

- **Sucrose** (from sugar cane or sugar beets): fructose + glucose; table sugar
- **Maltose** (from starch): glucose + glucose; sweetener in prepared foods
- **Lactose** (from milk): glucose + galactose; in drugs and infant foods; in baking

Breakdown of disaccharides in body (opposite of condensation):

**Hydrolysis**: splitting apart by water
Sweetness

**TABLE 15.1** Sweetness of Common Sugars and Artificial Sweeteners Relative to Sucrose

<table>
<thead>
<tr>
<th>Substance</th>
<th>Sweetness Relative to Sucrose as 1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lactose</td>
<td>0.16</td>
</tr>
<tr>
<td>Galactose</td>
<td>0.32</td>
</tr>
<tr>
<td>Maltose</td>
<td>0.33</td>
</tr>
<tr>
<td>Glucose</td>
<td>0.74</td>
</tr>
<tr>
<td>Sucrose</td>
<td>1.00</td>
</tr>
<tr>
<td>Fructose</td>
<td>1.17</td>
</tr>
<tr>
<td>Aspartame*</td>
<td>180</td>
</tr>
<tr>
<td>Saccharin*</td>
<td>300</td>
</tr>
<tr>
<td>Splenda*</td>
<td>600</td>
</tr>
</tbody>
</table>

* Artificial sweeteners.

Sucrose:
80 million + tons produced/year

From
Sugar beets 40%
Sugar canes 60%

Honey: mixture of glucose and fructose; sweeter than sucrose
Artificial Sweeteners

Saccharin: Body doesn’t digest; no calories. However, has bitter aftertaste. Small amount of natural sweeteners (with calories) added.

Aspartame (nutrasweet): can be digested, small amount of calories; because it is so sweet – very little is needed.

Sucralose (Splenda): 3 OH groups in sucrose replaced by Cl.
Glucose and Galactose are examples of
A. Structural Isomers
B. Stereoisomers
C. Disaccharides
D. Polymers
**15-2c Polysaccharides**

**Polysaccharides**: polymers made of repeating monosaccharides

Most common monosaccharide found in polysaccharides is D-glucose

**Amylose**: plant starch
- Straight-chain condensation polymer
- ~200 glucose monomers
- Humans can digest

**Glycogen**: energy reservoir in animals;
- stored in the liver and muscle tissues

**Cellulose**: found in woody part of trees, cotton, supporting material in plants and leaves, paper
- ~900-6000 glucose monomers
- Connected slightly differently
- Humans can’t digest (don’t have the enzymes need to breakdown the linkages); fiber
- Ruminant animals, termites, cockroaches can digest
Difference between Starch and Cellulose

**Starch** is common in potatoes and grains. It is a soft, pliable substance that we can easily chew and swallow.

During digestion, the links between individual glucose units are broken, allowing glucose molecules to pass through the intestinal wall and into the bloodstream.

**Cellulose**—also known as fiber—is a stiffer and more rigid substance. Cellulose is the main structural component of plants.

The bonding in cellulose makes it indigestible by humans. Other animals do contain microorganisms that make enzymes needed to digest cellulose.

When we eat cellulose, it passes right through the intestine undigested.
Lipids: limited solubility in water, but soluble in organic solvents
- Vary widely in their structure
- Include fats, oils, steroids and waxes
- 95% of lipids in our diet are fats and oils

Fats/Oils: triglycerides; triesters of glycerol and fatty acids
Most R groups in fats: saturated chains
Pack nicely → make solids
Most R groups in oils: unsaturated chains
Don’t pack nicely → make liquids

