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Stoichiometry - A Necessary Tool in Chemistry

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Introduction

I teach Honors Chemistry & AP Chemistry at Benjamin E. Mays High school. Mays High is a Magnet school for Science and Mathematics in the school district, in addition to other smaller learning communities. All together Mays High is serving about 1700 to 1800 students. The population at Mays is approximately 98% African American and 2% Hispanic. Mays High is a 'Title I' school where more than 50% students are eligible for Free or Reduced Lunch. Students in the Magnet Program are required to take a minimum of three Advanced Placement classes, in addition to regular graduation requirements, which include a one year of chemistry. These requirements send almost each and every Magnet Student through my door.

Some of my students have a strong background and interest in science, as their goal is to go to college for a science major, while others are not interested in a science major. I always find my class to contain a heterogeneous mixture of science knowledge. This forces me to teach the basic elements, principles of chemistry and math skills in a chemistry class while preparing them for more advanced classes, which is very challenging. The greatest challenge of students of chemistry is doing multi-step problems using some basic math skills and chemical concepts.

Food is one of the most important basic needs of life and most of us love food. The unit will associate the idea of healthy food habits with an understanding of key chemistry concepts. One key concept is stoichiometry, which is a necessary tool for chemists - this unit connects food with stoichiometry to drive student's interest towards chemistry. One particular goal of the unit is for students to do calculations without using the word "stoichiometry." Another goal is to educate students to make the right choices in selecting healthy food, which is good for their body This helps students to be physically healthier as they may tend to choose the right food and would be active in chemistry class, as well. Throughout the unit the activities will involve food and chemistry, emphasizing the importance of chemistry in healthy food choices. The activities incorporate math calculations that will lead students to central concepts of chemistry: stoichiometry and limiting reactant.

Rationale

We eat food for two physiologic reasons: energy and chemical building blocks[1] . Food undergoes several complex reactions in the digestive system before it is absorbed by the walls of intestine. Some knowledge of chemistry is critical to understanding the metabolism of food in our body.

Metabolism is the complete set of chemical reactions that occur within the cells of our bodies. These reactions extract energy from food, and convert it into movement, growth, and reproduction. Metabolism of carbohydrates is different from metabolism of protein and fat, and vice versa. With the help of this knowledge one can choose healthy food from the abundant varieties available to satisfy one's palate and lead a healthy life. On the other hand, poor food choices lead to overweight and obesity. Being overweight or obese increases the risk of many diseases and health conditions, including hypertension (high blood pressure), osteoarthritis (a degeneration of cartilage and its underlying bone within a joint), dyslipidemia (for example, high total cholesterol or high levels of triglycerides), type 2 diabetes, coronary heart disease, stroke, gallbladder disease, sleep apnea and respiratory problems, and some cancers (endometrial, breast, and colon)[2] .

This unit will focus on food facts, information on the nutritive values of food, and the connection of this information through stoichiometry. In the normal mode of teaching stoichiometry, I might ask a common question from industrial chemistry: "How many grams of ammonia can be produced by mixing 2.50 kg of nitrogen with excess hydrogen?" To solve this problem students require chemistry knowledge along with simple arithmetic knowledge and problem solving skills. I would like to highlight my student's responses before I discuss the process: 'Again math, are we in math class?', 'Involves many steps, I can't do it', 'It's very hard', 'Too many conversions, I am giving up.' Probably, these types of responses are common in high school chemistry class. I do not want to blame my students totally, because, in truth, the above question does involve several steps. Not only that, they can not relate the above question to their day-to-day life. Though the above process is very important to industry as 20,000 tons of ammonia is used every year in United States for making fertilizers,[3] it is not interesting to my students.

The following steps are involved in solving the above question:

1. Writing correct formulas for nitrogen, hydrogen and ammonia.
2. Writing a chemical equation for the process.
3. Balancing the equation.
4. Converting the mass of given substances to moles using molar mass of substance.
5. Using the stoichiometric coefficients from the balanced equation to convert the moles of given to moles of unknown.
6. Converting the moles of unknown to mass of unknown.
7. Making sure the mass of unknown is in correct unit with correct significant digits.

The unit focuses on achieving these same problem solving skills by using examples related to food. Hopefully, by selecting problems in which students care about the answers, they will be motivated to use math in chemistry.

I would like to show an example in order to achieve this goal. The problem: "How much energy did you gain from your breakfast/lunch, today?" Students can relate this question to their life. The question can be modified according to your situation and the time of the class. The above question works as it is for first block or the block after lunch. I would modify the question as "How much energy will you get from your lunch, today?" for the block before lunch. This question looks simple and doable to students because they relate it to themselves, though this problem involves many steps too. Since they can relate it to their life they do not mind doing this multi-step math problem. Besides doing math, they need to list the food items, collect facts, analyze the food for nutritive values, put them together, etc. I guess the driving force here is they will know the calories they got from food they had or are going to have, which will be an immediate connection to their life.

The following steps are involved in calculating the total energy from breakfast/lunch:

1. Collecting facts: energy per gram of fat, per gram of carbohydrate, and per gram of protein.
2. Listing the food items they had/going to have.
3. Estimating the number of servings of each food item.
4. Collecting the nutrition labels or nutrition facts from the internet for each food item.
5. Using nutrition facts, calculating the amount (in grams) of fat based on the servings for each food item.
6. Repeating step 5 for carbohydrates and proteins separately.
7. Converting grams of fat into energy calories for each item.
8. Repeating step 7 for carbohydrates and proteins separately for each food item.
9. Making sure that if 3 different food items have consumed, then there are 9 different calorie amounts.
10. Adding the caloric amounts obtained in step 7 and 8.

Though this problem is also a multi-step problem and involves math, the students do not mind because the end product of the problem is related to them. After the calculations are done we will have a class discussion and be able to make a list of good foods they had or will have. Hopefully, with this activity students' awareness about healthy food will increase in addition to analytical and problem solving skills. Those skills are essential to stoichiometry. After completing this activity, I would like to bring up the synthesis of ammonia problem. As students are familiar with multi-step problem solving with food analysis, they will do the stoichiometry with no difficulty.

Background

Chemistry as Central Science

Study of chemistry involves chemical changes in our body and around us. One major focus is on the structure and properties of substances. Chemistry is very important as it serves as interface to all of the other sciences and many areas of human endeavor. Hence, chemistry is often called as "Central Science".

