The Molecules of Life

BIO100 Biology Concepts
Fall 2007

TRACING LIFE DOWN TO THE CHEMICAL LEVEL

- Biology includes the study of life at many levels
- In order to understand life, we will start at the macroscopic level, the ecosystem, and work our way down to the microscopic level of cells
- Cells consist of enormous numbers of chemicals that give the cell the properties we recognize as life

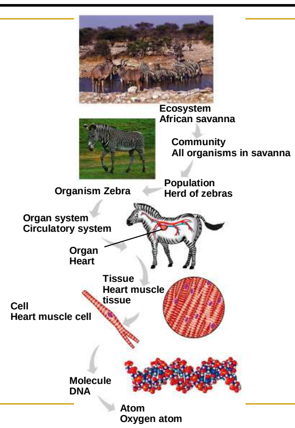


Figure 2.1

Ecosystem
Community
Population ex. all humans in city, all termites in class
Individual Organism
Organ Systems ex. respiratory, reproductive, circulatory
Organs ex. lungs, ovaries, heart
Tissue ex. connective, nervous, muscular
Cells ex. neuron, sarcomere, epithelial
Organelles ex, nucleus, chloroplast, mitochondria
Macromolecules ex. DNA, RNA, cellulose, lipids

SOME BASIC CHEMISTRY

- Take any biological system apart and you eventually end up at the chemical level.

Cells ex. Prokaryotic, Eukaryotic
Macromolecules ex. DNA, RNA, fat
Molecules ex. H_2O, HCl, H_2SO_4,
Atoms ex. C, H, O, N, Iodine C=carbon
Subatomic particles: within nucleus (neutron & proton)
around nucleus (electrons)

Matter: Elements and Compounds

- Matter is anything that occupies space and has mass
- Matter is found on the Earth in "3" physical states.
  - Solid
  - Liquid
  - Gas

- Matter is composed of chemical elements.
  - Elements are substances that cannot be broken down into other substances
  - There are 92 naturally occurring elements on Earth

- All the elements are listed in the periodic table.

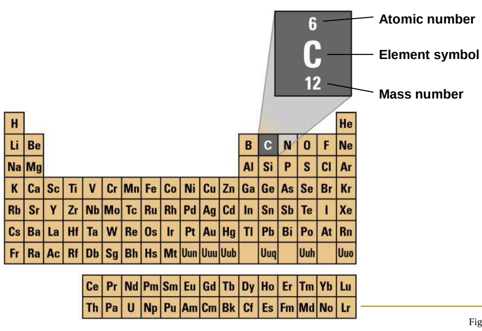


Figure 2.2

- Twenty-five elements are essential to life.
  - Four of these make up about 96% of the weight of the human body H,O,N,C
  - Trace elements occur in smaller amounts

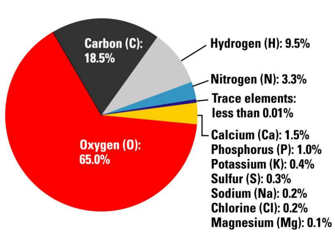


Figure 2.3

- Elements differ in the number of subatomic particles in their atoms
  - The number of protons, the atomic number, determines which element it is
  - An atom's mass number is the sum of the number of protons and neutrons
  - Mass is a measure of the amount of matter in an object; protons and neutrons each have an atomic mass unit of 1

Water's Life-Supporting Properties

- The polarity of water molecules and the hydrogen bonding that results explain most of water's life-supporting properties
  - Water's **cohesive** nature
  - Water's ability to moderate temperature
  - Floating ice D=M/V, see p. 30
  - Versatility of water as a solvent.

- The polarity of water results in weak electrical attractions between neighboring water molecules. These interactions are called **hydrogen bonds** and result in **cohesion** which accounts for **surface tension**

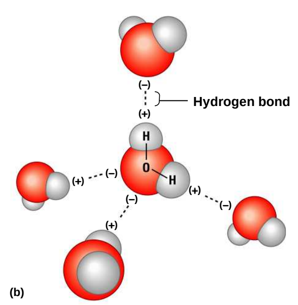


Figure 2.11b

The Cohesion of Water

- Water molecules stick together as a result of hydrogen bonding
  - This is called **cohesion**
  - Cohesion is vital for water transport in plants.

