Baking and Pastry Chemistry

DO YOU CONSIDER bakers and pastry chefs to be chemists? Think about each ingredient in a recipe or formula. Ingredients have properties and functions that react with the others to create a unique product. The chemical reactions and physical changes—fermentation, caramelization, and the Maillard reaction—are all used in baking and pastry. Each type of batter and dough has a specific ratio of ingredients. The ratio of flour to liquid to eggs to fat to leavening determines the type of cookie, bread, or cake. Baking and pastry preparation is chemistry in action.

Objective:

Analyze the properties and functions of essential baking and pastry ingredients and the chemical reactions and physical changes that occur during baking.

Key Terms:

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

Understanding Baking and Pastry Chemistry

Cooking and baking chemistry is a series of molecular-level chemical reactions and physical changes that occur in foodstuffs. Some are constant and obvious (ripening, odors, decay, etc.), and some occur under heating or cooling (e.g., leavening, browning, boiling, melting, or freezing). Cooking is probably the oldest chemistry (humans learned that it's easier to extract nutrients from cooked food than from raw food), and 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. In addition, a **bakery** is a shop that specializes in producing cakes and pastries. Also, **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.

WEIGHING VERSUS MEASURING

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). Generally, a spring platform or digital scale will help the baker produce consistent, standard products. For example, the way flour is measured impacts 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.

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.

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. You can, however, control measurement.

TABLE 1. 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

BAKING AND PASTRY INGREDIENTS

Ingredients are quite specific in many baking recipes, as substitutions can negatively impact the results.

Flour (Farine)

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 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.

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).

Gluten

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 items (unless contaminated during processing).

Glutenin and Gliadin

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.

- Yeast breads need a sturdy structure and have chewy/stretchy dough (especially French bread). Yeast bread needs high-protein flour that produces more gluten.
- Cakes, quick breads, and pastries require much less gluten formation to produce a soft, fine texture.

FIGURE 1. The longer bread dough is kneaded, the more gluten is developed.

Grains

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.

Bran

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 and is packaged in bags.

Endosperm

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.

Germ

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.

Refined Grains

Refined grains undergo processing to strip out the bran, the germ, or both. White flour is an example of refined flour.

Enriched Grains

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).

Chemistry

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.

All-Purpose Flour

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. Bleached flours are best for pie crusts, cookies, quick breads, pancakes, and waffles. In contrast, unbleached flours are best for yeast breads, Danish pastry, puff pastry, strudel, éclairs, cream puffs, and popovers.

Bread Flour

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 that slice without crumbling. Bread flour is preferred for use in bread machines.

FIGURE 2. From left to right: all-purpose, whole-wheat, and graham flours. Which, if any, of these flours are gluten-free?

Cake Flour

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.

Nut Flour

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

Pastry Flour

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.

Whole-Wheat Flour

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 should be all-purpose or bread flour.

Purpose

Flour adds, provides, and or creates:

- Body (bulk or mass) and structure (tender and crumbly or firm and chewy) to baked goods
- Flavor dependent upon the type
- Gluten

EXPLORING OUR WORLD...

SCIENCE CONNECTION: Gluten-Free Baking

Three million Americans have celiac disease. When those with celiac disease digest gluten, it causes antibodies (proteins made by the immune system) to attack the small intestines. One percent of Americans have celiac disease. Eighteen million have non-celiac gluten sensitivity (NCGS). Gluten sensitivity causes gas and stomach aches. For information about determining if you have celiac disease or gluten intolerance, see, “Are You Really Gluten-Intolerant? Maybe Not” at http://www.forbes.com/sites/rosspomeroy/2014/05/06/are-you-really-gluten-intolerant-maybe-not/#204c397270d6.

Those who want to bake gluten-free items must substitute other flours for wheat flour. Sometimes combinations of gluten-free flours are used. For examples of gluten-free flour blends you can make, see “DIY Gluten Free Flour Blend” at http://minimalistbaker.com/diy-gluten-free-flour-blend/. For gluten-free recipes, see “No-Wheat Treats” at http://www.kingarthurflour.com/recipes/gluten-free. For “A Guide to Gluten-Free Baking” and recipes, see https://glutenfreegirl.com/a-guide-to-gluten-free-baking/.