The language of chemistry includes symbols for elements, formulas for compounds, and equations for chemical reactions. The short hand representation of an element is called symbol. These symbols are recognized by International union of Pure and Applied Chemistry. Example: carbon is represented by C, sodium is by Na and xenon by Xe. The periodic table is used to catalog the symbols of elements.

The chemical formula indicates the relative numbers of atoms of the elements of a substance[4] . For example:

the chemical formula for baking soda (sodium bicarbonate) is $NaHCO_3$. The formula tells that 1 atom of sodium, 1 atom of hydrogen and 3 atoms of oxygen are present in one formula unit of baking soda. Propane, C_3H_8, is a common fuel used for cooking and home heating. In the chemical formula the numbers 3 and 8 are called the subscripts and they represent the number atoms/moles of carbon and hydrogen in one molecule/mole of propane.

Chemical formulas are of two types. The empirical formula is the simplest formula that gives the correct relative numbers of atoms of each element in a compound, where as the molecular formula specifies the number of atoms of each element in a molecule of that substance. For example, the molecular formula of glucose is $C_6H_{12}O_6$, the ratio of atoms of carbon, hydrogen and oxygen is 6:12:6. The empirical formula of glucose is CH_2O, the atoms of carbon, hydrogen and oxygen are in the ratio of 1:2:1.

In a chemical reaction the reactants are converted to products. During a chemical reaction, atoms are neither created nor destroyed; they are merely reorganized. A chemical equation represents the chemical reaction showing reactants on the left side of an arrow and products on the right.

$N_2 + 3H_2 \rightarrow 2NH_3$

The reactants in the above equation are nitrogen (N_2) and hydrogen (H_2) where as the product is ammonia (NH_3).

Food Chemistry

The chemistry of food includes water and three essential macronutrients - carbohydrates, proteins, and fats. There are also many important components of food that add to our health but are only present in small quantities; these components are called micronutrients and include vitamins, minerals like calcium, potassium, iron and many others.

Nutritionists recommend that a healthy adult woman consume ~2000 cal of energy per day. Of course, this number can change, depending on the level of activity of the woman. These total calories should come from a mixture of macronutrients: for example, carbohydrate intake might be ~60% of calories, fat intake ~30%, and protein intake ~10% per day. Experts disagree about the exact percentages that constitute a healthy diet, but these percentages are a good starting point.

A calorie is the unit of energy, which is defined as the amount of heat required to raise the temperature of one liter of water from 14.5 $^{\circ}$C to 15.5 $^{\circ}$C. This is equal to the amount of energy a 150 pound person burns each minute while sleeping[5] . The body converts food into energy. The human body can make four calories of energy for every gram of carbohydrate, nine calories per gram of fat and four gram per gram of protein. Choosing perfect proportions and correct combinations can be easier with knowledge about nutrition and simple arithmetic.

Carbohydrates

Carbohydrates, commonly known as sugars, are made of carbon, hydrogen and oxygen with a general chemical formula $C_n(H_2O)_n$. This formula represents hydrates of carbon, hence the name was given as carbohydrates. Though it is now known that there are no full water molecules attached to carbohydrates, still the name has stayed. Carbohydrates contain multiple hydroxyl (-OH) and carbonyl (>C=O) functional groups.

Carbohydrate molecules range in size from monomers (monosaccharide) to polymers (polysaccharides). Polymer (poly= many, mer = unit) is large a molecule with many repeating units called monomers.

Monosaccharides are the simplest carbohydrates and are referred as simple sugars. The most common monosaccharides, glucose, fructose and galactose, have either five or six carbon atoms. The presence of many polar groups makes these monosaccharides water soluble. Glucose is a six carbon sugar that has an aldehyde structure. Glucose is often called blood sugar as it is present in the blood at high concentration. It serves as major source of immediate energy. Fructose is a six carbon sugar with ketone structure. Fructose is known as fruit sugar as it is present in many fruits. Glucose and fructose are structural isomers, structurally different with same molecular formula[6] . Galactose is a stereo isomer of glucose. They differ in special arrangement of hydrogen atom and hydroxyl group around one of the six carbon atoms.

A disaccharide is formed when two monosaccharides are bonded together via a condensation reaction with the release of a water molecule. Sucrose and lactose are common disaccharides. Sucrose is also known as table sugar as it is mainly used as a sweetener. Sucrose is formed from glucose and fructose. Lactose is often called as milk sugar as it is important carbohydrate in milk. Lactose is formed from glucose and galactose is bonded together. After ingestion, disaccharides are too large to be absorbed into the blood stream directly, so the digestive enzymes sucrase and lactase break sucrose and lactose respectively into their monosaccharide units.

Polysaccharides contain 12 or more monosaccharide units bonded together. These are often termed complex sugars. Starch, glycogen and cellulose are important polysaccharides. Plants make starch and cellulose: starch is water soluble where as cellulose is insoluble. The animal counterpart of starch is a different polysacchride called glycogen. It is made by animals to store energy, mostly in muscles and liver. Glucose is the monomer for each of these three polymers. Although they have same monomer unit, they have different properties. This is because of the way the glucose monomers are bonded differ in the three polysacchrides. Cellulose has a linear structure which resembles a chain like fence. Starch molecules are either branched or unbranched, and glycogen is highly branched. Due to the difference in their bond shape, humans can digest starch and glycogen but not cellulose.

Digestive enzymes can't fit cellulose into their active sites due to the specific lock and key fit needed for enzyme action. As a result, the cellulose in the fruits, vegetables, and grains that we eat passes through the digestive system without being changed or absorbed. Molecules that behave like this are called dietary fiber.

The main function of carbohydrates is as a source of energy, both immediate and stored. When carbohydrates are oxidized they release carbon dioxide, water and energy. Foods that are rich sources of carbohydrates include bread, rice, pasta, potatoes, milk, pie, soft drinks, vegetables, fruits etc[7] . Because of the difference in the composition of the carbohydrates in each of these foods, their short and long-term effects on energy in the body differ.