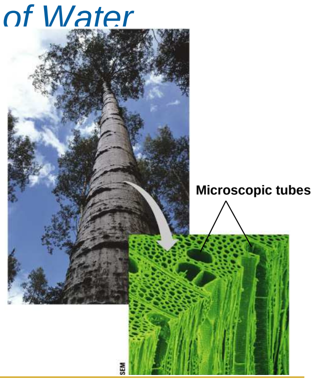


Figure 2.12

- **Surface tension** is the measure of how difficult it is to stretch or break the surface of a liquid
  - Hydrogen bonds give water an unusually high surface tension.

Figure 2.13

How Water Moderates Temperature

- Because of hydrogen bonding, water has a strong resistance to temperature change.

- Heat and temperature are related, but different
  - **Heat** is the amount of energy associated with the movement of the atoms and molecules in a body of matter
  - **Temperature** measures the intensity of heat
- Water can absorb and store large amounts of heat while only changing a few degrees in temperature.

The Biological Significance of Ice Floating

- When water molecules get cold, they move apart, forming ice
  - A chunk of ice has fewer molecules than an equal volume of liquid water, p. 30

- The density of ice is lower than liquid water
  - This is why ice floats

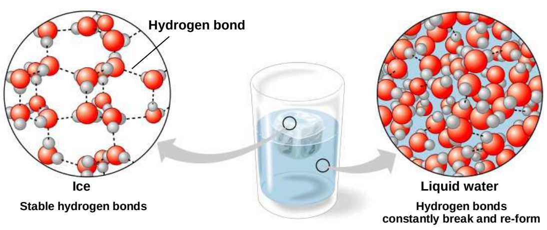


Figure 2.15

- Since ice floats, ponds, lakes, and even the oceans do not freeze solid
  - Marine life could not survive if bodies of water froze solid

Water as the Solvent of Life

- A solution is a liquid consisting of two or more substances evenly mixed
  - The dissolving agent is called the **solvent**, p. 30
  - The dissolved substance is called the **solute**

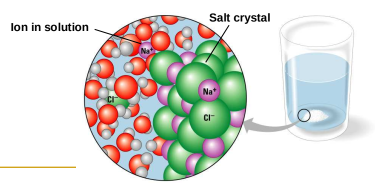


Figure 2.16

- When water is the solvent, the result is called an aqueous solution. Water is a very common solvent.

Jesus Lizard (*Basiliscus basiliscus*)

- http://www.societyofrobots.com/robot_jesus_lizard.shtml

Acids, Bases, and pH

- Acid
  - A chemical compound that donates H^+ ions to solutions. Acids are strong if pH near 1 and weak if pH near to 7. ex. HCl, H_2SO_4
- Base
  - A compound that accepts H^+ ions and removes them from solution. Strong bases have pH near 14, weak ones near 7.

- To describe the acidity of a solution, we use the pH scale

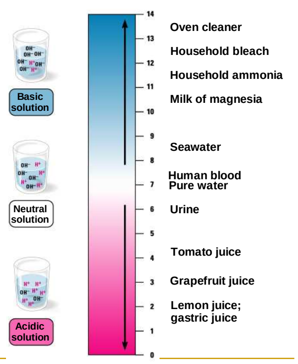


Figure 2.17

- **Buffers** are substances that resist pH change
  - They accept H^+ ions when they are in excess
  - They donate H^+ ions when they are depleted
- Buffering is not foolproof
  - Example: acid precipitation.

Figure 2.18

Polymers (*macromolecules*)

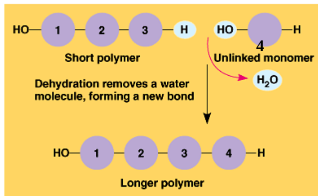
- **<u>Macro</u>molecules are large organic molecules.**
- **Most <u>macromolecules</u> are <u>polymers</u>**
- **<u>Polymer</u> : Large molecules containing many repeating subunits covalently linked together.**
- **<u>Monomer</u> : Subunits (*building blocks*) of a polymer.**

FYI: Poly = many , Di = two,
Mono = one, meros = parts

Construction & Deconstruction of Polymers

- **<u>Construction</u> (anabolic): joining subunits is via condensation (dehydration) reactions.**
- **<u>Deconstruction</u> (catabolic): breaking subunits from each other is via hydrolysis reactions.**

