Biology I  Lecture Outline 4  Fundamental Organic Groups


Organic Molecules

Carbon Atom

Carbon Skeleton and Functional Groups

Isomers

Four Fundamental Organic Groups

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   - Monosaccharides
   - Disaccharides
   - Polysaccharides

2. Lipids
   - Triglycerides
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   - Steroids
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Organic Molecules

1. Chemists in the 1800’s thought that the molecules of living cells must contain some kind of vital life force.

2. They divided chemistry into two branches.
   - Organic chemistry – the chemistry of living organisms.
   - Inorganic chemistry – the chemistry of the non-living world.

3. Organic molecules are simply defined as molecules that contain both carbon and hydrogen atoms.

4. A comparison of Inorganic and Organic Molecules

<table>
<thead>
<tr>
<th>Inorganic Molecules</th>
<th>Organic Molecules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usually contain positive and negative ions</td>
<td>Always contain carbon and hydrogen</td>
</tr>
<tr>
<td>Usually ionic bonding</td>
<td>Always covalent bonding</td>
</tr>
<tr>
<td>Always contain a small number of atoms</td>
<td>May be large with many atoms</td>
</tr>
<tr>
<td>Most often associated with nonliving matter</td>
<td>Most often associated with living organisms</td>
</tr>
</tbody>
</table>

Carbon Atom

1. Recall (Look back at Handout of Bohr's Model of Atoms) that the carbon atom is small with only 6 electrons, in 2 orbits or shells
2. To get to the 4 electrons needed to complete its outer shell, carbon almost always shares (covalent bonding!) with CHNOPS. (What have we already found out about these atoms?)
   - C - Carbon
   - H - Hydrogen
   - N - Nitrogen
   - O - Oxygen
   - P - Phosphorus
   - S - Sulfur

3. One important property of carbon is that it bonds with itself to form two kinds of molecules based on their shape.
   - Linear molecules - like octane
   - Ring molecules - like cyclohexane (These are sometimes called carbon rings)

Carbon Skeleton and Functional Groups

1. The carbon chain of an organic molecule is called its skeleton or backbone.
2. The carbon skeleton gives an organic molecule its shape.
3. A carbon skeleton with only hydrogen atoms attached is called a hydrocarbon. (octane and cyclohexane are examples of hydrocarbons).
4. Besides hydrogen, there are other atoms and groups of atoms attached to the carbon skeleton to form organic molecules.
There are 6 functional groups of these (add-on atoms or groups of atoms) that are repeatedly found in living organisms. (See Handout Figure 3.2, page 39 of textbook Mader 10 ed.) (Illustrate using Mr. Potato Head and his different hats, ears, noses, etc.)

A. Hydroxyl

1) **Written** as \( \text{OH} \)
2) When added to the **carbon skeleton** forms an **alcohol**.
3) Example – when the hydroxyl group (-OH) replaces 1 hydrogen in ethane - an alcohol called **ethanol** is formed. (Why is ethanol so well known?)

B. Carbonyl

1) **Written** as \( \text{C} = \text{O} \)
2) When added to the **carbon skeleton** forms an **aldehyde** or ketone
3) Example of aldehyde – formaldehyde
4) Example of ketone - acetone

C. Carboxyl

1) **Written** as \( \text{C} \text{H}_2 \text{C} = \text{O} \)
2) When added to the **carbon skeleton** forms a **carboxylic acid**.
3) Example – acetic acid

D. Amino

1) **Written** as \( \text{N} \text{H}_2 \text{C} \text{H} \)
2) When added to the **carbon skeleton** forms an **amine**.
3) Example – tryptophan
E. Sulfhydryl

1) Written as: \[ R-SH \]
2) When added to the carbon skeleton forms a thiol.
3) Example - ethanethiol

F. Phosphate

1) Written as: \[ R-P-OH \]
2) When added to the carbon skeleton forms an organic phosphate.
3) Example - phosphorylated molecules

Isomers

1. **Definition** from textbook - isomers are organic molecules that have identical molecular formulas but a different arrangement of atoms.

2. **Example** from textbook - 

   \[ C_3H_6O_3 \]
   
   **glyceraldehyde**
   
   \[ H-C-\overset{\text{H}}{\overset{\text{H}}{\overset{\text{H}}{\text{C}}} \sim C-H} \]
   \[ OH \quad OH \]
   
   **dihydroxyacetone**
   
   \[ H-C-\overset{\text{H}}{\overset{\text{H}}{\overset{\text{H}}{\text{C}}} \sim C-H} \]
   \[ OH \quad OH \]

3. **Isomers** have different shapes and act or behave differently in chemical reactions.
Four Fundamental Organic Groups

1. Carbohydrates

A. Carbohydrates contain carbon (C), hydrogen (H), and oxygen (O) at a ratio of 1:2:1. See example of formula for glucose below.

\[ \text{C}_6\text{H}_{12}\text{O}_6 \]

B. Hydrogen (H) is bonded to oxygen (O) as in water - so carbohydrates could simply be called “watered carbon”.

C. Carbohydrates are perhaps the most abundant of all biological molecules in nature.

D. Carbohydrates are almost universally used as an immediate energy source.

E. Carbohydrates are molecules of various sizes built of single-unit sugars linked together to form bio-polymers.

F. Based on their structure, there are 3 classes of carbohydrates.

Monosaccharides
Disaccharides
Polysaccharides

G. Three Classes of Carbohydrates

1) Monosaccharides

a) Saccharide comes from the Greek word meaning sugars.

b) Monosaccharides consist of only 1 sugar molecule and are called simple sugars

c) A simple sugar can have a carbon skeleton of 3 to 7 carbon atoms.

d) Most monosaccharides are sweet tasting.
c) Glucose.

