Baking and Pastry Chemistry

Unit: Preparing Foods

Problem Area: Baking and Pastry

Lesson: Baking and Pastry Chemistry

Student Learning Objectives.

Instruction in this lesson should result in students achieving the following objectives:

1. **Analyze the properties and functions of essential baking and pastry ingredients.**
2. **Explain chemical reactions and physical changes during baking.**
3. **Compare and contrast ingredient ratios for baked goods.**
4. **Explain the scientific method.**

Resources.

The following resources may be useful in teaching this lesson:

E-unit(s) corresponding to this lesson plan. CAERT, Inc. http://www.mycaert.com.

"Baking Without Recipes—Using Ratios," *Using Mainly Spoons.* Accessed Nov. 19, 2017. http://usingmainlyspoons.com/baking-without-recipes-using-ratios/.

"The Chemistry of Baking," *New Zealand Institute of Chemistry.* Accessed Nov. 19, 2017. http://www.nzic.org.nz/ChemProcesses/food/6D.pdf.

"The Chemistry of Cookies," *TEDEd.* Accessed Nov. 19, 2017. https://www.youtube.com/watch?v=n6wpNhyreDE.

Haegens, Nöel. "Baking: Bread and the Technology of Bread Production," *Bakery Technology.* Accessed Nov. 19, 2017. http://www.classofoods.com/page2_3.html.

Henry, Alan. "How to Free Yourself from Recipes with a Few Golden Cooking Ratios," *lifehacker.* Accessed Nov. 19, 2017. http://lifehacker.com/how-to-free-yourself-from-recipes-with-a-few-golden-coo-1450617561.

Lauterbach, Sharon, and Julie A. Albrecht. "Functions of Baking Ingredients," *University of Nebraska-Lincoln*. Accessed Nov. 19, 2017. http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1412&context=extensionhist.

"Principles of Baking," *Manley's TheBiscuitDoctor.* Accessed Nov. 19, 2017. http://www.thebiscuitdoctor.com/manufacturing-processes/biscuit-making-processes/81-resources/processes-baking/180-principles-of-baking

Smith, Brett. "Chemical Reactions that Occur During Baking," *seattlepi.* Accessed Nov. 19, 2017. http://education.seattlepi.com/chemical-reactions-occur-during-baking-5263.html.

"What Is Caramelization?" *Science of Cooking.* Accessed Nov. 19, 2017. http://www.scienceofcooking.com/caramelization.htm.

Equipment, Tools, Supplies, and Facilities

- ✓ Overhead or PowerPoint projector
- ✓ Visual(s) from accompanying master(s)
- ✓ Copies of sample test, lab sheet(s), and/or other items designed for duplication
- ✓ Materials listed on duplicated items
- ✓ Computers with printers and Internet access
- ✓ Classroom resource and reference materials

Key Terms.

The following terms are presented in this lesson (shown in bold italics):

- absorption
- all-purpose flour
- bakery
- baking
- baking powder
- baking soda
- bran
- bread flour
- cake flour
- caramelization
- carbon dioxide (CO_2)
- cellulose
- chemical reaction
- condensation
- conduction
- confectioners' sugar
- convection
- disaccharide
- emulsified shortening
- emulsifier
- emulsion
- endosperm
- endothermic reaction
- exothermic reaction
- fats
- fermentation
- flour
- fructose
- gelatinization
- germ
- glucose
- gluten
- grains
- heat transfer
- high fructose corn syrup (HFCS)
- homogeneous mixtures
- hydrogenation
- hydrolysis
- hydroscopic
- immiscible
- invert sugar
- leavening
- leavening agent
- lipids
- Maillard reaction
- mise en place
- monosaccharide
- nut flour
- osmosis
- pan flow
- pastry
- pastry flour
- pâte
- patisserie
- physical change
- powdered sugar
- radiation
- ratio
- saccharides
- salted sweet cream butter
- scientific method
- sucrose
- sugar
- unsalted sweet cream butter
- whole-wheat flour
- yeast

Interest Approach. Use an interest approach that will prepare the students for the lesson. Teachers often develop approaches for their unique class and student situations. A possible approach is included here.

> *Show the baking chemistry video, "The Chemistry of Cookies" at https://www.youtube.com/watch?v=n6wpNhyreDE or at http://ed.ted.com/lessons/the-chemistry-of-cookies-stephanie-warren. The video details the chemical reactions that take place in the oven when baking chocolate chip cookies. Ask students: What questions do you have after watching this video? Then use VM–A to introduce the baking and pastry concepts included in this lesson and to respond to some potential student questions.*

CONTENT SUMMARY AND TEACHING STRATEGIES

Objective 1: Analyze the properties and functions of essential baking and pastry ingredients.

Anticipated Problem: What are the properties and functions of essential baking and pastry ingredients?

I. Baking and pastry ingredients

A. Cooking and baking chemistry is a series of molecular-level chemical reactions and physical changes that occur in foodstuffs. Some are constant and obvious (e.g., ripening, odors, and decay), and some occur under heating or cooling (e.g., leavening, browning, boiling, melting, and freezing). Cooking is probably the oldest chemistry. Humans learned that it is easier to extract nutrients from cooked food than from raw food. Also, it is easily the most common application of chemistry. ***Baking*** is a process of cooking with dry heat, usually in an oven. It is a generic term that can refer to all bakery-related products: cinnamon bread, French bread, cakes, muffins, cookies, brownies, and quick loaf breads. ***Pastry*** is a general term for a mixture of flour, water, and fat that combine to make a paste. ***Pâte*** is another name for pastry. A paste is the uncooked pastry mixture with the fat added. [NOTE: Pâte should not to be confused with pâté. In French patisseries, a "pastry or pâté" is a lining paste. It encloses baked fish or meat dishes (typically termed a *terrine*).] A ***bakery*** is a shop that specializes in producing cakes and pastries. ***Patisserie*** is a French term for various preparations made from pâte, as well as a reference to a pastry-cook and to a shop that specializes in producing cakes and pastries. [NOTE: High-altitude baking requires an adjustment in ingredients and temperatures to produce standard products. At 3,000 feet, the amounts of liquid, leaven, and sugar and the oven temperature may need to be adjusted.]

B. Weighing versus measuring

1. Baking is about precision and accuracy. Weighing (e.g., pounds, ounces, and grams) ingredients for baked goods is always more accurate than measuring (e.g., cup). A spring platform or digital scale will help the baker produce consistent, standard products. For example, when measuring flour, the way it is measured will impact the outcome. Dipping a cup measure into a bag of flour will yield a different volume by weight than spooning flour from the bag into the cup. Why? Flour tends to compact during transport, so dipping into a bag will produce a "heavier" weight cup than spooning.
2. A baker or pastry chef will rarely use cup measures because baking is not like cooking where adding a bit more or a bit less is acceptable. Baking is about precision, accuracy, and proportions of flour to liquid to egg to leavening. Again, regardless of compaction—130 grams of flour will always be 130 grams of flour, but a "cup" is not always a "cup." Metric measurement is preferred for baking as it does not differentiate between weight ounces and fluid ounces as English standard measurement.
3. Accurate measuring with a scale is simple. "Zero" (tare) the scale, and then place the ingredient on the scale. Also, many variables exist in baking—pan type, oven type, humidity, altitude, mixing technique, air temperature, etc. The baker can, however, control measurement. TIP: Weighing is most critical when working with dry ingredients, as many recipes and pastry formulas indicate "sifting" the dry ingredient before measuring. Sifting granulated sugar can produce a more accurate cup measurement. Yet a true "cup of granulated sugar" is always 200 grams, and a true "cup of flour" is always 130 grams. [See VM–C.]

C. Baking and pastry ingredients

1. ***Flour*** (farine) is a powdered foodstuff made from ground and sifted grains. It can be enriched (augmented) or refined. Flour for baking is usually produced from wheat, but it could be from other food sources, such as corn, rice, nuts, legumes, and some fruits and vegetables. Based on volume, flour is often the largest ingredient in a baked product. Exceptions, such as a flourless chocolate cake, will occur in baking and pastry formulas (recipes). The most common grain used in baking is wheat. In the United States, all-purpose hard wheat flour is common. In contrast, French flour is made from soft wheat. Both types contain little germ or husk and keep longer than whole meal-type flours. Varying protein (gluten) content affects the way flours "handle," so some dessert and pastry recipes may call for $2^1/_2$ to $2^3/_4$ cups. In this case, the process is to measure and add the smaller amount first. Then—following the recipe directions—flour should be added to create the desired condition (e.g., cleans the sides of the bowl or not sticky to the touch).
   a. ***Gluten*** is an elastic protein (from the endosperm) found in wheat and cereal flours that gives dough elasticity and strength. In addition, gluten helps the dough rise. Wheat flour, barley, rye, and triticale (a cross

between wheat and rye flour) contain gluten. Rice, buckwheat, quinoa, corn, and oats are gluten free (unless contaminated during processing).

   b. Glutenin and gliadin are the two protein molecules in flour that combine to form gluten when liquid is added to the flour, and the dough is mixed or kneaded. Gluten stretches when moistened and expands to hold the gas produced by the leavening agent. It makes a framework that forms the structure of baked products.
   c. The type of wheat (hard or soft) affects the amount of gluten content. Hard wheat (grown in the U.S. Midwest) has high protein content and, as a result, produces more gluten. Soft wheat (grown in the southern area of the United States) has less protein content and produces less gluten. Baked products require different gluten content.
      (1) Yeast breads need a sturdy structure and have chewy/stretchy dough (especially French bread). Yeast bread needs high-protein flour that produces more gluten.
      (2) Cakes, quick breads, and pastries require much less gluten formation to produce a soft, fine texture.