**TABLE 15.2** Common Fatty Acids in Fats and Oils

<table>
<thead>
<tr>
<th>Acids</th>
<th>Melting Point (°C)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Saturated (All Solids at Room Temperature)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lauric</td>
<td>CH₃(CH₂)₁₀COOH</td>
<td>44</td>
</tr>
<tr>
<td>Palmitic</td>
<td>CH₃(CH₂)₁₄COOH</td>
<td>63</td>
</tr>
<tr>
<td>Stearic</td>
<td>CH₃(CH₂)₁₆COOH</td>
<td>69</td>
</tr>
<tr>
<td><strong>Unsaturated (All Liquids at Room Temperature)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oleic</td>
<td>CH₃(CH₂)₇CH ≡ CH(CH₂)₇COOH</td>
<td>4</td>
</tr>
<tr>
<td>Linoleic*</td>
<td>CH₃(CH₂)₄CH ≡ CHCH₂CH ≡ CH(CH₂)₂COOH</td>
<td>−5</td>
</tr>
<tr>
<td>Linolenic</td>
<td>CH₃CH₂CH ≡ CHCH₂CH ≡ CHCH₂CH ≡ CH(CH₂)₂COOH</td>
<td>−11</td>
</tr>
</tbody>
</table>

* An essential fatty acid that must be part of the human diet.
Double bonds in fatty acids are reactive. Oxygen can attack, making fat go bad. Can add H$_2$ to unsaturated fats, to create solid saturated fats. 

Store better

Look for hydrogenated or partially hydrogenated on label.
15-3b Steroids

Found in all plants and animals
Have same 4-ring skeleton

Cholesterol: Most abundant animal steroid

Synthesized in human body
Also, intake from diet

Undergoes biochemical modification to form hormones (vitamin, cortisone, sex hormones)
Steroid sex hormones made from cholesterol

**Female sex hormones:** progesterone, estrogens (estradiol and estrone)
- Estrogens important to the development of egg in ovary
- Progesterone causes changes in the wall of uterus and prevents release of a new egg after fertilization
- Birth control drugs use derivatives of estrogens and progesterone

**Male sex hormones:** testosterone and androsterone
- Synthesized in the testes from cholesterol
- Responsible for the development of male secondary sex characteristics and for promoting muscle and tissue growth.
Anabolic Steroids

- **Anabolic**: muscle building
- Natural androstenedione and synthetic steroids such as methandrostenolone (Dianabol) are used legally and illegally for anabolic properties
- Side effects of steroid abuse in men: shrinking testes, enlarged breasts and feminization, increased balding, high blood pressure, unpredictable and rapid mood changes (“roid rage”), and even death.
- Side effects in women: masculinization
15-3c Waxes

**Waxes**: esters formed from long-chain (16 or more C atoms) fatty acids and long-chain alcohols. General formula, $RCOOR'$, where R and R’ are alkyl groups with a large # of C atoms. Natural waxes are usually mixtures of several esters.

Protective properties:
- Leaves from disease
- Help plants conserve water
- Feathers of birds
- Ears

Natural waxes used in consumer products:
**Carnauba wax** (from a Brazilian palm tree)
- Used in floor waxes, automobile waxes, and shoe polishes

**Lanolin** (from lamb’s wool)
- Used in cosmetics and ointments (also contains cholesterol)
15-4 Soaps, Detergents, and Shampoos

**Saponification reactions**: hydrolysis of fats and oils in strongly basic solutions to produce glycerol and salts of fatty acids.

**Soaps**: Na or K salts of the fatty acids formed
Cleaning Action of Soap

Soap or detergent molecule consists of a long oil-soluble (hydrophobic, water-fearing) group and a water soluble (hydrophilic, water-loving) group.

When dissolved in H₂O, soaps and detergents bury the hydrophobic “tails” within a spherical particle called a micelle. The hydrophobic, nonpolar hydrocarbon interior encapsulates the oil/grease and makes it possible to remove the oil by rinsing with H₂O.
Detergents

Soap scum: insoluble precipitates of fatty acid salts with Ca$^{2+}$, Mg$^{2+}$, and Fe$^{2+}$ ions found in “hard” water; often contains trapped dirt

Detergents: artificial compounds from organic molecules designed to have better cleaning action than soaps, but less reaction with ions found in hard water.

Detergents generally have a benzene-like ring at one end.

