Introduction:

The following provides a basic introduction to the biochemistry of three major nutritional components of your diet, carbohydrates, proteins and fats. You may have had advice to avoid fat in your diet—but your body urgently needs certain essential fats and if you avoid fats you tend to get too much carbohydrate, as will be discussed. We will introduce two groups of essential fats called omega-3 and omega-6 fatty acids. It is extremely important for the best health to obtain a balance of omega-3 and omega-6 fatty acids and most modern diets have a very great excess of omega-6 fatty acids. This information will give you the background knowledge to better understand the material in BioScience Montana learning module 3, understand the processes you are using, and concepts you are exploring.

You are what you eat. This saying, handed down through the ages, is more true than you may realize. Your diet has a profound impact on your health and well being. Food provides the source of the molecular building blocks that are needed to build, maintain and repair your cells and connective tissue, that make up your entire body. Food also provides fuel for all your body's cellular processes which allows you to do all the things that you do, whether it's working on a project, sleeping, sitting on the couch watching TV, reading a book, playing with your dog, or riding your bike. The choices you make in your diet affect the type of building blocks you give your cells and the energy sources that you supply them. The balance of essential fats, essential protein components, and the amounts of different kinds of carbohydrates have a major impact the quality of your life and health. Therefore, it is important to translate knowledge gained in unit 3 into terms and concepts that are easy for people to understand, so that you and your family and friends can benefit from the cutting-edge research that is being done at labs across the world and here at Montana State University.
Vital life molecules: Carbohydrates, proteins, and fats.

You can't begin to delve into the beauty of the inner workings of biology without understanding at least a little bit of the chemistry behind it,--so let's learn a little about the chemicals that do so much in your body. The three groups of ”macro” nutrients in food that we will discuss here are; carbohydrates, proteins, and fats. The periodic table of the chemical elements contains 92 naturally occurring elements, but of these only six (carbon, hydrogen, oxygen, nitrogen, sulfur and phosphorous) make up most life molecules. The carbon, hydrogen, oxygen and nitrogen elements arranged in foods can be “burned” for fuel in our cells to make energy in the form of ATP (adenosine triphosphate). By far the most efficient means of making ATP in our cells is a process called cellular respiration¹, which also requires the oxygen that we breathe. ATP powers your muscles, the pumps that keep your brain and other cells electrically active, drives switches that control metabolism, and drives many of the transformations that convert food building blocks into body parts. Respiration is the main way your cells get energy and respiration is critical for you to do anything.

Carbohydrates:

Carbohydrates are a nutrient most people are familiar with because they are also known as starches and sugars. Simple carbohydrates have a basic chemical framework of carbon, hydrogen, and oxygen, usually in a ratio of 1:2:1. In chemical formulas, subscript numbers after each atom symbol tell you how many of that particular atom are in the molecule of interest. For example, the chemical formula of water is \( \text{H}_2\text{O} \), which means that there are two hydrogens and one oxygen atom in each water molecule. One of the most important carbohydrates in the body is glucose, which is the chemical name for blood sugar. The chemical formula for glucose is \( \text{C}_6\text{H}_{12}\text{O}_6 \), meaning that there are six carbon atoms, twelve hydrogen atoms, and six oxygen atoms in each glucose molecule. Carbohydrates are

¹ If you need a tutorial on cellular respiration you can check out [http://kidsresearchexpress-5.blogspot.com/2008/08/cellular-respiration.html](http://kidsresearchexpress-5.blogspot.com/2008/08/cellular-respiration.html).
named because they contain carbon (C) and H₂O (water)—you can test for carbohydrates by dropping sulfuric acid on them and you get black carbon and steam (water) released. In C₆H₁₂O₆ there are atoms from six molecules of water combined with the six atoms of carbon in each glucose molecule.

Illustration 1 shows a ball and stick model of a molecule of glucose. In this model the carbon atoms (black) and one oxygen atom are arranged in a ring with the hydrogen atoms (silver) and oxygen atoms (red) arranged around this ring.