- The glucose molecule is the **main energy source** for **organisms**.
- **Glucose** is the **cellular fuel** for all **living things**.
- To pass through the cell membrane and enter cells, all carbohydrates must be in the **form** of glucose.
- **Glucose** is a **small uncharged molecule** that cannot be stored within cells.
- The **same properties** that allow it to enter cells, results in it “leaking” out of cells.
- Therefore glucose is stored in the body as **larger, less soluble** starches and **glycogen molecules** (to be discussed later).
- **Glucose** is the **precursor** (or **parent**) molecule for many compounds and is a **building block** for larger carbohydrates. (like disaccharides and **polysaccharides** to be discussed later)
- **Structural formulas** for glucose and an isomer fructose—see Handout of Figure 3.5, Glucose, Fructose, and Formation of Disaccharide. (recall that an isomer is 2 or more compounds having the same molecular formula but differ structurally)
  - Count the number of carbon, hydrogen, and oxygen atoms in each molecule of glucose and fructose.
  - Note how the glucose and fructose are structurally different.
  - The chain structured glucose reacts in water to form the ring shaped glucose.

f) Other **monosaccharides** include

- **Galactose** – another isomer of glucose
- **Ribose**
- **Deoxyribose**
- **Pyruvic acid**
- **Lactic acid**
2) Disaccharides

a) Disaccharides are 2 monosaccharides that are covalently bonded.

b) Disaccharide (di - two) and (saccharide - sugar)

c) Our textbook defines a disaccharide as 2 monosaccharides that have joined during a dehydration reaction.

d) Example – See Handout of Figure 3.5

- 2 monosaccharides, glucose and fructose bond together to form sucrose.

- Sucrose is acquired from plants such as sugar beets and sugar cane and is the sugar we use to sweeten our tea.

- This is called a dehydration reaction because water is removed in the synthesis of the disaccharide – sucrose. Can be simply written as

\[
\text{Glucose} + \text{Fructose} \rightarrow \text{Sucrose} + \text{Water} \quad \text{(a dehydration reaction)}
\]

- The reverse reaction is called a hydrolysis reaction because water is added in the degradation of sucrose into glucose and fructose. Can be simply written as

\[
\text{Sucrose} + \text{Water} \rightarrow \text{Glucose} + \text{Fructose} \quad \text{(a hydrolysis reaction)}
\]

e) The chemical formula for sucrose is:

\[C_{12}H_{22}O_{11}\]

g) Other disaccharides include (all are isomers of sucrose)

- maltose
- cellobiose
- lactose
3) Polysaccharides

a) **Textbook definition of polysaccharides** - are **polymers** of monosaccharides.

b) **Textbook definition of polymer** - a very large *bio-molecule* constructed by linking together a large number of the same type of subunit called a monomer.

c) In the case of a polysaccharide, these monomers are monosaccharides, especially *glucose*.

d) **In short**, a polysaccharide is a large number of glucose and other molecules bonded together into a polymer.

e) Most *carbohydrates* in plants are polysaccharides.

f) Polysaccharides are larger and less soluble than *simple sugars* and will not pass thru the *plasma membrane* of the cell.

g) *Starch*, *glycogen*, and *cellulose* are the most common polysaccharides and consist only of glucose.

h) The **four** most important and common polysaccharides in living organisms are (1. Starch, 2. Glycogen, 3. Cellulose, 4. Chitin)

i) Starch.
   - An **energy storage molecule** (Contrast with a structural molecule)
   - Composed only of *glucose*
   - *Plants* store glucose as *starch*
   - Examples – *potatoes, beans, peas, corn*

j) Glycogen.
   - An **energy storage molecule**
   - Composed only of *glucose*
   - *Animals* store glucose as *glycogen*
• Glycogen is stored mainly in liver and muscle cells

• When needed to produce energy, glycogen can be broken down into glucose.

k) Cellulose.

• A structural molecule
• Composed only of glucose
• Found in plants
• The cell wall of plants is made of cellulose
• Cellulose is the most abundant carbohydrate and most abundant organic molecule on earth
• Our textbook states “over 100 billion tons of cellulose is produced by plants each year”
• Examples of important products of cellulose are wood and cotton
• Animals cannot digest the bond that holds the glucose molecules together in cellulose. Therefore, animals cannot digest cellulose
• How do termites eat and digest wood?
• How do cows eat and digest grass?
• Even though humans cannot digest cellulose, it is an important item in the diet of humans.
• Cellulose is a source of dietary fiber that helps maintain regularity of bowel movements.

l) Chitin.

• A structural molecule
• Found in animals and fungi
• Makes up the exoskeleton of crustaceans (like lobsters, crayfish, and crabs) and insects (like beetles and grasshoppers)
Unlike starch, glycogen, and cellulose, the chitin polymer is not just a large number of glucose molecules hooked together. Chitin has an amino group attached.

Like cellulose, chitin cannot be digested by animals.

Chitin contains glucosamine which is used as a vitamin to help improve and maintain healthy joints in humans.