Anionic surfactants have negatively charged head groups e.g. sulfate ($\text{OSO}_3^-$), sulfonate ($\text{SO}_3^-$), and phosphate ($\text{OPO}_3^{2-}$) groups.

Cationic (positively charged) surfactants are almost all quaternary ammonium (4 groups attached to N atom) halides (Br, Cl); R long hydrocarbon chain
Shampoos

Anionic detergents → good foaming characteristics
Nonionic surfactants → useful as thickeners and foam stabilizers
e.g. reaction of diethanolamine and lauric acid

\[
\text{HN(CH}_2\text{CH}_2\text{OH)}_2 + \text{CH}_3(\text{CH}_2)_{10}\text{COOH} \rightarrow \\
\text{Diethanolamine} \quad \text{Lauric acid}
\]

\[
\text{CH}_3(\text{CH}_2)_{10} - \hat{\text{C}} - \text{N(CH}_2\text{CH}_2\text{OH)}_2 + \text{H}_2\text{O} \rightarrow \\
\text{Lauric diethanolamide} \quad \text{(an amide detergent)}
\]

Shampoos work with micelles, like soaps
Conditioner/rinse containing **cationic detergent**: 
- Electrically attracts the anions from shampoo to remove
- Neutralizes neg. charges on damaged hair (from disrupted protein chains)
- Alkyl chain attaches to the hair and gives it a smooth feel
- Replaces some oils that were removed by the detergent

Correct amount of moisture is the key to hair control: too much water causes the hair to be limp and too little causes the individual hairs to attract static charge.
Creams and lotions are made by mixing an oily component with water and other ingredients in the right proportions to form a stable mixture that can be more like a solid (a cream) or more like a liquid (a lotion).

**Emulsion:** A stable mixture of water and an oily component

**Emulsifying agent:** A compound that has a water-soluble part as well as an oil-soluble part that stabilizes an emulsion

**Colloid:** A particle (dispersed phase) larger than most molecules or ions dispersed in a solvent-like medium (continuous phase)

Two kinds of emulsions can be formed between oil and water:
- oil droplets of colloid size dispersed in water
- water droplets of colloid size dispersed in oil

- oil-in-water more like aqueous solution
- water-in-oil emulsions more like oil
Test Your Knowledge

If water is the fourth ingredient on a skin cream, after a couple of ingredients that include the word oil, what kind of emulsion is used in this cream?

The listing of water after the names of the oils indicates that the mixture is a water-in-oil emulsion.
Test Your Knowledge

Which of the following is not a lipid?

A. Cholesterol
B. Starch
C. Coconut oil
D. Tristearin
All proteins are **condensation polymers** with amino acids as monomers.

(Analogous to nylon)

20 different amino acids

Different R groups

Essential amino acids must be ingested from food

Other amino acids can be synthesized by human body
# Common L-Amino Acids Found in Proteins

<table>
<thead>
<tr>
<th>Amino Acid</th>
<th>Abbreviation</th>
<th>Structure</th>
<th>Nonpolar R Groups</th>
<th>Polar but Neutral R Groups</th>
<th>Acidic R Groups</th>
<th>Basic R Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glycine</td>
<td>Gly</td>
<td>H—CH—CH—COOH</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
</tr>
<tr>
<td>Alanine</td>
<td>Ala</td>
<td>CH$_3$—CH—CH—COOH</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
</tr>
<tr>
<td>Valine*</td>
<td>Val</td>
<td>CH$_3$—CH—CH—CH—COOH</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
</tr>
<tr>
<td>Leucine*</td>
<td>Leu</td>
<td>CH$_3$—CH—CH—CH—COOH</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
</tr>
<tr>
<td>Isoleucine*</td>
<td>Ile</td>
<td>CH$_3$—CH—CH—CH—COOH</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
</tr>
<tr>
<td>Proline</td>
<td>Pro</td>
<td>H$_2$C—CH—CH—COOH</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
</tr>
<tr>
<td>Phenylalanine*</td>
<td>Phe</td>
<td>C$_6$H$_5$—CH—CH—COOH</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
</tr>
<tr>
<td>Methionine*</td>
<td>Met</td>
<td>CH$_3$—S—CH$_2$—CH—COOH</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
</tr>
<tr>
<td>Tryptophan*</td>
<td>Trp</td>
<td>Clipped Structure Image</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
</tr>
<tr>
<td>Serine</td>
<td>Ser</td>
<td>HO—CH$_2$—CH—COOH</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
<td>[Chemical Structure Image]</td>
</tr>
</tbody>
</table>

* Essential amino acids that must be part of the human diet. The other amino acids can be synthesized by the body.