Eating whole grain products helps the body's sugar control system[8] . Insulin, which is produced by pancreatic beta cells, is secreted into the blood circulation in response to the rise in blood glucose after meals. Insulin regulates blood glucose levels by suppressing glucose production from the liver and stimulating glucose uptake by cells throughout the body. When glucose (or other simple sugars) are eaten directly, blood sugar and therefore insulin rises dramatically. The fiber in whole grains leads to a slower rise in blood glucose and eases the workload for the insulin making cells in the pancreas[9] . Diabetes occurs when the pancreas is unable to secrete insulin—or cells in the body stop responding to insulin.

Proteins

The word protein came from the Greek root word *protos*, which means first[10] . Proteins are organic polymers made of amino acids linked together in a specific way. Each amino acid has a carboxyl and an amino group. The amino and carboxyl groups provide convenient bonding sites for linking amino acids together. The amide bond that joins two amino acids is known as a peptide bond. Proteins are not just large molecules but also randomly arranged chains of amino acids. There are 20 amino acids, which make up the tens of thousands of different proteins in our body. Our body makes some of these amino acids and rest are obtained from food. These amino acids are referred as essential amino acids as they are essential in the diet.

Proteins are the building blocks of the body. Proteins play many roles in our body. Proteins are involved in forming structures, digesting foods, catalyzing reactions, transporting substances, regulating cellular processes, recycling wastes, and even serving as an energy source when other sources are scarce. For example, insulin is a protein hormone, a small protein with 51 amino acids.

The recommended daily allowance of protein is 50 grams a day for a 140 pound person and almost 65 grams for a 180 pound person[11] . Common sources of protein are meat, milk, nuts, fish, and some fruits and vegetables. Protein is found in the body in high concentrations in muscle, hair, skin, bone and all other tissues. The effects of dietary proteins on health probably are approximately the same for animal protein and plant protein. Animal proteins tend to be complete, as they are sources of all essential amino acids. However one must be careful about eating too much of it, as animal protein tends to come with saturated fat. Though vegetable proteins are incomplete, that is, they do not have all essential amino acids, but still they are good source of proteins. Research says that eating a lot of protein does not harm the heart[12] . Choosing the right protein sources that are low in saturated fat will help you keep in good health.

Fats

Fats are large, non polar, biological molecules. Fats are insoluble in water as they are non polar. Fats have two major functions in living organisms. They store energy efficiently, and they make up most of the structure of cel1 membranes. Fats are convenient source of energy storage. Our dietary fat contains phospholipids, and cholesterol in addition to triglycerides. A triglyceride is formed by condensation of one molecule of glycerol with three molecules of fatty acid. Animal and vegetable fats are complex mixtures of triglycerides. The cell membrane is made up of phospholipids that regulate transportation of substances across the cell membrane. Our body requires cholesterol to make estrogen, testosterone and other vital compounds.

There are four types of fatty acids: monounsaturated, polyunsaturated, saturated and trans. All fatty acids are long chain hydrocarbons. Unsaturated fatty acids contain double bonds between some of the carbon atoms. Depending on the number of double bonds, the fatty acid can be monounsaturated (one double bond) or polyunsaturated (more than one double bond). Due to the cis orientation of double bonds naturally occurring in unsaturated fatty acids, they have a kink or bend that prevents them from packing together efficiently. This results in less intermolecular attractions, and lower melting points. Unsaturated fatty acids are in liquid phase at room temperature. These fatty acids are termed as good fats because eating these fats instead saturated fats and carbohydrates lowers levels of low-density lipoprotein (bad) cholesterol with out lowering the levels HDL (good or protective) cholesterol. Olive oil, vegetable oil, and fish oils are rich in unsaturated fats.

Saturated fatty acids do not contain double bonds hence they are saturated with hydrogen. Saturated fatty acids can pack together due to their straight chain structure. Saturated fatty acids have higher melting points, hence they are in solid form at room temperature. Whole milk, red meat, and coconut oil are good sources of saturated fats. These fats are termed as bad fats as they strongly increase the LDL (bad) cholesterol[13] . Hydrogenation, addition of hydrogen, to unsaturated fatty acids yields saturated fatty acids. For example, oleic acid can be hydrogenated to form stearic acid.

Trans fats are mostly man made fats. Polyunsaturated fatty acids upon partial hydrogenation yield trans acids. During this process, hydrogen will be added on to double bonded carbons, but not all, to create single bonds. At the same time, some of the remaining double bonds change their orientation, from *cis* to *trans,* resulting in new physical and chemical properties to fats. Like saturated fats, trans fats increase the LDL cholesterol. They also elevate the triglycerides and lipoproteins. A higher level of these in the blood stream increases the chances of heart disease. Trans fats not only increases the LDL levels but also decreases the HDL (protective form) levels. This does not happen with saturated fats. This indicates that trans fats are more dangerous than saturated fats. Vegetable shortenings, most margarine, deep fried fast food, most commercially baked foods, and partially hydrogenated vegetable oil[14] are sources of trans fat.

Including the good fats in the diet and keeping away the bad fats keeps a person healthy. In the recommended 30% of dietary calories, less than 1/3 should be saturated fats and rest of them should be unsaturated fats[15] . Most importantly, keep trans fats out of your meal.

Balancing Equations

The Law of Conservation of Mass states that 'the mass of the universe is constant'. This means that mass is neither created nor destroyed. According to the Law of Conservation of Mass, one has to balance every chemical equation so that the mass of substances remain the same before and after the chemical change. Another way of stating this, which is more convenient for chemists, is: all atoms present in the reactants must be accounted for among the products. A balanced equation gives the relative numbers of reactants and product molecules. In a balanced chemical equation the subscripts tell the number of atoms of each element in a molecule, where as the coefficients tell the number of molecules/moles of reactants and products.

As mentioned earlier, in our body several chemical reactions take place during digestion, respiration and other processes. Some examples of biochemical reactions:

Example1: During cellular respiration, our cells make energy from the breaking down of glucose by oxygen into carbon dioxide and water. The process is an exothermic process, the energy releasing process.

