Chemistry: The basis for life.

Almost everything around us can be broken down into simpler substances. These substances can be further broken down into other simpler substances. There is a point where substances can no longer be broken down into other substances while keeping their characteristic properties. These substances are called ELEMENTS. There are currently 116 named elements (92 naturally occurring), but this number is increasing because more man made elements are being created in laboratories.

From these 92 naturally occurring elements, only 25 are necessary for life. Of these 25 life elements, 6 make up 99% of all living matter:

Sulfur, Phosphorus, Oxygen, Nitrogen, Carbon and Hydrogen can be remembered as: SPONCH (pneumonic device). Living organisms still need the other 19 elements, but in smaller amounts.

What makes up an element? An ATOM is the smallest indivisible unit of an element that still has the characteristic of the element. Two or more atoms can combine chemically and form a MOLECULE. A COMPOUND is any pure substance that contains two or more different atoms.

i.e. Atom = H Molecule = H_2 Compound = H_2O

Atoms, elements and compounds are forms of matter. Matter can come in one of three states on the earth. I know, there are four states of matter, but biologically speaking, we are not concerned with plasma.:

Solid: has a definite shape and has a definite volume.
Liquid: has no definite shape but has a definite volume.
Gas: has no definite shape and has no definite volume.

Atoms can be broken down into smaller components called subatomic particles: protons, neutrons, and electrons.

Protons and Neutrons make up the nucleus of an atom, they roughly equal in mass, one atomic mass unit (amu) or Dalton. Protons are positively charged and neutrons are not charged. Electrons are negatively charged, have relatively small mass. An atom can be described as having a small, very dense nucleus with a very low-density electron cloud surrounding it. Therefore we can conclude that most of the mass of the universe is made up of protons and neutrons.

Strong nuclear forces hold the protons and neutrons together, while the electrons are attracted to the positive charge of the protons

All atoms of the same element have the same number of protons. The number of protons is the atomic number (written in subscript to the left of the atomic symbol). Unless otherwise noted, the number of protons equals the number of electrons. An atom is usually neutral in charge since the positive and negative charges are equal.

We can determine the number of neutrons by using the mass number, which is the sum of the protons and neutrons (written as a superscript to the left of the atomic symbol).

The number of protons is fixed, but the number of neutrons can vary within the same element. Thus the same element may have different atomic masses. Atoms of the same element that have different atomic masses are called isotopes.

i.e. Hydrogen: 1p,1e- Deuterium: 1p,1n,1e- Tritium: 1p,2n,1e-
1 amu 2 amu 3 amu

Some combinations of protons and neutrons are stable, but other combinations are internally unstable and break down spontaneously. When this happens, the atom releases various subatomic particles and radiation. These isotopes are called radioactive isotopes.

Most of the time the number of electrons equals the number of protons. Electrons move in undefined paths, in regions around the nucleus, called orbitals (orbitals are merely a volume in which the electron is probably moving). Only two electrons can occupy the same orbital. There are many orbitals; however, electrons move to the orbital that is lowest in energy, usually closest to the nucleus. There are other regions called energy levels that contain orbitals. The energy level closest to the nucleus contains one orbital. The second energy level holds four orbitals and the third energy level also contains four orbitals.

The first energy level can hold up to two electrons. (1s)
The second energy level can hold up to eight electrons. (2s, 2p)
The third energy level can hold up to eight electrons. (3s, 3p)

There are more than three energy levels, but as biologists are only concerned with 18 total electrons. Atoms are most stable when their outer energy level is filled with electrons.

Of the three atomic particles, only the electrons are directly involved in the chemical reactions between atoms. Not every electron has the same amount of energy. (Energy is the ability to do work.) There are two types of energy: Potential energy and Kinetic energy. Potential energy, the amount of energy that matter stores is due to the position or location of the matter.

Electrons have potential energy in relation to the nucleus. The potential energy that an electron has is determined by the distance from the nucleus (Potential energy is the amount of stored energy the electron contains). The more energy the electron contains, the further it will be from the nucleus; an electron with low energy will be closer to the nucleus.

Electrons can move to a higher energy level by having energy added to it (i.e. sunlight and light energy). Once the electron moves to the higher level, it contains that added energy. When this electron moves back to its original position, the same amount of energy that it took to move the electron is released.

An atom with its outer shell filled with electrons is a stable atom. Chemical behavior is determined by the electron configuration, the distribution of electrons in the atom's electron shells. The chemical properties of an atom is determined by the number of electrons in the outermost shell. These are called valence electrons. Atoms with a full valence shell are unreactive. Atoms with the same number of valence electrons have similar chemical behaviors.

Atoms react with other atoms chemically by filling their outer shells. Atoms can fill their outer shell in one of three ways:
1) Gain electrons from another atom.
2) Lose electrons from its outer shell.
Both 1 and 2 form Ionic Bonds.
3) Share one or more pairs of electrons with another atom.
When this happens, a Covalent Bond is formed.

When any one of these things happens, we get a chemical reaction and a formation of bonds. There are two types of bonds, and these correspond to how the atom attains their electrons.