† Growing children also require arginine in their diet.
Amino acids – side chains

- The R groups, or side chains, of different amino acids can be very different chemically.
- Alanine has a nonpolar side chain (—CH₃) while serine has a polar one (—CH₂OH).
- Aspartic acid has an acidic side chain (—CH₂COOH), while lysine has a basic one ((—CH₂)₄NH₂).
- When amino acids are strung together to make a protein, these differences determine the structure and properties of the protein.
15.7 Peptides and Proteins

peptide bond: amide bond formed between amino acids
polypeptide: condensation polymer of amino acids
Proteins: polypeptides containing ~50-1000s of amino acids

Simple proteins consist only of amino acids. e.g. insulin, chymotrypsin.

Conjugated proteins contain nonprotein parts called prosthetic groups.

Prosthetic groups: small nonprotein molecules covalently bonded to the protein. e.g. myoglobin and hemoglobin contain a heme group
The roles of proteins

• From a biochemical perspective, proteins have a broad definition and many roles.
• Within living organisms, proteins do much of the work of maintaining life.
• Most of the chemical reactions that occur in living organisms are catalyzed or enabled by proteins.
• Proteins that act as catalysts are called enzymes. Without enzymes, life would be impossible. Reactions inside cells would be too slow and the organism would die. Would digest food too slowly, die of hypothermia.
• Proteins are the structural components of muscle, skin, and cartilage.
• Proteins transport oxygen in the blood,
Primary structure: sequence of amino acids

Secondary structure: the shape of the backbone structure of the protein
2 most common: α-helix; β-pleated sheet
Secondary Protein Structure: The Alpha-Helix

The structure is maintained by **hydrogen-bonding interactions** between NH and CO groups along the peptide **backbone** of the coiled protein strand.

side chain to side chain

Interactions between amino acids
Secondary Protein Structure:
The beta-pleated sheet is maintained by interactions between the peptide backbones of neighboring protein strands. In this structure, the chain is extended (as opposed to coiled) and forms a zigzag pattern like an accordion pleat. The strongest inter-strand interactions are hydrogen bonds.
Protein Folding

**Tertiary structure:** folding of protein molecule

**Quaternary structure:** If protein has more than one chain – how chains fit together
TERTIARY STRUCTURE consists of the large-scale bends and folds within one polypeptide chain. Folds are due to interactions between the R groups of amino acids that are separated by large distances in the linear sequence of the protein chain.

These interactions include:

- hydrogen bonds
- disulfide linkages (covalent bonds between sulfur atoms on different R groups, such as Cys)
- hydrophobic interactions (attractions between large nonpolar groups on side chains) – dispersion forces
- salt bridges (acid–base interactions between acidic and basic groups on side chains) - a charge-charge attraction
Many proteins are composed of more than one amino acid chain.

The protein hemoglobin is composed of four amino acid chains—each chain is called a subunit. Amino acid sequences of subunits can all be the same or different.

The quaternary protein structure describes how these subunits fit together.

The same kinds of interactions between amino acids maintain quaternary structure and tertiary structure.
Interactions that create tertiary and quaternary structure include hydrogen bonds, disulfide linkages, hydrophobic interactions, and salt bridges.
Use the structures of amino acids in Table 15.5 to draw the structure of the tripeptide Ala-Ser-Gly. Give its name.