Pan Preparation

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.

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 to supply energy and build body tissue. Fats are available in liquid, solid, or hydrogenated forms.

Liquid

Unsaturated liquid fats are missing one or more hydrogen atoms. Oils used in baking include corn, soybean, and canola.

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.

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. For example:

- Solid shortenings (e.g., brand name Crisco, etc.) and margarines are hydrogenated.
- 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.

FIGURE 3. Baking and pastry preparations use a variety of fats and oils. Which do you recognize? Are there any hydrogenated fats pictured here?

Solid (Plastic) Fats

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:

Shortening

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.

Emulsified Shortening

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.

Butter

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.

Margarine

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.

Lard

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.]

Oil

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. To substitute oil for butter or margarine, $^7/_8$ cup oil = 1 cup butter or margarine.

Functions

The functions of flavor are:

- Flavor (especially butter or lard; others are nearly tasteless)
- 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)

- Shortens (tenderizes baked goods by shortening or weakening gluten strands; produces baked goods with soft mouthfeel; richness)
- 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)
- Emulsifies two liquid ingredients in a batter
- Other: Carries an added flavoring, such as vanilla, throughout the batter, crust, or dough, aids in browning, and adds moisture

SUGAR (SUCRE)

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. Sugars and other sweeteners add taste, tenderness, color, and aroma to baked goods and pastries.

FIGURE 4. Which of these solid cane and beet sugars can you identify? The image contains granulated, dark brown, caster, cane, and light brown sugars.

Processing

Sugars are available in solid and liquid forms.

Sucrose

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.

Brown Sugar

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.

Powdered Sugar

Powdered sugar is granulated sugar crushed into a fine powder: It is bright white and contains 3 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.)

Honey

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.

Molasses

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 ½ teaspoon of baking soda for every cup of molasses.

Liquid Sugars

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.

Artificial Sweeteners

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

Sugar by Volume

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

- 1 cup granulated sugar weighs about 7 ounces
- 1 cup powdered (confectioners') sugar weighs about 4 ounces
- 1 cup packed brown sugar weighs about 7$^1/_2$ ounces
- 1 cup molasses, honey, or corn syrup weighs about 12 ounces

EXPLORING OUR WORLD...

SCIENCE CONNECTION: Honey Used for Medicine

Pots of honey—thousands of years old—were found in Egyptian tombs. The ancient Egyptians used honey for medicinal purposes because bees have the enzyme glucose oxide in their stomach. When bees digest nectar and regurgitate it into the comb, they produce two byproducts: gluconic acid and hydrogen peroxide. Then the bees fan the hive to reduce the moisture content.

Ancient Egyptians used honey to heal gashes and burns because honey pulls the moisture out of a wound and hydrogen peroxide helps prevent infection. As a result, honey became a natural bandage. For more information on the medical uses for honey, see "The Science Behind Honey's Eternal Shelf Life" at http://www.smithsonianmag.com/science-nature/the-science-behind-honeys-eternal-shelf-life-1218690/. Then see "Ancient Egypt and Honey Bees" at http://thebeejournal.blogspot.com/2010/02/ancient-egypt-and-honey-bees.html. To learn more about the world's oldest edible honey—5,500 years old—see "Why Honey Doesn't Spoil" at http://www.compoundchem.com/2014/08/21/chemistryofhoney/.

Names for Sugar

Sugar is a carbohydrate and 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).

Sucrose

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

Fructose

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.

Glucose

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.