2. Lipids

A. Lipid is derived from the Greek word “lipos” meaning fat.

B. Lipids are normally insoluble in water due to their hydrocarbon chains.

C. There are a variety of organic compounds that are classified as lipids.

D. We will look at 4 groups:

- Triglycerides (fats and oils)
- Phospholipids
- Steroids
- Waxes

E. The following Table summarizes the functions and human uses of these 4 groups:

<table>
<thead>
<tr>
<th>TYPE</th>
<th>FUNCTIONS</th>
<th>HUMAN USES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triglyceride - Fats</td>
<td>Long-term energy storage in animals</td>
<td>Butter</td>
</tr>
<tr>
<td></td>
<td>Insulation in animals</td>
<td>Lard</td>
</tr>
<tr>
<td>Triglyceride - Oils</td>
<td>Long-term energy storage in plants and their seeds</td>
<td>Cooking oils</td>
</tr>
<tr>
<td>Phospholipids</td>
<td>Component of plasma membrane</td>
<td></td>
</tr>
<tr>
<td>Steroids</td>
<td>Component of plasma membrane (cholesterol)</td>
<td>Medicines</td>
</tr>
<tr>
<td></td>
<td>Sex hormones</td>
<td></td>
</tr>
<tr>
<td>Waxes</td>
<td>Protection - prevent water loss (cuticle of plant surfaces), Beeswax, Earwax</td>
<td>Candles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Polishes</td>
</tr>
</tbody>
</table>
F. Triglycerides (fats and oils)

1) **Triglycerides** are high energy fat-like substances that are usually composed of
   - Glycerol
   - 3 fatty acids

2) **Glycerol** (See Handout – Formation of a Fat, Figure 3.11, page 45 of Textbook, Mader, 10th ed.)
   a) **Chemical Formula**
      \[ \text{C}_3\text{H}_3\text{O}_3 \]
   b) **Structural Formula**
      \[
      \begin{array}{c}
      \text{H} \quad \text{C} \quad \text{O} \\
      \text{H} \quad \text{C} \quad \text{O} \\
      \text{H} \quad \text{C} \quad \text{O} \\
      \end{array}
      \]
   c) Glycerol is an alcohol and a component of all triglycerides
   d) Glycerol has 3 hydroxyl (-OH) groups (Recall functional groups) that make it soluble in HOH and serve as the 3 sites where bonding occurs with fatty acids to form a triglyceride

3) **Fatty Acid** (See Handout – Types of Fatty Acids, Figure 3.11, page 45 of Textbook, Mader, 10th ed.)
   a) A fatty acid consists of a long hydrocarbon chain with a (-COOH) carboxyl group (Recall functional groups) attached at one end
b) **Fatty acids** can be classified into 2 types

- **Saturated** – fatty acids with no double bonds (C=O) between carbon atoms in the chain. The carbon chain is **saturated** with all hydrogen atoms that can be held.
- **Unsaturated** – fatty acids with double bonds (C=C) between carbon atoms in the chain. These double bonds occur wherever the number of hydrogen atoms is less than 2 per carbon atom.

4) **Formation of Triglyceride (fat or oil)** (See Handout – Formation of a Fat, Figure 3.11, page 45 of Textbook, Mader, 10th ed.)

a) A **reaction** where 3 molecules of **fatty acids** (the same or different) bond with the 3 (OH) groups of the **glycerol** molecule to form 1 **fat molecule** and 3 molecules of **H2O**

b) The **fat molecule** is called a **triglyceride** because 3 **fatty acids** were involved in its formation.

c) The **synthesis** of a **fat or oil molecule** is called a **dehydration reaction** because water is **removed** and **released**

\[
\text{1 glycerol} + 3 \text{ fatty acids} \xrightarrow{\text{dehydration reaction}} \text{1 fat} + 3 \text{ water molecules}
\]

d) The **reverse** or **degradation** of a **fat or oil molecule** to **glycerol** and 3 **fatty acids** is called a **hydrolysis reaction** because **water** must be **added**.

\[
\text{1 fat} + 3 \text{ water} \xrightarrow{\text{hydrolysis}} \text{1 glycerol} + 3 \text{ fatty acids}
\]

- Recall our discussions of dehydration and hydrolysis reactions in the synthesis and degradation of a disaccharide

e) **Unlike** the glycerol molecule, a **fat or oil molecule** is relatively **insoluble** in **H2O**

5) **Triglycerides** may be **metabolized** in the body to release **Energy + CO2 + H2O**

6) **More calories** are **produced** per gram of **triglycerides (lipids)** than **carbohydrates** and other **organic molecules**

7) **Nearly all animals** use **fat (lipids)** in **preference** to **glycogen (a carbohydrate)** for **long term energy storage**
8) Fat below the skin of whales is called blubber.

9) Fat below the skin of humans is often called a "spare tire".

10) Fats comprise about 15% of the body weight of a normal young adult.

11) Remember that plants use oils for long term energy storage (Recall that fats and oils are triglycerides).