1) Ionic Bonds and Ions:
Let's look at Sodium and Chlorine. Sodium has 11 electrons:$1s^2$, $2s^2$,$2p^6$,$3s^1$. Sodium needs to gain seven more electrons or lose one electron. Chlorine has 17 electrons: $1s^2$,$2s^2$,$2p^6$,$3s^2$,$3p^5$. Chlorine has to lose seven electrons or gain one electron. Sodium donates one electron to Chlorine. These two atoms combine to form a compound, sodium chloride- salt. An ion is any charged atom. Sodium donates an electron, which is negatively charged and becomes a positively charged atom. The Chlorine receives an electron and becomes a negatively charged atom. The two ions are Sodium$^+$ and Chloride$^-$. When two atoms give and receive electrons, they form ions and ionic bonds. These bonds are fairly weak.
Cation: Positively Charged Ion. Anion: Negatively Charged Ion.

2) Covalent Bonds:
Sharing of electrons. The actual definition of a molecule is when two or more atoms are held together by a covalent bond. Two atoms that are close to each other can fill their outer shells by sharing electrons. In fact, atoms give up little by sharing. For example, 2 Hydrogen atoms share their electron to have two electrons in their shell. Oxygen ($1s^2$,$2s^2$,$2p^4$) shares two electrons to form O_2. Methane is another example. Carbon has six electrons:$1s^2$,$2s^2$,$2p^2$. The carbon shares its four electrons of its outer shell with 4 Hydrogen atoms to get CH_4=Methane.

If atoms share one pair of electrons, one electron from each atom, then they form one covalent bond (single bond). If two atoms share two pairs of electrons, two from each atom, they form two covalent bonds (double bond). If two atoms share three pairs of electrons, three from each atom, they form three covalent bonds (triple bond).

Nonpolar and Polar Covalent Bonds:
The attraction of electrons to an atom is called Electronegativity. The more electronegative an atom, the more a shared electron is pulled towards its nucleus. If there are two atoms of the same element or the same electronegativity, the pull of the electron is equal and the bond is a Nonpolar Covalent Bond. There is no charge associated with a nonpolar covalent bond.

If one atom is more electronegative than another atom, the electron is pulled closer to the atom and the electron is not shared equally. The atom with the greater electronegativity will be slightly negative-- due to the fact that a negative electron spends more time around its nucleus. The other atom has a slightly positive charge (lost the negative electron). This bond is called a Polar Covalent Bond.

Van der Waals Interactions:
Molecules with nonpolar covalent bonds may have positive and negative regions. However, these positive and negative charges are not equally distributed and the electrons are constantly in motion. As a result, the charges may accumulate by chance in one part of the molecule or another. These changing positive and negative charges enable the molecules to weekly bind to each other

Hydrogen Bonds:
Hydrogen bonds are the result of a polar covalent bond. When atoms with Nitrogen, Oxygen, and Fluorine share electrons with a Hydrogen atom. Hydrogen bonds happen between molecules. The electrons between hydrogen and the other atoms are shared unequally. (Hydrogen forms a polar covalent bond with an atom with greater electronegativity) This unequal sharing causes the hydrogen to have a partial positive charge, and the other atom (or molecule) to have a slightly negative charge. The hydrogen (with the slightly positive charge) is attracted to another atom, or molecule, (not the one it is covalently bonded to) with a slightly negative charge. Each H bond lasts for only one trillionth of a second, but they reform instantly. These are probably the most important bond in biology. We will be revisiting the H bond time and time again.

Water is a good example.
H_2O is 2 H and 1 O. The H are covalently bonded to the O.

This is a polar molecule, because it has partial positive and partial negative ends. The hydrogen atoms of the water molecule can now form bonds with other slightly negative (polar) compounds. In this case, each hydrogen of this water molecule can form hydrogen bonds with the oxygen atom of other water molecules.

Hydrogen bonds are 20 times weaker than covalent bonds. But hydrogen bonding between molecules is very important with organic compounds.

Chemistry of Water
Water Properties:
The unique structure of water gives water its seven important properties. Most of these properties are due to H bonds and electronegativity.
1) Water is a powerful solvent:
Water is able to dissolve anything polar due to its polarity. Water separates ionic substances. Many covalently bonded compounds have polar regions. Because of these polar regions, the covalent compounds dissolve in water and are called hydrophilic (water loving) compounds. Nonpolar substances do not dissolve in water and are called hydrophobic (water fearing). Soap is a amphipathic molecule. This means that soap has both hydrophobic and hydrophilic ends. The hydrophobic end binds to nonpolar molecules, and the hydrophilic end binds to water. This separates the dirt from your skin, and the water pulls the soap away from your skin.

2) Water is wet (water adheres to a surface): This is due to two properties: Adhesion and Cohesion.
Adhesion: the attraction between water and other substances
Cohesion: the attraction of water molecules to other water molecules, ie. Water adheres to itself and then other substances.

These two properties allow capillary action. Water is attracted to the polar substances (adhesion) and climbs these substances, while pulling up the other water molecules due to cohesion. The meniscus, in a column of water, is formed because gravity pulls down on the water molecules in the center while water molecules at the sides of the container "climb."

Imbition is the movement of water into a porous hydrophilic material. This occurs when water moves into a substance (due to capillary action) and that substance swells.

3) Water has high surface tension:
Since water is attracted to itself, the attraction of water to itself (due to hydrogen bonds) is higher than the attraction to the air above it.