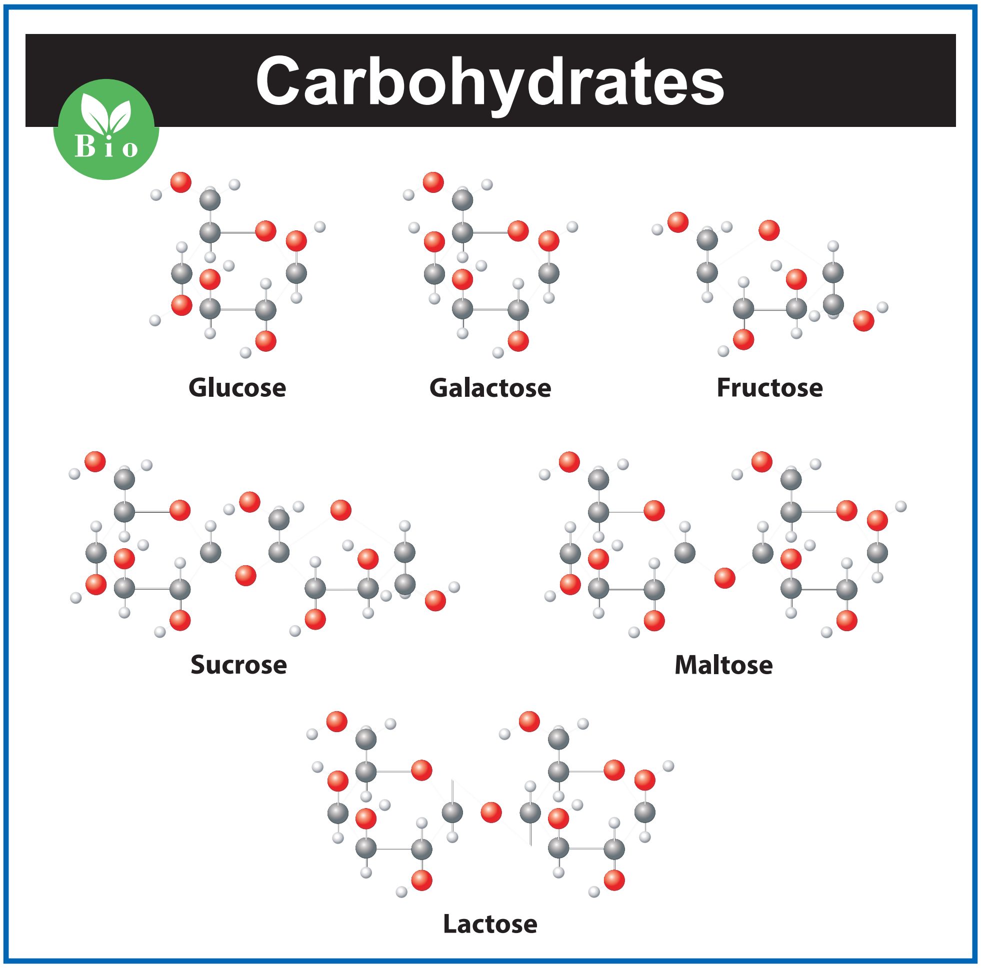

FIGURE 5. Notice the difference in the molecular structure of saccharides. According to the definitions, which are monosaccharides and which are disaccharides?

High Fructose Corn Syrup (HFCS)

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.

- Honey is a complex chemical compound.
- Molasses is composed of many chemical compounds: the sugar content is 50 percent.

Functions

The functions include:

- Flavor
- Tenderizes dough and batter (except for artificial sweeteners)

- Colors (caramelize and aid in browning)
- Feeds yeast organisms (aids in fermentation)
- Moisture retention (sweetened baked goods stay moist longer than unsweetened types)
- Cause cookie dough to spread [NOTE: Artificial sweeteners do not provide browning, tenderizing, and moisture retention of natural sugars.]

LEAVENING

Leavening is the production of a gas in a dough batter using an agent: steam, air, eggs, baking soda, baking powder, starter, and 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 that helps products rise.

Processes

- Steam: Moisture from a dough batter is converted to steam. Preheating of the oven encourages the greatest production of steam leavening.
- Air: Mechanical incorporation of air occurs during whipping, beating, folding, etc. results in dough batter leavening.
- Yeast: Yeast leavening is a result of the addition of wild, active dry, fresh compressed (cake), or instant yeast products.
- Chemical: CO_2 gas is formed by chemical leavening agents (e.g., baking soda or baking powder) that helps the product rise. Baking soda reacts once, and baking powder reacts twice (once at room temperature and once in the oven).

Chemistry

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.

Air Leavening

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.

Yeast

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.

Baking Soda

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." 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.

FIGURE 6. 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.

Baking Powder

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. Baking powder can lose strength. "Good" baking powder will bubble actively when one teaspoon is mixed with one-fourth cup of hot water.

Functions

- Cause a baked product to rise
- Flavor

EGGS (OEUFS)

Eggs are the structural element in baking, along with flour. Chicken eggs are the standard; all other types of eggs (lark, ostrich, etc.) 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 do not contain eggs, such as biscuits and pie crust.