Blood sugar provides “back up” energy to all cells in the body, but all your cells, except the brain, prefer to burn fat—if there is enough oxygen in your tissues. If your tissues are short of oxygen (usually because of high exertion or if you are holding your breath for a long time) your cells burn blood sugar very inefficiently, but fast to make lots of ATP to keep you going. Incidentally, if someone wants to loose fat they should use low intensity exercise to burn fat, not high intensity exercise that depletes tissue oxygen and burns sugar. Or, if you eat a lot of carbohydrate—the elevated blood sugar shuts off fat burning by the tissues so the body can reduce the blood sugar spike caused by eating the carbohydrates—and usually much of the sugar is turned into fat in your body to help bring down the blood sugar level. So high carbohydrate diets tend to add fat to your body (which you can use if you
are too skinny). If you exert yourself a lot, sugars can provide easy-to-use energy that is stored in the bonds between the carbon, hydrogen, and oxygen atoms. Your blood sugar level is also crucial for optimum brain function and taking in a lot of sugar can crash blood sugar in response. Energy in sunlight is used by plants to make chemical bonds in carbohydrates (starch), proteins and fats and when the bonds are broken in respiration or other metabolism, that energy is released to make ATP.

**Proteins:**

Proteins are amazing and complex molecules, which are involved in nearly every part of cellular life. Proteins are used to carry out thousands of chemical reactions in the body, send and receive hormone signals between cells, build cell and tissue structures, fight disease, move molecules in and out of cells, and produce muscle movement! Proteins are so important that, believe it or not, most of your DNA codes for instructions on how to make tens of thousands of different proteins. Like carbohydrates, proteins are made up of carbon, hydrogen, and oxygen, but they also contain nitrogen, some sulfur and a bit of phosphorous. Proteins are made up of smaller molecules, called amino acids, which are linked together in long chains.

When we eat proteins our body has to digest them back to individual amino acids so that our bodies can use the amino acids to build back into new proteins--with amino acid chains sequences that are coded by our genes. There are 20 different types of amino acids used to make the proteins found in your body and some of these amino acids are essential in your diet (thus the concern for the “quality” of proteins and combinations of proteins). The order of the amino acids in the protein chains are coded by your DNA and the order of the amino acids determine the “shapes” that the proteins fold into. The “shape” of particular proteins determines their activity and thus the function of that protein. There are tens of thousands of different types of proteins, and they all have different jobs to do as described briefly below.
Structural proteins give shape and strength to cells and tissues. Examples include collagen, which forms fibers in your bones and important connective tissue in your body and keratin, which makes up things like hair, fingernails, hooves and feathers. Signal receptor proteins receive messages from one cell to another cell or from a cell to a group of tissues. Some proteins are themselves signals that act between different cells. Insulin, which regulates blood sugar in our bodies, is a small but very vital signaling protein, that controls a wide range of activities in our bodies including carbohydrate, protein and fat metabolism.

Enzymes are another extremely important protein type. Enzymes can accelerate the speed of chemical reactions, up to millions of times faster than the reaction would progress without the enzyme. This means that a reaction that would take a hundred years without an enzyme could be completed in much less than a second by using the right enzyme! Your body uses thousands of different types of enzymes to carry out thousands of different chemical transformations—like digestion, respiration and synthesis of cellular building blocks. Enzymes also play key roles in the metabolism of omega-3 and omega-6 fatty acids, which you will be learning about in the on-campus portion of this module.

**Fats and Lipids:**

Fats are the last of the three classes of life molecules that we will be exploring here. Fats can be converted to molecules called lipids that are used by cells to form membranes that surround all cells as well as to store energy. Fats are key sources of energy for animals (recall that almost all of the cells in our bodies prefer to burn fat as fuel most of the time) and energy for seed germination comes from stored fat in the seeds. Fat in the body is also used for insulation and to pad and protect organs, and tissues called “brown fat” provide body heat, when needed.