4) Water has a high specific heat:
It takes a lot of heat to increase the temperature of water and a great deal of heat must be lost in order to decrease the temperature of water. Water heats up as the hydrogen atoms vibrate (molecular kinetic energy-- energy of molecular motion). The unit of heat that we're using is 'calorie.' A calorie is the amount of heat it takes to increase the temperature of 1 gram of water 1^oC. A kilocalorie (kcal or Calorie) is the amount of energy it takes to heat up 1 kg of water 1^oC. Microwaves cause the H to vibrate. The vibration of the H causes heat that will increase the temperature of the food.

5) Water has a high boiling point:
A great deal of energy must be present in order to break the Hydrogen bonds to change water from a liquid to a gas. The hydrogens vibrate so much, they can't reform H bonds. When they can reform the bonds, the water molecules are lost into the atmosphere as water vapor.

6) Water is a good evaporative coolant:
Because it takes a lot of energy to change water from a liquid to a gas, when the vapor leaves it takes a lot of energy with it. When humans sweat, water absorbs heat from the body. When the water turns into water vapor, it takes that energy (heat) with it.

7) Water has a high freezing point and lower density as a solid than a liquid.
Maximum density of water is 4^{o}C, while freezing is 0^{o}C. This is why ice floats, this fact also allows for aeration of still ponds in spring and fall and the reasons that ponds don't freeze from the bottom up. Water expands when cooled due to the hydrogen bonds. When water begins to freeze, molecules no longer move to break the hydrogen bonds. When the temperature decreases, the molecular movement slows down and the breaking and reforming of hydrogen bonds slow. After a while, the water molecule will slow so much that each water molecule is bonded to four other water molecules. These bonds are kept at a specific distance from each other. The water is locked into a crystalline lattice. The hydrogen bonds keep molecules far enough apart to make ice 10% less dense than liquid water. As ice is warmed, the molecules move and the lattice collapses on itself.

Dissociation and pH scale:
Many substances come apart (dissociate) in water. Some dissociate completely, while others dissociate only partly. In a solution, some molecules are intact while others are ionized (gain or lose electrons). Water dissociates into H+ and OH-. They do this equally (hydrogen and hydroxide)(10^{-7} Keq). Substances that yield H+ when they dissociate in water are called ACIDS (by Arrherrius definition). i.e. HCl ------> H+ and Cl- . Acids add H+ to the solution, increasing the H+ concentration, and they also decrease the amount of –OH in a solution.

Substances that yield OH- when they dissociate in water are called BASES. i.e. NaOH -----> Na+ and OH- Bases also accept H+ (by Bronstead Lowry definition). Bases reduce the amount of H+ in a solution: -OH + H+ ----> H_2O or NH_3 + H+ ---> NH_4+.

A SALT is a substance in which the H+ of an acid is replaced by another positively charged ion. i.e. HCl + Na -----> NaCl and H+

The acidity or alkalinity (base) is known as pH (from the term pouvoir Hydrogène meaning hydrogen power). pH=-log [H+].
i.e. pH=6. The concentration of H+ per liter is 10^{-6} in a solution.
The pH scale goes from 0-14, 7 is neutral. Acidic is < 7, and Basic is > 7. A pH of 5 is 10 times more acidic as something with a pH of 6. The more hydrogen ions present, the higher the hydrogen ion concentration, and the more acidic the solution.

Because H+ + -OH ---> H_2O. However, [H+][-OH] = $10^{-14}M^2$. i.e. Acid = 10^{-5} and then the base = 10^{-9}. [10^{-5}][10^{-9}]=$10^{-14}M^2$.

Buffers: substances that keep the pH constant by taking up or releasing H+ or OH-. An important buffer we have is H_2CO_3. These prevent the swings in pH. H_2CO_3 dissociates to H+ and HCO_3-. The H+ is a base acceptor, where the HCO_3- is an acid acceptor.

Biological Chemistry: Organic Molecules
Organic compounds are molecules containing carbon that are found in living things. 70-90% of the cell is made of water, the rest is made of carbon based compounds.

Let's discuss some concepts before delving into actual organic compounds.
Isomers: These are compounds that have the same molecular formula but different three dimensional structures and hence different physical and/or chemical properties.
There are 3 types of isomers:
a) Structural Isomers: these differ in the arrangement of atoms.
For example, glucose and fructose both have the formula C6H12O6, but have different bonding arrangements.
b) Geometrical Isomers: these have the same covalent partnership but different spatial arrangements because of the orientation of

groups around a double bond, which does not permit free rotation around it. The orientations of the constituent groups are spatially fixed around the double bond. Such arrangements around a double bond are called cis- when the named constituents are oriented on the same side of the double bond, and trans- when the constituents are oriented across from each other.
c) Stereoisomers (Enatiomers): these are molecules that are mirror images of each other. A central (not terminal) carbon atom is covalently bonded to four different atoms or groups of atoms; the carbon is called an asymmetrical or chiral carbon. The result is a pair of compounds that are mirror images, right handed and left handed isomers (which are synthesized in nature).

Functional Groups: A combination of the SPONCH elements.
These are the portions of an organic molecule that are usually involved in chemical reactions. Functional groups behave in a characteristic way regardless of what the rest of the molecule is like. These groups are attached to the carbon skeleton, replacing one or more of the hydrogens that would occur in a hydrocarbon. Here are the biologically important functional groups.

