Leavening Agents: Physical and Chemical Reactions

BAKING IS SCIENCE. Bakers use formulas to ensure consistent products. Baking formulas measure ingredients by weight: pounds and ounces or milligrams or kilograms. In contrast, a baking recipe measures ingredients by volume: teaspoons, tablespoons, cups, dashes, and pinches. The exact measurement of leavening agents is crucial to the success of baked products. Even a small change in the amount of a leavening agent can impact the quality of baked goods. Is the whipped egg white meringue pictured here a physical or a chemical leavening reaction?

Objective:

Analyze the physical and chemical reactions produced by leavening agents.

Key Terms:

- absorption
- baker's percentage
- budding
- carbon dioxide (CO_2)
- carboxyl group
- colloidal dispersions
- colloids
- condensation
- creaming
- disaccharide
- enzyme
- evaporation
- fermentation
- foam
- foaming
- formula
- fungus
- hydration
- hygroscopic
- leaven
- leavening agent
- Maillard reaction
- maltase
- maltose
- recipe
- solution
- suspension
- triglyceride
- Tyndall effect

Understanding Leavening Agents: Physical and Chemical Reactions

To **leaven** is to rise or to cause batter and dough to expand. The term “leaven” comes from the Latin *levare*, which means to *lift*. A **leavening agent** is any ingredient that causes a baked product to rise by the action of air, steam, yeast, or chemicals. Leavening agents increase a baked good’s volume and help determine its shape, texture, and flavor.

The exact measurement of leavening agents is crucial to the success of baked products. Even a small change in the amount of a leavening agent can impact the quality of baked goods. The gases and the process of fermentation caused by leavening agents lighten batter and dough. Leavening agents are divided into three main categories: physical, biological, and chemical.

PHYSICAL AND CHEMICAL REACTIONS PRODUCED BY LEAVENING AGENTS

Baking is science. Bakers use formulas to ensure consistent products. A baking **formula** is something that measures ingredients by weight (pounds and ounces or kilograms or milligrams); it is a general science and math construct that shows the relationship between given quantities. Weight measurement is especially helpful when flours and sugars (anything sifted) are added to a baking formula. In contrast, a baking **recipe** is written instructions that measures ingredients by volume: teaspoons, tablespoons, cups, dashes, and pinches, which are perfectly fine for small batches.

Weight

Accurately measuring 4.54 cups of cake flour by volume is, at best, a guess; whereas accurately weighing 1 pound of cake flour is precise. In baking and pastry formulas, all ingredients are based on percentages (ratios), and the percentages are what allow people to scale the batter or dough up or down (doubling, tripling, etc.).

FIGURE 1. Baking is science. Bakers use formulas. A baking formula measures ingredients by weight: pounds and ounces or kilograms and milligrams. A baking recipe measures ingredients by volume: teaspoons, tablespoons, cups, dashes, and pinches, which are perfectly fine for small batches. This digital electronic scale is helpful when measuring small amounts, such as 2 ounces of baking powder or 1 ounce of cinnamon or active dry yeast.

Baker’s Percentage

Baker’s percentage (or formula percentage) is a conventional way to list ingredients in dough in which the quantity of each ingredient is expressed as a percentage of the total amount of flour. For instance, 1000g flour, 660g water, 20g salt, and 10g yeast is expressed in baker's percentage as 100 percent flour, 66 percent water, 2 percent salt, and 1 percent yeast. In a baker's formula, all amounts are expressed in percent of the total flour weight, although the correct term is "ratio" as the percentages always add up to more than 100 percent. If a formula calls for 4 pounds of flour, 4 pounds = 100 percent. In the same formula, two ounces of baking powder = 3.1 percent of the total flour weight. Reasons to use baker's percentage are:

- It enables the baker to work with precision using only one unit of measure.
- Baker's percentages make it easy to scale a formula up or down (doubling, tripling, etc.).
- It is easy to compare which formula is drier, sweeter, or saltier.
- Baker's percentages more accurately measure uniformly an ingredient—such as eggs—in which the quantity per unit may vary.
- It serves as a common language among all bakers and baking operations. Often the scientific method is used to experiment with recipes and formulas that use leavening agents.