2. ***Grains*** are the edible fruits—kernels or seeds—of grass plants. Grains are packed with nutritional value: B-complex vitamins, antioxidants, complex carbohydrates, protein, fiber, minerals, and phytochemicals (chemical compounds found in plants, such as antioxidants). The husk is the outer covering over the whole-grain kernel (called berries). The three edible parts are bran, endosperm, and germ.
   a. ***Bran*** is the tough brown outer layer of a grain that covers the endosperm. It contains ***cellulose*** (fiber), some protein, phosphorous, and vitamins (thiamine, riboflavin, and niacin). Bran is only found in whole-grain flours. Wheat bran is also sold separately, packaged in bags.
   b. ***Endosperm*** is the largest part of a grain kernel and is composed of carbohydrates and some protein. It is the starchy part of the grain. All flours contain endosperm from the grain kernel.
   c. ***Germ*** is the embryo part of the kernel that sprouts into a new plant. It is the smallest part of the grain kernel and contains small amounts of healthy fats, B-vitamins, and some protein. Whole-wheat flours contain some or all of the germ and bran. Wheat germ is also sold separately—packaged in jars or bags.
   d. Refined grains undergo processing to strip out the bran, the germ, or both. White flour is an example of refined flour.
   e. Enriched grains, such as enriched all-purpose flour, are augmented with nutrients lost during milling and processing, such as iron and B vitamins (thiamine, riboflavin, and niacin).
3. Flours are best stored in air-tight containers. Whole grains last longer when stored in the freezer because the germ can become rancid (spoiled oil) at room temperature. [NOTE: See "Why You Should Probably Be Storing Your Whole Grain Flours in the Freezer" at http://www.thekitchn.com/why-you-should-probably-be-storing-your-whole-grain-flours-in-the-freezer-66194.]

a. ***All-purpose flour*** is a blend of hard and soft wheat that can be bleached or unbleached. It is the most common flour used in the United States, and it contains 8 to 11 percent protein (gluten). It is used for quick breads, pastries, and some cakes. Flour that bleaches naturally (usually via oxygen) is called "unbleached," and chemically treated (e.g., chlorine bleach or peroxide) flour is termed "bleached flour." Bleached flour has less protein than unbleached.
   (1) Bleached flours are best for pie crusts, cookies, quick breads, pancakes, and waffles.
   (2) Unbleached flours are best for yeast breads, Danish pastry, puff pastry, strudel, éclairs, cream puffs, and popovers.

b. ***Bread flour*** is white flour made from hard, high-protein wheat—about 12 to 14 percent protein. It is unbleached and produces more gluten than all-purpose or cake flours. In turn, bread flour develops loaves with more volume, and the loaves slice without crumbling. Bread flour is preferred for use in bread machines.

c. ***Cake flour*** is finely ground, soft-wheat flour with a high starch content. It is bleached with chlorine to allow it to absorb more water and thus produce a fine white crumb in cakes. Bleaching makes the flour slightly acidic, which has two effects. It "sets" the cake batter faster and distributes fat more evenly than other flours to improve texture. Cake flour contains 7.5 percent protein (gluten); its low gluten count produces tender products. Baked goods with a high sugar ratio benefit from the use of cake flour because it is able to hold the rise, and the product is less likely to collapse (than all-purpose or other wheat flours). In a pinch, 1 cup of all-purpose flour minus 2 tablespoons may be substituted for 1 cup of cake flour.

d. ***Nut flour*** is flour made from finely ground nutmeats and is used to produce breads, cookies, cakes, and especially pastry crusts.

e. ***Pastry flour*** (sometimes called cookie flour) is flour produced from soft wheat and, in terms of protein (gluten) content, is nested between all-purpose and cake flour. Its protein content is 9 to 10 percent, which makes it perfect to produce cookies, brownies, pie crusts, biscuits, and quick breads. Pastry flour should not be used for yeast breads as its properties best make crumbly products. In a pinch, pastry flour can be imitated by using a 2:1 ratio of all-purpose to cake flour. [TIP: In pastry dough preparations, flakiness and tenderness are desired. To achieve flakiness and tenderness, fat must be evenly distributed (cut in or rubbed) into the flour. Then it is necessary to avoid overworking the dough because overworked dough is tough due to the excessive gluten development from manipulation.]

f. ***Whole-wheat flour*** (also called graham flour) is flour produced from the whole kernel of wheat and is higher in fiber than other wheat flours. It is often used to replace part of the all-purpose flour in some recipes. All baked products that contain whole-wheat flour have reduced volume and height. The bran cuts through the gluten during mixing and produces a smaller (in size) and heavier product. For best results, no more than half whole-wheat flour should be used for baking, and the rest all-purpose or bread flour is recommended.

4. Flour adds, provides, and or creates:
   a. Body (bulk or mass) and structure (tender and crumbly or firm and chewy) to baked goods
   b. Flavor dependent upon the type
   c. Gluten
5. Flour is often used to prepare pans for cake batters and other baked goods to prevent sticking to the pan. Preparing the pan often requires the pan to be spread with butter, shortening, or vegetable spray and then lightly coated with flour that is "tapped" out to remove any excess flour. Baking sprays that contain vegetable spray plus flour are often substituted.

D. Fats (graisse): ***Fats*** are greasy ingredients that melt at low temperatures: compounds of carbon, hydrogen, and oxygen. Fat is found in animal (butter and lard) and vegetable (peanut, palm, corn, canola, olive, and shortening) tissue. ***Lipids*** are dietary fats that include fatty acids (with linoleic and alpha-linolenic acids being the essential fatty acids), triglycerides, and cholesterol. Fats are concentrated body fuel that helps supply energy and build body tissue.

1. Fats are available in liquid, solid, and hydrogenated forms.
   a. Liquid: Unsaturated liquid fats are missing one or more hydrogen atoms. Oils used in baking include corn, soybean, and canola.
   b. Solid: Saturated fats are solid fats that contain all the hydrogen atoms their molecular structure can hold. Foods made from animal fats include butter, cream, cheese, lard, and whole milk products (e.g., ice cream). Saturated vegetable fats are solid or semi-solid at room temperature and include coconut oil, palm kernel oil, and palm oil.
   c. Hydrogenated: ***Hydrogenation*** is a process of adding hydrogen molecules under pressure that solidify liquid vegetable oils and absorb the oxygen in the oil's free fatty acids to convert them to fats that are solid at room temperature. Some shortening may have added animal fats, emulsifiers, colorings, and flavorings (butter). Hydrogenated fats provide more volume for baked goods than butter. Hydrogenated oils are made solid by adding hydrogen to unsaturated fat molecules.
      (1) Solid shortenings (e.g., Crisco) and margarines are hydrogenated.
      (2) Peanut butter can be hydrogenated or partially hydrogenated. Natural peanut butter is partially hydrogenated, so the oil separates and comes to the top of the jar.
2. Solid (plastic) fats (e.g., butter, margarine, and other hydrogenated products) remain solid at about room temperature. Oils remain liquid at about room temperature and may solidify when refrigerated. The process to create hydrogenated shortenings also produces trans fatty acids that may cause health risks. An internal fat temperature of about 60°F produces a standard baked good. Examples of fats used in baked products are:

a. Shortening is 100 percent fat and can be plant-based or a combination product of plant and animal sources. Shortening is hydrogenated to make it solid at room temperature. Shortening gets its name from its ability to shorten gluten strands, which increases the tenderness of the baked product (e.g., short = tender). Fats with the greatest shortening power are lard, drippings, and cooking fat, but they tend to flavor baked goods in a dominating way. A good shortening mixture is half lard and half butter. A few shortenings contain palm and coconut oil that are *not* hydrogenated. Shortening produces light baked products since the emulsifiers in shortening help blend the ingredients in the batter. Shortening is used in cookies, cakes, quick breads, and pie crusts.

b. ***Emulsified shortening***—also known as cake, icing, or high-ratio shortening—is shortening that allows bakers to add more sugar and liquid to a baked product than a regular vegetable shortening would allow. Emulsified shortenings are a type of hydrogenated shortening that give cakes a finer texture and help keep cakes moist. When used in icings, the icing mixture is able to hold more sugar and is more stable than using a typical vegetable shortening. Butter does not contain emulsifiers, so the fat is not as easily kept in suspension in those cake batters. An ***emulsifier*** is an additive that reduces the tension between oil and water and improves a cake's softness, texture, stability, volume, and shelf life.

c. Butter is made from dairy cream and is 80 percent fat and 20 percent milk solids. Butter has a distinctive flavor without a greasy mouthfeel. ***Salted sweet cream butter*** is a product of churning (agitating cream to separate fat and water) fresh, sweet cream and is 80 percent fat, with some added salt. European butters contain up to 86 percent fat. ***Unsalted sweet cream butter*** is a product that has the same make-up as salted butter, with no added salt. Water and some milk solids comprise the remainder of butter's content. Butter is different from shortening in two major ways: enhanced flavor and the quality of melting in the mouth.

d. Margarine is made from fats or oils that are partially hydrogenated. Margarine uses the 80/20 ratio: 80 percent fat to 20 percent other ingredients. Margarine can replace butter in baking, but it does not give the baked good that distinctive buttery flavor. The use of reduced-fat substitutes or spreads for baking is not recommended because the lower fat content does not produce the desired results.

e. Lard is rendered pig fat used in many cuisines as a cooking fat or shortening. Lard is used in many pastry recipes for its ability to create "flaky" pastry. [NOTE: A German cultural favorite is lard sandwich. The lard is used as a spread instead of butter or margarine. The spread may include small bits of pork skin or bacon.]

f. Oil is used in some baking recipes for muffins, breads, and cakes and occasionally for oil-based pie pastry. Oil pastry is mealy instead of flaky and produces heavier textured baked products than those produced from solid fats. [TIP: To substitute oil for butter or margarine, $^{7}/_{8}$ cup oil = 1 cup butter or margarine.]

3. Functions
   a. Flavor (especially butter or lard; others are nearly tasteless)
   b. Layering (fats that are soft in a wide temperature range spread between pastry layers that separate and "flake" when baked; the process of "cutting-in" fats to flour produces layers)
   c. Shortens (tenderizes baked goods by shortening or weakening gluten strands; produces baked goods with soft mouthfeel; richness)
   d. Creaming (leavens by trapping tiny air bubbles within droplets of fat during the "creaming" of fat and sugar that eventually melts to form steam—a leavening agent)
   e. Emulsifies two liquid ingredients in a batter
   f. Other: Carries an added flavoring (e.g., vanilla) throughout the batter, crust, or dough; aids in browning; and adds moisture

E. ***Sugar*** (sucre) is a carbohydrate that is soluble in water, usually crystalline with a sweet taste. Sugars are produced from various types of plants: cane (sucrose), beet, sugar maple, and palm. In fact, all fruits and vegetables contain sugar (sucrose or fructose). Solid sugars include cane and beet. Liquid sweeteners include honey, molasses, corn syrup, and various humanmade liquid sugars produced initially for dietary purposes. Sugars and other sweeteners add taste, tenderness, color, and aroma to baked goods and pastries. [NOTE: Reducing more than one-third the volume of sugar in a recipe will negatively affect the tenderness, moistness, browning, and sweetness of the product.]