Formula	Group Name	Significance
R-OH	Hydroxyl Group (Alcohols)	Polar-- Water soluble, forms hydrogen bonds.
R-NH_2	Amino Group	Weak Base (H+ acceptor). Once the H+ is accepted, there is a positive charge.
R-COOH	Carboxyl Group	Weak Acid (H+ donor). Once the H+ is donated, there is a negative charge.
R-SH	Sulfhydryl (thiol) Group	Forms disulfide bridges in proteins.
R-C=O | H	Aldehyde Group	Polar. Water soluble. Characterizes some sugars.
R-C=O | R	Ketone Group	Polar. Water soluble. Characterizes other sugars.
R-O | C=O | R	Ester Group	Formed when carboxylic acid is added to alcohol. Found in lipids.
R-H_2PO_4	Phosphate Group	Acidic in solution, loses two H+ to become R-PO_4^{2-}. When the hydrogens are lost, the group has a negative charge.
R-CH_3	Methyl Group	Nonpolar, hydrophobic, insoluble in water.

Energy Factor: Covalent bonds are strong, stable bonds. These bonds have different strengths depending on the configurations of the electrons in orbitals. The atoms of the molecules are always moving-- vibrating, rotating and shuffling positions. If the motion becomes great enough, the bond will break, and the atoms will separate.

The bond strengths are expressed in terms of energy, in kilocalories or kilojoules per mole that must be supplied to break the bonds under standard conditions of temperature and pressure. The more energy required to break a covalent bond, the stronger that bond is. Weak bonds are easier, i.e. require less energy, to break.

Once the covalent bonds break, the atoms form new covalent bonds quickly. Depending on the temperature, pressure and the nature of the other reactants, the same compounds or new compounds are formed.

Elements involved with Organic Compounds: Along with carbon and hydrogen, other elements are found in organic compounds. The most common of these elements are nitrogen, phosphorus, sulfur and oxygen (The SPONCH elements).

Oxygen: Oxygen makes up 21% of the earth's atmosphere and is found in the great majority of organic compounds in living systems.

Nitrogen: Nitrogen is found in all proteins and nucleic acids. 79% of our atmosphere is N_2. The bond between the two nitrogen atoms is a triple bond and is a difficult bond to break. The only way for most organisms to get usable nitrogen is through nitrogen fixing bacteria.

Phosphorus and Phosphates:
Phosphorus is found in living systems as phosphates in ions such as HPO_4^{2-} or $H_2PO_4^-$. Phosphorus is covalently bonded to four oxygen atoms. When the oxygen-phosphate bond is broken, energy is released. Phosphorus is an important element in nucleic acids.

Sulfur:
Sulfur occurs in some proteins. The sulfur appears as part of sulfhydryl groups (-SH) in the amino acid cysteine. These groups allow parts of a proteins to bond together covalently via disulfide bridges.
R-SH + HS-R -----> R-S-S-R + H_2

Carbon Backbone:
Carbon can form covalent bonds directly with two to four atom since it has four valence electrons (carbon has six total electrons, 2 in the first orbital and 4 in the outer orbital). In many biological molecules carbon atoms forms long chains. Carbon is unique in that it can form single, double, and triple covalent bonds with itself and other atoms.

```
     |    |    |    |    |                    Lines=covalent
   - C - C - C - C - C -                 bonds
 |    |    |    |    |
```

Hydrocarbons: These compounds consist solely of H and C. They are not part of living systems except as the backbone to which functional groups are attached. Examples of hydrocarbons are methane (CH_4), butane (C_4H_{10}), and cyclohexane (6 carbons in a ring, C_6H_{12}.)

There are four main groups of biologically important organic molecules: carbohydrates, proteins, lipids, and nucleic acids. These molecules are called polymers. Polymers are chain like molecules that consist of many similar building blocks linked together by covalent bonds. The building blocks are called monomers. These monomers are joined together by dehydration/condensation reactions.

The condensation reaction, a synthesis reaction, is important because it is the reaction that puts together polymers from monomer units. Synthesis reactions require energy to complete.
Condensation reaction: the joining of two smaller organic compounds resulting in the formation of a larger organic molecule and the release of a water molecule.
ex. $C_6H_{12}O_6$ + $C_6H_{12}O_6$ -----> $C_{12}H_{22}O_{11}$ + H_2O
glucose + fructose ----> sucrose + water

Hydrolytic cleavage, or hydrolysis, is the opposite of a dehydration or condensation reaction. For example, in the human digestive system, sucrose, a disaccharide, is split into glucose and fructose, two monosaccharides.
Hydrolytic cleavage (hydrolysis): with the addition of water, the splitting of a large organic molecule into two smaller organic molecules. Hydrolysis reactions liberate energy.

I) Carbohydrates:
Most carbohydrates have the empirical formula $C(H_2O)n$. Carbohydrates are composed of covalently bonded atoms of carbon, hydrogen and oxygen. The basic unit of a carbohydrate is called a monosaccharide or simple sugar. There are two types of monosaccharides: aldose or ketose depending if the monosaccharide has an aldehyde or ketose group. Monosaccharides can be burned (oxidized) to yield carbon dioxide, water and energy. The principle source of energy for organisms is glucose. Structurally a sugar consists of a carbon backbone of three or more carbon atoms with either an aldehyde or ketone group on one carbon and hydroxyl groups on each of the other carbons. Most sugars end in '-ose.'

