Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
2020 Volume II: Chemistry of Food and Cooking

Introduction to Chemistry of Food and Cooking

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Introduction

The process of cooking, baking, and preparing food is essentially an applied science. Anthropologists and historians speculate that cooking originated when a pen holding pigs or other livestock caught fire or a piece of the day's catch of mammoth fell into the fire pit. The smell of roasted meat must have enticed early people to "try it"; the curious consumers found culinary and nutritional benefits to this new discovery. The molecular changes that occurred during cooking made the meat more digestible and the protein and carbohydrates more readily available as nutrients. Contaminating microbes were eliminated during cooking, which made the consumers healthier and able to survive. Moreover, the food was tastier due to the heat-induced chemical reactions between the oxygen in the air and the fat, proteins, and sugar in the meat. Harnessing the knowledge of what is happening to our food at the molecular level is something that good scientists and chefs use to create new appetizing food and cooking techniques.

Preparing food and drink is mostly a process of changing the chemical and physical nature of the food. Molecules react to form new compounds; heat changes the nature of how food molecules function and interact with each other, and physical change brings about new textures and flavors to what we eat. To get a better appreciation for these chemical and physical processes, a fundamental understanding of the building blocks of food and cooking must first be understood.

This unit is an attempt to inform high school students about some of the fundamental concepts that constitute this important area of science - the food chemistry. Students will review the concepts of chemical compounds, mixtures (solutions, suspensions, colloids and emulsions), physical and chemical changes and learn about food chemistry. They will also learn about some of the most important organic chemistry compounds, the hydrocarbon derivatives or functional groups.

This unit will be tied into students' chemistry courses, strengthening their knowledge of organic chemistry and preparing them for future college biochemistry, general and organic chemistry classes. The lesson plans require about 12 class periods and cover the concepts of covalent bonds (single, double and triple bonds), functional groups (alcohols, aldehydes and ketones, carboxylic acids, esters, amines, amides) and mixtures (suspensions, colloids, and emulsions). The last lesson is going to cover the basic concepts of hydrophilicity, hydrophobicity, and amphiphilicity of different molecules mixed with water.

Unit Content

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1. General Chemistry

The fundamental units of all food and cooking processes as well as the units of all living systems (animals, microbes, and smaller life forms) are still the atoms and molecules. How these atoms and molecules are organized, interact, and react provides the building blocks and chemistry of life. To understand cooking and baking at the molecular level, we must first realize how atoms and compounds are put together and function. The first question that arise is, what is the difference between an atom and a molecule? The answer is simple: an atom is the smallest basic building block of all matter, while molecules are made when two or more atoms are connected to one another.

Chemical Compounds

What about a compound or a molecule? How does a molecule differ from an atom or compound? A molecule is a substance of two or more atoms connected by sharing electrons (covalent bonds). A compound is a chemical substance made of different atoms. Compounds can be made of atoms held together by ionic or covalent bonds where molecules are made only of covalently bonded atoms. Thus, all molecules are compounds, but not all compounds are molecules. Molecules are often categorized further into organic (those molecules containing mostly carbon and hydrogen atoms) and inorganic molecules (everything else).

Most of the compounds found in living things contain carbon, hydrogen, nitrogen, and oxygen atoms. A group of other elements, including sulfur, magnesium, and iron, make up less than 1% of the atoms in most living systems. Trace elements, such as copper, zinc, chromium, and even arsenic, although necessary for biological function, only make up a minute portion of an organism, less than 0.01% of all atoms.

Large biological molecules such as proteins, carbohydrates, and fats comprise the basic building blocks of food. Smaller compounds, including micronutrients (e.g., vitamins and minerals) and salts add important components to cooking and the taste of food. Finally, the basics of plant and animal cells and cellular organization are key to understanding the nature of food and cooking processes.

One of the most important components of food is water; our bodies, food, and environment are dependent on the unique chemistry of this molecule. Water (moisture) is the predominant constituent in many foods. As a medium, water supports chemical reactions, and it is a direct reactant in hydrolytic processes. Therefore, removal of water from food or increasing the concentration of common salt or sugar retards many reactions and inhibits the growth of microorganisms, thus improving the shelf lives of a number of foods. Through physical interaction with proteins, polysaccharides, lipids, and salts, water contributes significantly to the texture of food.

Physical Changes in Food

Physical changes can occur without altering the chemical composition of a substance. Physical changes can include alternations in color, shape, state of matter, and volume of a substance. For many physical changes, the process can be reversed and return the product to its original state. During food processing and preservation, various physical changes (e.g., melting, crystallization, and glass transition) occur in food products, affecting their quality.

Phase Transition Processes

A phase change, or transition, occurs when a substance undergoes a change in state at a molecular level. For most substances, changes in temperature and/or pressure result in a phase change.