Since its abbreviation comes first, alanine should be written at the left with a free $\text{H}_2\text{N}^-$ group, glycine (listed last) should be written at the right with a free $-\text{COOH}$ group, and serine should be between them, connected by peptide bonds. The name is alanylserylglycine.
Enzymes: catalysts for biochemical reactions

- Increase reaction rates $10^6 - 10^{16}$ times
- Effective over narrow temperature and pH ranges

Many biomolecules broken down in digestion by hydrolysis (reverse of condensation); larger molecule is split into smaller molecules with the addition of $-\text{H}$ and $-\text{OH}$ where a bond was broken.

<table>
<thead>
<tr>
<th>Enzyme</th>
<th>Biomolecule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maltose</td>
<td>Maltase</td>
</tr>
<tr>
<td>Lysozyme</td>
<td>Polysaccharide</td>
</tr>
<tr>
<td>Trypsin</td>
<td>Proteins</td>
</tr>
</tbody>
</table>

Inherited diseases may affect how enzymes function; e.g., lactose intolerance is due to missing enzyme lactase.
Why can the human body metabolize D-Glucose, but not L-Glucose?

A. Enzymes have active sites that can only fit D-glucose and not the L-glucose.
B. L-glucose is a polymer and D-glucose is a monomer.
C. L-glucose has unnatural double bonds.
D. The tertiary structure in L-glucose can not be broken down.
Hair is made from protein keratin.

Bonds affect behavior of hair:

- **Disulfide bonds** between amino acid cysteine
- **Ionic bonds** between acidic (−COO⁻) and basic groups (−NH₃⁺)
  (e.g. lysine and glutamic acid)
- **Hydrogen Bonds**
In “permanent waving,” disulfide bonds are broken by a reducing agent (e.g. HSCH$_2$COO$^-$ NH$_4^+$) which relaxes the tension.

A typical waving solution contains 5.7% thioglycolic acid to break disulfide bonds, 2.0% ammonia to disrupt ionic bonds, and 92.3% water.

An oxidizing agent (H$_2$O$_2$ or NaBO$_3$•4 H$_2$O) generates new cross links, and the hair retains the shape of the roller, so it appears curly.
Test Your Knowledge

Which of the following is not a type of bond that holds protein strands together in hair?

A. Hydrogen Bonds
B. Ionic Bonds
C. Disulfide Bonds
D. Double Bonds
Energy for life comes from the sun as during photosynthesis: $6\text{CO}_2 + 6\text{H}_2\text{O} + 688 \text{kcal} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2$

Glucose is the major energy source for living organisms. During metabolism, proteins, fats, and carbohydrates are converted to glucose.

Energy stored in glucose is transferred to bonds in ATP.

When the body needs energy, ATP is converted to ADP.
Nucleic acids: Polymers of nucleotides that contain deoxyribose or ribose, nitrogen bases, and phosphate groups

Each monomer in these polymers includes:

- one of two simple sugars
- one phosphoric acid group
- one of a group of heterocyclic nitrogen compounds that behave chemically as bases: adenine (A), guanine (G), thymine (T) {DNA only}, cytosine (C), and uracil (U) {RNA only}.

Deoxyribonucleic acid (DNA): Nucleic acid that functions as a genetic information storage molecule; contains 2-deoxy-D-ribose

Ribonucleic acid (RNA): Nucleic acid that transmits genetic information and directs protein synthesis; contains D-ribose
**Nucleotide**: A biomolecule with a five-carbon sugar bonded to a nucleic acid base and a phosphate group. Molar masses ranging ~25,000 for tRNA to billions for human DNA.
Nucleotides and nucleic acids: DNA and RNA

• What ensures that proteins have the correct amino acid sequence? The answer lies in *nucleic acids*.  

• **Nucleic acids** contain a chemical code that specifies the correct amino acid sequences for proteins. A segment (gene) of DNA instructs for each protein the cell needs.  

• Nucleic acids can be divided into two types: deoxyribonucleic acid, or **DNA**, which exists primarily in the nucleus of the cell; and ribonucleic acid, or **RNA**, which is found throughout the entire interior of the cell.  