The most common monosaccharide is glucose, $C_6H_{12}O_6$. Glucose is the form of sugar generally transported in the human body and is the major fuel of cellular respiration. Joining two monosaccharides together forms a disaccharide. The two monosaccharides are linked by a reaction called dehydration or condensation reaction. A polysaccharide consists of many monosaccharides joined together by condensation reactions.

Disaccharides-- two monosaccharides that are joined by a glycosidic linkage, a covalent bond between two monosaccharides.
For example, maltose = glucose + glucose.
sucrose = glucose and fructose,
$2\ C_6H_{12}O_6 \text{ -----> } C_{12}H_{22}O_{11} + H_2O$
Glycosidic linkages can be oriented differently in space. Two monomers can be joined either by an alpha or beta linkage.

By a series of dehydration reactions, many monosaccharides can be put together to form a polysaccharide. Three examples of Polysaccharides are starch, glycogen, and cellulose. In starch and glycogen, the monomers are joined by alpha linkages; in cellulose the glucose monomers are joined by beta linkages.

A) Starch:
Starch is the storage polysaccharide in plants and is an important reservoir for energy. There are two common types of starch: amylose and amylopectin.
Amylose: the simplest starch, consisting of unbranched chains of hundreds of glucose molecules.
Amylopectin: large molecule consisting of short glucose chains with other glucose chains branching off of the main chain.

B) Glycogen:
Glycogen is the storage polysaccharide in animals. Glycogen is composed of branching glucose chains, with more branches than amylopectin. It is found in the liver and muscles and acts as the temporary storage form of glucose. The liver removes the excess glucose from the bloodstream, converts the glucose monomers to glycogen via condensation reactions, and stores it as glycogen; when vertebrates need glucose for energy, glycogen is converted by hydrolytic cleavage back to glucose.

C) Structural Polysaccharides:
1) Cellulose:
Cellulose is a structural polysaccharide and is the major building material made by plants. It is the most abundant organic material on earth. Cellulose is made up of long and straight glucose molecules. Cellulose is called a structural polysaccharide because it gives the plant cell its shape, is not soluble, and is very strong. Cellulose is flexible when the plant cell is young. As the cell grows, the cellulose becomes thicker and more rigid.

Cellulose is indigestible to animals because the linkages are 1-4 beta linkages, and our enzyme can only break down 1-4 alpha linkages because the shapes are different. Cellulose is the so-called fiber in our diets. Some bacteria, protists, fungi and lichens, can break down cellulose. For example, bacteria and protists found in the stomachs of termites and grazing animals break down the cellulose in the grass and wood to provide the animal with glucose.

2) Pectin and Carrageenan: These are extracted from algae. Pectin and carrageenan are put into food items such as jellies, jams, yogurt, ice cream and milkshakes to give them a jelly-like or creamy consistency.

3) Chitin: Chitin is the principal component of the exoskeletons of insects and other arthropods, including lobsters. Chitin is very soft but is combined with $CaCO_3$ (calcium carbonate or limestone) to become hard. Most animals cannot digest chitin.

II) Proteins:
Proteins are large, complex organic molecules that are made of smaller monomer units, amino acids. Proteins are naturally occurring biological molecules that are composed of amino acids linked together through dehydration reactions.

Amino acids are the building blocks of proteins. There are 20 amino acids.
Here is the basic structure of an amino acid:

```
          R
          |
H - N - C - C = O
    |   |   |
    H   H  OH
```

All amino acids except one, glycine, are asymmetrical. When amino acids are prepared in the lab pairs of stereoisomers form. In living systems, only the left-handed isomers are synthesized.

There are four different groups attached to the carbon.

1) an amine group, NH_2, (basic, can accept H^+ and thus have a positive charge).
2) a carboxyl group, COOH, (acidic, can donate H^+ and thus have a negative charge).
3) hydrogen
4) R group: The R group is the portion of the amino acids that is different in each amino acid. In the amino acid glycine, the R group is replaced with an H atom.

R groups:
The R group of the amino acid determines the physical and chemical properties of the protein. R groups can be nonpolar, polar, acidic, or basic. They can also be the site of the addition of prosthetic groups, inorganic groups that are essential for the functioning of the protein. These prosthetic groups often determine the protein's function, as in hemoglobin. Minerals in our diets are often essential parts of prosthetic groups; for example, iron (Fe^{2+}) in our diet is essential for the synthesis of the heme group the prosthetic group in hemoglobin. The activities of some proteins are dependent upon co-enzymes, which are small organic groups attached to the protein. Many of these co-enzymes cannot be made by animals and must be included in our diets in the form of vitamins.

To synthesize proteins, a dehydration reaction occurs. The amino end of one amino acid and the carboxyl end of a second amino acid are joined together. The covalent bond formed is called a peptide bond. The molecule that is formed by adding many amino acids together is called a polypeptide.

How do the cells in the body obtain amino acids? Many foods contain proteins; the proteins are broken down into small pieces called peptides. Peptides are about 30 amino acids long and are carried in the blood vessels. When a cell is actively making proteins, peptides are taken into the cell, broken down, and the constituent amino acids are reconfigured into a protein.