Processing

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 to use.

Weighing eggs is more accurate than measuring.

- 1 large egg white = about 1 oz. = about 2 tablespoons
- 1 large egg yolk = about ½ oz. = about 1 tablespoon

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.

Cracked eggs have a danger of Salmonella entrance and should be discarded.

Chemistry

Eggs are easiest to separate when they are cold.

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). Begin beating at low speed, building slowly as foaming begins. Stop beating before the egg whites become dry and start to separate.

To beat whole eggs or egg whites to their greatest volume, bring to an internal temperature of 65° to 75°F.

Egg yolk adds fat to baked goods.

Functions

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

SALT (SEL)

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.

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 and, as such 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 mixed well.

Functions

- Flavor (adds complexity; without it one would primarily taste sugar; heightens the flavor of other ingredients)
- Slows yeast fermentation and keeps the air bubbles small and uniform in size.
- Toughens the texture of soft fat-and-sugar mixtures.
- Strengthens gluten protein which impacts texture

LIQUID

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.

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.

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.

Functions

- Moisture
- Flavor (milks and creams, fruits and juices; yogurt and sour cream add tartness)
- Color (browning from milk and fruit sugars)
- Steam leavening
- Hydrate proteins, starches (including gelatins), and leavening agents
- Activate yeast organisms
- Mixes with flour for proper gluten development
- Binding agents (especially in quick breads and muffins)

CHEMICAL REACTIONS AND PHYSICAL CHANGES IN BAKING

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.

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

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.

Absorption

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.

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. 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. 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.

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.

Hydroscopic is the ability of a chemical to absorb water. Sugars are hydroscopic, such as table sugar, honey, brown sugar, and molasses. Sugar attracts water to keep the baked goods moist and soft.

Caramelization

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.

FIGURE 7. 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?

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).

The flavors of caramelization occur after 356°F. The sugar molecule breaks down and releases water resulting in steam. The flavors of caramelization include:

- Butterscotch: Diacetyl ($C_4H_6O_2$) is a flavor compound produced in the first stage of caramelization, which is known as a butterscotch flavor.
- Rum-like: Esters and lactones ($C_{28}H_{54}O_{13}$) produce a rum-like flavor.
- Toasty nut: Furan and Maltol ($C_6H_6O_3$) produce a toasty nut flavor.
- Bitter: The continued heating of sugar results in burning the sugar and producing a bitter flavor.

Condensation

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.

Hydrolysis

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.

Emulsion

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.

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.

FIGURE 8. Once the fat and sugar are creamed, 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.

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.

Gelatinization

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.

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. Sugar competes with flour for water absorption.

Heat Transfer

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.

Radiation

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.

Conduction

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.

Convection

Convection is heat transferred by circulating heat around food. In a convection oven, a fan blows hot air over and around the food.

