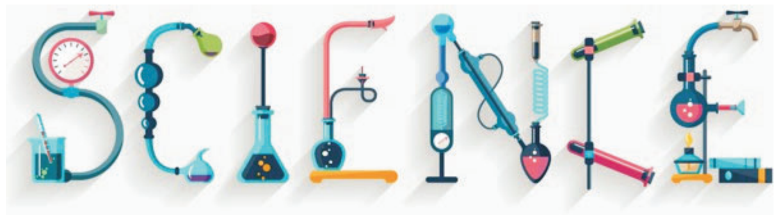
Foam Cakes: Baking Science



BAKING is a science. Numerous physical changes and chemical reactions are necessary to prepare the perfect foam cake. A cake mixture is complex, with relatively few basic ingredients. Foam cakes use only three main ingredients: eggs, sugar, and flour. The scientific processes that transform these limited ingredients into cake does not have to be completely understood, but knowledge is power. Knowing the reasons why foam cakes rise can make it easier to correct (or avoid) mistakes. Air bubbles are the main leavener for foam cakes. Understanding the science behind the leavening process will help you bake amazing, light, delicious cakes.

Objective:

Analyze physical changes and chemical reactions that occur in foam cake preparation.

Key Terms:

- absorption
- caramelization
- carbon dioxide (CO_2)
- chemical reaction
- coagulate
- coagulation
- colloidal dispersion
- condensation
- conduction
- convection
- denature
- denaturation
- emulsion
- endothermic reaction
- exothermic reaction
- evaporation
- foam
- gluten
- heat transfer
- homogenous mixtures
- hydrolysis
- hygroscopic
- immiscible
- invert sugar
- lipid
- Maillard reaction
- pan flow
- pH
- pH scale
- physical change
- radiation
- relative humidity (RH)
- saccharide
- surface area
- surface tension
- triglyceride
- viscosity

The Science of Foam Cakes

Baking is a science. Many scientific actions occur when making and baking foam cakes. Numerous physical changes and chemical reactions are necessary to prepare the perfect foam cake. The difference between a chemical reaction and a physical change is compositional. This section will discuss the definitions and various situations related to chemical reactions and physical changes when baking.

ANALYZING PHYSICAL CHANGES AND CHEMICAL REACTIONS

Cake mixtures are complex: they are simultaneously foam, emulsion, and complex colloidal dispersion. The three main components of a foam cake are eggs, sugar, and flour. The process to transform these ingredients into a foam cake (something solid) is part of a scientific process through physical changes and chemical reactions. Understanding the science behind these processes will help you bake amazing, light, delicious cakes.

Chemical Reactions

A **chemical reaction** is a process that produces a permanent change in the chemical composition and molecular structure of a substance. For example, fresh eggs that are fried cannot become fresh eggs again. The protein in the egg has been permanently changed, and the structural makeup is very different. When dough and batter are heated in an oven, a chemical reaction occurs and new bonds are formed. Heat creates exothermic and endothermic chemical reactions.

For example, baking a cake produces an endothermic reaction that changes sticky batter into a solid cake. An **exothermic reaction** produces heat. An **endothermic reaction** absorbs heat.

- Heat helps leavening agents produce tiny gas bubbles that make the cake light (by rising).
- Heat causes egg proteins to firm, helping to give the cake structure.
- Heat dries cake batter (fats are still able to keep the cake moist).

FIGURE 1. To be termed a chemical reaction a new substance must be formed. When water boils, liquid water changes into steam, but it's still water (in a gas form)—a physical change. It's possible for the steam gas to return to a liquid state; however, when vinegar is added to baking soda, the gas produced is a new substance, CO_2. It is not possible to turn this gas back into vinegar and baking soda—an example of a chemical reaction.

Physical Changes

A **physical change** is the transformation of a substance that does not alter its chemical properties—a phase change. The change can involve a difference in the way the substance displays appearance (color or shape), texture, temperature, or smell, but it usually results in a change of state, such as liquid to solid. Melting, boiling, and freezing are examples how to create a physical phase change. An ice cube that melts is still water, and its chemical properties remain intact. [NOTE: In the physical change described here, the ice cube and warm temperature are the reactants—the ingredients of physical change. The liquid water is the product, or result, of a physical change.]