Proteins have a three dimensional configuration which is determined by the amino acid sequence. Proteins can be stringy or globular. The CONFORMATION of the protein is its three dimensional shape. The function of the protein is determined by its conformation (shape). A protein may have four different levels of structure that determine its conformation.

Levels of Protein Structure:
The amino acid sequence is called the Primary Structure. The protein is defined by the amino acid sequence. Each protein has a different primary structure. Changing the amino acid sequence can change the protein shape and function.

The Secondary Structure of a protein refers to the way in which some segments of the polypeptide repeatedly coil or fold in patterns which contribute to the protein's overall shape. These folds and coils are the result of hydrogen bonding at regular intervals along the polypeptide backbone. The oxygen and nitrogen atoms of the polypeptide backbone have a partially negative charge. The partially positive hydrogen atoms attached to the nitrogen atom have an attraction to the oxygen atom of the nearby peptide bond.

Individually, the hydrogen bonds are weak, but since they are repeated many times, they can support a particular shape of the protein. An example of a secondary structure is the a helix. The a helix is a coil held together by hydrogen bonds between every fourth peptide bond. If a protein is fibrous in appearance, it is made mostly of a helices.

Another secondary structure is the beta pleated sheet. When the polypeptide chain folds back and forth or when two regions of the chain lie parallel to each other, the amine groups and carboxyl groups between the parallel regions form hydrogen bonds. These bonds will maintain the protein's secondary structure. A globular protein will have a beta sheet core.

Whether the secondary structure forms a helix or a pleated sheet depends on the sizes of the R groups. If the R groups are small and repeated many times, then the pleated sheet forms. If the R groups are too large, pleated sheets are unable to form and the alpha helix structure results.

The Tertiary Structure is the actual three dimensional shape of the polypeptide. There are two types of three dimensional shapes: fibrous and globular. Some fibrous proteins are keratin and collagen. Globular proteins are more numerous. An example of a globular protein is hemoglobin.

The bends and loops of the amino acid chain are caused by the R groups of the amino acids reacting with R groups of other amino acids on the same polypeptide.

The nonpolar (hydrophobic) R groups will tend to group together away from the surface of the polypeptide since water is the usual medium surrounding these molecules. Once the nonpolar groups are close together, Van der Waals attractions reinforce the hydrophobic interactions. Hydrogen bonds can form between polar R groups. Two sulfhydryl groups can form a disulfide bridge. Charged R groups (acids and bases) can repel or attract each other. These bends and twists cause the polypeptide to have a three dimensional shape.

A protein consisting of two or more polypeptide chains has a quaternary structure. Polypeptide chains interacting with other polypeptide chains form the quaternary structure. These interactions are of the same types that are responsible for tertiary structure, namely hydrogen bonds, disulfide bridges, electrostatic attractions and hydrophobic forces (London or dispersion forces).

Factors that Determine Conformation:
A polypeptide will spontaneously arrange itself into a three dimensional structure. However, if the pH, salt concentration, temperature, or other environmental aspects are altered, the protein may unravel and lose its shape. This is called DENATURATION. A protein that denatures is biologically inactive.

Chemicals can disrupt hydrogen bonds, ionic bonds or disulfide bridges, and change the structure of proteins. Excessive heat will also cause the protein to denature, the hydrogens will vibrate and won't be able to reform the H bonds. H+ will also affect H bonds. The H+ are attracted to the negatively charged –OH group. Once they bond to the –OH group, there is no place for the slightly positive H atom to be attracted to, thus the bond breaks.

The folding of polypeptide is very important in determining the function of the polypeptide. It is thought that there are proteins (Chaperonins—chaperone proteins) that can assist in the folding of the polypeptides. Chaperonins are hollow cylinders (they are huge proteins) that provide a shelter for folding proteins. They protect the folding protein from band influences like prions.

Types of Proteins:
A) Binding proteins/Transport proteins: These proteins have the unique ability to take specific shapes, which enable them to bind to other substances.
Example:
Hemoglobin, a globular protein), binds with oxygen.

B) Structural proteins help with support, shapes, and structures.
Examples:
1) Collagen: Collagen consists of long fibrous molecules that clump together to make large fibers; these fibers are the principle component in connective tissues such as tendons, ligaments, and muscle coverings. Collagen can compose up to 25% of a person's body weight.
2) Elastin: Elastin has the ability to stretch and gives elasticity to connective tissue such as skin. Loss of elastic property over time causes bagginess in the face, neck and skin.
3) Keratin: Keratin is found in hair, nails, and outer layer of skin, feathers, claws, horns and scales. Cells fill up with keratin, then die and leave the keratin behind.

C) Hormonal Proteins: These proteins coordinate organism's activities. For example, insulin regulates the sugar concentration in the organism's blood.

D) Receptor Proteins: These polypeptides are found on the cell membrane and are responsible for the response of a cell to chemical stimuli.

E) Defense Proteins: Defense proteins protect the organism against disease. The example is antibody proteins produced by B-cells.