12) A few summary statements about fats and oils:

<table>
<thead>
<tr>
<th>FATS</th>
<th>OILS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most often of animal origin</td>
<td>Most often of plant origin</td>
</tr>
<tr>
<td>Primarily made of saturated fatty acids</td>
<td>Primarily made of unsaturated fatty acids</td>
</tr>
<tr>
<td>Solid at room temperature</td>
<td>Liquid at room temperature</td>
</tr>
<tr>
<td>Examples – butter, lard</td>
<td>Examples – corn oil, cranola oil</td>
</tr>
</tbody>
</table>

G. Phospholipids - (See Handout - Structure of Phospholipid, Figure 3.12, page 46 of Textbook, Mader, 10 ed.)

1) Structure

a) A phospholipid is a molecule built like a fat molecule, except in place of the 3rd fatty acid is a polar phosphate group.

\[ \text{Glycerol} \xrightarrow{\text{Phosphate Group}} \text{Fatty Acid} \]

b) The phosphate group is usually bound to another organic group shown as \(R\) above.

c) The phospholipid molecule can be said to have a HEAD, NECK and 2 TAILS and can be simply drawn as:

\[ \text{Phosphate Group} + R \text{ (Hydrophilic) \rightarrow Glycerol \leftarrow Fatty Acids (Hydrophobic)} \]
d) **HEAD.** Because of the phosphate group, the **head** of the **phospholipid molecule** is

- Polar
- Hydrophylllic (attracted to water)

e) **TAILS.** The **fatty acid hydrocarbon chains** form the **2 tails** of the **phospholipid molecule** and are

- Non polar
- Hydrophobic (repelled by water)
- Double bonded carbon atoms (**C**=**C**) cause the tail to kink

2) **Hydrophobic vs Hydrophylllic**

a) **Hydrophylllic** - polar molecules that can **attract water** and are **potentially soluble in water**. Example – table salt

b) **Hydrophobic** - non polar molecules that **cannot attract water** and are **insoluble in water**. Example – gasoline

3) **Summary of Divergent Characteristics of Head and Tails**

<table>
<thead>
<tr>
<th>HEAD</th>
<th>TAILS</th>
</tr>
</thead>
<tbody>
<tr>
<td>polar</td>
<td>Non polar</td>
</tr>
<tr>
<td>hydrophylllic</td>
<td>Hydrophobic</td>
</tr>
<tr>
<td>Potentially soluble in H2O</td>
<td>Insoluble in H2O</td>
</tr>
</tbody>
</table>

4) **With hydrophylllic heads and hydrophobic tails, phospholipid molecules will arrange** themselves so heads are **adjacent to water.**
5) Surround a bunch of phospholipid molecules with water and they will form a double layer (bilayer) with the hydrophilic heads pointing outward and the hydrophobic tails pointing inward. (Reminds one of settlers circling the wagons during an Indian attack)

6) The plasma membrane that surrounds cells is mostly a phospholipid bilayer as shown above and in the Handout Figure 3.12

7) Kinks in the tails of phospholipids cause the plasma membrane to be fluid in nature

8) The plasma membrane that covers a living cell is built like a soap bubble and is almost as delicate

H. Steroids

1) Steroids are lipid molecules that have skeletons of 4 fused carbon rings

2) Steroids differ by the type and arrangement of functional groups attached to the carbon skeleton (Recall functional groups)

3) Examples:

![Testosterone](image)

![Estrogen](image)
4) **Testosterone** and **estrogen** are **sex hormones**. Note they **differ** only by **functional groups** attached to the **carbon skeleton**.

5) Another steroid is **cholesterol**
   
a) **Cholesterol** is an **essential component** for stability in an animal’s cell **plasma membrane**
   
b) **Cholesterol** can cause **circulatory diseases** by **encouraging fat deposits in arteries**

I. **Waxes**

1) **Waxes** are long-chain fatty acids with long chain alcohols

2) **Waxes** have a high melting point and are solid at normal temperatures

3) **Waxes** are hydrophobic

4) They are **waterproof** and resistant to degradation

5) They form the **protective cuticle** covering the leaves of plants to help **retard water loss** (Gives the shiny look and slick feel to some leaves)

6) **Humans** produce ear wax that can act as an **insect repellent**

7) **Honeybees** produce beeswax to build their **combs**

8) We use waxes for **candles** and to **polish cars, furniture, floors**, etc
3. Proteins

A. Protein is derived from the Greek word proteios which means 1st place

B. Of the 4 kinds of organic molecules, Proteins can be considered 1st in importance in terms of the structure and function of cells.

C. A much as 50% of the dry weight (What is dry weight?) of most cells consists of protein.

D. Over 100,000 different proteins have been identified.

E. There are 6 major functions of proteins.

1) Metabolism (metabolism is all the chemical reactions that occur in a cell during growth and repair)
   a) Enzymes are proteins that bring reactants together and speed up chemical reactions in cells.
   b) Enzymes are often called catalytic agents that govern the total chemical life of organisms.
   c) Enzymes are usually specific for one type of reaction.

2) Support
   a) Many proteins provide the building blocks for structures in living organisms.
   b) Hair and nails are made of the protein keratin.
   c) Collagen is a protein that supports ligaments, tendons and skin.

3) Transport
   a) Certain types of proteins in the plasma membrane of cells allow the passage of substances in and out of the cell.
   b) Hemoglobin is a complex protein that transports O2 in blood.
4) Defense
   
a) Antibodies are proteins that help fight against disease organisms and foreign substances that seek to destroy the cell

5) Regulation
   
a) Hormones are proteins that have a regulatory function
   
b) Hormones are intercellular messengers that influence the metabolism of cells
   
c) Insulin is a hormone that regulates the content of glucose in the blood and in cells

6) Motion
   
a) Proteins make up the contractile substances found in muscles
   
b) The proteins actin and myosin allow parts of the cells to move and cause muscles to contract

F. Composition

1) Proteins can be very large and are composed mostly of the elements
   
a) Carbon – about 53%
   
b) Hydrogen – about 6%
   
c) Oxygen – about 23%
   
d) Nitrogen – about 16%

2) Some proteins contain small amounts of other elements like sulfur (S), phosphorus (P), iron (Fe) and copper (Cu)