You may have previously learned that the cell membrane, the outer layer of a cell that separates it from its external environment, is made up of a double layer of lipids called the phospholipid bilayer.
Phospholipids also insulate and protect nerve fibers together with high levels of cholesterol.

Cholesterol is an important molecule that is also classed as a lipid and is essential for the function of cell membranes, bile detergents that are essential for digestion of fat and absorption of fat soluble vitamins (A, D, E and K), and for the synthesis of sex hormones. Our body makes at least ten times as much cholesterol than we typically can eat in our diets, because it is so important for health. There is good evidence that the only people that should reduce cholesterol in their diets are a relatively small number of individuals (less than 1%) that have a defective LDL receptor and extremely high blood cholesterol. Lipids and fats are truly vital life molecules because of their many important roles in providing structure for all cells, being the material that is made into many hormones and for providing energy in the body. Fats are also the molecules that you will be exploring the most, as you progress through this BioScience Montana module 3.

Fats consist of carbon, hydrogen, and oxygen bonded together. Lipids are made up of at least two parts, and the two separate parts of a very simple lipid are shown in purple and green in Illustration 2 below (most lipids have a more complex structure than this, but this example is a good start). The purple part on the left is a molecule called glycerol which is a type of alcohol, and which is a building block for many lipids. The green part to the right of the glycerol is a long, chain-like structure that is called a fatty acid. Fatty acids play a major role in most all fats and a large fraction of lipids and the types of fatty acids in your diet are crucial for health and disease.

Illustration 2: **Glycerol**, shown in purple, makes up one part of many lipid molecules. The **fatty acid**, shown in green, contains a carbon spine with hydrogens attached to it, forming a lipid hydrocarbon chain usually joined to the glycerol. Modified from: http://library.thinkquest.org/12090/lipids.html
The fatty acid has two structural parts that are designated as the “head” and “tail”. The “head” is made of a group of oxygen-containing atoms called a carboxyl group (that is shown in Illustration 3 and is also seen on the left of the fatty acid in illustration 2). Illustration 3 shows the arrangement of the hydrogen, carbon and oxygen atoms in the carboxyl group that make up the heads of the fatty acids. The lines between the C, H, and O on illustrations 2 and 3 represent chemical bonds, which will be discussed in more depth in the next section. The “tail” of the fatty acid is made up of long chains of carbon atoms with hydrogen atoms sticking off of them. Because the tail is made out of hydrogens and carbons, it is often called a hydrocarbon chain.

Saturated, unsaturated, and polyunsaturated fats:

You have probably heard of saturated, unsaturated and maybe also polyunsaturated fats that are frequently discussed in relation to the foods that you eat, but what do these terms mean? The terms saturated, unsaturated, and polyunsaturated are actually referring to the chemical structures of the fatty acid molecules, so let’s explore that a little more. In order to understand the chemistry of fats, you need to understand a bit about how atoms bond together. Carbon atoms can bond to one another in single or in double bonds. Saturated fatty acids contain all carbon-carbon single bonds, unsaturated fatty acids contain a carbon-carbon double bond and polyunsaturated fatty acids contain two or more carbon-carbon double bonds. The concepts of double and single bonds will be explained a bit more below.