$C_6H_{12}O_6 + 6O_2 \text{ -> } 6\ CO_2 + 6H_2O + \textit{Energy}$

Example 2: The hydrolysis of sucrose into glucose and fructose

$C_{12}H_{22}O_{11} + H_2O \text{ -> } C_6H_{12}O_6 + C_6H_{12}O_6$

Example 3: Peptides are synthesized by coupling of carboxylic group of one amino acid with amino group of another amino acid to form peptide bond.

$$H_2N-R-C(O)OH+H_2N-R-C(O)OH \rightarrow H_2N-R-C(O)HN-R-C(O)OH+H_2O$$

Example 4: Fermentation of sugars into alcohol:

$$2C_6H_{12}O_6 \Leftrightarrow 2C_2H_5OH + 2CO_2$$

A fraction of chemical reactions that occur in our body during metabolism, cellular respiration, and protein synthesis is mentioned above to show the importance of chemistry in understanding the metabolism, and our food.

Mole Concept

We are all familiar with measuring the quantity of substances by their mass: I have one pound of oranges or 10 grams of gold. But there is another way of measuring amounts that is convenient for chemists, or anyone interested in substances that can react. A mole is a unit of measure equal to the number of carbon atoms in exactly 12 grams of pure Carbon -12. A mole of any other substance is this same number of units of that substance.

One mole of any substance contains Avogadro's number of units of that substance. Avogadro's number has been determined experimentally to be 6.022 X 10^23, which is a large number. The molar mass of a compound is the mass in grams of one mole of the compound and is computed by summing the average masses of its constituent atoms.

As I mentioned in the rationale, a stoichiometry problem requires the understanding the mole concept, molar mass, balancing equations, and conversions. As a mole is such a big number, I use Mole Facts[16] to fascinate my students. Some of the mole facts are listed here:

- 6.02 X 10^23 Donut Holes: Would cover the earth and be 5 miles (8 km) deep.

- 6.02 X 10^23 Watermelon Seeds: Would be found inside a melon slightly larger than the moon.

- 6.02 X 10^23 Grains of Sand: Would be more than all of the sand on Miami Beach.

- 1 Liter bottle of Water contains 55.5 moles H_2O

- 5 Pound Bag of Sugar contains 6.6 moles of $C_{12}H_{22}O_{11}$ (Sucrose)

Stoichiometry

Stoichiometry (from the Greek *stoicheion*, element, and *metria*, science of measurement)[17] deals with the calculation of the quantities of material consumed and produced in chemical reactions. It is like chemical arithmetic. Stoichiometry is used in industry quite often to determine the amount of materials required to produce the desired amount of products in a given useful equation. Stoichiometry calculations help scientists and engineers working in industry to estimate the amount of products they will obtain from a given procedure: it can also help decide whether the product is profitable to produce or not.

Companies make many chemical substances, through chemical reactions, that are helpful in our lives. For example, addition of stannous fluoride, SnF_2, to tooth paste to prevent the tooth decay in tooth paste industry; aspartame, a sugar substitute, in soft drinks in soft drink industry; preparation of citric acid from the fermentation of sugars (sucrose) in air in food industry; synthesis of aspirin in pharmaceutical industry; use of titanium metal and its alloys in aerospace industry; extraction of titanium from its ore rutile, TiO_2, in metallurgy; production of the bleaching agent, calcium hypochlorite, from sodium hydroxide, calcium hydroxide, and chlorine in detergent industry; manufacture of polyethylene (which is found in some milk cartons) in polymer industry; removal of dangerous mercury compounds from industrial waste in environmental chemistry. The list could go on. Each one of these products requires stoichiometry.

There would be no products from these industries without chemical stoichiometry. Amounts of reactants consumed and products formed can be calculated from the balanced equation for a reaction by using the mole ratios relating the reactants and products. In this unit we will concentrate on understanding and making use of these mass relations.

Limiting Reactant/ Limiting Reagent

The limiting reactant is the one which is consumed first and hence determines the amount of products that can be formed. The other reactants in the chemical reaction are called excess reactants. The excess amount of these reactants will be left over, without reacting, when the reaction is complete. For example, if you are hungry, the number of grilled cheese sandwiches you can make depends on how many slices of bread and slices of cheese you have. You can make five sandwiches from sixteen bread slices and five cheese slices. You could not make eight sandwiches, even though you had sixteen slices of bread, because you had only five slices of cheese. In this situation, the limiting reactant is cheese and excess reactant is bread. Your products are five sandwiches and six slices of bread (which is the unreacted excess substance).

Percentage Yield

The theoretical yield of a product is the maximum amount that can be produced from a given amount of limiting reactant. The actual yield, the amount of product actually obtained in a given experiment, is always less than the theoretical yield. The ratio of actual yield to theoretical yield, multiplied by 100%, gives the percentage yield in a given reaction. In the above mentioned example about making sandwiches, if for some reason (say, accidentally, a cheese slice fell on the floor) you could make four sandwiches instead five, then the percentage yield will be (4/5) 100% = 80%.

Percent yield = (Actual yield/ theoretical yield) 100%

Teaching Strategies

In my class most of the time students work in groups. I use two different types of grouping based on the requirement: i.e., ability grouping and co-operative grouping. Co-operative grouping will work better at the beginning of the concept where as ability grouping works for students to gain mastery in a topic.

Nutrition Label Analysis

How many molecules of water are required to burn a lunch meal? This activity focuses on studying the nutritive values in a meal and then to determine the number of moles and molecules of water required for the digestion of that meal. The process involves the determination of caloric values from carbohydrates, proteins, and fats separately.

For example: A student picked the following items from the existing lunch options in the school cafeteria on Monday[18] - orange chicken (two servings, steamed rice (1 cup), Lo Mein Noodles (1cup), pepperoni pizza (1 serving), French fries (1 serving) along with a piece of chocolate cake. Students will research and study the nutritive labels to find the food calories for each item. This process involves a great deal of math. Therefore, this would be the stepping stone to incorporate math into chemistry, without mentioning about stoichiometry. Students identify which item in the meal is healthy and which is not based on the knowledge they gained from Eat, Drink and be Healthy book and their research. After the food caloric calculation, students will calculate the volume of water required to digest the meal from the information that an average person requires about a milliliter (mL) of fluid for every calorie burned[19] . The first step in the calculation of water molecules is determination of volume of fluid. For instance, the number calories obtained from the above meal is 750 calories: therefore, the volume of the fluid required, with the assumption as water is the only fluid available for our case, is 750 milliliter. Then the volume of water is converted into the mass of water using the density (density of water = 1.00 g/mL). In the third step mass of water is converted into moles of water using water molar mass. The last step is converting the number of moles of water into molecules of water.