Physical Reactions

Air trapped in beaten egg white foams and in fat molecules (due to beating and/or creaming) physical reactions cause products to rise (leaven).

Foaming

Foaming is the beating of eggs, with or without sugar, to add air. Egg whites are a protein that microscopically resembles small spiral shapes. When whipped or beaten, the spirals stretch and are capable of holding air cells in suspension. The egg whites begin to look foamy and white as they hold more and more air and finally become quite fluffy. If these fluffy egg whites (soft and/or stiff meringue) are added to other batters, all the little air pockets are added too. When the lightened batter is exposed to heat, the air pockets swell and make the mixture rise. Albumin (egg white) contains the protein lecithin. When albumin is beaten, the protein lecithin lines the outside of the air bubbles and creates bubbles that do not collapse during baking.

Creaming

Creaming is the process of beating fat and sugar together rapidly to add air. When properly creamed, the mixture becomes light and fluffy by incorporating air into the mixture. As with the

FIGURE 2. Creaming is the process of beating fat and sugar together rapidly to add air, which leavens the mixture by trapping air in fat molecules.

whipped egg whites, the air mixed into the fat/sugar mixture swells when heated, and the product rises.

Cream

Cream is fat that rises to the top when raw milk sets. In the United States, the FDA defines heavy cream as 36 percent milk fat with the rest being water. Whipped cream is an example of **foam** (suspended gas bubbles). The foam is stabilized with the fat found in cream. Milk and cream contain colloids.

- **Colloids** are mixtures of small, insoluble particles found in solutions and suspensions that are evenly distributed without "settling out." Milk and cream are examples of **colloidal dispersions** or mixtures of colloid particles in a dispersing medium. [NOTE: A mixture is a combining of two or more substances, not "chemically" combining them.] Milk fat or cream is a mixture of lipids (fats). The most numerous is **triglyceride** (a glyceride and three fatty acids). Triglycerides are composed of carbon, hydrogen, and oxygen that form a **carboxyl group** (COOH) and the rest (R) of the compound.
- A **solution** is a homogeneous mixture (a uniform composition) of two or more components. Water and sugar is an example of a homogeneous solution, and the sugar dissolves in the water.
- A **suspension** is a heterogeneous mixture (a non-uniform composition, such as sand and water) of a fluid and solid particles in which these components are mechanically dispersed and eventually settle out. In an oil and water mixture, shaking the mixture causes it to temporarily "suspend" the heavier water in the oil.
- Colloids and suspensions are different primarily because the suspension components eventually settle out. Colloids are different than solutions due to the **Tyndall effect**, which is a situation in which a beam of light passes through a colloid. The true solution, such as air, is not visible. However, the particles in colloids are large enough to deflect the light.