3) Nitrogen is the distinctive element comprising 12% - 19% of the molecule
   (Note nitrogen is not found in carbohydrates and lipids)
4) The basic **building blocks** or **constituent units** of proteins are **amino acids**.

   a) **Amino acids** are composed of **three groups** (Recall functional groups)
      
      - Amino group
      - Carboxyl group
      - **R group** (rest of molecule) a **hydrocarbon chain**

   b) **Structural formula** – **glycine** as the example

![Glycine structural formula]

   c) There are **twenty amino acids** currently identified. (See Handout of Figure 3.16, Amino acids, page 49 of Textbook, Mader, 10th ed)

   d) Amino acids **differ** by the particular **R group attached** to the central carbon atom

   e) The **R groups range** from a **single hydrogen atom** (like glycine) to **complicated ring molecules** (See Handout of Figure 3.16)

5) **Proteins** are **polymers** with **amino acid monomers**. (Review definition of polymer and monomer and application to carbohydrates-polysaccharides)

6) **Another way** to say this is **proteins are macromolecules** consisting of **linked amino acids**

7) Peptide – **defined** as **two or more amino acids bonded together** by a **peptide bond**.

8) A **peptide bond** is the **covalent bond** that **holds the 2 amino acids together**

9) **Polypeptide** – **defined** as a **chain of many amino acids joined** by peptide bonds
10) **Formulas** for *Synthesis* and *Degradation* of a *Peptide* (See Handout, Figure 3.15, page 48 of Textbook, Mader 10th ed)

a) *Synthesis* of a *dipeptide* involves the bonding of 2 *amino acids* by way of a *dehydration reaction* *(WATER REMOVED)*

\[ \text{1 amino acid} + \text{1 amino acid} \rightarrow \text{1 dipeptide} + \text{water} \]

b) *Degradation* of a *dipeptide* involves the breaking of the *peptide bond* to form the two original *amino acids* by way of a *hydrolysis reaction* *(WATER ADDED)*

\[ \text{1 dipeptide} + \text{water} \rightarrow \text{1 amino acid} + \text{1 amino acid} \]

c) Recall use of dehydration and hydrolysis reactions in the formation of disaccharides and fat compounds

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G. **4 Shapes or 4 Levels of Structure**

1) **Primary** (Level 1)

   a) The **level of structure and shape** is formed by a sequence of amino acids forming a polypeptide chain

2) **Secondary** (Level 2)

   a) When the polypeptide chain coils and folds in a way to form an *alpha helix* or pleated sheet molecule

   b) The coils are stabilized by *hydrogen* and *ionic bonding* between coils

   c) Some of these are often called *fibrous proteins* and most are *structural* in their function.

   d) Examples are *keratin* in hair and *silk*

3) **Tertiary** (Level 3)

   a) *Continued folding* gives the polypeptide molecule a 3-dimensional aspect

   b) These are often called *globular proteins*
c) They are held together and stabilized by hydrogen, hydrophobic, covalent, and ionic bonds.

d) Enzymes are globular proteins.

e) The shape of an enzyme is very important in its function and an enzyme works best when it possesses its normal shape, which is usually at normal body temperatures.

f) Denatured proteins (including enzymes) are those proteins (enzymes) that have lost their natural shape which is usually due to high heat.

4) Quaternary (Level 4)

a) Quaternary or Level 4 proteins result when 2 or more polypeptide chains join to form a single protein.

b) Hemoglobin is an example of a quaternary protein.

H. Amino acids are essential to life.

1) During digestion, proteins are hydrolyzed by digestive juices (enzymes) into amino acids. The peptide bonds are broken during digestion.

2) Amino acids may pass thru the stomach wall and intestines into the bloodstream.

3) There amino acids are carried by the blood to the tissues (cells) where they are used as building units for the manufacture of specific proteins needed by the body.

4) There are 8 essential amino acids required in the diet of humans.

5) The human body is able to synthesize the remaining 12 for its needs.

6) Proteins eaten in excess of the body's structural needs are not stored (like carbohydrates and lipids), but are broken down in the liver.

7) Foods high in protein are meat, cheese, eggs, milk, beans, peas, etc.
4. Nucleic Acids

A. Overview and Functions

1) Nucleic acids are found in all living organisms

2) They are mainly found in the nucleus of the cell, but do occur elsewhere in the cell

3) The 2 major types of nucleic acids we will study are DNA and RNA

4) DNA – short for Deoxyribonucleic acid
   a) Your textbook lists two functions for DNA.

   DNA is the genetic material that
   (1) Stores information regarding its own replication and
   (2) Stores the information regarding the order in which amino acids are to be joined to make a protein

   b) DNA is the molecular “paper” upon which the blue-print for the construction of a new individual is written

   c) DNA has the ability to split and make duplicates of itself

   d) Life depends on the ability to pass on traits and characteristics from 1 generation to the next

   e) This inherited information is stored in DNA

5) RNA – short for Ribonucleic acid

   a) RNA is the nucleic acid that serves as the vehicle or “messenger” in the process that puts the “messages” of DNA into action in the cell

   b) The specific type of RNA that accomplishes this task is called messenger RNA or mRNA.

   c) Messenger RNA conveys the information provided by DNA in the synthesis of proteins

   d) We will look at other types of RNA when we study Protein Synthesis
B. Nucleotide Structure  (See Handout of Figure 3.19 Nucleotides, page 52 of textbook, Mader 10th Ed.)