Burning Calories[20] : The energy in food

This activity focuses on calculation of energy in food items using a calorimeter. All foods contain energy, but the amount of potential energy stored will vary greatly depending on the type of food. Moreover, not all of the stored energy is available to do work. When we eat food, our bodies convert the stored energy, known as calories, to chemical energy, thereby allowing us to do work. A calorie is the amount of heat (energy) required to raise the temperature of 1 gram (g) of water 1 degree Celsius (°C). The density of water is 1 gram per milliliter (1g/ml) therefore 1 g of water is equal to 1 ml of water. When we talk about caloric values of food, we refer to them as Calories (notice the capital "C"), which are actually kilocalories. There are 1000 calories in a kilocalorie (or dietary Calorie). So in reality, a food item that is listed as having 38 Calories has 38,000 calories. Calories are a way to measure the energy you get from the food you eat.

Neutralizing ability of stomach acids

The focus of this activity is on stoichiometry of acid base neutralization between stomach acid and commercially available antacids. Students are required to do research to find information on the chemistry of stomach acid and commercially available antacids. At least, it is expected that students will come up with the chemical name of stomach acid, hydrochloric acid, and its neutralization with antacid, either Tums - calcium carbonate, or milk of magnesia - magnesium hydroxide. Students then write the balanced chemical equation between the stomach acid and the antacid chosen. After students understand the concept of neutralization of stomach acid with antacid (base) to maintain the pH, students will be given a virtual lab[21] as home work. This virtual lab familiarizes students through the process of acid-base titration. The following class period students will complete the titration lab - neutralizing ability of stomach acids[22] . At the end of lab students are required to find the post lab questions and write lab report. Approximately the entire activity will be completed in three class periods.

Gas stoichiometry and cellular respiration

The activity will begin with asking students: if we are locked in the classroom and can not go out the room, how long we can survive? The activity involves: measuring the dimensions of the classroom, subtracting the volume of the tables, lab stations, etc., determination of amounts oxygen and carbon dioxide from the room dimension and composition of air, research to learn about the cellular respiration, inhalation amount of oxygen and exhalation amount of CO_2, hazardous indoor levels CO2 etc. They are supposed find the inhalation amount of oxygen and exhalation amount of CO_2 per student and multiply with number of students to calculate indoor air quality. I estimate that this activity may take one class period.

Baking cookies

This activity will focus on limiting reactants and percent yield. Students are required to calculate the maximum number of cookies they can make from the given set of ingredients. Students are required to make a list of ingredients that were excess. Students are required to identify the ingredient that will limit the number of cookies they can bake. They are required to report these amounts in SI Units. Finally they are supposed to write the reason for making such a number of cookies (limiting reactant).

After baking cookies, students will count the number of cookies they actually could bake. Using the estimated number and the actual number students will calculate the percent yield. This activity will take one ninety minute class period.

Hopefully, by the end of these activities students will be able to understand healthy food choices, ways to avoid obesity, conversions, stoichiometry relationships, limiting reactant and percent yield.

Activities

Nutrition Label analysis & Calculation of water molecules

Problem:

How many molecules of water are required to burn a meal?

Purpose:

To understand the nutritive values in the given meal.

Background Research:

Students are required to research and obtain the information about macronutrients from our diet such as carbohydrates, proteins and fats, and their caloric values. They are required to find the information on the types of fluids and the amount of fluids required for the vital metabolic reactions in our body. Students are required make an effort to practice the conversions.

Hypothesis:

Student will make an educated guess.

Procedure:

1. List the food items from your meal (this can be your lunch or combination of items from school lunch menu)
2. Go to the website http://www.nutritiondata.com/ to get the nutrition labels for each food item from your list.
3. Identify the number of grams carbohydrates, proteins and fats for each food item from the nutritive label.

4. Calculate the caloric value for carbohydrates, proteins and fats for each food item using this information - four calories per every gram of carb, nine calories per every gram of fat, and four calories per every gram of protein.
5. Add the calories obtained in step 4 to get total calories for the meal.
6. Determine the volume of fluid (assuming water is the only fluid available).
7. te: An average person requires one mL of fluid per each calorie.
8. Convert the volume of water to mass of water using density of water (1gm/mL)
9. Convert the mass of water into moles of water using the molar mass of water (18.016 g/mol)
10. Convert the moles of water into molecules of water using mole concept and Avogadro's number (6.022 X 10^23 particles per mole of a substance)

Data & Calculations:

In this section students are required to show all the calculations with proper units and to correct significant digits.

Results & Analysis:

Students are required to report their answer and will list good food items from the meal.

"Burning" Calories -The Energy in Food

Objective

To determine the number of Calories in food.

Introduction

Why are marathon runners advised to eat a large plate of pasta the night before a competition? Because pasta is a good source of energy, or fuel, for the body.

Just as pasta can provide a runner energy to run a marathon, a tiny peanut contains stored energy that can be used to heat a container of water. For this lab exercise, you will indirectly measure the amount of Calories in couple of food items using a calorimeter. A calorimeter (*calor* = Latin for heat) is a device that measures the heat generated by a chemical reaction, change of state, or formation of a solution. There are several types of calorimeters but the main emphasis of all calorimeters is to insulate the reaction to prevent heat loss. We will be using a homemade calorimeter modeled after a constant-volume calorimeter. A particular food item will be ignited, the homemade calorimeter will trap the heat of the burning food, and the water above will absorb the heat, thereby causing the temperature (T) of the water to increase. By measuring the change in temperature (ΔT) of a known volume of water, you will be able to calculate the amount of energy in the food tested because the heat gained by the water will equal the heat lost by the food item:

$\mathbf{Q_{lostbyfood} = Q_{gainedbywater}}$

The energy gained by the water can be calculated as follows:

$Q_{water} = (m(c)(\Delta T)$

where **Q** is the heat gained in calories (cal); **m** is the mass of water in grams (g); **c** is the specific heat capacity of water (1 calorie/g °C); and Δ**T** is the change in temperature in degrees Celsius (°C). Note: Energy can also be measured in Joules (J) or British thermal unit (Btu). There are 4.184 J in 1 calorie. A Btu is the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit and 1 Btu is equivalent to 252 Calories.