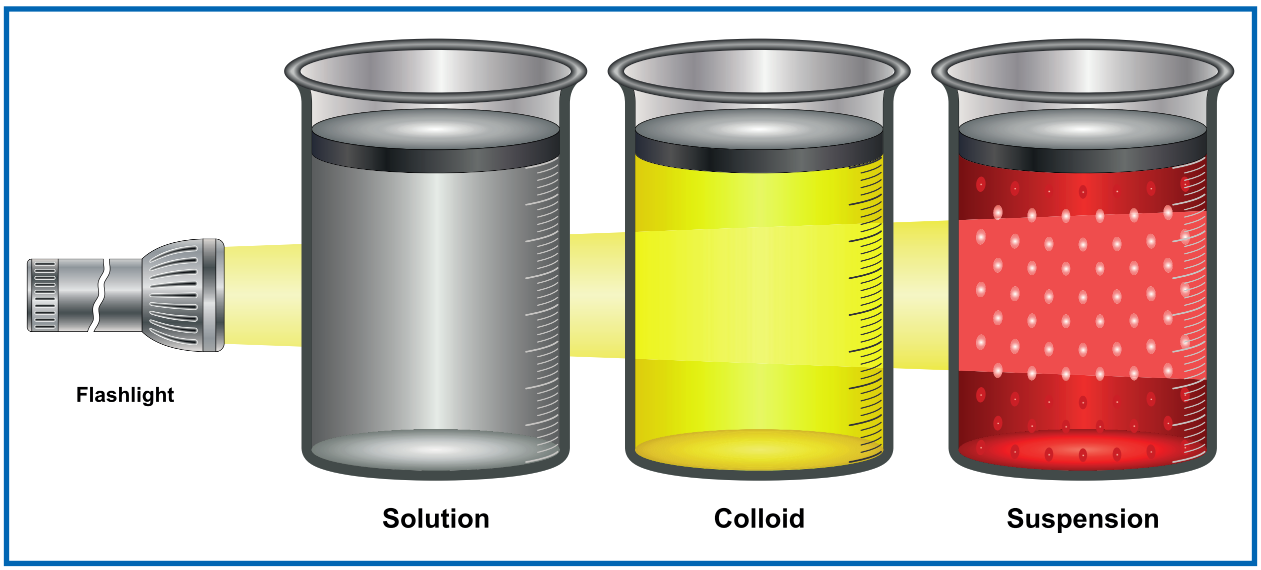


FIGURE 3. Colloids and suspensions are different primarily because the suspension components eventually settle out. Colloids are different than solutions due to the Tyndall effect. A beam of light passing through a true solution, such as air, is not visible. However, the particles in colloids are large enough to deflect the light.

Steam Leavening

Steam leavening is created by physically heating moisture in batter and dough to convert that moisture to steam. Steam leavening, to some degree, is part of all baked goods' lift. It is a powerful form of leavening. When water turns to steam, it increases to 1,100 times its original volume. As the gas rises, it takes the batter or dough with it. Steam loses its ability to leaven when temperatures drop below the boiling point (212°F). Ovens, griddles, and some pans must be preheated for the process of steam leavening to work to capacity. As steam cools, it produces condensation.

Condensation

Condensation is the conversion (changing) of a vapor or a gas to a liquid; it is the reverse of evaporation. When cold batter and dough are placed into a warm oven, moisture (condensation) is produced on the surfaces. This action cools down the crust and allows the baked goods to rise before the crust hardens. In fact, a porous surface on baked goods is due, in part, to moisture condensation.

Evaporation

Evaporation is the conversion of a liquid to a vapor at temperatures below the boiling point. The rate of evaporation increases with the rise in temperature. Evaporation is used in many culinary processes to concentrate a solution (e.g., "cooking down" pan sauces to thicken and intensify the flavor and simmering tomatoes to release moisture and thicken a pasta sauce).

Chemical Reactions

Yeast is tiny **fungus** or "microorganism," according to scientists. Yeast reproduces asexually by **budding**, which is a type of reproduction in which a new organism grows atop the first and only detaches when it is mature. They are egg-shaped cells that can only be viewed with a microscope. It takes 20,000,000,000 (20 billion) yeast cells to weigh one gram or 1/28 of an ounce, according to Red Star Yeast.

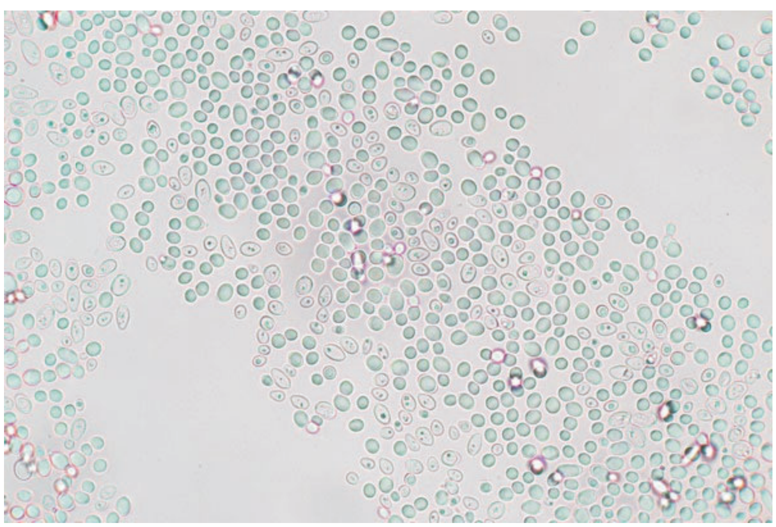


FIGURE 4. This is a microscopic image of the baker's yeast *Saccharomyces cerevisiae* budding.