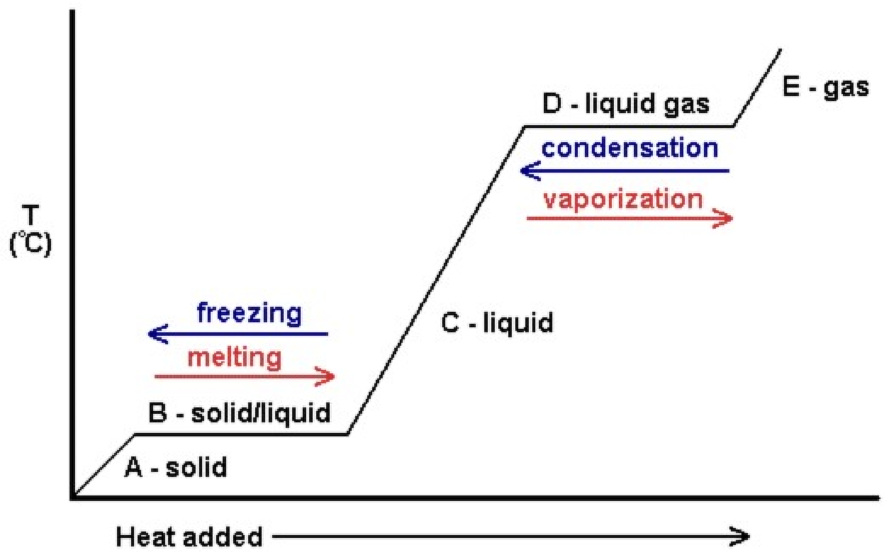


Figure 1 Heating Curve Diagram of a Substance Source: https://opentextbc.ca/introductorychemistry/chapter/phase-transitions-melting-boiling-and-subliming-2/

There are several processes of phase changes, including melting, freezing, vaporization, condensation, sublimation and deposition. Each substance has three phases: solid, liquid, or gas. Every substance is in one of these three phases at certain temperatures and pressures. The temperature and pressure at which the substance will undergo a phase change is very dependent on the intermolecular forces that are acting on the molecules and atoms of the substance. There can be two phases coexisting in a single container at the same time. This typically happens when the substance is transitioning from one phase to another. This is called a two-phase state. In the example of ice melting, while the ice is melting, there is both solid water and liquid water.

There are six ways a substance can change between the three phases. These phase transition processes are reversible and each transfer between phases differently:

1. Melting: the transition from the solid to the liquid phase
2. Freezing: the transition from the liquid phase to the solid phase
3. Vaporization (Evaporation): the transition from the liquid phase to the gas phase
4. Condensation: the transition from the gas phase to the liquid phase
5. Sublimation: the transition from the solid phase to the gas phase
6. Deposition: the transition from the gas phase to the solid phase

How Phase Transition works

There are two variables to consider for phase transition: pressure (*P*) and temperature (*T*). For the gas state, the relationship between temperature and pressure is defined by the Ideal Gas equation below:

PV=*n*R*T*

where *V* is volume, *n* is number of moles of gas, and R is gas constant. The ideal gas law assumes that no intermolecular forces are affecting the gas in any way. For real gases, a more complicated equation (van der Waals) includes two constants, *a* and *b*, that account for any intermolecular forces acting on the molecules of the gas.

Temperature

Temperature can change the phase of a substance. One common example is putting water in a freezer to change it into ice. When the ice is placed on a heat source, like a burner, heat is transferred to the ice, increasing the kinetic energy of the water molecules. The temperature increases until the ice reaches its melting point. As more and more heat is transferred beyond the melting point, the ice begins to melt and becomes a liquid. This type of phase change is called an isobaric process because the pressure of the system stays at a constant level.

Pressure

Pressure can also be used to change the phase of the substance. Imagine a container fitted with a piston that seals in a gas. As the piston compresses the gas, the pressure increases. The gas will condense into a liquid.