Atoms consist of protons and neutrons in the positively-charged nucleus and negatively-charged electrons that orbit around the nucleus. The electrons orbit the atomic nucleus in distinct orbital shells.
and each shell can hold a specific number of electrons. Electron interactions can bond/glue atoms together in chemical bonds to form molecules. Atoms can bond in different ways by giving or taking electrons from other atoms or by sharing electrons with other atoms. **Atoms gain or lose or share electrons to try to fill up their outermost orbital shell**, called their valence shell—to reach a stable state. **When atoms share electrons, this type of bond is called a covalent bond** and such shared electron bonds are the type of bonds found in fats. A **single covalent bond is present when two atoms are sharing one pair of electrons and a double covalent bond is when the two atoms are sharing two pairs of electrons.**
Recall that the “tail” of a fatty acid, such as shown in illustration 2, consists of a chain of carbon atoms bonded together. Illustration 4 shows a molecule of the simplest hydrocarbon called methane (chemical formula CH$_4$ one carbon atom and four hydrogen atoms). Hydrocarbons are molecules that contain hydrogen and carbon, not surprisingly. Carbon has four electrons in its outermost shell, that are colored blue in illustration 4, but it has eight spots in it’s outermost shell in which to put electrons. Having eight electrons in its outermost shell would make it full. Hydrogen, on the other hand has only one electron in its first shell, which is shown in red in illustration 4. The outer shell of hydrogen would like to have two elections to be full. So as diagrammed in Illustration 4, each hydrogen atom shares one electron with the carbon atom and the carbon atom shares its four electrons with one of each of the hydrogens to form the molecule of methane, with chemical formula CH$_4$. Each shared pair of electrons form a covalent bond and there are four single bonds between the carbon atom and the four hydrogens.

Illustration 4 is a type of diagram that represents the elections as dots; however, it is more common to show molecules in terms of the atoms and the types of bonds present but not show each electron (for example, Illustrations 1 and 2). Therefore, by far the most common way to show the structure of methane, in terms of the bonds present, is shown in illustration 5. This diagram represents
single bonds (containing one pair of shared electrons) as single lines between the letters that represent the atoms.

![Illustration 5: A the most common representation of methane, showing single bonds between the carbon and hydrogen atoms, where bonds are represented by single lines.](image)

Double bonds form when two atoms share four electrons (two pairs) between them. An example of a double bond using carbon is in carbon dioxide, CO$_2$, that you probably have heard quite a lot about. Again, carbon has four electrons in its outermost shell but a filled outer C shell would have eight electrons. Oxygen, in contrast, has six electrons in its outermost shell and it’s filled outer shell would also have eight electrons. If oxygen gets or shared two electrons it will have a filled outer shell. Thus, if carbon shares electrons with two oxygen atoms, both oxygens and carbon can have full outer shells as diagrammed in Illustration 6. When two pairs of electrons are shared between each oxygen and carbon these form double bonds. This arrangement of shared electrons is diagrammed below in illustration 6. Illustration 7 shows the same arrangement of electrons but is drawn in the more standard notation, where each covalent bond (formed from a shared pair of electrons) is shown as a solid line.

The double bonds sharing two pairs of electrons are shown as two parallel lines in Illustration 7.
Now that you have seen a little basic chemistry and have seen the difference between a single and a double bond we hope that you can understand the difference between a saturated and unsaturated fat. See again the fatty acid in illustration 2. The “tail” of that fatty acid chain of carbons bonded together with single bonds and two hydrogens also bonded to each carbon (except for the right hand end carbon that had three hydrogens bound). Also remember that discussion of basic chemistry above taught that a carbon atom has four locations where it can bond with single electrons with other atoms, like we saw with the methane example. This is because carbon needs to share four elections from other
atoms to attain a full outer (valence) shell, and it has four electrons to share with other atoms. Carbon can also bond with two single bonds and a double bond to fill its outer shell. Can you find an example of this in illustration 2? Alternatively, carbon has two spots where it can bond in double bonds, again because it wants to gain four electrons and it has four to share, as in the CO₂ example.

If you look at the fatty acid tail of the lipid in illustration 2 each carbon (other than the end carbons) is bonding at all four spots in single bonds: with the carbon to its left, with the carbon to its right, with the hydrogen above it, and with the hydrogen below it. The carbon on the far right of the fatty acid is bonded to three hydrogens and only one carbon on its left. The carbon farthest to the left in the fatty acid is participating in two single bonds and one double bond to oxygen (carbons in stable molecules always form four bonds to other atoms). The left-most fatty acid carbon is part of the carboxyl group, that makes up the “head” of the fatty acid molecule.