The scientific name for a species of baker's yeast is *Saccharomyces cerevisiae*: a sugar-eating fungus. Yeast requires carbohydrates (which convert to glucose) and moisture (water or milk) to begin fermentation. Adding water or other liquids hydrates (causes liquid to be absorbed) the flour and allows fermentation to begin.

Yeast cells digest food to get energy to grow. The food they use is sugar in various forms: sucrose (table sugar), fructose (fruit), glucose (honey and molasses), and maltose (starch in flour). Yeast is able to ferment and make bread rise without the addition of typical sugars via the maltose starch in flour that converts into sugar. Additional sugar and warmth speeds up the fermentation reaction. Salt slows the growth of yeast and creates smaller air pockets.

Enzymatic Action

An **enzyme** is a special protein that causes an increase in the rate of a chemical reaction (acts as a catalyst) without changing the chemical reaction at the end of the reaction period. In yeast leavening, enzymes are used to break down starches and sugars.

Wheat flour contains starch molecules, amylose, and amylopectin. Amylose is a straight chain of glucose, and amylopectin is a branched chain. Amylase is the enzyme that breaks down the long chains of starch into smaller chains.

Maltase is the enzyme that breaks down maltose into two units of glucose. **Maltose** is a disaccharide made up of two units of glucose. A **disaccharide** is a sugar made up of two monosaccharides bonded together. [NOTE: Enzymes end in the suffix "ase" and sugars end in the suffix "ose." Maltase is the enzyme that reacts with maltose.]

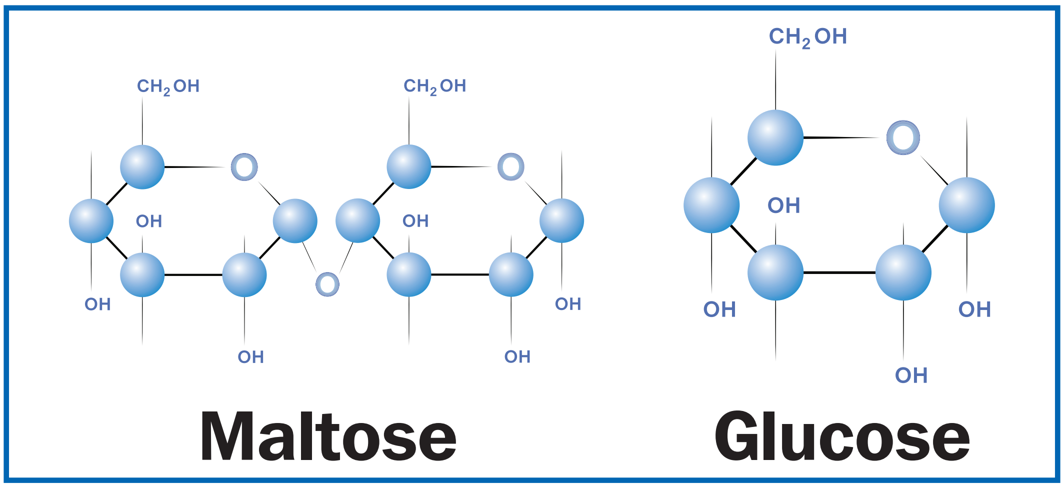


FIGURE 5. Compare the chemical structures of maltose and glucose.

Fermentation

Fermentation is the process yeast uses to convert sugars into carbon dioxide and alcohol. The sugar may be table sugar or honey and/or maltose (sugar from wheat starch). Maltose is broken down into glucose before it is converted into carbon dioxide gas.