• Like proteins, nucleic acids are polymers. Made of many connected nucleotides.
The individual units composing nucleic acids are nucleotides. Each nucleotide has three parts: a phosphate, a sugar, and a base. In DNA, the sugar is deoxyribose, while in RNA the sugar is ribose.

RNA’s sugar piece has an extra oxygen atom compared with DNA’s sugar piece. Both sugar molecules have a 5-membered ring, and multiple -OH groups.
Components of DNA

DNA is a polymer of nucleotides. Each nucleotide has three parts: a sugar group, a phosphate group, and a base. Nucleotides are joined by phosphate linkages.

DNA has a sugar-phosphate “backbone”
Every nucleotide in DNA has the same phosphate and sugar, but can have one of four different bases. In DNA, the four bases are adenine (A), cytosine (C), guanine (G), and thymine (T). In RNA, the sugar is different, and the base uracil (U) replaces thymine.
Nucleotide Formation

\[
\text{Sugar} - \text{base} + \text{phosphate} \rightarrow \text{Sugar} - \text{phosphate} + \text{H}_2\text{O}
\]
Practice—Would the Nucleotide Shown Below Be Found in DNA or RNA? Is the Base a Purine or Pyrimidine? What Is the Name of the Base?
Practice—Would the Nucleotide Shown Below Be Found in DNA or RNA? Is the Base a Purine or Pyrimidine? What Is the Name of the Base?,

2 hydroxyls at bottom of sugar ring, so this is a ribose sugar.
• The order of bases in a nucleic acid chain specifies the order of amino acids in a protein.
• Since there are only four bases and about 20 different amino acids to be specified, a single base cannot code for a single amino acid.
• It takes a sequence of three bases—called a **codon**—to code for **one** amino acid.
• The genetic code—the understanding of which amino acid is coded for by which specific codon—was discovered in 1961.
• It is nearly universal—the same codons specify the same amino acids in nearly all organisms.
• In DNA the sequence AGT codes for the amino acid serine and the sequence TGA codes for the amino acid threonine.
• In a rat, a bacterium, or a human, the code is the same.
Codons: A sequence of three consecutive nucleotides with their associated bases is called a *codon*. Each codon codes for one amino acid. Some amino acids have more than one codon (redundancy).
### Messenger RNA Codes for Amino Acids

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<td></td>
<td>U</td>
<td>C</td>
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<tr>
<td>U</td>
<td>Phenylalanine</td>
<td>Serine</td>
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<tr>
<td>U</td>
<td>Phenylalanine</td>
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<tr>
<td>U</td>
<td>Leucine</td>
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<td>C</td>
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<td>C</td>
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<td>A</td>
<td>Isoleucine</td>
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<td>A</td>
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<td>Threonine</td>
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<tr>
<td>A</td>
<td>Isoleucine</td>
<td>Threonine</td>
</tr>
<tr>
<td>A</td>
<td>START or methionine</td>
<td>Threonine</td>
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<tr>
<td>G</td>
<td>Valine</td>
<td>Alanine</td>
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<td>G</td>
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<td>Alanine</td>
</tr>
<tr>
<td>G</td>
<td>Valine</td>
<td>Alanine</td>
</tr>
</tbody>
</table>

*In groups of three (called codons), bases of mRNA code the order of amino acids in a polypeptide chain. A, C, G, and U represent adenine, cytosine, guanine, and uracil, respectively. Some amino acids have more than one codon, and hence more than one tRNA can bring the amino acid to mRNA.*
Nucleic Acids: Molecular Blueprints

• A gene is a sequence of codons within a DNA molecule that codes for a single protein.
• Because proteins vary in size from 50 to thousands of amino acids, genes vary in length from \((50 \times 3)\) to thousands of bases.
• Each codon is like a three-letter word that specifies one amino acid, in the protein.
• String the correct number of codons together in the correct sequence, and you have a gene.
• Genes are contained in structures called chromosomes—46 in humans—within the nuclei of cells. 23 pairs.
Organization of the genetic material (large to small size):