1. Sugars are available in solid and liquid forms.
   a. Granulated sugar or ***sucrose*** is a naturally occurring carbohydrate from cane and beet plants made of fine or extra-fine white sugar crystals. Granulated sugar (often called *white* sugar) is the most common sweetener used in baking. The various grinds of sugar used in baked goods impact the qualities of the baked goods.
   b. Brown sugar is sugar crystals maintained in a molasses-based syrup (a combination of refined white sugar and molasses). It is moister than white sugar and provides a characteristic caramelized flavor to baked goods. Brown sugar is available in light and dark varieties, according to how much molasses is included.
   c. ***Powdered sugar*** is granulated sugar crushed into a fine powder: It is bright white and contains three percent cornstarch to prevent clumping. Powdered sugar is also called ***confectioners' sugar***. When powdered sugar is measured, rather than weighed, it is measured as for flour. (It should be spooned into a measuring cup and leveled rather than scooped from a bag, box, bin, or canister.)
   d. Honey is an all-natural sweetener produced from flower nectar; it is a sweet, sticky substance made by bees. It has a distinctive flavor (based on origin: clover, soybean, or fruit blossoms) and is sweeter than sucrose

because it contains fructose. Too much honey in baked goods will result in extremely moist and often overly brown baked goods. [TIP: To substitute for honey: 1 cup sugar can be replaced by $^{3}/_{4}$ cup plus 1 tablespoon honey. However, it is also necessary to reduce 2 tablespoons of liquid from the recipe.]

e. Molasses is a thick byproduct of refining sugar cane or sugar beets into sugar and is two-thirds as sweet as crystalline sugars. The third boiling of the sugar syrup yields blackstrap molasses, which is used in baking for its distinctive brown color and strong flavor (e.g., gingerbread, dark rye breads, and gingersnap cookies). Molasses is acidic. To decrease acidity, add $^{1}/_{2}$ teaspoon of baking soda for every cup of molasses. [TIP: To substitute molasses for granulated sugar, use $1^{1}/_{3}$ cup of molasses, and reduce the liquid in the recipe by 5 tablespoons. It is recommended that no more than half of the total sugar be substituted with molasses in a baked goods recipe.]

f. Liquid sugars—corn syrup, honey, and molasses—do not react in baked goods in the same fashion as solid sugars. It is important to consult a reference to substitute liquid for solid sugars.

g. Artificial sweeteners may leave a bitter taste (e.g., saccharin). In addition, aspartame is not heat stable in baking. Therefore, sugar is combined with an artificial sweetener (Acesulfame K or Acesulfame potassium) in some reduced calorie commercial products.

[NOTE: See the pros and cons of Acesulfame K at http://www.medicinenet.com/artificial_sweeteners/page10.htm.]

h. Sugar by volume (cups) may seem to be comparable, but sugar by weight is not. For example:

(1) One cup granulated sugar weighs about 7 ounces.

(2) One cup powdered (confectioners') sugar weighs about 4 ounces.

(3) One cup packed brown sugar weighs about $7^{1}/_{2}$ ounces.

(4) One cup molasses, honey, or corn syrup weighs about 12 ounces.

2. Sugar is a carbohydrate and is hydroscopic (attracts water). Chemicals that are sugars often end in the suffix "-ose," such as fructose, glucose, galactose, sucrose, lactose, and maltose. Sugars are ***saccharides*** (organic compounds containing sugar or sugars). The main categories of sugars are ***monosaccharide*** ("mono" = one) or simple sugars (e.g., fructose and glucose) and ***disaccharide*** ("di" = two) or two monosaccharide molecules joined together (e.g., sucrose, lactose, and maltose).

a. Sucrose ($C_{12}H_{22}O_{11}$) is a disaccharide molecule, which is a combination of two monosaccharide molecules: glucose and fructose.

b. ***Fructose*** is a monosaccharide twice as sweet as sucrose when in crystal form. Fructose attracts more water molecules than sucrose. Fructose-sweetened baked products tend to be very moist and are darker brown in color than those produced with sucrose. [NOTE: Consider projecting the chemical structure of glucose, fructose, and sucrose at https://cdavies.wordpress.com/2009/01/27/simple-sugars-fructose-glucose-and-sucrose/. Point out that glucose has the same chemical formula as fructose (5-member ring) but has a 6-membered ring. See an additional explanation below the images.]

c. ***Glucose*** is a simple sugar or monosaccharide derived from the breakdown post-consumption of food and is a major source of energy. In baking, glucose is primarily a sweetening agent. It also adds moisture and tenderness to baked goods. Corn syrup is sometimes called glucose syrup. Its chemical formula is $C_6H_{14}O_7$. Corn syrup or glucose syrup should not be confused with high fructose corn syrup.

d. ***High fructose corn syrup (HFCS)*** is a sweetener made from corn composed of 42 to 55 percent fructose, with the remaining sugars being primarily glucose and higher sugars. Its chemical formula is $C_{12}H_{22}O_{11}$. High fructose corn syrup is added to many sweetened beverages and commercially produced baked products. [NOTE: See a comparison chart for sugar, honey, HFCS, and corn syrup at http://www.cornnaturally.com/CornNaturally/media/Interior/Charts/composition_chart.png. The Dietary Guidelines for Americans shows strong evidence that added sugars, especially HFCS and sucrose, are associated with excessive body weight and Type 2 diabetes. See the Dietary Guidelines scientific report on added sugars on the U.S. Health and Human Services Office of Disease Prevention and Health Promotion at https://health.gov/dietaryguidelines/2015-scientific-report/11-chapter-6/d6-3.asp.]

e. Honey is a complex chemical compound. [NOTE: For the chemical compounds found in honey, see the University of Bristol website at http://www.chm.bris.ac.uk/webprojects2001/loveridge/index-page3.html.]

f. Molasses is composed of many chemical compounds, and the sugar content is 50 percent.

3. Functions
   a. Flavor
   b. Tenderizes dough and batter (except for artificial sweeteners)
   c. Colors (caramelize and aid in browning)
   d. Feeds yeast organisms (aids in fermentation)
   e. Moisture retention (sweetened baked goods stay moist longer than unsweetened types)
   f. Cause cookie dough to spread

   [NOTE: Artificial sweeteners do not provide browning, tenderizing, and moisture retention of natural sugars.]

F. ***Leavening*** is the production of a gas in a dough batter using an agent: steam, air, eggs, baking soda, baking powder, starter, or yeast. A ***leavening agent*** is a substance that causes expansion in a dough batter by releasing gases within the mixture. Chemical leavening agents (baking soda and baking powder) produce CO_2 gas, which helps products rise.

1. Processes
    a. Steam: Moisture from a dough batter is converted to steam. [TIP: Preheating of the oven encourages the greatest production of steam leavening.]
    b. Air: Mechanical incorporation of air occurs during whipping, beating, folding, etc. and results in dough batter leavening.
    c. Yeast: Yeast leavening is a result of the addition of wild, active dry, fresh compressed (cake), or instant yeast products.
    d. Chemical: CO_2 gas is formed by chemical leavening agents (baking soda or baking powder) that help the product rise. Baking soda reacts once, and baking powder reacts twice (once at room temperature and once in the oven).
2. Chemistry
    a. Steam leaven is the expansion of water vapor that produces pressure and, as the interior of the baked good nears the boiling point, the vapor exerts pressure in the form of bubbles that produce swelling (leavening) of the product. Puff pastries are an example.
    b. Air leavening occurs when vigorous mixing entraps air and creates bubbles that produce foam: air leaven. Egg whites are often used as an air leaven because their structure expands and creates a strong foam product that dries in the baking process. Angel food, chiffon, and sponge cakes are examples of products leavened with air.
    c. ***Yeast*** is a living single-cell, microscopic fungus that converts sugars to alcohol and carbon dioxide (CO_2) to make bread dough rise. The process of fermentation, which releases CO_2 gas, achieves leavening. The specific yeast used in active dry yeast is *Saccharomyces cerivisiae*. Sugars and starches feed the yeast and cause it to multiply. Salt slows the growth of yeast enough to allow for kneading and proofing of the yeast dough.
    d. ***Baking soda*** (sodium bicarbonate) is a chemical leaven with no leavening power until combined with an acid that then creates tiny bubbles of carbon dioxide that push against the batter and cause it to expand (leaven or rise). Baking soda reacts when wet. As a result, many baking and pastry formulas add baking soda to products that already contain an acid, such as sour milk, yogurt, buttermilk, sour cream, vinegar, honey, or molasses. Because baking soda only reacts once (single-action), it is often added to the dry ingredients (e.g., Irish Soda Bread dough). When wet and dry ingredients come together, the bread must be panned and baked as quickly as possible to ensure good volume. Breads that use a chemical leaven are called "quick breads." [TIP: For a beginning baker who uses a recipe containing baking soda, mise en place is essential. The oven must be preheated, and the pans must be prepared prior to mixing. ***Mise en place*** is a French cooking term that literally means everything in its place.]
    e. ***Baking powder*** is a chemical leaven composed of a combination of baking soda (alkaline), various acid salts (e.g., cream of tartar), and a starch (e.g., cornstarch) to prevent clumping. When wet, baking powder will react

without an acid from other ingredients. For baking powder leavening to occur, two elements must be available: an acid and an alkaline material. The acid and alkaline materials react separately in the presence of moisture to form a gas (tiny bubbles in the batter) that causes expansion of the batter, which in turn causes leavening. The most common form of baking powder is a double-acting variety in which one acid reacts in the cold (room temperature) batter, and the second reacts in the oven at an approximate temperature of 140°F. Baking powder's ability to react twice makes it a good choice for most baked products. [TIP: Baking powder can lose strength. "Good" baking powder will bubble actively when one teaspoon is mixed with $^1/_4$ cup of hot water.]

3. Functions
   a. Cause a baked product to rise
   b. Flavor

G. Eggs (oeufs): Eggs are the structural element in baking, along with flour. Chicken eggs are the standard; all other types of eggs (e.g., lark and ostrich) are not used in baking and pastry formulas. Eggs are valuable sources of vitamins A and B and a fair source of vitamin D. Some baked products, such as biscuits and pie crust, do not contain eggs.

1. Processing
   a. Grade A or AA large eggs (about 2 ounces each or 8 per pound) are the most common size used in baked goods. Eggshell color does not affect the functions eggs provide in baking and pastry products. Eggs must be refrigerated until ready for use.
   b. Weighing eggs is more accurate than measuring.
      (1) One large egg white = about 1 oz. = about 2 tablespoons
      (2) One large egg yolk = about $^1/_2$ oz. = about 1 tablespoon
   c. A fresh egg sinks to the bottom of a bowl of water and has a nicely rounded yolk that is well centered in the white.
   d. Cracked eggs have a danger of Salmonella entrance and should be discarded.
2. Chemistry
   a. Eggs are easiest to separate when they are cold.
   b. To whip egg whites and ensure a good foam or meringue requires a clean container and clean equipment (grease or oil in contact with egg whites inhibits foaming). It is necessary to begin beating at low speed, building slowly as foaming begins, and to stop beating before the egg whites become dry and start to separate.
   c. To beat whole eggs or egg whites to their greatest volume, it is necessary to bring them to an internal temperature of 65° to 75°F.
   d. Egg yolk adds fat to baked goods.