Thus the difference between saturated and unsaturated fatty acids can be explained. Illustration 8 compares the chemical structure of a saturated and unsaturated fatty acid. The carbon atoms in a saturated fatty acid (above in Illustration 8) are bonded to each other with single bonds which allows them to bond with a hydrogen both above and below. Therefore, the single bonded carbons are full or “saturated” with hydrogen, meaning they have the maximum possible number of hydrogens bonded to the carbon chain. An example of an unsaturated fatty acid is shown below in Illustration 8. The unsaturated fatty acid has a double bond between two of the carbons in the chain and, as a result, the carbons can't hold as many hydrogens. Therefore, the fatty acid is said to be unsaturated. Polyunsaturated fatty acids have two or more double bonds between carbons and we shall see more of these later in unit 3.
The unsaturated fat in illustration 8 shows the effect of a double bond between two of the carbon atoms on the fatty acid structure. As you can see, the double bond makes less sites for hydrogens to bond on the hydrocarbon chain, so the chain is less saturated with hydrogen. Double bonds between carbon atoms can produce kinks or bends in the fatty acid tail.

These subtle differences in chemistry on the atomic scale actually produce some dramatic, differences between the two types of fats. Longer chain saturated fats are solid at room temperature. Animal fats are largely saturated, but contain quite a bit of monounsaturated fatty acids and some polyunsaturated fatty acids, depending on what the animals have been eating. Two classic examples of largely saturated animal fats are butter and lard (with some unsaturated and polyunsaturated fatty acids depending on what the animals have been eating), while two examples of saturated plant fats are coconut oil and palm oil. Unsaturated and polyunsaturated fats, on the other hand, are liquid at room temperature and as a result we call them oils. Oils generally, but not always, come from plant sources. Some examples of oils are olive oil, peanut oil, canola oil, corn oil, and fish oil. Olive oil contains mostly monounsaturated fatty acids and solidifies in the refrigerator. [Incidentally, our bodies can and
do make a lot of the fatty acids in olive oil out of saturated animal fats by putting in a single double bond in the right place!]. Fish oil is rich in polyunsaturated omega-3 essential fatty acids that will be a major topic of Unit 3.

Remember the kinks in the unsaturated fats? It turns out that those kinks prevent the molecules from packing closely enough together to solidify at room temperature. Saturated fats don't have the kinks so they can pack together more easily and form solids at higher temperatures. There are some notable exceptions to this. You have probably heard of hydrogenated and partially hydrogenated oils. Hydrogenation is a way to force hydrogen, through a chemical process, into the fatty acid chain in order to reduce the number of double bonds and increase the shelf life of products that contain these oils. Partial hydrogenation only adds hydrogen to some of the double bonds, but as we shall see later partial hydrogenation kills off the omega-3 fatty acids first. The omega-3 fatty acids are already very scarce in most of our diets and more omega-3 fatty acids are crucial for health, but tend to be wiped out by hydrogenation. Partial hydrogenation also changes the chemical structure of the remaining double bonds (producing “trans fats) that will be discussed later in unit 3.

**Fatty acids and Essential Fatty Acids (EFAs):**

As you have probably figured out by now, fatty acids are the key components of fats and lipids and lipids are vital components of cell membranes. Membranes are important because they serve as the boundaries and chemical barriers around cells and organelles within the cell, membranes carry pumps and signal receptors, and membranes also are surfaces where many important chemical reactions occur. If not for membranes, photosynthesis and respiration couldn’t take place, muscles couldn't contract, and electrical conduction of nerve impulses essential for brain and muscle function would not occur. If not for properly functioning membranes your body quite simply wouldn't work.