1) Nucleic acids are polymers made of monomers called nucleotides.
   a) Recall the polysaccharide polymer is made of monomers called glucose
   b) And the protein polymer is made of monomers called amino acids

2) Like proteins, nucleic acids are large molecules with high molecular weights.

3) There are 3 types of molecules in every nucleotide.
   a) Phosphate (phosphoric acid)
      • Structural formula can be written as
        \[
        \begin{array}{c}
        O \\
        \| \\
        O - P - O \\
        \| \\
        O
        \end{array}
        \]
   b) Pentose Sugar
      • A five sided ring structure
      • There are 2 types of pentose sugars in nucleotides
        Deoxyribose - found in DNA
        Ribose - found in RNA
      • Deoxyribose - structural formula can be written as
        \[
        \begin{array}{c}
        O \\
        H
        \end{array}
        \]
Ribose – structural formula can be written as

Note that the only structural difference in these 2 pentose sugars is that deoxyribose lacks an oxygen atom found in ribose (See Handout of Figure 3.19, Nucleotides)

c) Nitrogenous base

There are 2 types of nitrogenous bases found in nucleotides

Pyrimidines - single ring molecules
Purines - double ring structures

There are 3 specific pyrimidines (single ring molecules) – their names and structural formulas are as follows

Cytosine
Thymine
Uracil

There are 2 specific purines (double ring molecules) – their names and structural formulas are as follows

Adenine
Guanine

In summary an abbreviated way to show the structural formula for 1 nucleotide is as follows

---
• Remember that a nucleic acid is merely a large polymer made of monomers called nucleotides

• In living organisms remember there are 2 important nucleic acids DNA and RNA

• Now that we know how a nucleotide is built and what it looks like, we will look at how nucleotides fit together to make the polymers DNA and RNA.

C. DNA and RNA

1) The synthesis of a nucleic acid (the polymers DNA and RNA) results when nucleotides (monomers) join in a definite sequence by a series of dehydration reactions (water removed).

\[
\text{Nucleotide} + \text{Nucleotide} + \text{Nucleotide} \rightarrow \text{Nucleic Acid} + \text{Water}
\]

2) The reverse reaction or the degradation of a nucleic acid (either DNA or RNA) into separate nucleotides is accomplished by a hydrolysis reaction (water added)

\[
\text{Nucleic Acid} + \text{Water} \rightarrow \text{Nucleotide} + \text{Nucleotide} + \text{Nucleotide}
\]

3) DNA (See Figure 3.21, DNA Structure, page 53 of textbook, Mader, 10th Ed.)

a) DNA is double stranded

b) DNA includes 2 linear chains of nucleotides that are held together by hydrogen bonding

c) These 2 linear chains are twisted and coiled into a double helix similar to a spiral staircase or "twisted" ladder.

d) Each nucleotide in DNA contains deoxyribose

• covalently bonded to 1 phosphate group
• covalently bonded to 1 of 4 nitrogenous bases
c) Leaving the twist out for simplicity, the DNA strands can be illustrated in shorthand as follows. (Draw on blackboard)

* - The 2 series of sugar-phosphate-sugar-phosphate molecules is called the 2 backbones of the DNA polymer
* - Illustrate nucleotide by circling only 1 in drawing

<table>
<thead>
<tr>
<th>P</th>
<th>O</th>
<th>P</th>
<th>O</th>
<th>P</th>
<th>O</th>
<th>P</th>
<th>O</th>
<th>P</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>A</td>
<td>C</td>
<td>A</td>
<td>C</td>
<td>A</td>
<td>C</td>
<td>A</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>G</td>
<td>T</td>
<td>G</td>
<td>T</td>
<td>G</td>
<td>T</td>
<td>G</td>
<td>T</td>
<td>G</td>
<td>T</td>
</tr>
</tbody>
</table>

- = Covalent bond
... = Hydrogen bond
P = Phosphate group
D = Deoxyribose
A = Adenine (a purine base)
G = Guanine (a purine base)
T = Thymine (a pyrimidine base)
C = Cytosine (a pyrimidine base)

f) The strands are held together by hydrogen bonding between pyrimidine and purine nitrogenous bases

g) Nitrogenous bases can be in any order within a strand, BUT

h) Note that between strands

- Adenine (A) is always paired with (T) Thymine
- Cytosine (C) is always paired with (G) Guanine

i) This is called complementary base pairing and results in

- The number of purine bases (adenine + guanine) is always equal to the number of pyrimidine bases (cytosine + thymine)
- The quantity (number) of adenine equals the quantity of thymine
- The quantity (number) of cytosine equals the quantity of guanine
4) RNA (See Figure 3.20, RNA Structure, page 52 of textbook, Mader, 10th Ed.)

a) RNA is **single stranded polymer** of nucleotides

b) When the nucleotides join, the phosphate group of 1 nucleotide is **joined** to the pentose sugar (Ribose) molecule of the next nucleotide

c) This forms the **sugar-phosphate backbone** of RNA

d) The **nitrogenous bases** project out to one side of the backbone

e) The **RNA strand** can be **illustrated** in shorthand as follows

\[
\begin{array}{cccccccc}
\text{U} & \text{A} & \text{G} & \text{U} & \text{A} & \text{C} \\
\text{P} & \text{R} & \text{P} & \text{R} & \text{P} & \text{R} & \text{P} & \text{R} \\
\end{array}
\]