Materials per pair

Graduated cylinder, Water bottle with distilled water, Homemade calorimeter, Coffee can, Small metal can (2), Glass rod, Cork with wire attached, Thermometer (in °C), Lighter, Safety glasses, Forceps.

Materials in lab

Roasted cashew nuts, Popcorn, Weigh boats, Scale, Distilled water, Gloves

CAUTION!!! Flames will be used and items may be hot! All long hair must be tied back.

Procedure

1. Of the 2 food items you will be testing, hypothesize which one will have more Calories (energy). Record your prediction in the Laboratory Report.
2. Obtain a weigh boat and determine its weight. Record your data.
3. Obtain a cashew nut and using the same weigh-boat, determine the weight of the cashew (wi). Record your data.
4. Using the graduated cylinder, measure out 100 ml of distilled water from the water bottle and pour it into the small metal can.
5. Measure the initial temperature of the water (Ti). Record your data.
6. Slide the glass rod through the holes in the top of the small can.
7. Gently wrap the wire attached to the cork around the cashew. It is better to have the cashew at a slight angle. If the cashew breaks, use another one; however, you will have to reweigh the new cashew.
8. Place the cork with the cashew on a nonflammable surface. Put on your safety glasses and light the peanut. It may take a while for the cashew to catch on fire.
9. As soon as the cashew catches fire, immediately place the large can around the nut. Then carefully balance the small can, using the glass rod, on top of the large can and over the burning cashew (see figure above).
10. . Allow the cashew to burn until it goes out. If possible try to keep an eye on it and if it goes out quickly (less than a minute), relight the cashew.
11. Once the cashew has finished burning, carefully remove the small can by holding the glass rod and place it on the lab bench. Then remove the glass rod.

	Weight (Mass) of Food(g)a			Temperature of Water (° C)		
Food Item	Initial Weight (w_i)a	Final Weight (w_f)a	Mass of Sample Burned ($\Delta w = w_i - w_f$)	Initial Temperature (T_i)	Final Temperature (T_f)	Change in Temperature ($\Delta T = T_f - T_i$)
Cashew						
Popcorn						

1. ution! The cans and water will be warm!

2. Using the thermometer, carefully stir the water and then measure the temperature again (T_f). You may have to leave the thermometer in the water for a while in order to get the highest reading. Record your data.
3. After the burnt cashew has cooled, transfer it to the original weigh-boat (use the forceps if necessary) and weigh the remnants (w_f). Record your data.
4. Repeat Steps 2 - 11 with the popcorn. Make sure you use a new small can and fresh
5. ter. Also, you can just poke the popcorn into the tip of the wire. Record all your data.
6. on't forget to subtract the weight of the weigh-boat.

Laboratory Report

1. Which food item do you predict to contain more energy?
2. Weight of weigh-boat:
3. ______________________g_
4. ______________________g_
5. Record your data.
6. Determine the Calories of the food:
7. ***Make sure you show all your calculations and you include all proper units***.
8. able>

Food		Energy or calories (cal)	Calories (Cal) or kilocalories (kcal)	Cal/g
Cashew	calculations			
	answer			
Popcorn	calculations			
	answer			

9. emember that the density of water is 1g/ml therefore 1 g of water = 1 ml of water.
10. How many Calories are in 1 whole cashew? In1 popcorn?
11. Were you able to determine the entire Calorie content of the food item? Why?
12. Do you think the number of Calories you calculated is likely to be lower or higher than it really is? Explain why.
13. What is the original source of energy in all of the foods tested?

The Neutralizing Ability of Stomach Antacids

Reading Assignment:

Section 4.5 and 4.6 in "*Chemistry: The Central Science*" 9th Ed.

I. Pre-Lab Preparation

(This section must be completed before student come to lab, it replaces the intro in lab notebook).

1. Give the formula and the name of two common active ingredients found in commercial antacids.
2. Why is it important to rinse the buret with the solution you will be dispensing from it?
3. After adding the antacid to the HCl in this experiment, do you expect the solution to be acidic, basic, or neutral? Explain Briefly.
4. Why is it necessary to titrate the NaOH first with KHP then with HCL?

Background

A common laboratory procedure is a titration, which determines the concentration of a solution of acid. The volume of base of known concentration needed to react completely with a known volume of acid is used to determine the acid concentration.

Do you ever found yourself wondering "why did I eat the whole thing?" and respond by popping an antacid? What does an antacid do to relieve discomfort?

The parietal cells in the stomach secrete hydrochloric acid at a concentration of about 0.155 *M* (pH normally between 2 and 3). The amount of HCl secreted increases when food enters the stomach. When you eat or drink too much, your digestive system may generate too much acid. You may develop a condition called "heartburn" or indigestion. Antacids are swallowed to neutralize the excess acid and return the pH to normal.

In this experiment, you will test different brands of antacids to compare their effectiveness. The base in antacids varies with the brand. The table below lists the active ingredients in several brands.

Brand Active	Ingredient (Base)
Pepto-Bismol	$BiO(HOC_6H_4COO)$
Milk of Magnesia	$Mg(OH)_2$
Rolaids	$CaCO_3$ and $Mg(OH)_2$
Tums	$CaCO_3$
Alka-Seltzer	$NaHCO_3$
Gaviscon	$Al(OH)_3$

Stomach acid is neutralized by these bases as illustrated below.

1. $BiO(HOC_6H_4COO) + 3H^+ \rightarrow Bi^{3+}(aq) + H_2O9l) + HOC_6H_4COO(s)$

2. $Mg(OH)_2(s) + 2H^+ \rightarrow Mg^{2+}_{(aq)} + 2H_2O(l)$

3. $CaCO_3(s) + H^+ \rightarrow Ca^{2+}(aq) + HCO_3^-(aq)$

$HCO_3^-(aq) + H^+ \rightarrow CO_2(g) + H_2O(l)$

4. $Al(OH)_3(s) + H^+ \rightarrow Al(OH)_2^+(aq) + H_2O(l)$

$Al(OH)_2^+(aq) + H^+ \rightarrow Al(OH)^{2+}(aq) + H_2O(l)$

In addition to the active ingredient, tablets may also contain flavors, sweeteners, binders, fillers, antifoam agents, pain relievers (aspirin), etc. In this experiment, the tablets will be analyzed only for their ability to neutralize acids. We will dissolve the antacid in excess acid and then titrate the unreacted acid with a standard NaOH solution. Since you know how much acid you started with and how much of it is left and reacted with NaOH, you will be able to determine how much reacted with the antacid.