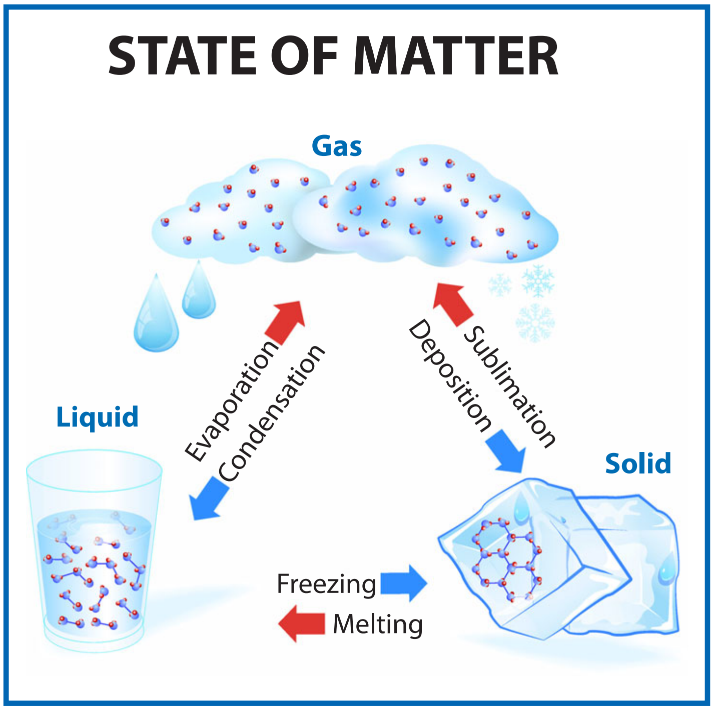


FIGURE 2. A physical change can involve a difference in the way the substance displays appearance (color or shape), texture, temperature, or smell, but it usually results in a change of state, such as liquid to solid. Melting, boiling, and freezing are examples of physical phase changes. An ice cube (frozen water) that melts is still water and its chemical properties remain intact.

Absorption

Absorption is the act of one substance (liquid or solid) taking up (soaking up) particles from another substance (gas or liquid) by physical or chemical means.

Hygroscopic

Hygroscopic is a term relating to the ability of a substance to absorb water from its surroundings. Liquid is absorbed into flour. The more water absorbed into flour, the more the batter stretches. This creates more **pan flow** (ease of the batter filling the pan's shape). Sugars are hygroscopic, including table sugar, honey, brown sugar, and molasses. Foam cakes often use caster or superfine sugar that dissolves easily in the egg foam. Sugar attracts water, keeping baked goods moist and soft. [NOTE: The prefix "hygro" relates to humidity. A hygrometer measures humidity, while a hygroscope indicates when humidity is present.]

Gluten

Gluten is an elastic protein found in wheat and cereal flours that gives batter and dough elasticity, strength, and the rising ability. Gluten comes from a plant's endosperm (the starchy portion of a grain), and it forms when water is added to the two flour proteins of glutenin and gliadin (found in wheat, barley, or oats). Gluten continues to develop as the foam cake batter is mixed. Most foam cakes use cake flour that contains less protein, so foam cakes generally have less gluten development. Gluten provides chew.

Condensation

Condensation is the conversion (a physical change) of a vapor (gas) into a liquid—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 it allows the baked good to rise before the crust hardens. A porous surface on a baked good can be due to too much condensation.

FIGURE 3. Condensation on this water bottle is similar to the physical change that happens when cake batters are placed in a preheated oven. Water beads appear on the surface of the batter, and they also aid in steam leavening.

Evaporation

Evaporation is the conversion (a physical change) of a liquid into a vapor (gas). The rate of evaporation increases with the rise in temperature. Evaporation is used in many culinary processes to concentrate a solution; such as cooking down pan sauces to thicken and intensify the flavor, simmering tomatoes to release moisture, or thickening a roux.

Emulsion

An **emulsion** is a semi-liquid, stable mixture in which one or more liquids are suspended within another. An emulsion can have two or more **immiscible** (unmixable) ingredients. While emulsions are immiscible, **homogeneous mixtures** are a mix of ingredients that have a uniform composition (the same properties throughout).