3. Functions
   a. Leavening (via air incorporation; egg whites contain lecithin, which is a protein that lines the outside of the air bubbles created during beating and prevents them from collapsing)
   b. Emulsification (a binding agent, a structure that holds other ingredients together; eggs are second to flour in providing structure to baked goods)
   c. Moisture
   d. Color (an egg wash provides a glaze to baked goods that browns the surface with a Maillard reaction)
   e. Other: Flavor, tenderizes baked goods (the addition of egg yolk makes baked goods more tender than those that do not contain egg yolks), texture, and thickener

H. Salt (sel)
1. Description: Salt is a crystalline compound (NaCl or sodium chloride) primarily used as a condiment that comes in two types: sea salt and rock salt.
2. Processing: Sea salt is distilled from seawater, and rock salt is found in the earth.
3. Chemistry: Sodium chloride is the first salt discovered by humans and is typically called table salt. Iodized salt (table salt with added iodine) is the type most often used in baked goods. It is mined and processed to remove minerals and has an additive to prevent clumping. Salt retards (slows) yeast growth and will kill yeast if it comes in direct contact. As a result, it is not added to a starter. To disperse salt evenly in a dough or batter, it is added with the flour and other dry ingredients and is mixed well.
4. Functions
   a. Flavor (adds complexity; without it people would primarily taste sugar; heightens the flavor of other ingredients)
   b. Slows yeast fermentation and keeps the air bubbles small and uniform in size
   c. Toughens the texture of soft fat-and-sugar mixtures
   d. Strengthens gluten protein, which impacts texture

I. Liquid
1. Liquids include water (the most common liquid in baking and pastry production), milk, light and heavy cream, buttermilk, yogurt, sour cream, and mashed fruits and juices.
2. Processing: Weighing liquids is more accurate than measuring. The metric system is preferred for measuring liquid, as it does not differentiate between fluids and solids. A gram is a gram, and a kilogram is a kilogram. The English standard system has different volume measures for fluid ounces and for dry ounces. For example, the old saying, “a pint’s a pound the world around” only refers to fluid volume. A pint of milk is 2 cups or 16 ounces, but a pint of all-purpose flour is 2 cups or about 8 ounces.

3. Chemistry: Liquids are needed for chemical changes in structure and texture. When liquid evaporates under the dry heat of an oven, it produces steam. In turn, air bubbles develop and increase the volume of the baked good.
4. Functions
    a. Moisture
    b. Flavor (milks and creams, fruits and juices; yogurt and sour cream add tartness)
    c. Color (browning from milk and fruit sugars)
    d. Steam leavening
    e. Hydrate proteins, starches (including gelatins), and leavening agents
    f. Activate yeast organisms
    g. Mixes with flour for proper gluten development
    h. Binding agents (especially in quick breads and muffins)

Teaching Strategy: *Many techniques can be used to help students master this objective. Use VM–A through VM–L to review. Have students observe the appearance of gluten and compare the gluten content of different types of flour with the following experiment: "Goodness Gracious! Great Balls of Gluten!" The experiment and step-by-step picture instructions are on the Science of Cooking website at http://www.exploratorium.edu/cooking/bread/activity-gluten.html.*

When the starch is removed from the flour, a gluten ball is formed. After the gluten ball is baked, you see how gluten creates the structure in baked products. Students can compare the amount of gluten in various types of flour by weighing the gluten balls. This experiment is worth the time. If you do not have a variety of flours (e.g., bread, cake, and all-purpose), each lab group can use all-purpose flour.

Objective 2: Explain chemical reactions and physical changes during baking.

Anticipated Problem: What chemical reactions and physical changes occur during baking?

II. Chemical reactions and physical changes during baking

A. The difference between a chemical reaction and a physical change is composition. A ***chemical reaction*** is a permanent change in the chemical composition of a substance. Molecules are broken apart and rearranged into new molecules. For example, fresh eggs that are fried cannot become fresh eggs again. The protein in the egg is permanently changed, and the appearance is different. When dough batters are heated in an oven, a chemical reaction occurs, thereby forming new bonds. Heat creates chemical reactions: exothermic and endothermic. For instance, baking a cake produces an endothermic chemical reaction that changes sticky batter into a "cake." An ***exothermic reaction*** is a reaction that produces heat. An ***endothermic reaction*** is a reaction that absorbs (takes in) heat.

1. Heat helps chemical leavens produce tiny gas bubbles that make the cake light (rise).
2. Heat causes egg protein to change and “firm up” the cake structure.
3. Heat dries a cake batter, but fats help keep the cake moist.

B. A ***physical change*** is the transformation of a substance that does not alter its chemical properties; it is just a phase change. The change involves a difference in the way the substance displays: appearance (color or shape), texture, temperature, smell, or a change of state of the substance (e.g., melting, boiling, or freezing). Melting, boiling, and freezing are examples of a physical phase change: an ice cube (frozen water) that melts is still water (liquid water), and its chemical properties remain intact. [NOTE: In the physical change described here, the ice cube and warm temperature are the reactants or the ingredients of physical change. The liquid water is the product or result of a physical change.]

C. ***Absorption*** is the act of attracting particles of gas or liquid into a liquid or a solid substance. For example, liquid absorption is usually based on flour weight: 60 percent water absorption would mean 60 pounds of water is required for every 100 pounds of flour.

1. Flour cells absorb liquid. The percentage of absorption varies by baked good. For instance, cookies have 50 to 54 percent water absorption; white bread has 60 to 62 percent water absorption; and ciabatta bread has 80 to 90 percent water absorption.
    a. The larger the amount of water absorbed into flour, the more the dough stretches and the more ***pan flow***—the ease with which dough fills the pan shape or spreads or rolls based on water absorption.
    b. Gluten is formed when water is added to the two proteins in flour (glutenin and gliadin). Gluten is developed when the dough is mixed or kneaded.
    c. In pie crust recipes, the dough is often chilled for 10 minutes to 24 hours for the water to be more fully absorbed into the flour. Pie crust dough may be frozen.
2. ***Hydroscopic*** is the ability of a chemical to absorb water. Sugars (e.g., table sugar, honey, brown sugar, and molasses) are hydroscopic. Sugar attracts water to keep the baked goods moist and soft.

D. ***Caramelization*** is the oxidation of sugar and is a cooking process that results in intense nutty flavors and non-enzymatic browning. Carbohydrates (sugars) are heated to remove water from a sugar. Non-enzymatic browning is the result of the Maillard reaction. Caramelization is the final chemical reaction to occur during baking.

1. Caramelization occurs when sugars are heated. Each type of sugar caramelizes at a different temperature. For example, fructose caramelizes at 230°F (110°C), and sucrose caramelizes at 320°F (160°C). Baked goods made with honey or fructose develop a dark color because they start browning at a lower temperature (honey contains fructose).

2. The flavors of caramelization occur after 356°F. The sugar molecule breaks down and releases water resulting in steam. The flavors of caramelization include:
   a. Butterscotch: Diacetyl ($C_4H_6O_2$) is a flavor compound produced in the first stage of caramelization, which is known as a butterscotch flavor.
   b. Rum-like: Esters and lactones ($C_{28}H_{54}O_{13}$) produce a rum-like flavor.
   c. Toasty nut: Furan and maltol ($C_6H_6O_3$) produce a toasty nut flavor.
   d. Bitter: The continued heating of sugar results in burning the sugar and producing a bitter flavor.

E. ***Condensation*** is the change in the physical state of a substance from a gas phase into a liquid phase. For instance, if cold batter and dough are placed into a warm oven, it creates moisture condensation on the surface of the batter or dough. This "sweat" cools down the crust area and allows the baked goods to rise before the crust hardens. Porous (spongy openings) surfaces on some baked goods are due to moisture condensation.

F. ***Hydrolysis*** is the splitting of a compound into smaller parts by the addition of water (e.g., Sucrose + Water → Glucose + Fructose). The result of hydrolysis of sucrose is ***invert sugar***, which is equal parts glucose and fructose. [NOTE: Inversion is the process of hydrolysis of sucrose with an acid and heat (used in candy making). See the America's Test Kitchen's "Science of the Perfect Chewy Chocolate Chip Cookie" video for an explanation about sugar hydrolysis (letting sugar / liquid fat batter set 10 minutes before adding flour to ensure the sucrose becomes an invert sugar) at https://www.youtube.com/watch?v=M5fzyhIJYOw.]

G. An ***emulsion*** is a semi-liquid and stable mixture in which one liquid is suspended in another (two or more immiscible ingredients). ***Immiscible*** is unmixable or incapable of being mixed unless in an emulsion. Emulsions are uniform mixtures or ***homogeneous mixtures*** that have a uniform composition and the same properties throughout.
   1. Typical emulsions include a fat or oil and a liquid. The process involves slowly adding one ingredient to another while whisking rapidly, such as for oil and vinegar salad dressings. The goal in baking is to form a water-in-fat emulsion. For example, an unstable cake batter emulsion curdles or weeps.
   2. Creaming fat and sugar together is a common step in baking and pastry recipes. Typically, room temperature eggs are added one at a time. This slow procedure adds more air to the batter and adds the emulsifier from egg yolks to keep the fat and liquids as a homogenous mixture. [NOTE: See the CraftyBaking website for more information about emulsions in cake batters at https://www.craftybaking.com/howto/emulsify.]

H. ***Gelatinization*** is the heating of starch granules in a liquid and is a thickening process. It is an irreversible thickening process in which the hydrogen bonds that hold the starch together weaken, allowing water to penetrate the starch molecules and causing them to swell.

1. Gelatinization occurs during baking when the starch granules in flour begin to swell. The available water, the water temperature, and the length of time the starch is exposed to excess water all influence flour gelatinization.
2. Sugar competes with flour for water absorption.

I. ***Heat transfer*** is the process of a food coming into contact with a heat source and becoming hot or the exchange of thermal energy between two objects. The action that occurs during heating is food molecules absorbing energy, vibrating quickly, and bouncing off each other. Each collision produces heat, which is transferred to the food during cooking. Three methods of heat transfer are radiation, conduction, and convection.
   1. ***Radiation*** is heat transmitted as infrared rays. Radiant heat is evident when opening a preheated oven, as a person can "feel" the warmed air. The warmed air is transferred to food and cooks it.
   2. ***Conduction*** is heat passed between objects by direct contact. For example, stovetop burners conduct heat to pots and pans, and pots and pans transfer or conduct heat to the food. Grilling a steak or a hamburger is an example of conduction heat transfer.
   3. ***Convection*** is heat transferred by circulating heat around food. In a convection oven, a fan blows hot air over and around the food. [NOTE: See the Biscuit People website article, "Heat Transfer for Biscuit Baking," for more information on heat transfer at http://biscuitpeople.com/heat-transfer-for-biscuit-baking/.]

J. The ***Maillard reaction*** is a chemical effect that occurs when proteins and sugars break down under heat; it is a rearranging of amino acids and simple sugars into rings that reflect light and produce a browned appearance and tantalizing aromas in many foods. The Maillard reaction is a series of three complex reactions between amino acids (proteins) and reducing sugars (monosaccharide and some disaccharide sugars that can donate electrons to another chemical) that occur at increased temperatures. The Maillard reaction produces different aromas in bread than it does in standing rib roast or baked fish because the amino acids and simple sugars differ in those foods. [NOTE: See the Food-Info website for more information on complex reactions and about Louis Camille Maillard at http://www.food-info.net/uk/colour/maillard.htm.]