This experiment is divided into two parts.

1. Titration of a solution of sodium hydroxide against the primary standard KHP

(potassium hydrogen phtalate, KC8H5O4).

2. Titration of an antacid tablet with the standardized NaOH solution.

From these results, it is possible to calculate the concentration of the sodium hydroxide and then of the hydrochloric acid solution. The chemical reactions are:

$$NaOH + KC_8H_5O_4 \rightarrow H_2O + NaKC_8H_4O_4$$

$$NaOH + HCl \rightarrow H_2O + NaCl$$

The acid and base solutions are colorless, how one will know when sufficient base solution has been added to react with all the acid (this is known as the equivalence point)? An indicator will be used which changes colors when the equivalence point is reached. A number of different indicators are available for acid-base titrations.

Hydrochloric acid is a strong acid while KHP is weak. We will use two indicators: Phenolphthalein and thymol blue.

Procedure

A. Preparing a buret and pipet.

1. Obtain a 50mL buret and a 10mL pipet. Fill the buret with water and check for proper drainage. A clean buret should drain smoothly, and there should not be drops left behind sticking to the walls of the drain buret.
2. Obtain about 200 mL of the 0.2*M* NaOH in a beaker
3. Fill the pipet with deionized water and check it for proper drainage in similar fashion.
4. nse the buret with several small portions (3-6 mL each) of the NaOH solution. This is done by adding the NaOH, and then tipping the buret so that it is nearly horizontal (open end over a sink!) And rotating the buret so that the solution can wash over the walls. After this, let the solution drain through the tip to rinse that part of the buret out. The purpose of all this is to leave a solution residue which will be exactly the same concentration as that of the final fill with your NaOH.
5. Finally, fill the buret, and let the fill rinse out the tip a little, and check to be sure there are no air bubbles trapped in the tip.
6. Clean the pipet in a similar way. Use the squeeze bulb to blow out most of the liquid inside the pipet, and dry off the outside. Put about 20mL of HCl in a clean dry beaker. Then pull a little HCl solution into the pipet (part-way up into the fat part of the pipet). Put your index finger over the top of the pipet to stop outflow, remove the partially filled pipet from the solution, and again turn it nearly horizontal and rotate it over a sink to wash off the walls. Repeat this rinse 2-3 additional times, and after final drainage, set the pipet down on a horizontal surface where it will not roll off the table. Dump out the remaining HCl solution.

B. Titration of KHP with NaOH

1. Weigh two individual 0.7- to 0.8-g samples (to the nearest mg) of KHP onto weighing paper. Be sure to record all digits to the right of the decimal point for each weighing. (If the last digit is 0, record it.) Use the same balance for each pair of weighings.
2. Dissolve each of the KHP samples in 50 to 75 mL of deionized water in separate Erlenmeyer flasks. Add 2 drops of phenolphthalein, and titrate with NaOH.
3. Carry out titrations of the samples as follows: First allow the liquid level in the buret to drain down to somewhere between 0 and 15 mL in a waste beaker. Do not try to adjust the volume exactly to a

particular line. Carefully read the position of the liquid level and record this in your notebook. You should estimate the reading to 0.01 mL. To do this accurately, it is imperative that your eye be on a level with the liquid level. Slowly add NaOH from the buret with frequent swirling of the flask and watch for the first signs of gradual color change from colorless to pink. With experience, the amount of local pink color where the NaOH solution runs in will provide a clue as to how near you are to the end point. When you think you are near the end point, stop and rinse down the sides of the flask with deionized water from your wash bottle. Add the NaOH a few drops at a time, swirling thoroughly after each addition and watching the color change. Continue the addition until the pink color of the indicator persists for 30 seconds. Read the buret volume and record it in your notebook. (If you accidentally add too much solution and "overshoot" the end point, simply record the volume and add a note of explanation beside the reading, then go on to the next sample.) Refill the buret and proceed in the same manner to titrate the second sample of KHP.

C. Titration of HCl with NaOH

1. Get about 120 mL of 0.5*M* HCl solution (in the beaker you just used for the pipet preparation. Carefully pipet two 50 mL samples of this solution into two clean 250-mL titration flasks, labeled *1* and *2*, respectively. To do this properly, fill the pipet above the mark using a rubber bulb, hold your finger over the top and with the mark at eye level allow the solution meniscus to drain slowly down to the mark. This takes practice! If a drop is clinging to the tip of the pipet, touch the tip to the side of the beaker to remove it, and then quickly transfer the pipet to one of the titration flasks. Allow the solution to drain freely and when it has drained to the bottom, touch the tip of the pipet to the side of the flask to remove the final drop. Do not shake or blow out the remaining liquid. These pipets are calibrated to deliver 50.00 mL with this procedure, and that would be changed
2. the pipet were shaken or blown out.
3. Obtain two antacid tablets from the same brand. Each group will analyze a different antacid and the class results will be pooled at the end for comparison. Make sure you get a copy of the class results before leaving lab. Record the exact mass of each tablet. Add one tablet to each titration flask containing HCl. Cover each flask with a watch glass and bring to a gentle boil for 5 minutes on a hot plate. This helps the tablet to dissolve and expels any CO2 produced by reaction with HCl. set it aside to cool.
4. Add several drops (4-5) of the indicator, bromothymol blue, to the cooled solution of antacid tablet containing the unreacted acid. The solution will be yellow.
5. Now take the first flask, slowly add NaOH from the buret with frequent swirling of the flask. As you are adding NaOH, the solution in the beaker will change from yellow to blue. The endpoint is reached when the blue color persists for 15 seconds or more. As it gets more difficult to get rid of the bluish color when you swirl the flask, add smaller amounts.
6. Read and record the final volume.
7. Refill the buret if necessary and proceed in the same manner to titrate the second sample of HCl. Once you know how much it takes for a tablet, you can add slightly less in the next trial and add the last milliliter or so drop wise and you won't go past the endpoint. When finished with experimental work, rinse the buret and leave it filled with pure water.