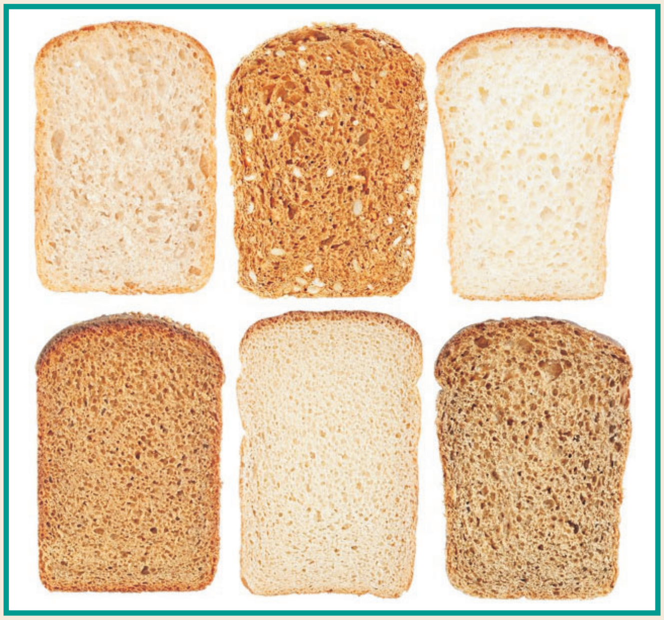
The chemical equation of glucose fermentation is:

$C_6H_{12}O_6$	÷	$2C_2H_5OH$	+	$2CO_2$
glucose	÷	ethanol (a type of alcohol)	+	carbon dioxide

UNDER INVESTIGATION…

LAB CONNECTION:
Experimenting With the Effect of Salt and Sugar on Yeast Bread

See the experiment, "Making Bread," on the Red Star Yeast website at http://redstaryeast.com/science-yeast/yeast-experiments/. Experiment #1 tests the effect of salt in yeast bread dough. Experiment #2 tests the effect of sugar in yeast bread dough. Each experiment makes one recipe with and one recipe without the ingredient studied. Try these experiments. Report how each ingredient, and the amount, affects the yeast bread's texture and volume.



Describe the texture of each of these bread slices.

Fermentation occurs in the absence of oxygen with bacteria. This type of fermentation produces numerous dairy foods (e.g., yogurt, cheese, and kefir), vegetables (e.g., pickles, Korean kimchi, sauerkraut, chocolate), and sauces (e.g., fish sauce and soy sauce).

FIGURE 6. Fermentation is the process yeast uses to convert sugars into carbon dioxide and alcohol. Fermentation also occurs in the absence of oxygen with bacteria and includes the Korean kimchi dish, pictured here.

Maillard Reaction

The **Maillard reaction** is the browning that occurs as proteins (amino acids) and sugars (carbohydrates) in the same food are exposed to heat and merge together to form the exterior surface crust of a cooked or baked product. In short, it is a chemical reaction between an amino acid and a reducing sugar, usually requiring the addition of heat. Bread's flavor is formed in the crust as it reaches a temperature of 302° to 356°F, while the internal bread temperature does not exceed 210°F. Higher temperatures cause the sugar in the dough to brown, creating a fruity or wine-like fragrance. Removal of the crust too soon after baking prevents the crumb from absorbing the crust flavor, causing it to taste different (Red Star Yeast). The Maillard reaction is evident in:

FIGURE 7. Bread's flavor is formed in the crust as it reaches a temperature of 302° to 356°F while the internal bread temperature does not exceed 210°F. The Maillard reaction is evident on this loaf of nicely browned bread.

- Caramel made from milk and sugar
- The browning of bread into toast
- The color of beer, chocolate, coffee, and some syrup
- Self-tanning products
- The crust and flavor of roasted meats
- The color of dried or condensed milk

Absorption

Absorption is the act of taking in or soaking up particles of gas or liquid in a liquid or solid. (Absorption can be physical or chemical.) **Hygroscopic** is the ability of a chemical to absorb water from its surroundings. Leavening agents absorb liquids and require the absorption of liquid to begin the leavening process. Liquid is absorbed into flour. The more water absorbed into flour, the more the dough stretches and the more pan flow (ease of dough filling the pan's shape). **Hydration** is the ratio of liquid ingredients (mainly water) to flour in the dough. Dough with 500g of flour and 310g of water has a hydration of 62 percent. The percentage of absorption varies by baked good.

- Cookies have a water absorption rate of 50 to 54 percent.

EXPLORING OUR WORLD...

SCIENCE CONNECTION: Bread Hydration

Professional bakers determine the hydration of bread by comparing the percentage of flour to liquids. Bakers consider hydration the most important factor in mixing to achieve the final appearance of the product and texture of the crumb. Bagels have a 50 to 57 percent hydration ratio. In contrast, rustic breads, such as ciabatta or focaccia, have 65 to 80 percent hydration. For more information, see "Hydration—Bread Dough" at http://www.craftybaking.com/howto/hydration-bread-dough.