K. ***Osmosis*** is the movement of fluid through a semipermeable cell membrane—from a less concentrated solution to a more concentrated solution—to create an equal concentration of a solute on both sides of the membrane. A solute is the substance that dissolves another substance in a solution.
   1. Fruit has semipermeable cell membranes. As a result:
      a. Fruit cells release water when cut.
      b. Frozen fruit and cooked fruit wilt.

2. When sugar is added to fresh sliced/diced fruit, the concentration of sucrose is higher around the fruit than inside the fruit cells. Sucrose is too large a molecule to move into the fruit cells. Osmosis occurs when:
   a. The moisture from the fruit moves into the sugar solute to help create an equal concentration.
   b. Fresh apple slices are mixed with dry ingredients (e.g., sugar, spices, and flour) to create an apple pie filling. [NOTE: See simple osmosis and diffusion experiments on the Kitchen Pantry Scientist website at http://kitchenpantryscientist.com/diffusion-and-osmosis-experiments/.]

L. ***Fermentation*** is a chemical reaction in which molecules, such as glucose, are broken down anaerobically (without air). Fermentation produces carbon dioxide that leavens breads and dough. ***Carbon dioxide (CO_2)*** is a colorless gas with a faintly sharp odor and a sour taste. Baking soda and baking powder are two common chemical leavening agents, while yeast is a living organism; all produce CO_2 gas.

1. Baking soda ($NaHCO_3$), or sodium bicarbonate, is a chemical leavening agent that, *when heated*, produces and releases carbon dioxide using the following formula:

$\mathbf{2NaHCO_3}$	$\rightarrow$	$\mathbf{CO_2}$	+	$\mathbf{Na_2CO_3}$	+	$\mathbf{H_2O}$
(Sodium bicarbonate)	(*releases*)	(Carbon dioxide)		(Sodium carbonate)		(Water vapor)

   a. Sodium bicarbonate must be used with acid in a recipe.
   b. If baking soda is used in a recipe without an acid, it will produce a bitter taste and a yellowish color.

2. Baking powder ($NaHCO_3$), or sodium bicarbonate, is a chemical leavening agent that contains baking soda, dry acid salts (monocalcium phosphate and sodium acid pyrophosphate or sodium aluminum sulfate), and a starch. It produces more carbon dioxide gas than baking soda. When heated, it produces carbon dioxide using the following formula:

$$\mathbf{NaHCO_3 + H^+ \text{ (from the acid)} \rightarrow Na^+ + H_2O + CO_2}$$

3. Yeast is a living organism used to make baked goods rise. Yeast also produces carbon dioxide gas to make leaven breads by feeding on the sugars in flour. As the yeast feeds, it expels CO_2 gas that causes breads to rise. [NOTE: See the Science of Cooking website for a simple experiment or demonstration about yeast and carbon dioxide at https://www.exploratorium.edu/cooking/bread/activity-yeast.html.]

Teaching Strategy: *Many techniques can be used to help students master this objective. Use VM–M and VM–N to review caramelization and heat transfer chemistry terms. As a class, watch "The Chemistry of Cookies" at https://www.youtube.com/watch?v=hDH-Gu4C42w as an introduction to LS–A.*

To identify the science behind developing a chewy chocolate chip cookie, project the America's Test Kitchen video, "The Science of the Perfect Chewy Chocolate Chip Cookie" at https://www.youtube.com/watch?v=M5fzyhIJYOw. This explains the scientific difference in procedures for a cake-like texture and a chewy texture. (This chef explains scientific reasons for browning the butter before adding sugar and letting the sugar/butter/egg mixture set 10 minutes before adding flour.)

See the National Science Teachers Association "Food Chemistry in the HS Classroom" PowerPoint for more information about including food science and chemistry in culinary curriculum at http://learningcenter.nsta.org/products/symposia_seminars/ACS/files/Food%20Chemistry%20in%20the%20High%20School%20Classroom-9-22-2011.pdf. Have the students research information on flavor compounds (e.g., diacetyl, esters and lactones, furan, and maltol) as needed or desired.

Objective 3: Compare and contrast ingredient ratios for baked goods.

Anticipated Problem: What are common ratios of the ingredients in baked goods?

III. Ingredient ratios

A. A ***ratio*** is a statement about how two or more numbers compare. In baking and pastry, it is the proportion of one ingredient to another. For example, if the proportion of flour to liquid in a baked product is 2:1, it is two parts flour to one part liquid. "Parts" refer to the same measurement, usually in weight, for each ingredient: ounces, pounds, kilograms, etc.

B. Common batter and dough ratios

1. Liquid or pour batter ratios include:

a. 0:5:1:1 ratio: Crepes or French-style thin grilled "pancakes" filled with sweet or savory ingredients are typically half-part flour to one part liquid to one part eggs. [NOTE: See the Food Network website for crepes recipes at http://www.foodnetwork.com/recipes/alton-brown/crepes-recipe.html.]

b. 1:2:1 ratio: Popovers and/or Yorkshire pudding are airy, hollow rolls baked in an extremely hot oven and are a 1:2:1 ratio or one part flour to two parts liquid to one part eggs. They have a larger proportion of eggs than other pour batters.

c. 1:1:1:1 ratio: Sponge cake rolls begin as pour batters that are baked in a sheet pan, filled, and rolled up. Their ratio is one part flour to one part fat to one part eggs to one part sugar. [NOTE: See the Yummly website for several sponge cake roll recipes at http://www.yummly.co/recipes?q=sponge%20cake%20roll&&noUserSettings=true.]

2. Drop batter ratios include:

a. 3:1:2 ratio: Biscuits are three parts flour to one part fat to two parts liquid.

b. 2:1:2:1 ratio: Muffins are two parts flour to one part fat to two parts liquid to one part eggs.

c. 1:1:2:2 ratio: Pâte á choux (cream puffs) are one part flour to one part fat to two parts liquid to two parts eggs.

3. Soft dough ratios include:
   a. 3:1:2 ratio: Scones are three parts flour to one part fat to two parts liquid.
   b. 3:2:1 ratio: Cookies are three parts flour to two parts fat to one part sugar.
   c. 1:1:0.6 ratio: Full puff pastry is one part flour to one part butter to 0.6 part water.
   d. 3:2:1 ratio: Traditional pie dough is three parts flour to two parts fat to one part liquid.
4. Stiff dough ratios include:
   a. 5:3 ratio: Yeast dough is five parts flour to three parts liquid.
   b. 3:2 ratio: Pasta is three parts flour to two parts eggs.

Teaching Strategy: *Many techniques can be used to help students master this objective. Use VM–O to review.*

Objective 4: Explain the scientific method.

Anticipated Problem: What is the scientific method?

IV. The ***scientific method*** is a problem-solving process that follows seven logical steps to answer questions by experimentation and by analyzing data from the experiment. Food scientists use the scientific method to evaluate food techniques and products. The scientific method is used in all types of scientific investigation.

A. STEP 1: Formulate the question or state the problem.
   1. Write the problem as a question.
   2. Limit the problem to something that may be tested in an experiment.
   3. Simplify and test complex questions as separate problems.

B. STEP 2: Identify known information about the problem (givens).
   1. Gather relevant information from previous experiments.
   2. Focus the scope of the experiment using the added information.

C. STEP 3: Form a hypothesis (a statement that predicts what will logically happen during the experiment) based on the currently known information.
   1. Hypotheses may be proved or disproved during the experiment.
   2. Scientists often form several new hypotheses before arriving at a hypothesis that is proven.

D. STEP 4: Design an experiment.
   1. All experiments have variables that a person wishes to change and measure. Two types of variables are independent and dependent.

2. Independent variables are the factors a person is changing in the experiment. For example, an independent variable could be:
    a. The procedure or techniques used to mix the batter
    b. The temperature of an ingredient
    c. Variation in the amount of an ingredient
3. The dependent variables (something that depends on other factors) are those elements studied during the experiment or those studied when one independent variable is changed. For example, a dependent variable could be:
    a. Height
    b. Texture
    c. Flavor of the product
4. A controlled variable remains constant at all times during the experiment and is necessary to show the validity of the experiment. For instance, the temperature for baking could be a controlled variable.

E. STEP 5: Observe and collect data during the experiment.
1. Record accurate observations using a data table.
2. Use scientific measurements for data collection.
3. Compare the independent variable data to the controlled data.

F. STEP 6: Analyze the data.
1. Review collected data for trends or averages.
2. Determine whether the data prove or disprove the hypothesis.

G. STEP 7: Form a conclusion.
1. Summarize the results of the experiment.
2. Write a conclusion statement based on the experiment results.

Teaching Strategy: *Many techniques can be used to help students master this objective. Use VM–P to review. Examples of food science labs and blank lab experiment sheets are found in the Food Science Curriculum document on the Illinois State Board of Education's website at https://www.isbe.net/Documents/fcs_guide.pdf. Review some of the experiments to see how the lab experiment sheets are used and for examples of data tables. Also, see the safety issues and what each safety picture indicates. For more information on formulating questions, hypotheses, and variables, see the "Scientific Method Handbook" at http://www.gowcsd.org/files/267778/Scientific%20Method%20Packet.pdf. An excellent example of the sections of a scientific method experiment lab sheet is at the Biology Corner website at https://www.biologycorner.com/worksheets/labreport.html. The website includes a link to a Lab Report Rubric. Assign LS–A.*

■ **Review/Summary.** Use the student learning objectives to summarize the lesson. Have students explain the content associated with each objective. Student responses can be used in determining which objectives need to be reviewed or taught from a different angle. If a textbook is being used, questions at the ends of chapters may be included in the Review/Summary.

- **Application.** Use the included visual master(s) and lab sheet(s) to apply the information presented in the lesson.

- **Evaluation.** Evaluation should focus on student achievement of the objectives for the lesson. Various techniques can be used, such as student performance on the application activities. A sample written test is provided.

Answers to Sample Test:

Part One: Matching

1. e
2. k
3. h
4. c
5. m
6. b
7. j
8. g
9. d
10. a
11. n
12. l
13. i
14. o
15. f

Part Two: True/False

1. T
2. T
3. T
4. F
5. F
6. F
7. T
8. T
9. T
10. T

Part Three: Short Answer

1. Fermentation is a chemical reaction in which molecules, such as glucose, are broken down anaerobically (without air). Fermentation produces carbon dioxide that

leavens breads and dough. Carbon dioxide (CO_2) is a colorless gas with a faintly sharp odor and a sour taste. Baking soda and baking powder are two common chemical leavening agents, while yeast is a living organism; all produce CO_2 gas.

2. Answers will vary and should be similar to the following difference between a chemical reaction and a physical change. The difference between a chemical reaction and a physical change is composition. A chemical reaction is a permanent change in the chemical composition of a substance: molecules are broken apart and rearranged into new molecules. For example, fresh eggs that are fried cannot become fresh eggs again. The protein in the egg is permanently changed, and the appearance is different. A physical change is the transformation of a substance that does not alter its chemical properties; it's just a phase change. The change involves a difference in the way the substance displays: appearance (color or shape), texture, temperature, smell, or a change of state of the substance (e.g., frozen or melting or boiling). Melting, boiling, and freezing are examples of a physical phase change: an ice cube (frozen water) that melts is still water (liquid water), and its chemical properties remain intact.