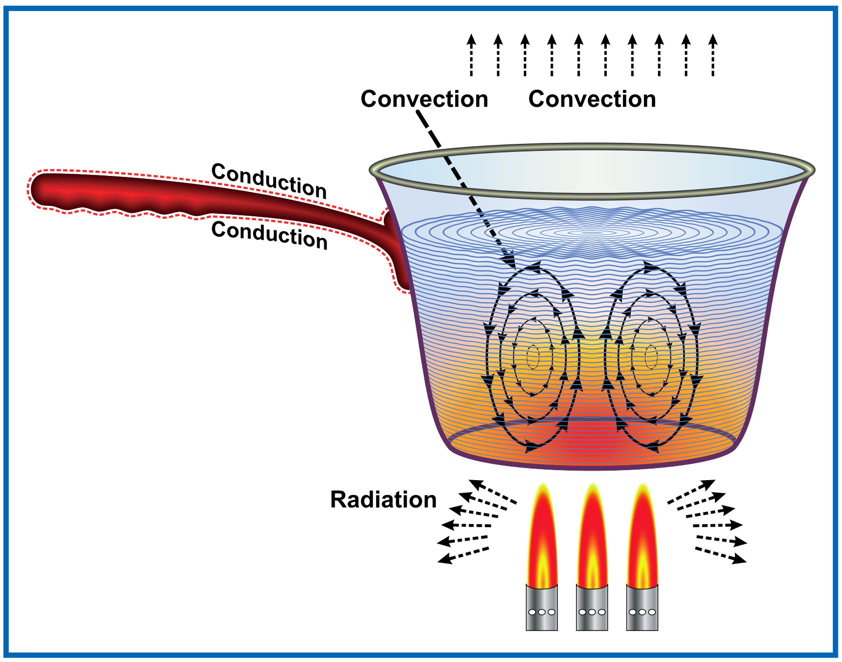

FIGURE 9. Heat transfer is the process of a food coming into contact with a heat source and becoming hot or the exchange of thermal energy between two objects.

Maillard Reaction

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.

FIGURE 10. The Maillard reaction causes this loaf of challah bread to brown. Most challah recipes also call for an egg wash to be applied just before baking to enhance browning.

Osmosis

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. Fruit has semipermeable cell membranes. As a result:

- Fruit cells release water when cut.
- Frozen fruit and cooked fruit wilt.

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:

- The moisture from the fruit moves into the sugar solute to create an equal concentration.
- Fresh apple slices are mixed with dry ingredients (e.g., sugar, spices, and flour) to create an apple pie filling.

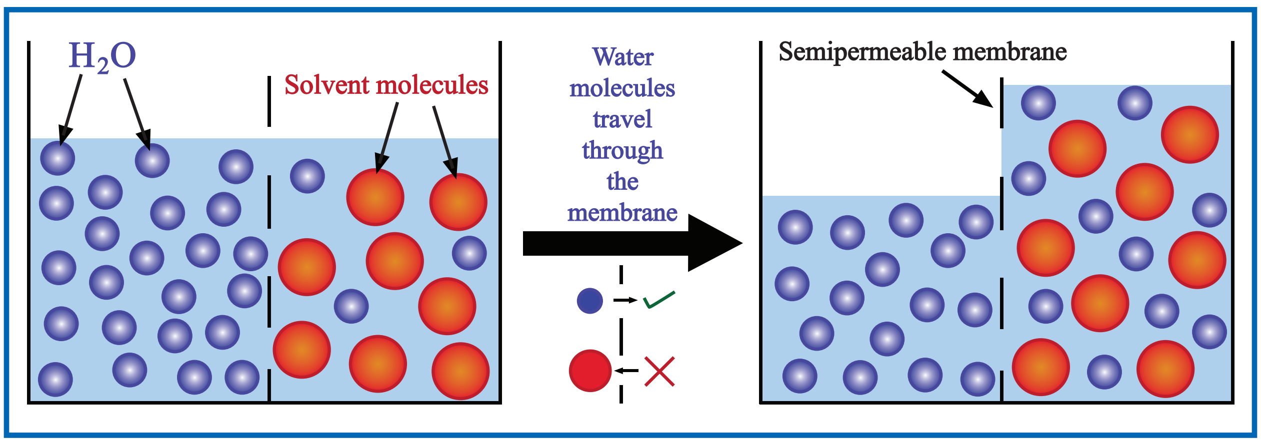

FIGURE 11. In this diagram of osmosis, the red circles represent sucrose, which will not move across the semipermeable membrane.

DIGGING DEEPER...

UNCOVERING ADDITIONAL FACTS: What Is Food Science and Technology?

Without food science and technology we would not have safe and sustainable foods that are innovatively packaged. Read more about this important science and think about whether these careers are in your future. To begin your research, go to the Institute of Food Technologists website at http://www.ift.org/knowledge-center/learn-about-food-science/what-is-food-science.aspx.

Fermentation

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.

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

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

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

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:

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

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.

INGREDIENT RATIOS

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.

Common Batter and Dough Ratios

Liquid or pour batter ratios include:

- 0:5:1:1 ratio: Crepes or French-style thin grilled "pancakes" filled with sweet or savory ingredients are typically half flour to one part liquid to one part eggs.
- 1:2:1 ratio: Popovers and/or Yorkshire pudding are airy, hollow rolls baked in an extremely hot oven and are one part flour to two parts liquid to one part eggs. They have a larger proportion of eggs than other pour batters.
- 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.