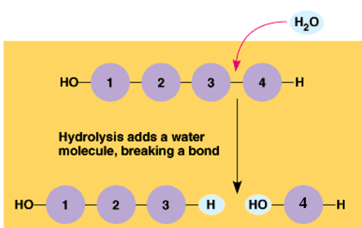
- <u>CONDENSATION</u> <u>REACTION</u> (*<u>dehydration</u> <u>reaction</u>*) : Polymerization reaction that <u>links</u> monomers together via covalent bonding.
- The chemical mechanism cells use for <u>making</u> polymers is similar for all macromolecules.
  - One monomer provides a <u>hydroxyl</u> <u>group</u> *and* the other provides a <u>hydrogen</u> and together these form water.
  - Requires energy and is aided by enzymes.



(a) Dehydration reaction in the synthesis of a polymer

Hydrolysis reaction

- The chemical mechanism cells use for <u>breaking</u> polymers is similar for all macromolecules.
- <u>Hydrolysis</u> : The reaction that <u>splits</u> monomers in a polymer.
- Hydrolysis reactions dominate the digestive process, guided by specific enzymes.



(b) Hydrolysis of a polymer

Polymers (*macromolecules*)

There are four categories of macromolecules:

- Carbohydrates
- Lipids
- Proteins
- Nucleic Acids

Carbohydrates

- Organic molecules made up of sugars and their polymers ***(serve as <u>fuel</u> and a <u>carbon source</u>)***.
- *Monomers* are simple sugars called <u>monosaccharides</u>.
  Also known as *simple carbohydrates*.
  Examples: fructose, glucose, galactose
- Sugar *Polymers* are joined together by condensation reactions.
  Also known as *complex carbohydrates*.
  Examples: starches and fibers

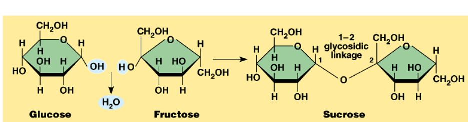
Carbohydrates are classified based on the number and type of simple sugars they contain

Monosaccharides (Simple Sugars)

- <u>Monosaccharide</u>: simple sugar in which C,H,O ratio is 1:2:1 (CH_2O).
  - ***Example:*** Glucose is $C_6H_{12}O_6$
  - Usually end in ***-ose***
- Simple sugars are the main nutrients for cells.
  - <u>Glucose</u> is the most common.
- Monosaccharides also function as the raw material (skeleton) for the synthesis of other monomers, including those of amino acids and fatty acids

Disaccharides

- <u>Disaccharide</u> : a double sugar consisting of 2 monosaccharides joined by a <u>glycosidic</u> <u>linkage</u> .
- <u>Glycosidic</u> <u>Linkage</u> : Covalent bond formed by a condensation reaction between 2 monomers.



Polysaccharides

- <u>Polysaccharides</u> : macromolecules that are polymers of *monosaccharides*.
- Formed by condensation reactions *(mediated by enzymes)* between lots of monomers.

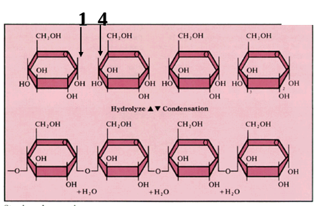
Two very important biological functions:

- **Energy Storage *(starch and glycogen)***
- **Structural Support *(cellulose and chitin)***

Starch

<u>Starch</u> : a glucose polysaccharide in <u>plants</u>.

- Monomers are joined by an α 1-4 linkage between the glucose molecules.



Starch — glucose polymer

Starch

- Plants store starch within plastids, including chloroplasts.
- Plants can store surplus glucose in starch and withdraw it when needed for energy or carbon.
- Animals that feed on plants can also access this starch and break it down into glucose.

Glycogen

Glycogen : a glucose polysaccharide in animals.

- Highly branched with α 1-4 *and* α 1-6 linkages between the glucose molecules.
- ~1 day supply stored in muscle and liver cells.

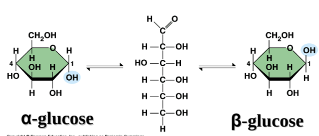
Cellulose

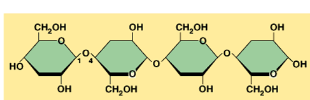
- Cellulose is a major component of the tough wall of plant cells.
  - alpha 1-4 linkages between glucose that forms helical structures: starch
  - beta 1-4 linkages between glucose forms straight structures: cellulose
  - This allows hydrogen bonding between strands.