Sample Test

Name ______________________________

Baking and Pastry Chemistry

Part One: Matching

Instructions: **Match the term with the correct definition.**

a. absorption
b. baking
c. caramelization
d. chemical reaction
e. emulsion
f. fat
g. flour
h. fructose
i. gluten
j. high fructose corn syrup
k. leavening
l. Maillard reaction
m. physical change
n. ratio
o. sucrose

_____1. A semi-liquid and stable mixture in which one liquid is suspended in another: two or more immiscible ingredients

_____2. The production of a gas in a dough batter using an agent (e.g., steam, air, eggs, baking soda, baking powder, and yeast)

_____3. A monosaccharide twice as sweet as sucrose when in crystal form

_____4. The oxidation of sugar, a cooking process that results in intense nutty flavors and non-enzymatic browning; carbohydrates (sugars) are heated to remove water from a sugar

_____5. The transformation of a substance that does not alter its chemical properties

_____6. A process of cooking with dry heat—usually an oven

_____7. A sweetener made from corn and composed of 42 to 55 percent fructose with the remaining sugars being primarily glucose and higher sugars

_____8. A powdered foodstuff made from ground and sifted grains that can be enriched (augmented) or refined

_____9. A permanent change in the chemical composition of a substance; molecules are broken apart and rearranged into new molecules

____10. The act of attracting (taking up) particles of gas or liquid into a liquid or a solid substance

____11. A statement about how two or more numbers compare

____12. A chemical effect that occurs when proteins and sugars break down under heat; a rearranging of amino acids and simple sugars into rings that reflect light and produce a browned appearance and tantalizing aromas in many types of food

____13. An elastic protein found in wheat and cereal flours that gives dough elasticity and strength in addition to helping the dough rise

____14. A naturally occurring carbohydrate from cane and beet plants made of fine or extra-fine white sugar crystals

____15. Greasy ingredients that melt at low temperatures: compounds of carbon, hydrogen, and oxygen

Part Two: True/False

Instructions: **Write *T* for true or *F* for false.**

_____1. Liquids are needed for chemical changes in structure and texture.

_____2. Salt adds complexity to the flavor of baked products.

_____3. Eggs help develop the structure of the baked product by binding ingredients together.

_____4. Artificial sweeteners brown, tenderize, and add moisture to baked goods.

_____5. Another name for corn syrup is sucrose.

_____6. Because molasses is acidic, bakers add $^1/_2$ teaspoon baking powder for every cup of molasses.

_____7. Adding too much honey in baked goods results in moist and often overly brown baked goods.

_____8. Sugar is produced from various types of plants: cane, beet, sugar maple, and palm.

_____9. Sweeteners tenderize dough and batter and help with the browning.

____10. Coconut oil, palm kernel oil, and palm oil are saturated vegetable fats.

Part Three: Short Answer

Instructions: **Answer the following.**

1. Describe the chemical reaction of fermentation.

2. Describe the difference between a chemical reaction and a physical change in terms of baking and pastry.

AN INTRODUCTION TO BAKING AND PASTRY CHEMISTRY

- **Video:** "The Chemistry of Cookies"
  - Watch the video, "The Chemistry of Cookies," by Stephanie Warren at https://www.youtube.com/watch?v=n6wpNhyreDE or at http://ed.ted.com/lessons/the-chemistry-of-cookies-stephanie-warren. The video details the chemical reactions that take place in the oven when baking chocolate chip cookies.
- **Video Questions and Resources:** Click the "Think," "Dig Deeper," and "Discuss" Buttons.
  - Sample multiple-choice quiz questions about the baking chemistry video are available on the TEDEd website link by clicking the "Think" button. As a class, discuss each question, and come to a consensus on a correct answer. Additional resources from the TEDEd website link include the French scientist Louis Camille Maillard (Maillard Reaction). Click the "Dig Deeper" button.

♦ Key Chemistry Concepts:

1. At 92°F, butter melts and cookies spread out.
2. Butter is an emulsion (the suspension of a liquid in a fat).
3. Eggs may contain Salmonella (a bacterium that causes food poisoning).
4. *Salmonella* bacteria are destroyed at 136°F.
5. At 144°F, the protein from eggs changes. The protein strings uncoil and tangle with other ingredients, causing the mixture to "hold together" (bind).
6. At 212°F, water boils away from the cookie dough and evaporates, resulting in steam (a leavener) that helps the cookie rise and serves to dry the dough.
7. Leavening agents, such as sodium bicarbonate (baking soda), produce CO_2 (carbon dioxide) gas that also causes dough to rise.
8. At 310°F, the Maillard reaction (browning) occurs; proteins and sugars break down and rearrange themselves and cause foods to brown and to create warm, sweet smells.
9. From 356°F to 390°F, caramelization (browning; butterscotch flavor) begins; sugar molecules break down under high heat.

Chemistry concepts explain how a crispy chocolate chip cookie is produced from raw dough.

♦ **Debrief:** Video and the "Discuss" Question

1. Agree or disagree: Chemists (cooks and chefs) create chocolate chip cookies.
2. Which chemical terms and reactions were familiar?
3. Why are some cookies baked at 350°F or lower?
4. When I eat raw cookie dough, why don't I get salmonellosis?
5. Discuss question: Would knowing a little chemistry make cooking easier? Would it make it more fun?

AN INTRODUCTION TO BAKING AND PASTRY CHEMISTRY

Teacher Notes for VM–A

A. Extra credit: Students could have the option to create a class presentation on the history of Louis Camille Maillard and a demonstration of the Maillard Reaction.

B. Debrief:

1. Agree.
2. Cookies are baked at or under 350°F when the baker does not want the cookies to brown.
3. For more information on *Salmonella* infection, see the Centers for Disease Control and Prevention (CDC) article "*Salmonella* and Eggs" at http://www.cdc.gov/features/salmonellaeggs/. For a confirmed outbreak of *Salmonella* infection in shell eggs, see the CDC article, "Multistate Outbreak of *Salmonella* Oranienburg Infections Linked to Good Earth Egg Company," at http://www.cdc.gov/salmonella/oranienburg-10-16/index.html.

VM–C

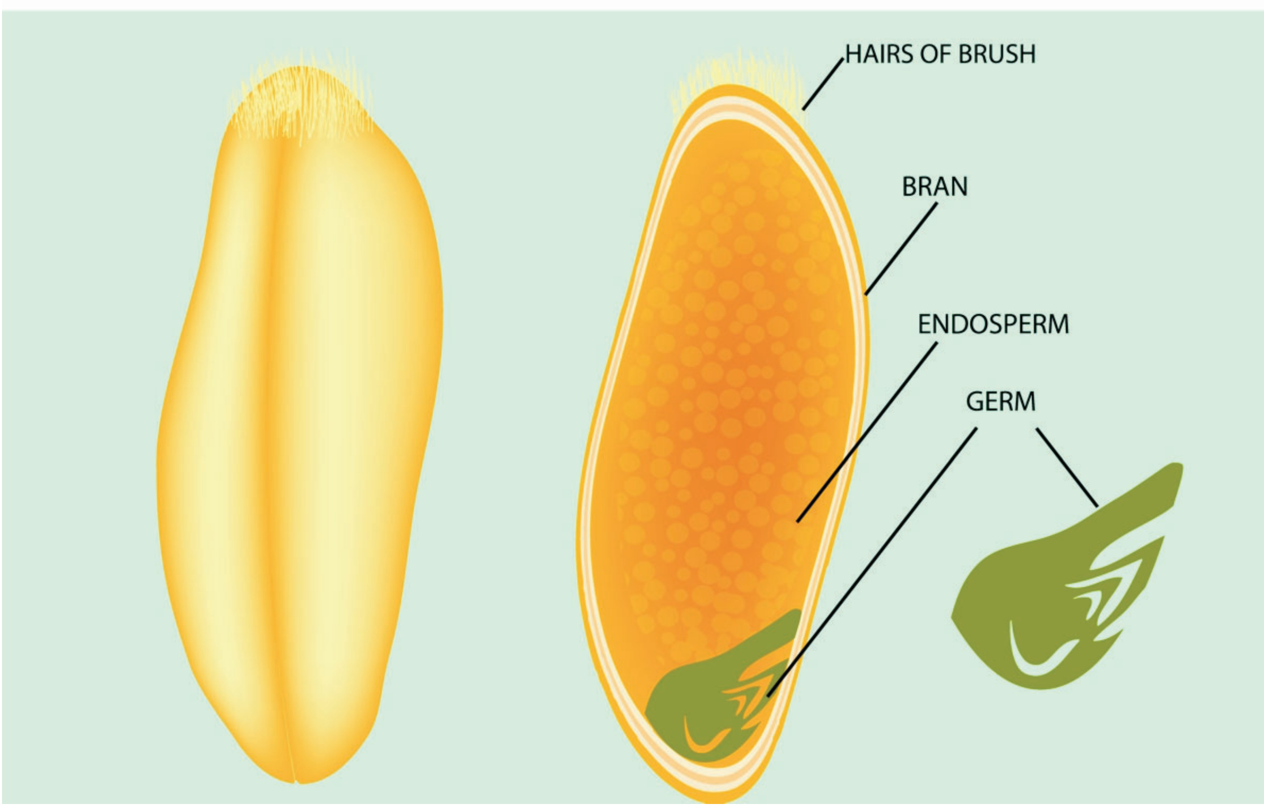
COMMON DRY INGREDIENT VOLUME TO WEIGHT CONVERSIONS

Ingredient	Volume	Weight (grams)
Butter (salted or unsalted)	1/2 cup 1 cup	113 grams 226 grams
Flour (all-purpose) Flour (cake) Flour (whole wheat)	1 cup 1 cup 1 cup	130 grams 120 grams 130 grams
Cornstarch (corn flour)	1 tablespoon	10 grams
Sugar (granulated white) Sugar (brown; light pack) Sugar (powdered)	1 cup 1 cup 1 cup	200 grams 210 grams 120 grams
Chocolate chips	1 cup	170 grams
Cocoa powder	1 tablespoon	6 grams
Rolled oats	1 cup	95 grams

FLOUR

Flour is a powdered foodstuff made from ground and sifted grains. It can be enriched (augmented) or refined. Flour for baking is usually produced from wheat but could be from other food sources: corn, rice, nuts, legumes, and some fruits and vegetables. Based on volume, flour is often the largest ingredient in a baked product. Flour contains gluten, which forms the structure of baked items. Gluten is an elastic protein (from the endosperm) found in wheat and cereal flours that gives dough elasticity and strength. In addition, it helps the dough rise. Wheat flour, barley, rye, and triticale (a cross between wheat and rye flour) contain gluten.