Typical emulsions include a liquid suspended in a fat or an oil. (Think of vinegar and oil dressing.) The goal in baking is to form a water-in-fat emulsion. An unstable cake-batter emulsion can curdle or weep. [NOTE: The addition a tablespoon or more of flour to a curdled cake batter may reverse the appearance of curdling. Foam batters are whisked for air leavening, and must have a stable emulsion for proper rise.]

Chiffon cakes often use oil or butter. Some génoise cakes use solid butter, melted butter, or clarified butter in their recipe. Solid butter should be used at 60°F to 70°F. Whole eggs, egg whites, and egg yolks must be at room temperature to whip to their maximum volume. [NOTE: For more general information about emulsions, see MYcaert CA B3–8 lesson and e-unit.]

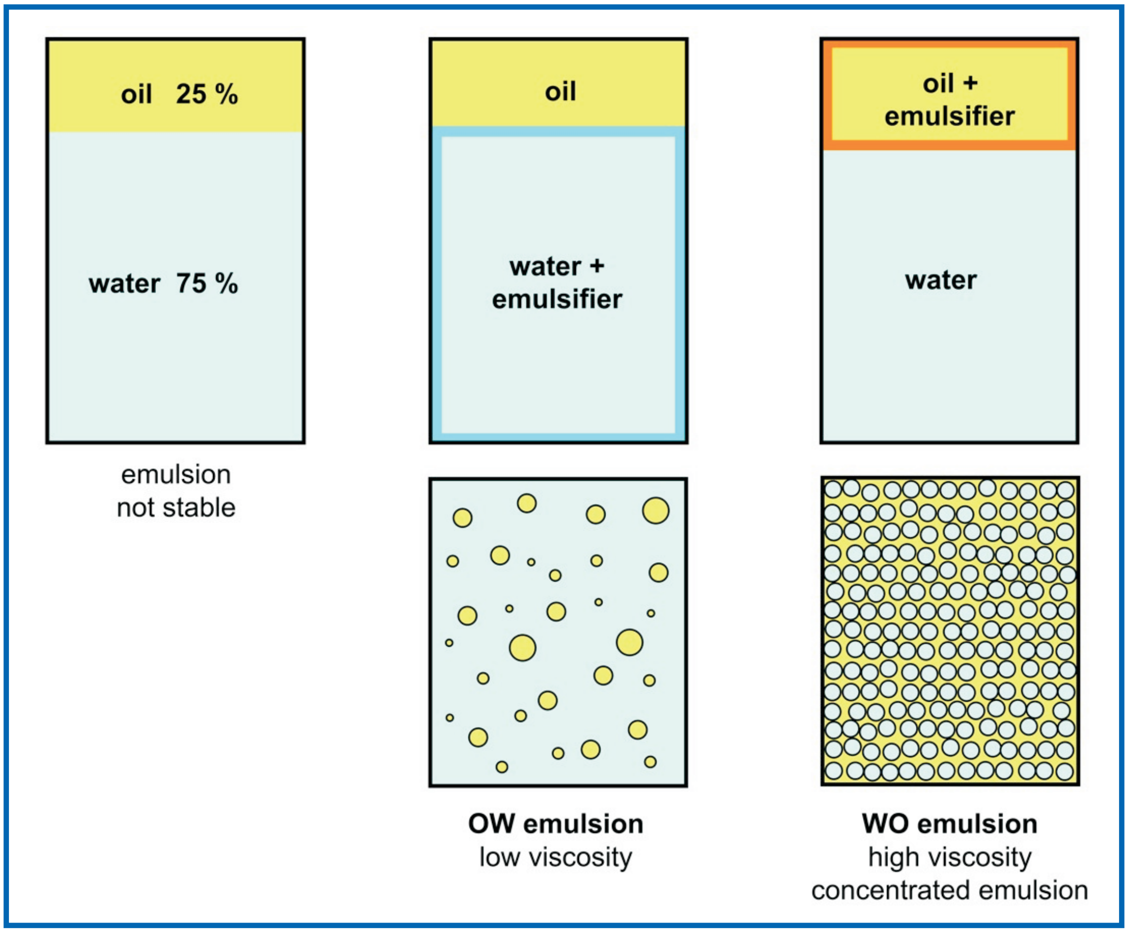


FIGURE 4. This illustration is of three types of emulsions. Think about an oil and vinegar salad dressing as an example of the "emulsion not stable" (before you shake the dressing ingredients). The "OW (oil/water) low viscosity" emulsion occurs after you shake the dressing ingredients. Now, consider the "WO (water/oil) high viscosity" emulsion. In terms of foam cakes, what ingredient serves as the emulsifier?