F) Enzymes: An important class of proteins.
All chemical reactions need energy to get started; this energy is known as activation energy. The rate of a chemical reaction is related to the activation energy for that reaction. Generally, reactions with low activation energies are rapid while those with high activation energies are quite slow. The rate of a chemical reaction can be increased by the addition of a catalyst. A catalyst decreases the activation energy needed for the reaction to occur, thus increasing the rate at which the reaction proceeds. A catalyst participates in the reaction but is not consumed in that reaction. In living systems, enzymes are the catalysts. For each chemical reaction that occurs in an organism, a specific enzyme is required. All enzymes are proteins.

Every chemical reaction involves the breaking and reforming of bonds. This bond rearrangement requires energy, which must be absorbed by the reactants from their surroundings. Energy is released when the new bonds are formed. The initial energy is called activation energy. This is usually provided as heat. The heat increases molecule movement that causes the molecules to collide more frequently and more forcefully (increase Brownian motion). As molecules obtain their new arrangement, energy is released. However, you can't increase your own body heat. If you do, then you have the chance of denaturing your own proteins by breaking H bonds. How cay you have chemical reactions happen quickly without increasing body temperature—catalysts.

Proteins make efficient catalysts because their shapes are very specific. Each enzyme has an active site. The active site is a groove or depression on the surface of an enzyme. The shape of the active site allows the enzyme to bind with a specific compound, called the substrate. When the substrate binds to an enzyme, the complex is called the enzyme-substrate complex (ES). The molecules are no longer dependent upon heat to move them faster to increase collisions. The activation energy is lowered because the molecules 'meet' in the active site. Each reaction in your body requires an enzyme which must have a specific shape.

The "Induced Fit" model:
The active site isn't usually rigid. In fact, the active site can move around a bit, actually changing shape slightly to accommodate the shape of the substrate. When the substrate(s) is in the active site, then the enzyme catalyzes the reaction(s) of the substrate so that the product(s) form:

S	+	E ----->	ES	------>	P	+	E
Substrate		Enzyme	Enz-Sub Complex		Product		Enzyme

A single enzyme acts on approximately 1,000 substrate molecules per second.

Rate of Enzyme Reactions: Enzyme Kinetics
How do time, temperature, pH, cofactors/coenzymes, and enzyme inhibitors affect the rates of enzyme reactions?
1) Time: Initially, the substrate concentration is high, which leads to a high rate of reaction. After time, the substrate concentration decreases, which causes a decrease in the reaction rate. The enzyme has more products binding with the active site. This is competitive inhibition or negative feedback.

2) Temperature:
When there is an increase in temperature up to 40^{o}C, the rate of reaction increases. With the increase in temperature, you increase molecular movement, you increase collisions, you increase products. Above this temperature, hydrogens vibrate, and hydrogen bonds break. When the hydrogen bonds break, the enzyme loses its three dimensional shape, the active site cannot bind to the substrate and no product can be formed. The enzyme has been denatured. Each enzyme has an optimal temperature, which is usually closest to the organism's ambient temperature.

3) pH:
Different enzymes have different optimal conditions of pH. Pepsin (found in stomach, breaks down protein) works at pH of 2. Trypsin (found in the small intestine, also breaks down protein) works best at a pH of 8. If there is a decrease in pH because more acid is added, hydrogen bonds break and the enzyme is denatured and no longer effective. The H^+ affect the hydrogen bonds by bonding to the partially negative atoms, to which the partially positive hydrogens are attracted.

4) Free Radicals: these molecules have a free electron. These electrons can bind to the positively charged H atom. Once they bond, the H bond is broken and the enzyme denatures. Antioxidants will decrease free radicals. Free radicals are naturally formed during aerobic respiration, however, increase alcohol and drug use, also increases free radicals.

5) Cofactors/coenzymes:
These non-protein molecules help enzymes. They can either bind to the enzyme or substrate, reversibly.

6) Enzyme inhibitors:
They are certain chemicals, which specifically inhibit specific enzymes. These molecules attach to the enzyme. These molecules can be classified into two categories:

a) Competitive inhibitors: these block enzyme at the active site.
b) Noncompetitive inhibitors: these molecules don't compete with the substrate for the active site. They bind to another site on the enzyme, which changes the shape of the enzyme (allosteric sites).

Control of Metabolism: How a cell regulates it's metabolic processes by controlling enzyme activity.
1) Negative feedback/Competitive Inhibition

2) Allosteric control

Negative Feedback/Competitive Inhibition:
This is a common method of regulation in living systems. As the product is formed, it hinders the mechanism that produced the product. If there is too much product being formed, then excess product remains in the active site. When this happens, the substrate can no longer enter the active site. When the level of product decreases, the product leaves the active site, and the reaction can resume.

Allosteric Control:
Sometimes an enzyme may have a second binding site, called an allosteric site. When a small molecule binds to the allosteric site, the enzyme's active site changes shape. When the active site changes, the enzyme can no longer bind to the substrates. This type of control usually happens in multi-step reactions. The molecule will bind to one of the first enzymes of this multi-step reaction, which causes the decrease in the final product.