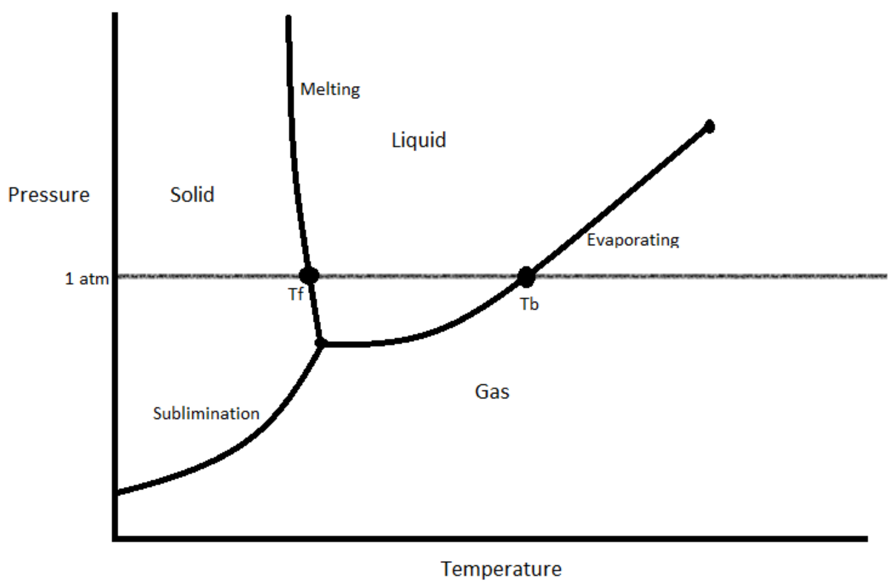


Figure 2 Example of a Phase Diagram Source: https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Physical_Properties_of_Matter/States_of_Matter/Phase_Transitions/Fundamentals_of_Phase_Transitions

Melting Process

Melting is a physical process that results in the phase transition of a substance from a solid to a liquid. Each substance has a melting point. The melting point is the temperature that a solid will become a liquid. At different pressures, different temperatures are required to melt a substance. Each pure element on the periodic table has a normal melting point, the temperature that the element will become liquid when the pressure is 1 atmosphere.

The objective of melting in cooking is to prepare ingredients for further processing (e.g., cheese and fat) or to recover the melted fraction. Milled cheese and other ingredients are put into a processing kettle and heated to a temperature normally not less than 75°C to ensure a complete pasteurization of the processed cheese. The temperature and duration of the process depends on the type of processed cheese aimed for and the nature of the raw cheese.

To recover fat from meat residues, two processing methods are used: wet melting or dry melting. In the wet melting process, the raw material is heated in the process kettle by direct steam injection to a temperature of about 90°C. This results in a watery phase and a fat containing phase. The phases are separated by decantation and centrifugation. In the dry melting process, the raw material is indirectly heated in the processing kettle (a kettle with a steam jacket). All the water which evaporates is removed from the kettle (under vacuum). The liquid phase (molten fat) and dry phase (fat free meat residue) are separated by decantation.

Freezing Process

Freezing is a physical process that results in the phase transition of a substance from a liquid to a solid. Solidification is an important step in the production of chocolate. The tempering process, sometimes called pre-crystallization, gives chocolate a smooth and glossy finish and is a major contributor to the mouth feel and enjoyment of chocolate. Tempering is a process that makes the cocoa butter in the chocolate to harden into a specific crystalline pattern, which maintains the gloss and texture for a long time.

Boiling Process

Each substance also has a boiling point. The boiling point is the temperature that a liquid will evaporate into a gas. The boiling point will change based on the temperature and pressure. Just like the melting point, each pure substance has a normal boiling point at the atmospheric pressure.

Boiling is a cooking method that happens when the water's temperature reaches 212 °F (100 °C). Food is completely submerged in water for even heat distribution. The full boil is a vigorous one, where bubbles rapidly and violently break over the entire surface of the water. A slow boil is a lazy boil, almost a simmer, at 205 °F. In the case of a slow boil, bubbles will slowly break over the surface of the water. Depending on the type of food, food is either added to already boiling water, or added to cool water and brought up to boiling temperature.

Water is a good solvent for cooking because if its high latent heat (its ability to absorb large amounts of heat before undergoing a phase change from liquid to gas). This is partly accounted for because of water's chemical composition (H_2O) and the ways in which the water molecules interact with one another through their intermolecular interactions of hydrogen bonding. This is why water can absorb much heat before changing state; overcoming those types of interactions requires a significant amount of energy. At its boiling point, the water molecules have more energy than at the room temperature. Accordingly, some of this energy is transferred to the food to cook it [3]. Boiling is used to enhance the texture of starchy foods and make the meat tender. It also revives grains, dried pasta, and dried legumes, making them soft and more edible.

Mixtures

A physical combination of substances is called a mixture. All chemicals remain the same even though they are close together. A mixture can be separated back into the original substances. Mixtures are heterogeneous if different parts can be plainly seen. However, not all heterogeneous mixtures look “chunky” to the eye. They may look smooth or creamy. However, under a microscope, all different parts may be clearly observed. This kind of heterogeneous mixture is called a suspension.

A colloid is a suspension, except that its parts do not settle. The suspended particles are just small enough not to layer out. At the same time, they are large enough to make the mixture look cloudy or creamy. Smoke, mayonnaise, and foam are all examples of colloids.

An emulsion is a mixture of two or more liquids that are normally immiscible. Emulsions belong to a class of colloids. Although the terms colloid and emulsion are sometimes used interchangeably, emulsion should be used when both phases, dispersed and continuous, are liquids. In an emulsion, one liquid (the dispersed phase) is dispersed in the other (the continuous phase). Examples of emulsions include vinaigrettes that contain oil and water.