WHEAT GRAIN STRUCTURE



FLOUR TYPES

Functions: Flour adds, provides, and/or causes:

- Body (bulk or mass) and structure
- Flavor
- Gluten development

From left to right: all-purpose, whole-wheat, and graham flours. Which, if any, of these flours are gluten-free?

From left to right: corn, barley, and buckwheat flours. Which, if any, of these flours are gluten-free?

FATS

Fats are greasy ingredients that melt at low temperatures: compounds of carbon, hydrogen, and oxygen. Fat is found in animal (e.g., butter and lard) and vegetable (e.g., peanut, palm, corn, canola, olive, and shortening) tissue. Fats are available in liquid (oil), solid (butter), or hydrogenated (shortening) forms.

Functions: Fats add, provide, cause, or create:

- Flavor
- Layering (soft fats spread between pastry layers that separate and “flake” when baked)
- Shortening (tenderizes baked goods by shortening or weakening gluten strands)
- Creaming (traps tiny air bubbles within droplets of fat during the “creaming” to leaven)
- Emulsification (suspending two liquid ingredients in a batter)
- Other: Carries an added flavoring (e.g., vanilla) throughout the batter, crust, or dough; aids in browning; and adds moisture

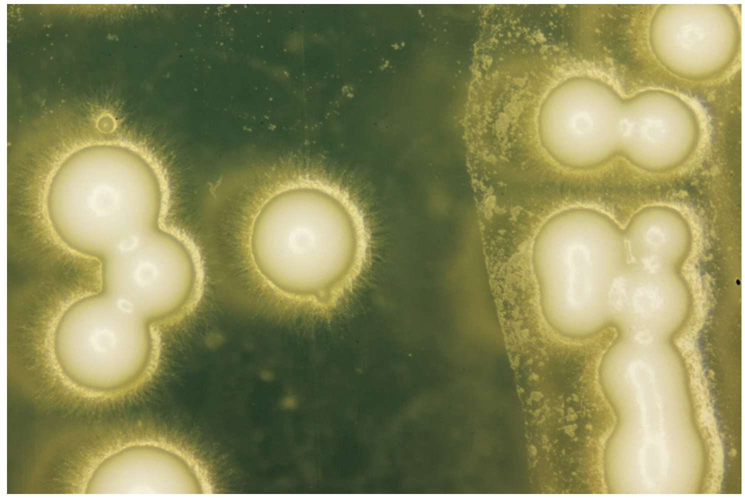
SUGARS

Sugar is a carbohydrate that is soluble in water, usually crystalline with a sweet taste. Sugars are produced from various types of plants: cane (sucrose), beet, sugar maple, and palm. In fact, all fruits and vegetables contain sugar (sucrose or fructose). Solid sugars include cane and beet. Liquid sweeteners include honey, molasses, corn syrup, and various humanmade liquid sugars produced initially for dietary purposes.

Functions: Sugars add, provide, or cause:

- Flavor
- Natural tenderizer
- Color
- Yeast food
- Moisture retention
- Dough to spread under heat

LEAVENING: YEAST



Leavening is the production of a gas in a dough batter using an agent: steam, air, eggs, baking soda, baking powder, or yeast. A leavening agent is a substance that causes expansion in a dough batter by releasing gases within the mixture. Yeast leavening is a result of the addition of wild, active dry, fresh compressed (cake), starter, or instant yeast products.

LEAVENING: STEAM, AIR, AND CHEMICAL

Leavening is the production of a gas in a dough batter using an agent: steam, air, eggs, baking soda, baking powder, or yeast. A leavening agent is a substance that causes expansion in a dough batter by releasing gases within the mixture. When egg whites are beaten for a meringue, air is added, so the mixture expands.

Genoise is a French sponge cake made without chemical leavening agents. The pastry chef beats whole eggs with sugar over heat to the ribbon stage to provide air leavening.

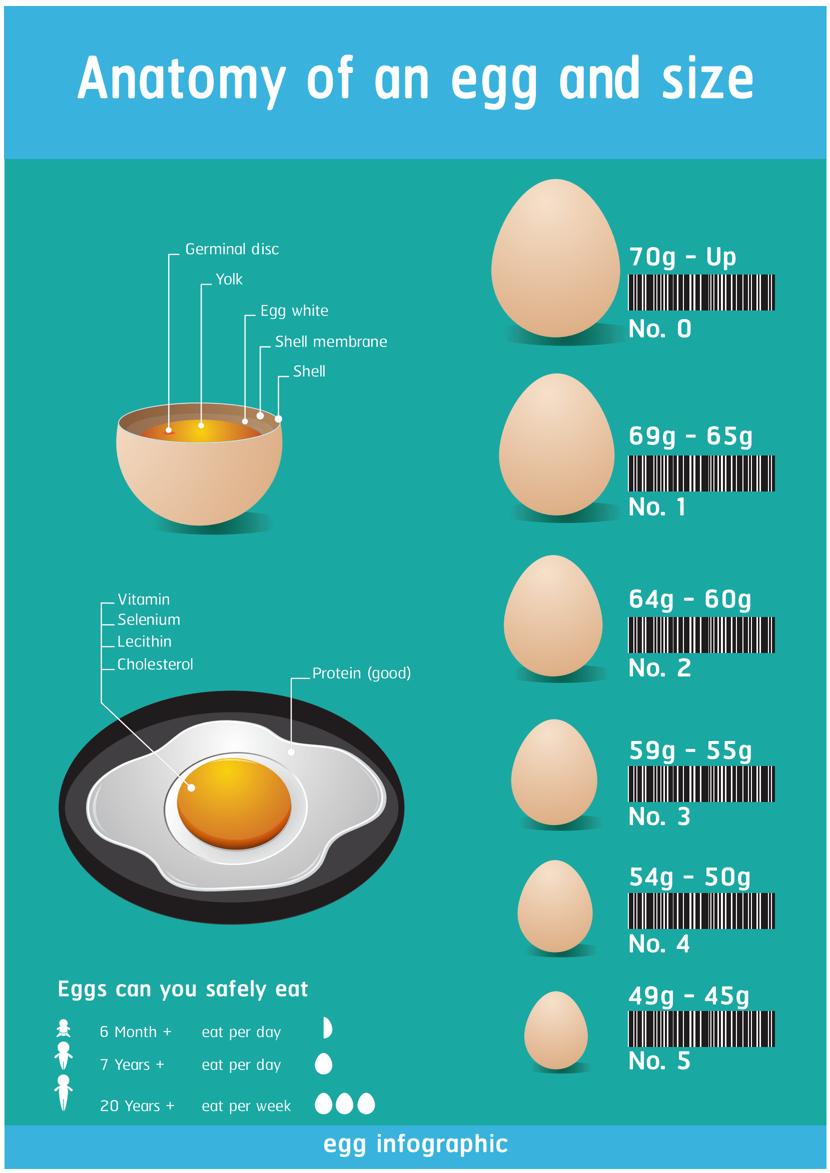
Chemical leavening agents—baking soda and baking powder—produce CO_2 gas that helps products rise. Most cookies rise under heat due to a combination of chemical, steam (moisture), and natural leavening from eggs.

Processes:

- Steam: Moisture from a dough batter is converted to steam.
- Air: Mechanical incorporation of air occurs during whipping, beating, folding, etc. and results in dough batter leavening.
- Chemical: CO_2 gas is formed by chemical leavening agents (e.g., baking soda and baking powder) that help the product rise.

EGGS

Eggs are the structural element in baking, along with flour. Chicken eggs are the standard in Grade A or AA. Large eggs (about 2 ounces each or 8 per pound) are the most common size used in baked goods. Eggshell color does not affect the functions eggs provide in baking and pastry products.



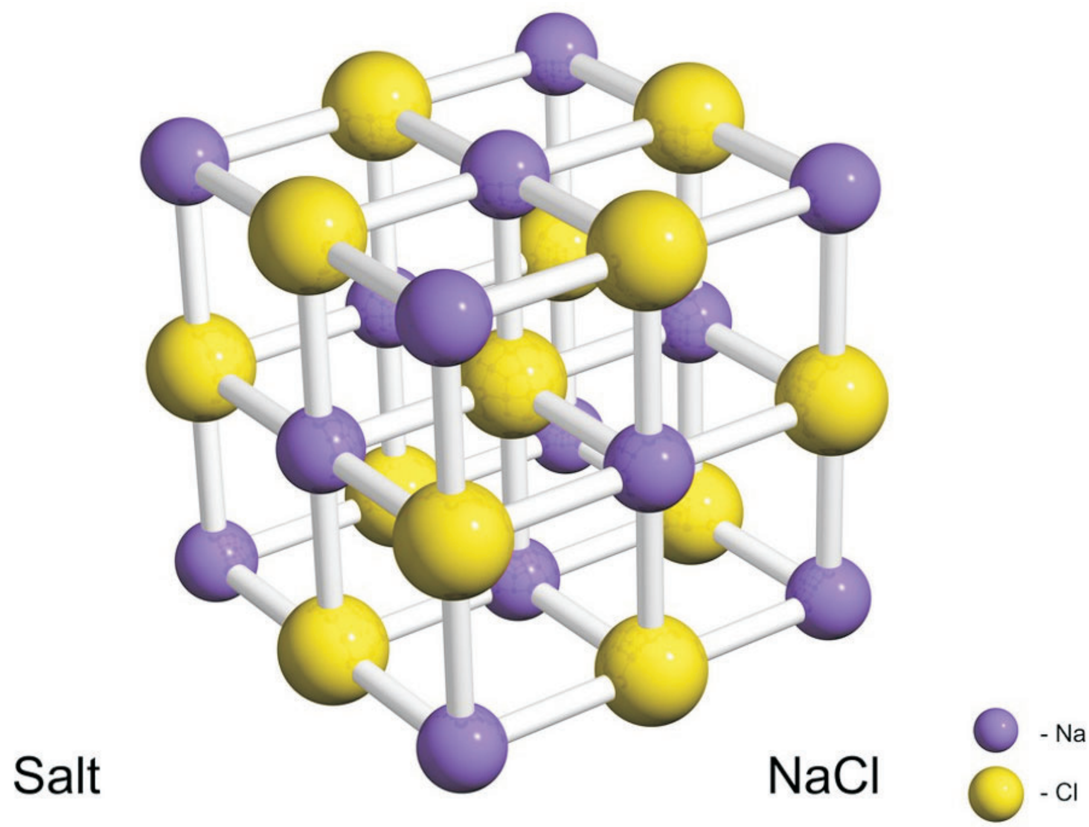
Weighing baking and pastry ingredients is more accurate than measuring; eggs included. Look again at the egg chart. It does not matter how eggs are marketed: Jumbo or 0, Extra Large or 1, Large or 2, Medium or 3, Small or 4, or Pee Wee or 5. If you weigh the shelled egg, it will not matter which size you purchase.