- White bread has a water absorption rate of 60 to 62 percent.
- Ciabatta bread has a water absorption rate of 80 to 90 percent.

Carbon Dioxide

Two widely used chemical leavening agents and one living organism (yeast) produce the carbon dioxide (CO_2) gas in baked goods. Carbon dioxide is used to leaven or make baked goods rise.

Baking soda ($NaHCO_3$) (or sodium bicarbonate) produces carbon dioxide using the following formula when heated:

$2NaHCO_3$	÷	CO_2	+	Na_2CO_3	+	H_2O
sodium bicarbonate		Carbon dioxide		sodium carbonate		water vapor

Baking soda must be used with acid in a recipe or formula. Baking soda has no leavening power until it is combined with an acid. If baking soda is used in a recipe or formula without an acid, it produces a bitter taste and a yellowish color. In addition, baking soda is a single-action leavening agent that only reacts once when mixed with an acid (e.g., cream of tartar, buttermilk, molasses, sour cream, yogurt, lemon juice, vinegar, brown sugar, or cocoa). As a result, no dough or batter prepared with baking soda is allowed to "sit" before baking. Adding baking soda to other dry ingredients of a recipe or formula prevents activation until liquids are added. Baking soda works best on soft or weak batters, such as pancakes, muffins, and some quick breads.

Baking powder is a chemical leavening agent that produces more carbon dioxide gas than baking soda. It contains baking soda, dry acids, and starch filler. Most baking powder is double acting. It reacts once when liquids are added to the dough or batter at room temperature and again when the dough or batter reaches 140°F. It produces carbon dioxide using the following formula when heated:

$NaHCO_3$	+	H^+	÷	Na^+	+	H_2O	+	CO_2
baking soda		hydrogen from acid		salt		water		carbon dioxide

Summary:

Baking is science. Bakers use formulas to ensure consistent products. Baking formulas measure ingredients by weight: pounds and ounces or milligrams or kilograms. In contrast, a baking recipe measures ingredients by volume: teaspoons, tablespoons, cups, dashes, and pinches. The exact measurement of leavening agents is crucial to the success of baked products. Even a small change in the amount of a leavening agent can impact the quality of baked goods.

Air trapped in beaten egg white foams and in fat molecules (due to beating and/or creaming) are physical reactions that cause products to rise (leaven). Steam leavening is created by physically heating moisture in batter and dough to physically convert that moisture to steam. Steam leavening, to some degree, is part of all baked goods' lift. It is a powerful form of leavening.

Budding, enzymatic action, fermentation, the Maillard reaction, absorption (including hygroscopic and hydration action), and carbon dioxide production all influence the leavening process, appearance, texture, and flavor of baked goods. Expand your knowledge, your artistic skills, and your experimentation in the science of baking.

Checking Your Knowledge:

1. Differentiate between a baking formula and a baking recipe.
2. How does baker's percentage influence baking and pastry product formulas?
3. What are the advantages of using baker's percentage formulas?
4. Describe physical leavening agent reactions: air and steam.
5. Describe chemical leavening agent reactions: biological and chemical.

Expanding Your Knowledge:

"Oh no! We're out of baking powder!" Has this ever happened to you? You can make your own baking powder and bake your favorite homemade cookies if you have cream of tartar, baking soda, and cornstarch on hand. (If you have a grain allergy, use arrowroot instead of cornstarch.) Once prepared, store in an airtight container. Find different recipes online to try for comparisons.

Web Links:

All About Leavening
http://bigbaketheory.com/2012/01/23/all-about-leavening/

Homemade Baking Powder Recipe
http://allrecipes.com/recipe/229290/homemade-baking-powder-recipe/

Organic Homemade Baking Powder Formula
http://simplelifemom.com/2015/03/12/homemade-baking-powder-recipe/

Preferments
http://www.kingarthurflour.com/professional/preferments.html

The Science of Baking Cookies
http://luckypeach.com/the-science-of-baking-cookies/