II. Data and Calculations

1 *Standardization of NaOH with Potassium Hydrogenphthalate (KHP)*

	Trail 1	Trail 2
mass of KHP (g)		
Initial buret reading (mL NaOH)		
Final buret reading (mL NaOH)		
Volume of NaOH (mL)		
Molarity of NaOH (mol/L)		

2- Titration of HCl with NaOH

Brand name of antacid used: ___________ Active ingredient: ________________

	Trail 1	Trail 2
mass of antacid used (g)		
Volume of HCl added		
Molarity of HCl		
millimoles of HCl added to antacid		
Initial buret reading (mL NaOH)		
Final buret reading (mL NaOH)		
Net Volume of NaOH (mL)		
millimoles of NaOH required to neutralize excess		
millimoles of HCl neutralized by the antacid (mmol)		
HCl (mmol)		
millimoles of HCl per gram antacid		

III- Questions

In an early TV commercial for Rolaids antacid tablets, the manufacturer claimed that the tablet would neutralize 47 times its own weight of stomach acid. A tablet weighed 1.4g and contained 0.334 g of the active ingredient, NaAl(OH)2CO3. Assume that the active ingredient reacts with HCl according to the reaction:

$$NaAl(OH)_2CO_3 + 4HCl \rightarrow NaCl + AlCl_3 + 3H_2O + CO_2$$

a) How many moles of HCl would one Rolaids tablet neutralize?

b) Stomach acid is about 0.155 *M* HCl and has about the same density as water. Did the Rolaids tablet neutralize 47 times its own weight of HCl solution?

Gas Stoichiometry and Cellular Respiration

Concepts:

Measurement techniques, quantities and units, SI system of units, conversion, significant figures, precision and accuracy, cellular respiration, gas stoichiometry

Investigatory Question:

What is the relationship between air quality and volume of air in living space?

Pre lab Questions:

1. Where do you spend most of the time during the day? Estimate the percentage of time you spend at home, school, driving, field etc. Fill and label the pie chart with this information.
2. Do you know any air pollutants that can make you sick?

Procedure & Calculations:

1. Measure indoor air volumes: Collect measurements of the room (in m) and determine the volume of the room.

Length: __________ Width: _________ Height : ___________

Volume of the room = ________ ——-(1)

The unavailable space in the room occupied by objects is to be approximated to roughly 4 times the volume of one of the lab tables if it were solid .

Measurements of lab Table:

Length: Width: Height :

Volume = ___________

Volume unavailable = ________________ ——-(2)

Total volume of air in the room = _____________

1 m^3 = 1000 L

Convert the volume of the room to liters using appropriate conversion factors.

Total volume of air in the room in L = _______________

2. Calculating human ventilation rates: Count the number of breaths you take per minute using a stop watch.

Ventilation rate = _________breaths per minute

Assume that you inhale 0.5 L of air for each breath. Volume of air inhaled per minute = tidal volume (L/breath) x ventilation rate (breath/minute)

Volume of air inhaled every minute =

Volume of air inhaled every hour =

3. Comparing volumes

Total volume of air in the room (L)
Ventilation rate of a single person (L/hr)
Ventilation rate of entire class (L/hr)

4. Determine using the total volume of air in the room and the number of persons in the room, the amount of air that is available for you. Is there enough air for you and everybody else in the classroom?

5. If the room were to be sealed (no outside air coming into the room) how long you and your classmates would survive at your current breathing rates. (Assume that you do not inhale the same air more than once)

1. The fresh air supply is from the air ducts in the classroom. Measure the total surface area of the air ducts in the classroom. What should be the speed of air flow from the ducts if it should replace the air that is being used per hour? Check the units and do appropriate conversion before substituting.
2. eed of air flow (m/s) x area of the ducts (m^2) = volume of air required per hour by entire class (m^3/s)
3. If your ventilation rate is 600 L per hour, how long would it take for you to inhale all the air in a tiny space capsule with 1800 L space assuming you do not inhale the same air more than once? (show your work)
4. How do you think astronauts get fresh air on the International Space Station?

6. If the average density of air at the room temperature today is ____ kg/m3, calculate the mass of the air in the room.

Mass (in kg) = density (kg/ m^3) x volume (m^3)

How does the mass of the air in the room compare to your weight?

(1 kg = 2.2 pound)

7. The density of air changes with temperature. Determine how heavier the air in this room would be on a cold day in winter as compared to a very hot day in summer.

	Temperature	Density	Volume	Mass
Hot day	40 C			
Cold day	4 C			

8. Fresh outdoor air contains about 21% O_2 and 0.03 per cent CO_2 on a volume basis[23] (the remainder being mainly nitrogen). Significant variations in these proportions can render it unfit for human use. For prolonged exposure a minimum concentration of 16 per cent O_2 and a maximum concentration of 0.5 per cent CO_2 (sometimes extended to 1 ½ per cent) are commonly accepted standards.

9. A person, when seated, usually inhales about 510 L of air per hr. The exhaled air contains about 16 per cent O_2 and about 4 per cent CO_2. Thus, if only 1510 L per hr of fresh air were provided for each person in a continuously occupied space the concentrations of O_2 and CO_2 would approach these levels. Exposure for even a short time to a CO_2 level of 4 per cent would result in a temporary loss of vitality and ability. If, **however, ten times this amount of fresh air were provided** (5100 L per hr or 85 L per minute), the ultimate CO_2 level would be only 0.4 per cent and the O_2 deficiency would be only 0.5 per cent, instead of 5 per cent.

10. Calculate the amount of fresh air that your class would require per hour for the levels of oxygen and carbon dioxide to be maintained.

Baking Cookies

Purpose

To understand the concept of limiting reactant and percent yield

Background

The recipe for baking cookies calls for one cookie mix, one egg and a stick of butter to make 24 cookies. First group students received 3 packs of cookie mix, 12 eggs and 2 butter sticks. Second group students received 2 packs of cookie mix, 1 egg and 3 butter sticks. Third group students received 3 packs of cookie mix, 5 eggs and 2 butter sticks. Fourth group received 5 packs of cookie mix, 12 eggs and 3 butter sticks. Each group is required to calculate the maximum number of cookies they can make from the given ingredients. They need to justify their answer and show their calculations.

Materials required for each group

Cookie mix packs, Eggs, Butter, Oven for baking, baking utensils

Procedure

Each group will follow the recipe to bake cookies.

Results and discussion

Expected number cookies__________________

Actual number cookies baked_________________

Percent yield = ___________________________

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