When sugar is mixed into water, the sugar dissolves and seems to disappear. Even under a microscope, the sugar water looks the same everywhere - it is a homogeneous mixture. A mixture like sugar and water is called a solution. A solution is a mixture with parts that blend so that it looks the same everywhere, even under a microscope. The part of a solution in the smaller amount and that is dissolved is called the solute. The part of the solution in the larger amount that dissolves the other substance is called the solvent. In sugar water, for example, sugar is the solute, and water is the solvent. Solutions can be made by dissolving solid or gas in liquid.

Chemical Changes in Food

Protein denaturation is what makes eggs solidify, collagen break down and convert to gelatin in slow-cooked meat, fish and chicken become more opaque, and all meats firm up and change color. This is primarily achieved by applying heat, but can also occur in the presence of acidic and basic ingredients.

The Maillard reaction is the primary effect taking place in “browning”, and produces more flavor compounds, resulting in more complex flavors in food that people generally find enjoyable. It involves reaction between amino acids (proteins) and a class of sugars called reducing sugars (mostly the monosaccharides, such as glucose and fructose).

Caramelization is a secondary browning effect that occurs in foods with high sugar content, even though all browning is often referred to as “caramelizing”. It mostly takes place at higher temperatures than Maillard reaction (with the notable exception of fructose).

Pyrolysis, or the thermal breakdown, begins at higher temperatures. While caramelization is technically in this category, the main effect of pyrolysis is carbonization. This is what happens when we talk about “burning” food, even though no combustion has taken place. It is also what happens when oil darkens and produces smoke.

Acid-base reactions are sometimes used for protein denaturation (e.g., upon extended contact with fish fillets, citrus juices will impart a wonderful flavor and also serve to denature proteins). Some of these reactions produce carbon dioxide, which creates the rise in quick breads such as biscuits. These often occur at room temperature, but some also don’t occur until higher temperatures - which is how “double-acting” baking powder works. One of the most familiar applications of acid-base chemistry is antacids, which are bases that neutralize stomach acid. The human stomach secretes hydrochloric acid (HCl) that helps in the digestion of food. Sometimes, overeating or emotional stress leads to hyperacidity (too much acid secreted). To treat this condition, a great variety of antacids is available to consumers.

Functional Groups

The structure of a molecule defines how it functions in a cell and how food may taste or react when cooking or baking. Functional groups are arrangements of atoms that have specific chemical and biochemical behavior. Hence, molecules contain a specific functional group or a combination of functional groups have different properties. Knowledge about functional groups is useful to predict and understand properties of organic molecules and molecules important in food and cooking. Specific functional groups and examples of molecules that are important in food and cooking are as follows:

Alcohol (─OH). An alcohol functional group contains an oxygen atom covalently bonded to a hydrogen atom, often designated as ─OH. Sugars, like fructose, have many alcohol groups. Molecules of ethanol (Figure 3a) and glycerol (Figure 3b) both contain alcohol functional groups. The **─OH** plays key roles in allowing these molecules to interact with and dissolve in water. It can be found in fructose (honey) and ethanol (alcoholic drinks).

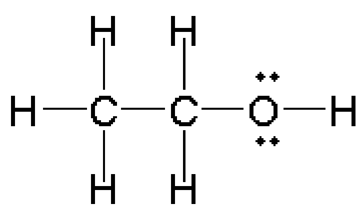
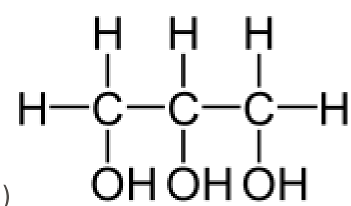
(a)  (b) 

Figure 3 Lewis Structures of (a) Ethanol and (b) Glycerol molecules (Source: Wikipedia)

Glycerol is an alcohol. It is a sweet, sticky, and thick compound that is often added to bread, cookies, and cakes to keep them moist. A glycerol molecule also provides the molecular framework for fat molecules.

Aldehydes (R-CO-H, R ≠ H) and Ketones (R-CO-R, R ≠ H). Aldehydes and ketones are organic compounds which incorporate a carbonyl functional group, C=O. The carbon atom of this group has two remaining bonds that may be occupied by hydrogen or an alkyl group. If at least one of these substituents is hydrogen, the compound is an aldehyde (R-CO-H) as seen in Figure 4a. If neither is hydrogen, the compound is a ketone (R-CO-R) . The addition of hydrogen across a C=O double bond raises several important points. First, it shows the connection between the chemistry of primary alcohols and aldehydes. But it also helps to understand the origin of the term aldehyde. If a reduction reaction in which hydrogen is added across a double bond is an example of a hydrogenation reaction, then an oxidation reaction in which an H_2 molecule is removed to form a double bond might be called dehydrogenation. Thus, using the symbol [O] to represent an oxidizing agent, the product of the oxidation of a primary alcohol is literally an "al-dehyd" or aldehyde. It is an *al*cohol that has been *dehyd*rogenated.