Cellulose

Cellulose : a glucose polysaccharide in plants.

Cellulose is biologically inactive in humans. We don't have the enzymes to break it down (Fiber).





(c) Cellulose: 1–4 linkage of β glucose monomers

Summary

- Polymers and Monomers
- Construction (dehydration synthesis) and deconstruction (hydrolysis)
- Carbohydrates
  - Monosaccharides: define
  - Disaccharides: define
  - Polysaccharides: define
    - Starch
    - Glycogen
    - Cellulose

Lipids

- **<u>Lipids</u> : Macromolecules that are insoluble in water *(hydrophobic).***
  - **Because their structures are dominated by nonpolar covalent bonds.**

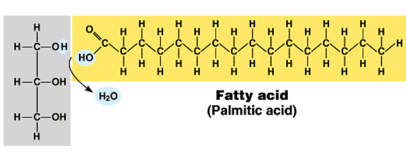
Three important groups of lipids :

- Fats (energy storage molecules)
- Phospholipids (cell membranes)
- Steroids (Hormones)

Fats

- **<u>Fat</u> : a macromolecule composed of glycerol (notice *–ol*) linked to a <u>fatty acid</u>**
- **<u>Fatty Acid</u> : a carboxyl group attached to a long carbon skeleton, often 16 to 18 carbons long**.

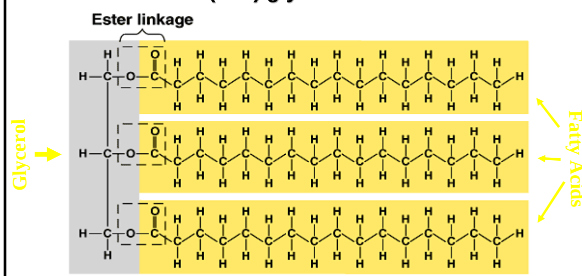
Glycerol's 3 OH groups can each bond to a fatty acid.



(a) Dehydration synthesis

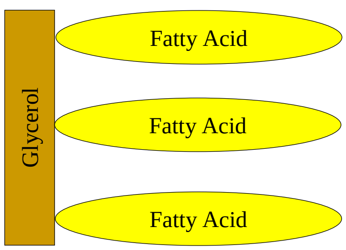
Triacylglycerol *(Triglyceride)*

__Triacylglycerol__ : A fat composed of 3 fatty acids bonded to 1 (one) glycerol.



(b) Fat molecule (triacylglycerol)

Fats: A triglyceride



Characteristics of Fats

- Fats are water insoluble (why?)
- Fatty acids may vary in length (*number of carbons*) and in the number and locations of __double__ bonds.

Two main types of fats :

- Saturated *(all C bonds taken by H)*
- Unsaturated *(not all C bonds taken by H)*

(C_2H_6) (*Saturated*)

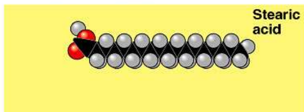
```
  H   H
H - C – C - H
  H   H
```

```
H         H
    C = C
H         H
```

(C_2H_4) (*Unsaturated*)

Saturated Fats

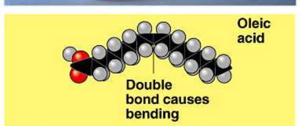
- <u>NO</u> double bonds between carbons
- Maximum (*saturated*) number of hydrogens
- <u>Solid</u> at room temp.
- Mostly <u>animal</u> fats
- <u>Straight</u> chains



(a) Saturated fat and fatty acid

Unsaturated Fats

- <u>One</u> <u>or</u> <u>more</u> double bonds between carbons
- <u>Liquid</u> at room temperature
- Mostly <u>plant</u> fats
- Tail "<u>kinked</u>" at double bond



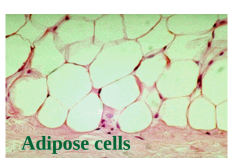
(b) Unsaturated fat and fatty acid

Function of Fats

- Long term fuel storage in adipose *(fat)* cells

  (more energy than carbos)