Chromosomes

Genes

Codons

Nucleotides

**Chromosome**—a macromolecule of DNA.

**Gene**—portion of DNA that codes for a single protein.

**Codon**—sequence of three nucleotides and their associated bases. A codon codes for one amino acid.

**Nucleotide**—individual links in the nucleic acid chain. Nucleotides are composed of a sugar group, a phosphate group, and a base.
DNA Structure

- The ability of DNA to copy itself is related to its structure.
- DNA is stored in the nucleus as a double-stranded helix.
- The bases on each DNA strand are directed toward the interior of the helix, where they hydrogen-bond to bases on the other strand.
- The hydrogen bonding between bases is not random.
• Each base is **complementary**—capable of precise pairing—with only one other base.

• Adenine (A) hydrogen-bonds only with thymine (T), and cytosine (C) hydrogen-bonds only with guanine (G). A-T and G-C pairs...

• Adenines hydrogen bonding groups are not oriented correctly to interact well with a cytosine or guanine base.
Transfer of coded information begins with the replication of DNA and continues with natural protein synthesis.

**Replication**: The process by which DNA is copied when a cell divides.

In replication, the double helix of the DNA structure unwinds, and each half of the structure serves as a template from which the other complementary half can be reproduced.

Replication of DNA occurs in the nucleus of the cell before the cell divides.
• Humans and animals must synthesize the proteins they need to survive from the dietary proteins that they eat.

• Dietary protein is split into its constituent amino acids during digestion. By *breaking* the peptide bonds using enzymes....

• These amino acids are reconstructed into the correct proteins—those needed by the particular organism—in the organism’s cells.

• Nucleic acids direct the process. Results in formation of **new** peptide bonds, and proteins with the correct amino acid sequence and thus **structure**.
• **Draw the complementary strand** of this DNA strand.

• **How many hydrogen bonds (base-base) would be possible for this segment of DNA?**

• **How many amino acids could this segment of DNA code for, at most?**
Practice - Complementary strand DNA (answers)

• The complementary strand has a sequence of: T-A-T-G-G-C-T-A-C (A with T, G with C)

• How many hydrogen bonds would be possible for this segment of DNA? A-T = 2 HB’s, G-C = 3 HB’s, 
  \# = (5 x 2) + (4 x 3) = 22 maximum

• How many amino acids could this segment of DNA code for, at most? 9/3 = 3 amino acids
Molecular Blueprints for Protein Synthesis

section of the DNA that codes for that specific protein—unravels.

• The segment of DNA corresponding to the gene acts as a template for the synthesis of a complementary copy of that gene in the form of another kind of nucleic acid, messenger RNA (or mRNA).

• The mRNA moves out of the cell’s nucleus to a cell structure within the cytoplasm called a ribosome.

• At the ribosome, protein synthesis occurs. A protein “factory”

• The mRNA chain that codes for the protein moves through the ribosome.

• As the ribosome “reads” each codon, the corresponding amino acid is brought into place (by tRNA molecules) and a peptide bond forms with the previous amino acid.

• As the mRNA moves through the ribosome, the protein (or polypeptide) is formed. Protein is “built” one amino acid at a time. Until a “stop” codon (signal) is read in the gene.
• **Protein Synthesis**  The mRNA strand that codes for a protein moves through the ribosome.

• At each codon, the correct amino acid is brought into place and bonds with the previous amino acid. The peptide bonds form one at a time....
Proteins are continually being replaced and resynthesized from the amino acids available in body

\[
\text{DNA} \rightarrow \text{RNA} \rightarrow \text{protein}
\]

**Transcription:** The process by which the information in DNA is read and used to synthesize RNA (specifically mRNA)

**Translation:** The process for sequential ordering of amino acids that is directed by mRNA during protein synthesis

**Codon:** A three-base sequence carried by mRNA that codes a specific amino acid in protein synthesis
Summary of Protein Synthesis Process

To summarize:

- DNA contains the code for the sequence of amino acids in proteins.
- A **codon**—three consecutive nucleotides in the **DNA molecule**, with their bases—codes for one amino acid.
- DNA strands are composed of four bases, each of which is complementary—capable of precise pairing—with only one other base. A-T and G-C pairs only...
- A **gene**—a sequence of codons—codes for one protein.
- Chromosomes are molecules of DNA found in the nuclei of cells. Humans have 46 chromosomes. These occur in pairs.
- When a cell divides, each daughter cell receives a complete copy of the DNA—all 46 chromosomes in humans—within the parent cell’s nucleus.
- When a cell synthesizes a protein, the base sequence of the gene that codes for that protein is transferred to mRNA. The mRNA then moves out of the nucleus to a ribosome, where the amino acids are linked in the correct sequence to synthesize the protein.
- The general sequence is DNA $\rightarrow$ RNA $\rightarrow$ protein. Transcription, then translation.
If the base sequence in a DNA segment is ...GCTGTA..., what is the base sequence in the complementary mRNA? What is the order in tRNA?

The base pairs between DNA and mRNA are G...C, A...U, and T...A.
G→C
C→G
T→A
G→C
T→A
A→U
Therefore, the resulting mRNA segment is CGACAU.
The order in tRNA is the complement of the mRNA segment.
The allowed base pairs are G...C and A...U, so the order in tRNA is GCUGUA.
Chapter 15 in Review

- **The Cell**: The main chemical components of the cell can be divided into four categories: carbohydrates, lipids, proteins, nucleic acids.
- **Carbohydrates** are aldehydes or ketones containing multiple \(-\text{OH}\) groups. Monosaccharides include glucose and fructose. Disaccharides are two monosaccharides linked together by glycoside linkages. Polysaccharides include starch and cellulose and contain many saccharide monomers linked together.
- **Lipids** are chemical components of the cell that are insoluble in water but soluble in nonpolar solvents. Important lipids include fatty acids, triglycerides, phospholipids, glycolipids, and steroids.
- **Proteins** are polymers of amino acids. Amino acids have an amine group on one end, a carboxylic acid on the other and a central carbon atom that has an R group attached. Amino acids link together by means of peptide bonds (amide groups). Functional proteins are composed of hundreds or thousands of amino acids and come in a range of sizes and shapes.
- **Nucleic acids** are polymers of nuclotides, of which 4 occur in DNA and 4 in RNA. These large molecules contain the instructions to make proteins in a cell.
Protein Structure:

- Primary protein structure is the linear amino acid sequence in the protein chain. It is maintained by the peptide bonds.
- Secondary structure refers to the small-scale repeating patterns found in proteins. These are maintained by interactions between the peptide backbones (and certain side chains) of amino acids that are close together in the chain sequence or on neighboring chains.
- Tertiary structure refers to the large-scale twists and folds within the protein. These are maintained by interactions between R groups (side chains) of amino acids that are far apart in the chain sequence.
- Quaternary structure refers to the arrangement of two or more peptide chains in proteins. Quaternary structure is maintained by interactions between amino acids on the individual chains.
DNA and RNA, are polymers of nucleotides.

- In DNA, each nucleotide contains one of four bases: adenine (A), cytosine (C), thymine (T), and guanine (G). The order of these bases contains a code that specifies the amino acid sequence in proteins.
- A **codon**, a sequence of three bases, codes for an amino acid.
- A **gene**, a sequence of hundreds to thousands of codons, codes for one protein. Genes are contained in cellular structures called chromosomes.
- Complete copies of DNA are transferred from parent cells to daughter cells via **DNA replication**.
- In this process, the two complementary strands of DNA within a cell unravel and two new strands that complement (due to h-bond matching of A-T and G-C bases) the original strands are synthesized. In this way, two complete copies of the DNA are made, one for each daughter cell.
- When a cell synthesizes a protein, the base sequence of the gene that codes for that protein is transferred to mRNA. The mRNA then moves out to a ribosome, where the amino acids are linked in the correct sequence to synthesize the protein.
- The general sequence is: DNA $\rightarrow$ RNA $\rightarrow$ protein. **Transcription**, and then **translation** to form the protein.