The simplest aldehyde in use is acetaldehyde CH_3CHO, which is present in fruit formulations; a dilute solution has a pleasant apple taste. As the chain extends, a fatty character develops, which is exhibited by the C_{12} lauric aldehyde and the synthetic material methyl nonyl acetaldehyde. Many aldehydes have pleasant odors and are often used in fragrances. Benzaldehyde (C_6H_5CHO) is responsible for the odor of almonds and cherries; cinnamaldehyde is found in the bark of cinnamon tree. Vanillin is responsible for the pleasant odor in vanilla beans and is used as a food additive (artificial flavor). On the other hand, the unpleasant odor in rancid butter arises from the presence of butyraldehyde (butanal). The breakdown of fats and fatty acids is a key to the flavor, aroma and properties of many foods in positive and sometimes not so positive ways. The molds found in blue cheese such as Penicillium roqueforti transform fatty acids into methyl ketone molecules, such as 2-pentanone, 2-heptanone and 2-nonanone, that create the cheese's characteristic and pungent aroma (1).

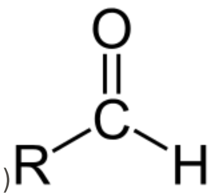
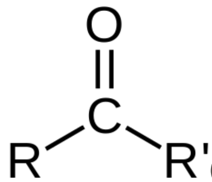
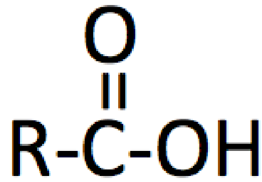
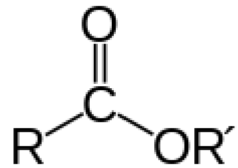
(a)  (b)  (c)  (d) 

Figure 4 General structures of some functional groups: (a) an aldehyde; (b) a ketone; (c) a carboxylic acid; (d) an ester (Source: Wikipedia)

Carboxylic Acid ($-COOH$ and $-COO^-$). The tangy taste associated with a nice cool glass of lemonade or a sour citrus hard candy is provided by carboxylic acids. This functional group consists of a carbon bound to two oxygen atoms, one forms a double bond with the carbon atom and the other form a single bond with the carbon atom and a single bond with a hydrogen atom (Figure 4c). Thus, it is designated as $R-COOH$ or $R-COO^-$. Why is the hydrogen sometimes absent? Due to oxygen's affinity for electrons and hydrogen's lack of affinity for electrons, the bond between the hydrogen and oxygen in carboxyl groups is easily broken, yet the oxygen keeps the electron from the previously shared covalent bond, yielding a carbonate group that is negatively charged and a hydrogen ion (H^+) that is positively charged. The $R-COO^-$ is a weak organic acid and hence it has the name of carboxylic acid. Carboxylic acids are found throughout food and cooking, most notably in citrus fruits (citric acid) and vinegar. The acetic acid or ethanoic acid is a major component in vinegar. It dissolves in and reacts with water forming a complex anion:

$CH_3COOH + H_2O$ à $CH_3COO^- + H_3O^+$

The acid component of these foods stimulates the sour taste receptor on our tongues giving these foods a sour taste. An example is malic acid. Malic acid is an organic acid that is found in unripe fruit like green apples and gives it a sour green apple flavor.

Esters (R-COO-R', R ≠ H). An ester is a functional group derived from a carboxylic acid in which the **–OH** (hydroxyl) group is replaced by an –O–alkyl (alkoxy) group (Figure 4d). Usually, esters are derived from a dehydration reaction between a carboxylic acid and an alcohol. Although carboxylic acids often have strong, unpleasant odors, the esters derived from them are usually quite fragrant, especially when it is diluted (11). Many esters have fruity odors and tastes. For example, butyl acetate has an apple flavor, while isobutyl acetate yields a raspberry fragrance. Glycerides, which are fatty acid esters of glycerol, are important esters in biology, being one of the main classes of lipids, and making up the bulk of animal fats and vegetable oils. Esters with low molecular weight are commonly used as fragrances and found in essential oils and pheromones.