- Cushion for vital organs



- Insulation against heat loss (whale blubber)

Blue whale

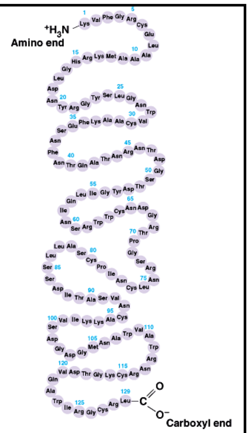
Proteins

- *Most complex molecules known to exist*
- *100s of 1000s different kinds*
- *Variety of proteins: variety of life on earth.*
- *Polymers of amino acids (20 different kinds)*
- *Roles (examples)*

  - Structural Support (keratin)
  - Storage of AA (albumin)
  - Transport (hemoglobin)
  - Signaling (insulin)
  - Stimuli (receptors)
  - Movement (actin)
  - Immune (antibody)
  - Enzyme (catalyst)

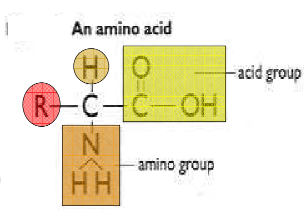
Proteins

- Polypeptides : polymers of amino acids *(monomers)* arranged in a linear sequence and joined by peptide bonds
- Proteins : one or more polypeptide chains folded into specific conformations

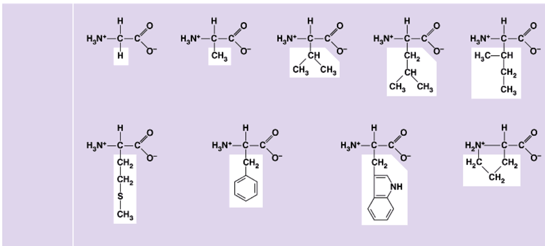


Amino Acids

- Amino Acids : Building blocks *(monomers)* of proteins.
  - A central carbon covalently attached to these groups:
- Hydrogen
- Carboxyl group
- Amino group
- Variable "R" group
  (20 different possibilities)

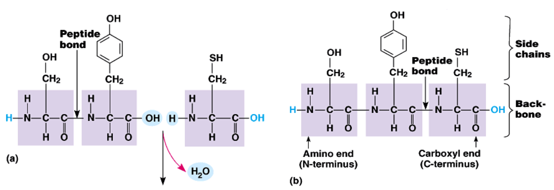


Amino Acids



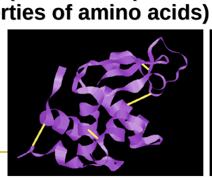
Peptide Bonds

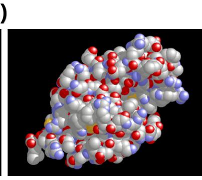
- **<u>Amino acids</u> are joined by covalent bonds: peptide bond formed by condensation reactions**



Protein Conformation

- **<u>Protein</u> <u>Conformation</u> : 3D structure *(shape)* of a protein.**
  - **Determined by the sequence of A.A.s**
  - **Determines protein function**
  - **Formed by folding and coiling of the polypeptide chain (results from the different properties of amino acids)**



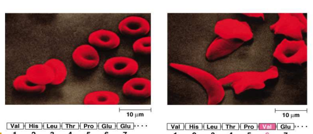


Protein Conformation

- **Four Different Levels of Organization:**
  - **Primary**
  - **Secondary**
  - **Tertiary**
  - **Quarternary**

Primary Structure

- **Linear sequence of Amino Acids:**
- **Determined by genes *(DNA sequence)***
- **Can be sequenced to determine the order of AAs**
- **Small changes can have large effects *(sickle cell)***

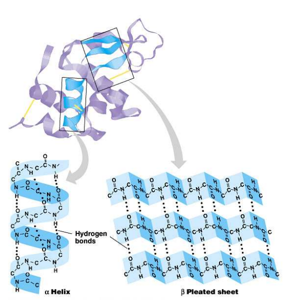


(a) Normal red blood cells and the primary structure of normal hemoglobin

(b) Sickled red blood cells and the primary structure of sickle-cell hemoglobin

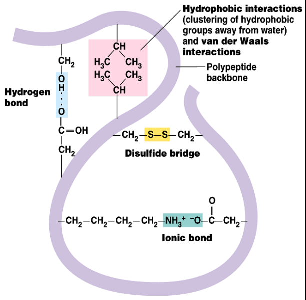
Secondary Structure

- **Formed by regular intervals of hydrogen bonds along the backbone.**
- **Coiling/Folding**
- **2 structures:**
  - **Alpha Helix *(coil)***
  - **Beta Sheet *(fold)***