III) Lipids:
Lipids are a diverse group of molecules defined by their solubility rather than by their structures. Lipids dissolve in nonpolar solvents such as chloroform, ether, and benzene. Lipids are hydrophobic and do not dissolve in water. Important groups of lipids include triglycerides (fats and oils), phospholipids, glycolipids, waxes and steroids.
A) Triglycerides: fats and oils.
Fat= a lipid that is solid at room temperature.
Oil= a lipid that is a liquid at room temperature.
A triglyceride is composed of one glycerol molecule and three fatty acid molecules.

```
        Glycerol                              Fatty Acids
     H                            O
     |                            ||
 H - C - OH                  HO-C-C-C-C-C-C-C-C-R
     |
 H - C - OH
     |
 H - C - OH
     |
     H
```

The synthesis of a triglyceride occurs when a glycerol molecule joins with three (of the seventy different) fatty acids. Fatty acids usually have an even number of carbons, differ in the length of the carbon chain, and may contain double covalent bonds.

Glycerol combines with three fatty acids by dehydration synthesis.

```
                 O                        O
                 ||                       ||
   C-OH  HO-C-R                 C-O-C-R
   |             O                   |    O
   |             ||                  |    ||    +3H2O
   C-OH    HO-C-R      ---->         C-O-C-R
   |            O                    |    O
  |     ||                       |    ||
   C-OH  HO-C-R                C-O-C-R
```
The R-COOC-R linkages are called ester linkages.

Saturated, unsaturated and polyunsaturated fats:
Some fatty acids have no double bonds. They have the most hydrogens possible. These are called saturated fats. Animal fats are usually saturated fats and solidify at room temperature.
Some fatty acids have a double bond between two adjacent carbons. This structure means that they have fewer hydrogens than the saturated fats; these are called unsaturated fats. Unsaturated fats tend to be oily liquids. They can be found in plants (olive oil, peanut oil, corn oil) more commonly than animals and are usually liquids at room temperature. We can't make unsaturated fats, so we need to eat small amounts of unsaturated fats. However, hydrogenated vegetable oils hare unsaturated fats changed to saturated fats by adding hydrogen. This prevents the lipids from separating in liquid form.

Polyunsaturated fats have more than one double bond.

Triglycerides are a concentrated source of energy. When the fat is combined with oxygen, the fats release a large amount of energy, more than twice as much per gram as carbohydrates (Fats provide 9 kcal energy/gram as compared to 4 kcal of energy/gram for both carbohydrates and proteins). Seeds store triglycerides, animals store energy as fat for lean seasons or migration or insulation, humans store fat under the skin and around internal organs. Fat serves for insulation and flotation. Storage fat serves as padding in your fingers and your bottom.

B) Phospholipids are closely related to triglycerides. Two fatty acids, one saturated and the other unsaturated are linked to a backbone of glycerol. In the place of the third fatty acid is a phosphate group. The phosphate group is hydrophilic while the hydrocarbon chains are nonpolar and hydrophobic. The cell membrane is made up of two layers of phospholipids and proteins.

C) Glycolipids: The third carbon in the glycerol molecule isn't bound to a phosphate group. Instead, it is bonded to a short carbohydrate chain (1-15 monosaccharides). The carbohydrate head is hydrophilic; thus glycolipids behave in the same way as phospholipids. They are also important components of the cell membrane.

D) Steroids:
Steroids are not structurally similar to fatty acids or lipids. Since they are hydrophobic, however, they are called lipids. All steroids have four linked carbon rings. Steroids have a tail and many have an -OH group. Some steroids:
1) Lanolin: commercially refined from sheep's wool. Humans have a small amount of lanolin in the hair and skin; lanolin helps give these structures flexibility.
2) Cholesterol: a major constituent of the cell membrane. When bombarded with ultraviolet light, it rearranged into vitamin D. When modified slightly, it makes sex hormones.

E) Waxes: similar in structure to triglycerides, but instead of glycerol there is a long chain alcohol. Because of their hydrophobic quality, waxes are found in many living things that need to conserve water. Insects have waxy cuticles, plants have wax on their leaves, and fruit skins and petals have wax as an outer covering.

IV) Nucleic Acids:
Nucleic acids are the largest organic molecule made by organisms. There are two types: DNA (Deoxyribonucleic Acid) and RNA (Ribonucleic Acid). The pentose sugar in DNA, deoxyribose, has one fewer oxygen atoms than ribose, the sugar in RNA.
DNA contains an organism's genetic information. Basically, DNA encodes the instructions for amino acid sequences of proteins. RNA carries the encoded information to the ribosomes, carries the amino acids to the ribosome, and is a major constituent of ribosomes.

Nucleotides are the basic units of both DNA and RNA and can exist as free molecules. A nucleotides is made up of

1) pentose sugar: deoxyribose or ribose.
2) phosphate: in free nucleotides, they occurs as a group of three phosphates bonded to the sugar.
3) nitrogenous base: there are two types of nitrogenous bases. They are called bases because of the amine groups, which are basic.
    a) Pyrimidines: single ring compounds. The two pyrimidines in DNA are cytosine and thymine. In RNA thymine is replaced by uracil.
    b) Purines: double ring bases. The two purines are adenine and guanine.

The importance of nucleic acids:
a) DNA is the hereditary material; RNA enables proteins to be synthesized from the DNA instructions.
b) A cell's energy source for chemical reactions is stored as ATP (adenosine triphosphate). Between the phosphate groups are bonds, which can be broken to yield usable energy, 7 kcal/mole.
c) cAMP (cyclic adenosine monophosphate) is used as a second messenger in many hormonal reactions.