- = Covalent bond  
P = Phosphate group  
R = Ribose  
A = Adenine (a purine base)  
G = Guanine (a purine base)  
U = Uracil (a pyrimidine base)  
C = Cytosine (a pyrimidine base)

f) Note that in RNA, **uracil replaces the thymine** found in DNA

5) **Summary comparison** of DNA and RNA structure

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>DNA</th>
<th>RNA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pentose sugar</td>
<td>Deoxyribose</td>
<td>Ribose</td>
</tr>
</tbody>
</table>
| Nitrogenous bases | Adenine (a purine base)  
Guanine (a purine base)  
Thymine (a pyrimidine base)  
Cytosine (a pyrimidine base) | Adenine (a purine base)  
Guanine (a purine base)  
Uracil (a pyrimidine base)  
Cytosine (a pyrimidine base) |
| Strands | Double stranded with base paring | Single stranded |
| Helix | Yes | No |
D. DNA Replication (See Figure 12.6, DNA Replication, page 217 of textbook, Mader 10th Ed.)

1) *All DNA is copied from other DNA* by a process called replication

2) Following replication, there is usually an *exact copy* of the parental DNA double helix

3) Using the *same shorthand drawing* we used to show the *structure* of DNA, we will discuss the *3 major steps* in DNA replication. Draw following on blackboard)

\[ \text{\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{dna_replication_diagram.png}
\caption{Diagram showing DNA replication process.}
\end{figure}} \]

a) Step 1 – Unwinding

- The *old strands* that make up the *parental DNA molecule* are unwound and “unzipped”
- The weak *hydrogen bonds* between the *paired bases* are broken
- A special *enzyme* called *helicase* unwinds the *molecule*
b) Step 2 – Complementary base pairing

- *New* complementary *nucleotides* are always *present* in the *nucleus* of the *cell*
- These *new* complementary *nucleotides* are *positioned* along the *new strands* by *complementary base paring*.
- *Pairing* is *carried out* by a *enzyme complex* called *DNA polymerase*

c) Step 3 – Joining

- The *complementary nucleotides* join to *form new strands*
- Each *daughter DNA molecule* contains an *old strand* and a *new strand*
- *Pairing* is *carried out* by a *enzyme complex* called *DNA polymerase*

4) DNA REPLICA nON MUST OCCUR BEFORE A CELL CAN DIVIDE

E. Protein Synthesis

1) *Proteins* are synthesized (*formed*) based on *information stored* in *DNA*

2) The *synthesis* of *proteins* is a *2 step process*
   - Step 1 - Transcription
   - Step 2 – Translation
3) Step 1 – Transcription (See Handout, Figure 12.11, Transcription, page 222, Textbook, Mader, 10th Ed.) and Figure Summary of Transcription & Translation and Figure 22.10, Summary of Protein Synthesis

a) All RNA is copied from DNA by a process called transcription.

b) An enzyme called RNA polymerase attaches to 1 strand of DNA and causes the DNA double helix to unzip (similar to the unzipping during DNA replication).

c) 1 strand of DNA serves as the template for the formation of messenger RNA (mRNA).

d) mRNA contains triplet codons or sequences of 3 bases complementary to DNA code.

e) DNA is transcribed nucleotide by nucleotide to form mRNA.

   * note how uracil replaces thymine as the pyrimidine nitrogenous base in RNA.

f) During transcription complementary RNA nucleotides are joined together.

g) At the completion of transcription, the 2 DNA strands rejoin and the new mRNA (single strand) is set free.

h) mRNA moves out of cell nucleus and into cell cytoplasm and becomes associated with ribosomes.

4) Step 2 - Translation

a) Ribosomes are composed of ribosomal RNA (rRNA) and proteins.

b) Transfer RNA (tRNA) molecules in the cytoplasm are bonded to a particular amino acid.

c) tRNA have anticodons that pair complementarily to the codons in mRNA.

d) tRNA carries the amino acid to mRNA.
e) As the ribosome moves along mRNA, the newly arrived tRNA molecule with its attached amino acid receives the growing polypeptide chain from a tRNA that has already given up its amino acid and is ready to leave to bond to another amino acid to bring to the assembly line.

f) In summary, during translation, ribosomes use the sequence of codons in mRNA to produce a polypeptide with a particular sequence of amino acids.

g) The primary structure of a protein is determined by the order of its amino acids.

h) An analogy to help remember the roles of mRNA, ribosomes, and tRNA
   - mRNA - an assembly line in a factory
   - ribosomes - “traveling workbenches” where workers assemble the products
   - tRNA – specialized forklifts scurrying back and forth between the stockroom and assembly line delivering parts to be assembled.

F. Summary

1) Because of its ability to specify proteins, DNA directs the development of unique structures and traits that
   a) Make each species different (examples of frog vs fish, man vs ape)
   b) Make every individual of the same species different (examples of tall vs short humans, hair color in humans, etc)

2) Proteins can be thought of as the link between the genotype and phenotype of an individual.
3) When thinking about gene expression, keep the following sequence in mind:

DNA's SEQUENCE OF NUCLEOTIDES (the genotype) → SEQUENCES OF AMINO ACIDS IN PROTEINS → SPECIFIC ENZYMES → STRUCTURES IN ORGANISMS (the phenotype)

G. Human Genome Project

1) The Human Genome Project was begun in 1990 and completed in 2003.