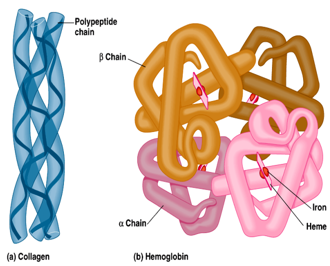
Tertiary Structure

- 3-D shape
- Determined by "R" group interactions :
  - Hydrogen bonds
  - Ionic bonds
  - Hydrophobic interactions
  - Disulfide Bridges (strong covalent bonds)

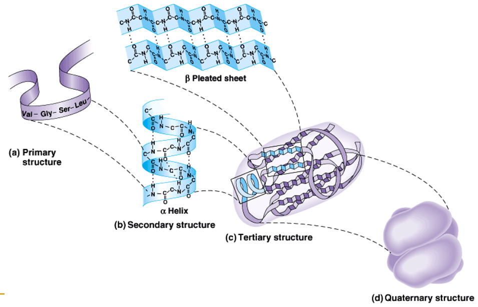


Quarternary Structure

- Structures formed from two or more polypeptides
- Examples:
  - Collagen
  - Hemoglobin

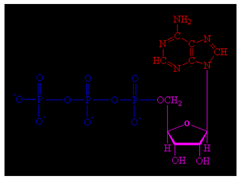


Protein Conformation Summary



Nucleic Acids

- Polymers of nucleotides
  - Nucleotides are made from subunits
    - Nitrogen base
    - Sugar
    - Phosphate group
- Examples:
  - DNA
  - RNA
  - ATP



Deoxyribonucleic Acid (DNA)

- DNA is found in the nucleus of most cells and contains coded information (*on genes*) that programs all cell activity.
- DNA is not directly involved in the day to day operations of the cell.
  - Proteins are responsible for implementing the instructions contained in DNA.
- Contains the directions for its own replication.
  - DNA passes an exact copy of itself to each subsequent generation of cells.
  - All cells in an organism contain the exact same set of instructions.

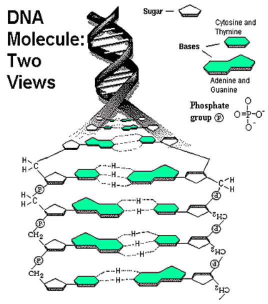
Ribonucleic Acid (RNA)

- Involved in the actual synthesis of proteins encoded in DNA
- Three types :
  - Messenger RNA (mRNA)
    - Carries encoded genetic messages (from DNA)
  - Transfer RNA (tRNA)
    - Transfers the Amino Acids to a forming protein
  - Ribosomal RNA (rRNA)
    - Involved in the actual synthesis of proteins *(ribosome)*

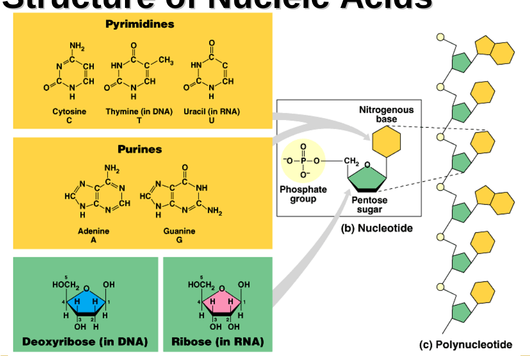
Properties of RNA and DNA

- Both molecules contain four of the five possible nucleotides (A,G,C, & T or U) linked together.
- RNA
  - Single stranded
  - Contains Uracil rather than Thymine
  - Unstable
- DNA
  - Double stranded (helix)
    - Complimentary
    - Nucleotides pair up
      - A-T *(2 H bonds)*
      - C-G *(3 H bonds)*
  - Contains Thymine rather than Uracil
  - Very stable

DNA Molecule: Two Views



Structure of Nucleic Acids



(a) Nucleotide components

(b) Nucleotide

(c) Polynucleotide

Nucleic Acids