Amine ($-NH_2$ and $-NH_3^+$). A group of atoms containing a nitrogen covalently bonded to hydrogen is called an amine or amino group. An amine is derived from ammonia by replacing one, two or three of the hydrogen atoms by one, two, or three alkyl or aromatic groups:

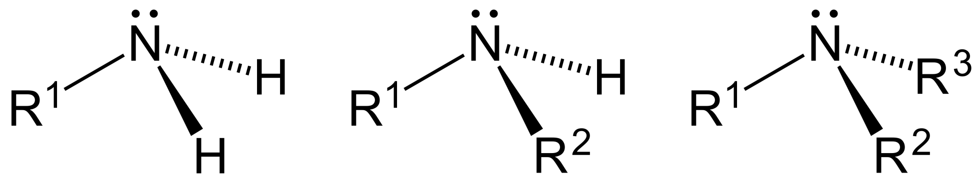


Figure 5 Primary, secondary and tertiary amine structures (Source: Wikipedia)

Two or three hydrogen atoms can bond to the nitrogen, creating a neutral $-NH_2$ or positively charged $-NH_3^+$ group. The amine with an $-NH_2$ group attached directly to a benzene ring has the special name aniline. Aromatic amines tend to be toxic and some of them are strongly carcinogenic. Many amines have unpleasant “fishlike” odors. The molecule trimethylamine provides the unique odor associated with fish. Saltwater fish contain high amounts of trimethylamine oxide in their muscle cells to counter the high salt content in water balancing the resulting osmotic pressure in the cells of the fish. Another interesting amine is pyridoxamine, which is a form of vitamin B.

Amide ($R-CO-NH_2$). Amide also known as an organic amide or a carboxamide, is a derivative of a carboxylic acid RC(=O)OH with the hydroxyl group –OH replaced by an amine group $–NH_2$. The carbon-nitrogen bond in the amide group is called a peptide bond when it is part of the main chain of a protein, and isopeptide bond when it occurs in a side chain, such as in the amino acids asparagine and glutamine.

Sulfhydryl or Thiol (─SH). Sulfhydryl group contain sulfur atoms that have a very important and diverse role in cooking and baking, depending upon its bonding partners. The amino acid cysteine has an **─SH** group. When sulfur is bonded to a hydrogen atom, we call the functional group a sulfhydryl or thiol group and designate it as ─SH. Most proteins found in plant and animal tissues have various amounts of cysteine and therefore sulfhydryl groups. However, the sulfur in cysteine does not have to remain bonded to a hydrogen; it can also be bonded to another sulfur atom resulting in the formation of a covalent disulfide bond (─S-S─).

Classroom Activities

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1. Covalent Bonds Lesson Plan (three class periods)

Learning objectives

Students will be able to:

- Write the correct chemical formula for different covalent compounds

- Use the electron dot diagrams to show the formation of single, double and triple covalent bonds

- Describe and give examples of compounds with molecules made by covalent bonds

Materials and teacher-developed resources

- Paper (Student Notebook), pencils, software (ActivInspire/Promethean)

Learning activities

The teacher will review the concepts of ionic and molecular compounds, emphasizing the differences between the two. He or she will also review the definitions of molecule and molecular compound. Molecular compounds are composed of molecules and almost always contain only nonmetals. Molecular compounds form covalent bonds. Non-metals hold onto their valence electrons. They cannot give away electrons to bond, but still want noble gas configuration and get it by sharing valence electrons with each other. (Octet rule still applies)

The teacher will explain that single covalent bonds form by sharing a pair of valence electrons. Bonds that involve two shared pairs of electrons are called double covalent bonds and bonds that involve three shared pairs of electrons are called triple covalent bonds. Students will draw Lewis structures of molecules with single covalent bonds (fluorine, chlorine, bromine, iodine, hydrogen, water, ammonia, methane), double covalent bonds (oxygen, carbon dioxide, ethene) and triple covalent bonds (nitrogen, acetylene carbon monoxide).

The teacher will emphasize that carbon, nitrogen, oxygen, fluorine, chlorine, bromine and iodine are atoms contain unshared pairs of electrons (also called lone pairs or nonbonding pairs). The teacher will show on the board the completion of orbitals 2p with electrons. Students will note that the chemical formulas for ionic compounds describe formula units, while chemical formulas for covalent compounds describe molecules. The teacher will also emphasize that ionic compounds are not composed of molecules and there are no single units of an ionic compound, while individual molecules actually do exist.

The students will be asked to write the correct Lewis dot diagrams and structural formulas for several compounds. They will be provided with pairs of elements and will be asked to select the pairs that are likely to form molecular compounds with a single covalent bond.

2. Organic Compounds - Functional Groups: Alcohols Lesson Plan (two class periods)

Learning objectives

Students will be able to define alcohol, identify the name and properties of alcohols, differentiate primary, secondary and tertiary alcohols and draw the structural formula of some common alcohols. They will also differentiate between single and poly-hydroxyl alcohols (diols, triols)

Materials and teacher-developed resources

- Paper, pencils, software (power point presentation)

- Few jars containing 10 ml each of methanol and ethanol

Learning activities

The teacher will explain that alcohols are organic compounds that contain the hydroxyl (–OH) group bond together with an alkyl radical (R). Students will identify the most commonly used alcohols and using IUPAC system, name them (the alkane/ alkyl group root followed by the termination -ol for each term of the series.) Examples of simple alcohols are ethanol, propanol, and butanol.