2) The goal of the project was to map all genes in the human body, specifically to discover the complete nucleotide sequence of the human genome.

3) Knowledge gained will:
   a) Help to identify and learn the functions of new genes
   b) To discover medically important genes,
   c) To explore the genetic variability of individuals

4) Major impacts of the project are:
   a) improved diagnosis of genetic disorders or predispositions which will hopefully lead to treatments or even cures for genetic disorders in the future

5) Increased knowledge of the molecular basis of disease should lead to therapies that treat the cause, rather than the symptoms of illness.
6) **Definition of Genome** – The *complete genetic make-up* of an organism. The *genetic material* found in *DNA* in the *nucleus* of the cell.

7) **Size of the Human Genome**

   a) There are over 3 *billion base pairs* or nucleotides

   b) There are 20,000 to 23,000 individual *genes*

   c) There are 23 *pair of chromosomes*

   d) If DNA in a *single human cell* were *stretched* out and laid *end-to-end*, it would measure about 6.5 *feet*.

   e) The *average human body* contains 10 – 50 *trillion* cells, so the *human body* contains *billions* of *miles* of DNA.

   f) One web site cites the *Centre for Integrated Genomics* and *states* that there are 113 *billion miles* of DNA in the *average human body* of 100 *trillion cells* – enough material to reach to the *sun and back* - 610 times.
### Functional Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Structure</th>
<th>Compound</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydroxyl</td>
<td>R–OH</td>
<td>Alcohol as in ethanol</td>
<td>Polar, forms hydrogen bond, present in sugars and some amino acids</td>
</tr>
<tr>
<td>Carboxyl</td>
<td>R–C=O</td>
<td>Aldehyde as in formic acid</td>
<td>Polar, present in sugars</td>
</tr>
<tr>
<td>Carboxyl</td>
<td>R–CO2H</td>
<td>Ketone as in acetone</td>
<td>Polar, present in sugars</td>
</tr>
<tr>
<td>Carboxyl (acido)</td>
<td>R–CO2OH</td>
<td>Carboxylic acid as in acetic acid</td>
<td>Polar, acidic, present in fatty acids and amino acids</td>
</tr>
<tr>
<td>Amino</td>
<td>R–NH2</td>
<td>Amine as in tryptophan</td>
<td>Polar, basic, forms hydrogen bonds, present in amino acids</td>
</tr>
<tr>
<td>Sulfhydryl</td>
<td>R–SH</td>
<td>Thiol as in ethanethiol</td>
<td>Forms disulfide bonds, present in some amino acids</td>
</tr>
<tr>
<td>Phosphate</td>
<td>R–O2P–OH</td>
<td>Organic phosphate as in phosphorylated molecules</td>
<td>Polar, acidic, present in nucleotides and phospholipids</td>
</tr>
</tbody>
</table>

R = remainder of molecule

**FIGURE 3.2 Functional groups.**

Molecules with the same carbon skeleton can still differ according to the type of functional group attached to the carbon skeleton. Many of these functional groups are polar, helping to make the molecule soluble in water. In this illustration, the remainder of the molecule (does not include the functional group) is represented by an R.
Figure 3.5  Straight-chain and ring forms of (a) glucose and (b) fructose. For reference purposes, carbon atoms of simple sugars are commonly numbered in sequence, starting at the end closest to the molecule's aldehyde or ketone group. (c) Condensation of two monosaccharides into a disaccharide.

Figure 3.5. Glucose, fructose, Formation of Disaccharide
Figure 3.11, page 445 of Textbook, Mader, 10th ed.
Figure 3.11, page 115 of Textbook, Medio, 10th ed

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corn → corn oil

unsaturated fatty acid with double bonds (yellow)

milk → butter

saturated fatty acid with no double bonds

Types of Fatty Acids
Figure 3.16. Amino Acids
Figure 3.15. Synthesis of a Peptide

Synthesis and Degradation of a Peptide
a. Nucleotide structure

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b. Deoxyribose versus ribose

c. Pyrimidines versus purines
Nitrogen-containing bases
FIGURE 12.6  Semi-conservative replication (simplified).

After the DNA double helix unwinds, each old strand serves as a template for the formation of the new strand. Complementary nucleotides available in the cell pair with those of the old strand and then are joined together to form a strand. After replication is complete, there are two daughter DNA double helices. Each is composed of an old strand and a new strand. Each daughter double helix has the same sequence of base pairs as the parental double helix had before unwinding occurred.
FIGURE 12.11 Transcription.
During transcription, complementary RNA is made from a DNA template. At the point of attachment of RNA polymerase, the DNA helix unwinds and unzips, and complementary RNA nucleotides are joined together. After RNA polymerase has passed by, the DNA strands rejoin and the mRNA transcript dangles to the side.
SUMMARY

TRANSCRIPTION & TRANSLATION

DNA double helix

DNA transcription

mRNA translation

polypeptide - N-C-C-N-C-C-N-C-C-

R₁ (Amino Acid) R₂ (Amino Acid) R₃ (Amino Acid)
Summary of Protein Synthesis

Figure 22.10

Summary of protein synthesis.

1. DNA in nucleus contains code.

2. mRNA moves into cytoplasm and becomes associated with ribosomes.

3. As tRNA departs, polypeptide chain is transferred to newly arrived tRNA.

4. tRNA with anticodon carries amino acid to mRNA.

5. mRNA moves into cytoplasm and becomes associated with ribosomes.

DNA

mRNA

tRNA

polypeptide chain