Your body does an excellent job of manufacturing a wide array of fatty acids, but it can't make
them all. You need an important group of fatty acids called the essential fatty acids or EFA's. **EFA's are fatty acids that are necessary for normal growth and development but your body can't make them, and you can only get them from food.** This is one of the key reasons why it is so important to have a healthy diet. There are two groups of EFAs called the omega-3 and omega-6 fatty acids. You may have heard about the omega-3 group of important nutrients in the press, as higher levels of omega-3 fatty acids have been linked to many significant health benefits. Omega-6 fatty acids are also essential for health, but our typical modern diets provide far too much omega-6 and not enough omega-3, and the imbalance is quite harmful. Omega-3 and omega-6 fatty acids are polyunsaturated fats which, as you recall, means that they have a several double bonds between pairs of carbons in the fatty acid chains.

The omega-6 and omega-3 fatty acids get their name from the location in chain where the first double bond occurs. Recall that a fatty acid molecule has a carboxyl head and a fatty acid tail. The head of the fat is said to be the alpha or beginning of the molecule, whereas the far end of the tail is referred to as the omega end of the molecule. These terms are applied because alpha (α) and omega (ω) are the first and last letters of the Greek alphabet, respectively. Sometimes you will see these Greek letters used in notations with other names for the omega-3 and omega-6 molecules and sometimes you may see them referred to as n-3 or n-6 fatty acids.
Illustration 9: Here you can see a diagram (note hydrogens are not shown for simplicity) showing the location of the first double bond in an omega 3 fatty acid (top) and an omega 6 fatty acid (bottom). The carboxyl head on the right is considered the beginning of the molecule (the alpha side) the end of the tail is called the omega end.

Illustration 9 is a simplified diagram of examples of omega 3 and omega 6 fatty acid molecules (note the hydrogens are not shown for simplicity). In this illustration you can see the head of the molecule on the right and the tail on the left for both the omega 3 and omega 6 examples. The top diagram shows an example of an omega-3. By starting at the omega end of the molecule and counting the atoms you can see that the first double bond starts at the third carbon atom. This bond closest to the omega end is the third bond from the omega end of the molecule, thus this example is referred to as an omega-3 fatty acid. The bottom figure in illustration 9 shows an omega-6 fatty acid. If you count bonds from the omega end of the lower molecule you will see that the sixth atom is the starting point of the first double bond closest to the omega end, thus its name, omega-6. This particular omega-3 is known as alpha linolenic acid (also named α linolenic acid or ALA) and this particular omega-6 fatty acid is known as linoleic acid (or LA). ALA is found in green plants or algae and in animals that eat green plants or algae, like grass-fed animals and fish, and in a few seeds including flax, camellina, and salba. Linoleic acid (LA) is rich in most seed oils and nuts including corn, soy, sunflower, safflower, and peanut.
Both the omega-3 ALA and omega-6 LA fatty acids are the essential fatty acids (EFAs) and our bodies can make other longer and more unsaturated omega-3 and omega-6 fatty acids out of the EFAs. LA and ALA compete for the same enzymes in our bodies and if we have too much LA it will inhibit the metabolism of ALA. The longer omega-3 and omega-6s are converted in our bodies into powerful hormones and compounds that affect our brain function. Very considerable research indicates that the ratio of omega 6 to omega 3 in a person's diet can have an impact on several critical aspects of health. Diets high in omega 6 and low in omega 3 may make a person prone to poor brain function and ill health conditions such as headaches, ADHD, depression, PMS and diseases such as cancer, cardiovascular, and autoimmune disease. Diets high in omega 3 and low in omega 6 seem to help to prevent these types of disease and health problems. It appears that supplements of the longer omega-3 fatty acids in fish oils or products made from algae can overcome excessive omega-6 to a substantial extent. The average American diet has a omega-6/omega-3 ratio of 15 to 1 or higher. Where do you think you are? You're about to find out.

As you learn and explore nutrition, diet, and the complex science behind it all in this BioScience Montana learning module think about how your newly acquired knowledge can impact your life and the lives of your families and friends. We hope that you will be able to use this knowledge and experience to take responsibility for your health, help build a better community, create leadership opportunities, develop life skills, and ? Enjoy, explore, learn, and discover!