Drop batter ratios include:

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

Soft dough ratios include:

- 3:1:2 ratio: Scones are three parts flour to one part fat to two parts liquid.
- 3:2:1 ratio: Cookies are three parts flour to two parts fat to one part sugar.
- 1:1:0.6 ratio: Full puff pastry is one part flour to one part butter to 0.6 part water.
- 3:2:1 ratio: Traditional pie dough is three parts flour to two parts fat to one part liquid.

Stiff dough ratios include:

- 5:3 ratio: Yeast dough is five parts flour to three parts liquid.
- 3:2 ratio: Pasta is three parts flour to two parts eggs.

THE SCIENTIFIC METHOD

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.

Step-by-Step Process

Step 1: Formulate the question or state the problem.

- Write the problem as a question.
- Limit the problem to something that may be tested in an experiment.
- Simplify and test complex questions as separate problems.

Step 2: Identify known information about the problem (givens).

- Gather relevant information from previous experiments.
- Focus the scope of the experiment using the added information.

Step 3: Form a hypothesis (a statement that predicts what will logically happen during the experiment) **based on the currently known information.**

- Hypotheses may be proved or disproved during the experiment.
- Scientists often form several new hypotheses before arriving at a hypothesis that is proven.

Step 4: Design an experiment.

- All experiments have variables that one wishes to change and measure. There are two types of variables: independent and dependent.
- Independent variables are the factors one is changing in the experiment. For example, an independent variable could be:
  - The procedure or techniques used to mix the batter
  - The temperature of an ingredient
  - Variation in the amount of an ingredient
- The dependent variables (something that depends on other factors) are those elements studied during the experiment; studied when one independent variable is changed. For example, a dependent variable could be:
  - Height
  - Texture
  - Flavor of the product

- A controlled variable remains constant at all times during the experiment and is necessary to show the validity (soundness) of the experiment. For example, the temperature for baking could be a controlled variable.

Step 5: Observe and collect data during the experiment.

- Record accurate observations using a data table.
- Use scientific measurements for data collection.
- Compare the independent variable data to the controlled data.

Step 6: Analyze the data.

- Review collected data for trends or averages.
- Determine whether the data prove or disprove the hypothesis.

Step 7: Form a conclusion.

- Summarize the results of the experiment.
- Write a conclusion statement based on the experiment results.

FIGURE 12. 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.

Summary:

Baking and pastry preparations are chemistry in action. Each recipe or formula ingredient has properties and functions that react to create a unique product. The terminology of chemical reactions and physical changes help describe the chemistry and physics of baking: fermentation, caramelization, heat transfer, etc. Each type of batter and dough utilizes a specific ratio of ingredients to create a perfect baked good: flour to liquid to eggs to fat to leavening. Understanding the scientific method makes it easier to evaluate recipes and adapt recipes.

Checking Your Knowledge:

1. List five essential baking ingredients and their functions.
2. Describe how flour affects baked goods.
3. Explain five scientific terms related to baking. Define each in your own words.

4. How do recipe and formula ratios affect baked goods?
5. Describe the steps of the scientific method.

Expanding Your Knowledge:

What is so special about 350°F? Baking at 350°F is a default for a moderate oven temperature. How did 350°F become the default? Early ovens did not have digital temperature displays. Recipes would state oven temperatures as "moderate oven," "hot/high oven," or "slow oven." Early recipes used the terms "slow" oven for delicate foods, "moderate" oven for cakes and cookies, and "hot/high" oven for crusty breads. Some recipes even used "gas marks" to indicate the oven temperature. (Gas marks were placed on early ovens in Great Britain as a heat gauge.)

Different chemical and physical reactions happen to foods at different temperatures. Research how temperature impacts baking, and create a PowerPoint to share with your class.

Web Links:

How Temperatures Affect Food
http://www.fsis.usda.gov/shared/PDF/How_Temperatures_Affect_Food.pdf

The Maillard Reaction
http://modernistcuisine.com/2013/03/the-maillard-reaction/

Oven Temperatures
http://www.cookingforengineers.com/article/134/Oven-Temperatures

Starch Gelatinization
https://www.bakerpedia.com/processes/starch-gelatinization/

What's So Special About 350°F?
http://www.thekitchn.com/whats-so-special-about-350-f-food-science-217960