Functions: Eggs add, provide, cause, or create:

- Leavening (natural and via air incorporation)
- Emulsification (a binding agent or a structure that holds other ingredients together)
- Moisture
- Color (an egg wash glaze browns the surface: a Maillard reaction)
- Other: Flavor, tenderizes (via egg yolk fat), texture, and thickener

SALT

Salt is a crystalline compound (NaCl or sodium chloride) primarily used as a condiment that comes in two types: sea salt and rock salt. Sea salt is distilled from seawater, and rock salt is found in the earth. Iodized salt (table salt with added iodine) is the type most often used in baked goods. It is mined and processed to remove minerals and has an additive to prevent clumping. Salt retards yeast growth to ensure activity during mixing, proofing, shaping, and baking. Salt can kill yeast if it comes in direct contact with it. Therefore, salt is not added to a starter. To disperse salt evenly in a dough or batter, it must be added with the flour and other dry ingredients and mixed well.



Functions: Salts add, provide, cause, or create:

- Flavor complexity
- Slower yeast fermentation (keeps the air bubbles small and uniform in size)
- Toughening of the texture of soft fat and sugar mixtures
- Strengthening of the gluten protein, which impacts texture

LIQUIDS

Liquids include water (the most common liquid in baking and pastry production), milk, light and heavy creams, buttermilk, yogurt, sour cream, and mashed fruits and juices. Weighing liquids is more accurate than measuring. Liquids are needed for chemical changes in structure and texture. When liquid evaporates under the dry heat of an oven, it produces steam. In turn, air bubbles develop and increase the volume of baked goods.

Functions: Liquids add, provide, cause, or aid:

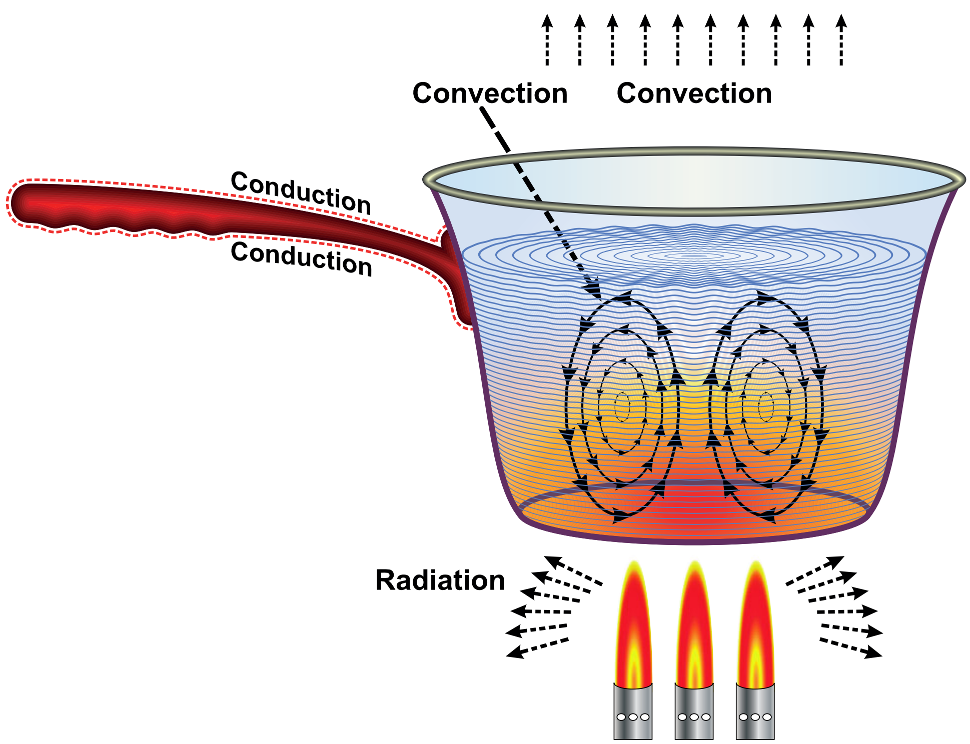
- Moisture
- Flavor
- Color
- Steam leavening
- Hydrate proteins, starches (including gelatins), and leavening agents
- Yeast organisms to activate
- Gluten development
- Binding

CHEMICAL REACTIONS AND PHYSICAL CHANGES: CARAMELIZATION

Caramelization is the oxidation of sugar, which is a cooking process that results in intense nutty flavors and non-enzymatic browning. Carbohydrates (sugars) are heated to remove water from a sugar. Non-enzymatic browning is the result of the Maillard reaction. Caramelization is the final chemical reaction to occur during baking. These two images illustrate "boiling" sugar to remove the water and the final product of caramel. Is caramelization a chemical reaction or a physical change?

CHEMICAL REACTIONS AND PHYSICAL CHANGES: HEAT TRANSFER

Heat transfer is the process of a food coming into contact with a heat source and becoming hot; it is the exchange of thermal energy between two objects. The action that occurs during heating is food molecules absorbing energy, vibrating quickly, and bouncing off each other. Each collision produces heat, which is transferred to the food during cooking. Three methods of heat transfer are radiation, conduction, and convection.



- **Radiation** is heat transmitted as infrared rays. Warmed air is transferred to food and cooks it.
- **Conduction** is heat passed between objects by direct contact. For example, stovetop burners conduct heat to pots and pans, and pots and pans transfer or conduct heat to the food.
- **Convection** is heat transferred by circulating heat around food. In a convection oven, a fan blows hot air over and around the food.

INGREDIENT RATIOS IN BAKING AND PASTRY PREPARATIONS

- Ratio is a statement about how two or more numbers compare. In baking and pastry, it is the proportion of one ingredient to another. For example, if the proportion of flour to liquid in a baked product is 2:1, it is two parts flour to one part liquid. "Parts" refer to the same measurement, usually in weight, for each ingredient: ounces, pounds, kilograms, etc.
- Drop batter ratios include:
  - 3:1:2 ratio: Biscuits are three parts flour to one part fat to one part liquid.
  - 2:1:2:1 ratio: Muffins are two parts flour to one part fat to two parts liquid to one part eggs.
  - 1:1:2:2 ratio: Pâte á choux (cream puffs) are one part flour to one part fat to two parts liquid to two parts eggs.

SCIENTIFIC METHOD

The scientific method is a problem-solving process that follows logical steps to answer questions by experimentation and by analyzing data from the experiment. Food scientists use the scientific method to evaluate food techniques and products. The scientific method is used in all types of scientific investigation. In your own words, describe what happens in each step of the scientific method.

- ♦ STEP 1: Formulate the question or state the problem.
- ♦ STEP 2: Identify known information about the problem.
- ♦ STEP 3: Form a hypothesis.
- ♦ STEP 4: Design an experiment.
- ♦ STEP 5: Observe and collect data during the experiment.
- ♦ STEP 6: Analyze the data.
- ♦ STEP 7: Form a conclusion.

Name ______________________________

The Chemistry of Baking: Day 1

Purpose

The purpose of this activity is to design an experiment to show the effects of variables on the chemistry of baking.

Objectives

1. Use the scientific method steps to design an experiment that provides proof of chemistry in baking.
2. Write the step-by-step procedure, and design a data table for the experiment.

Materials

- lab sheet
- computer
- printer

Procedure

1. STEP 1: **Become familiar with experimentation:** Watch the "How to Cookie with Science" at https://www.youtube.com/watch?v=3b4shT7EBZQ. This experiment compares the difference between chilled, room temperature, and melted butter on chocolate chip cookies. A hypothesis was presented. The following variables are tested:
   a. Independent variable: butter temperature
   b. Dependent variables: cookie height, chewiness, and browning
   c. Control: baking temperature, length of cooking time, how the cookie is tested for doneness, etc.
2. STEP 2: **Select a baked product for the experiment.** (Do not use chocolate chip cookies.)

Product Selected	Group Name or Number

3. STEP 3: **Select a control recipe for the product your group selected:** Determine possible independent variables, and select one. Determine the physical characteristics that might be evaluated when the recipe is changed (e.g., example, texture, height, and color). List the independent variable and the physical characteristics.

4. STEP 4: **Write the scientific experiment.**
   a. STEP 1: Formulate the question or state the problem.

   b. STEP 2: Identify known information about the problem.

   c. STEP 3: Form a hypothesis.

   d. STEP 4: Design the experiment and the step-by-step procedure you will follow. Have your instructor approve the steps in the experiment. Revise as needed. Then design a data table to collect experiment data. A sample data table is shown here. [NOTE: Other criteria that might be evaluated includes flavor, mouthfeel, diameter (if exact same volume is used), etc.]

Data Table for ______________________ Date _________

Variables	Height	Texture (cut open)	Color	Aroma
Control				
Variation: ________				

The Chemistry of Baking: Day 1

If facilities, budget, and/or time do not permit completing the experiment by making the food, only complete the first four steps, or conduct a whole group experiment.

Name ______________________________

The Chemistry of Baking: Day 2

Purpose

The purpose of this activity is to perform a chemistry of baking experiment and to collect data on the effects of variables on the baked product.

Objectives

1. Conduct a chemistry of baking experiment using scientific method steps.
2. Summarize the chemistry reactions observed during the experiment in a written report.

Materials

- lab sheet
- computer
- printer
- printed experiment sheet and data table
- food supplies and equipment needed to perform experiment

Procedures

1. Make revisions to the experiment plan as needed. Have your instructor approve the steps again. Prepare the control recipe and the variation recipe you designed.
2. STEP 5: Observe and collect data during the experiment: control and experimental data. Record your observations on the data table.
3. STEP 6: Analyze the data. Products can be sampled if experiments follow food safety and sanitation rules.

4. STEP 7: Form a conclusion. Your summary should include the *chemical reactions* that occurred during baking and the difference in any observed *physical changes* between the control and the variable recipe. For example:

   a. A ________________________ chemical reaction occurred when ________________________. This chemical reaction allowed the baked product to ________________________. The variation was different from the control recipe in that ________________________. (More than one chemical reaction may occur. Your conclusion may be extensive based on the variables you selected.)

   b. Print your STEPS 5 to 7 summary report, and submit it to your instructor as directed. If instructed, share your findings with the class.

The Chemistry of Baking: Day 2

1. Students could prepare a YouTube video of their project. You could also present images to the ACS ChemClub (though students must wear safety goggles). For more information, see the ACD ChemClub website at https://www.acs.org/content/acs/en/education/students/highschool/chemistryclubs/activities/baking.html.
2. Examples of food science labs and blank lab experiment sheets are found in the Food Science Curriculum document on the Illinois State Board of Education's website at https://www.isbe.net/Documents/fcs_guide.pdf. Review some of the experiments to see how the lab experiment sheets are used and for examples of data tables. Also, see the safety issues and what each safety picture indicates.
3. For more information on formulating questions, hypotheses, and variables, see the "Scientific Method Handbook" at http://www.gowcsd.org/files/267778/Scientific%20Method%20Packet.pdf. Also, you can find an excellent example of the sections of a scientific method experiment lab sheet at the Biology Corner website at https://www.biologycorner.com/worksheets/labreport.html. The website also includes a link to a Lab Report Rubric.