Students will learn about diols - alcohols containing two hydroxyl groups and triols - alcohols containing three hydroxyl groups. The teacher will emphasize the role of glycols (especially polyethylene glycols) in pharmaceutical, cosmetic, and food industries.

One of the main uses of alcohols, is combustion. Ethanol and methanol are used as the fuel in some race cars, and is often added to gasoline. Students will answer what are the combustion products of alcohols, besides heat.

The teacher will take 1 mL of methanol in an evaporating dish and ignite the alcohol with a match or burning splint. Repeat this experiment with small volumes of ethanol and isopropanol.

3. Organic Compounds - Functional Groups: Aldehydes and Ketones Lesson Plan (two class periods)

Learning objectives

Students will be able to define aldehydes and ketones, identify the name and some properties of aldehydes and ketones and draw the structural formula of some common aldehydes and ketones.

Materials and teacher-developed resources

- Paper, pencils, software (power point presentation)

- Few 100 ml jars containing acetone, acetaldehyde

Learning activities

The teacher will explain that aldehydes and ketones are two families of organic compounds. Both families contain the carbonyl group (C=O), but aldehydes have a hydrogen atom and an alkyl radical (R) attached to the carbonyl group whereas ketones have two alkyl groups (R) attached to the carbon atom involved in the carbonyl group.

Students will identify the most commonly used aldehydes. Using IUPAC system, the students will name them (the alkane/alkyl group root followed by the termination -al for each term of the series.) Examples of simple aldehydes are methanal (formaldehyde), ethanal (acetaldehyde) and propanal (propionaldehyde). When naming ketones, according to IUPAC, the alkane/alkyl group root is followed by the termination -one for each term of the series. Examples of ketones are propanone (acetone), butanone (methyl ethyl ketone), 2-pentanone (methyl propyl ketone) 3-pentanone (diethyl ketone).

The teacher will emphasize that many carbohydrates (e.g., glucose, fructose) has both the alcohol and carbonyl functional groups in their molecules. Some aldehydes have pleasant odors and are often used in fragrances or as food additives. Acetone is a common solvent for organic materials as fats, rubbers, plastics and varnishes and is an ingredient in some fingernail polish removers.

4. Organic Compounds - Functional Groups: Carboxylic Acids Lesson Plan (one class period)

Learning objectives

Students will be able to identify and name the most usual carboxylic acids.

Materials and teacher-developed resources

- Paper, pencils, and software (power point presentation)

- Few 100 ml jars containing acetic acid

Learning activities

The teacher will explain that carboxylic acids are organic compounds that contain the carbonyl group C=O bond together with the hydroxyl group –OH. Students will identify the most commonly used organic acids and using IUPAC system, name them (the alkane/alkyl group followed by the termination -oic for each term of the series). Examples include ethanoic (acetic), propanoic, and buthanoic acids.

5. Organic Compounds - Functional Groups: Esters Lesson Plan (one class period)

Learning objectives

Students will be able to define esters, identify the name and some properties of esters and draw the structural formula of some common esters,

Materials and teacher-developed resources

- Paper, pencils

- Organic alcohols in dropper bottles

- Organic acids in dropper bottles

- Sulfuric acid H_2SO_4 (18 M)

- Sodium carbonate, Na_2CO_3

- Test tube holder

- Test tubes

- Bunsen burner

Learning activities

The teacher will explain that esters are the products of a dehydration reaction between a carboxylic acid and an alcohol, then introduce the characteristics of esters and their roles. Students will identify the most common esters, and using the IUPAC system, will name those compounds. The name of an ester ends in -oate and is formed by naming the part from the parent alcohol first (with the -yl ending) and the part from the carboxylic acid last.

The teacher will emphasize that many fruits such as bananas, raspberries, and strawberries as well as consumer products such as perfumes, oil of wintergreen, etc., contain esters.

As a safety measure, the teacher will perform the following experiment under the hood.

- Using the pipettes, add 15 drops of glacial acetic acid to 20 drops of ethanol into a test tube

- Stir the tube

- Add one drop of concentrated sulfuric acid

- Mix the reactants by gently tapping the test tube

- Heat the bottom of the test tube for several minutes

- If solution starts to boil, remove from heat

- Carefully smell by wafting

- Dilute with water if the smell is still too strong

The teacher will pick up one or two combinations at the top of the chart (because of low toxicity) and mix the appropriate acids and alcohols:

Acid	Alcohol	Odor
Acetic Acid	Ethanol	Nail Polish Remover
Acetic Acid	1-Pentanol	Pear
Acetic Acid	1-Butanol	Raspberries
Acetic Acid	2-Butanol	Strawberries
Salicylic Acid	Methanol	Wintergreen
Butanoic Acid	Ethanol	Pineapple

6. Organic Compounds - Functional Groups: Amines Lesson Plan (one class period)

Learning objectives

Students will be able to identify and name the organic compounds containing the amino ($-NH_2$) group, define primary, secondary and tertiary amines and draw the structural Lewis formula for some common amines.

Materials and teacher-developed resources

- Paper, pencils, software (power point presentation)

Learning activities

The teacher will explain that amines are organic compounds containing the elements carbon, hydrogen and nitrogen. An amine derives from ammonia (NH_3) by replacing one or more hydrogen atoms by one, two or three alkyl or aromatic groups. Students will learn that amines are categorized based on the number of organic substituents as primary (one alkyl group), secondary (two alkyl groups) or tertiary (three alkyl groups) They will identify the most commonly used amines and using IUPAC system, name them. The teacher will present some of their physical and chemical properties and mention that simple amines are similar to ammonia in odor and basicity. Students will draw Lewis structures of some primary, secondary and tertiary amines.

7. Organic Compounds - Functional Groups: Amides Lesson Plan (one class period)

Learning objectives

Students will be able to define amides, name and identify some properties of amides and draw the structural formula of some common amides.

Materials and teacher-developed resources

- Paper, pencils, software (power point presentation)

Learning activities

The teacher will ask the following question: "Do you think the life would be possible without amides?" The answer is no and the teacher will explain that the amide bond is the connector between different amino acids that make all proteins found in living systems. Students will identify the most commonly used amides and using IUPAC system will name them. The teacher will explain that amides form when a carboxylic acid reacts with an amine (with loss of water), present some of their physical and chemical properties, and mention that the amide functional groups are linkage of amino acids that form proteins.

8. Suspensions, Colloids, Emulsions Lesson Plan (one class period)

Learning objectives

Students will be able to identify and describe the properties of solutions, suspensions, colloids and emulsions.

Materials and teacher-developed resources

- Paper, pencils

- 2 tablespoons beaten egg

- 1 large egg yolk

- 4 teaspoon dry mustard

- 1 teaspoon lemon juice

Learning activities

The teacher will introduce the characteristics of mixtures, solutions and their role in chemistry.

Cooking is a practical application of mixtures. One such application is the recipe for making mayonnaise. Mayonnaise is classified as a colloid. A liquid-liquid colloid is also called an emulsion. Students will try to make mayonnaise in class. Combine in a blender: 2 tablespoons beaten egg, 1 large egg yolk, 4 teaspoons dry mustard, and 1 teaspoon lemon juice. Blend the mixture for 20 seconds. While the blender is still running, add 3/4 cup of vegetable oil slowly in the thinnest stream.

9. Hydrophilicity, Hydrophobicity and Amphiphilicity Lesson Plan (one class periods)

Learning objectives

Students will be able to identify and describe the hydrophilic ("love for water"), hydrophobic ("fear of water") and amphiphilic ("of both kinds") character of different chemical compounds.

Materials and teacher-developed resources

- Paper, pencils, software (power point presentation)

Learning activities

The teacher will review the basic concepts of molecular interactions including the following important points: (1) two or more molecules getting close to each other and if they like each other, they stay together, or if they don't like each other, they stay away from each other; (2) each molecule remains chemically intact during molecular interactions, i.e., no chemical reactions occurring, with no bond breaking and no bond forming; and (3) molecular interactions can lower the energy and therefore stabilize the molecular systems. The teacher will emphasize two important molecular interactions leading to hydrophilicity (affinity for water): polar interactions and hydrogen bonding interactions. The teacher will also introduce amphiphilic compounds (i.e. the active ingredients in soap and detergents) along with the explanation of their role and how they work.

Students will give examples of hydrophilic, hydrophobic and amphiphilic molecules.

The teacher will inform students that phospholipids are examples of natural occurring amphiphilic molecules. The chemical structure of phospholipid is very similar to oil (triglyceride).

Appendix on Implementing District Standards

CT New Generation Science Standards:

HS-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties

HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy

HS-LS1-1. Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins, which carry out the essential functions of life through systems of specialized cells.

HS-LS1-6. Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.

HS-LS1-7. As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products.

District Standards:

D 1. Describe the effects of adding energy to matter in terms of the motion of atoms and molecules, and the resulting phase changes.

P12.1: Differences in the physical properties of solids, liquids, and gases are explained by the ways in which the atoms, ions, or molecules of the substances are arranged and the strength of the forces of attraction between the atoms, ions, or molecules.

P12.5: Changes of state require a transfer of energy. Water has a very high specific heat, meaning it can absorb a large amount of energy while producing only small changes in temperature.

D 11. Describe how atoms combine to form new substances by transferring electrons (ionic bonding) or sharing electrons (covalent bonding)

Describe the existence and uses of some organic compounds.

Be able to draw structural formulas and name organic compounds.

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