Heat Transfer

A **heat transfer** is the exchange of thermal energy between two objects, or the physical process of a food absorbing heat from a source. While heating food, molecules absorb energy, vibrate quickly, and bounce off each other. Each collision produces heat, which is transferred to the food. This is the basis of cooking. There are three methods of heat transfer. [NOTE: For more detailed information, the Biscuit People article, "Heat Transfer for Biscuit Baking," can be read at http://biscuitpeople.com/heat-transfer-for-biscuit-baking/. Their process described for biscuits is the same for foam cakes.]

Radiation

Radiation is the transmission of heat through waves of energy. Microwave and infrared waves are two types of radiation in cooking. Radiant heat is evident when opening a preheated oven, stretching your hand over coals, or feeling your skin near a boiling pot. Warmed air is transferred to food and cooks it (radiation cooks through indirect contact).

Conduction

Conduction is the passing of heat between solid objects through direct contact. For example, heat is conducted from stovetop burners to pots and pans. Heat is then conducted from the pots and pans to the food. Cake pans transfer heat, by conduction, to the batter.

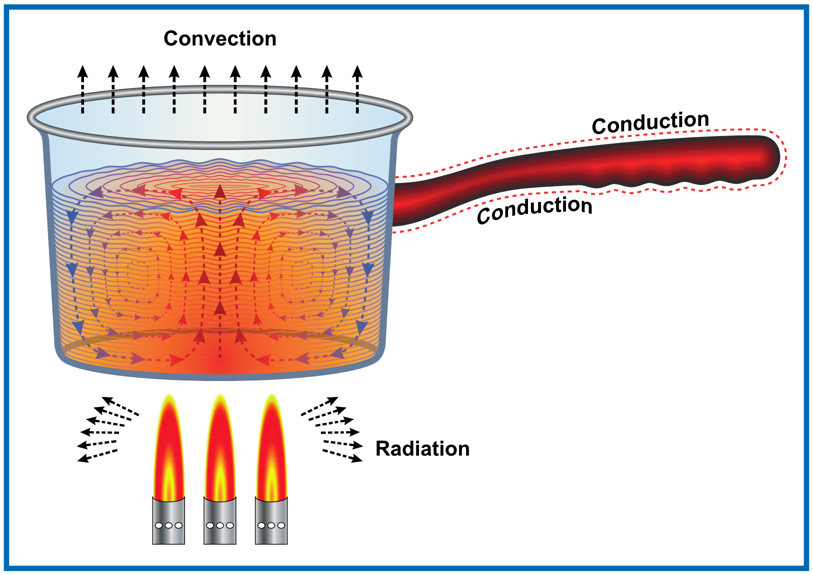


FIGURE 5. Heat transfer is the physical process of food absorbing heat from a source. In foam cakes, how does convection transfer happen? How does radiation heat transfer occur in a foam cake? What causes conduction to occur during baking? [HINT: Think about what's happening with each of these elements during baking—the baking pan, the oven, and the batter.]

Convection

Convection is the transfer of heat by the circulation of warm air or water. In a convection oven, a fan blows hot air over and around the food. (In savory cooking, sous-vide is a method of cooking sealed bags of food in a warmed water bath. In foam cakes, the double boiler and bain-marie are two convection heat sources used.)

Caramelization

Caramelization is the oxidization (browning) of sugar, or the natural sugars in fruits and vegetables, in order to get a sweet, nutty, brown sauce or coating. Caramelization is the last chemical reaction to occur during baking. It only occurs when sugars are heated. The flavors of caramelization occur after 356°F is reached. Cakes baked at 350°F have no caramelized flavor, but might have ingredients that caramelize. Each sugar type caramelizes at a different temperature.

- Fructose caramelizes at 230°F (110°C).
- Sucrose caramelizes at 320°F (160°C).
- Baked goods made with honey or fructose develop a darker color, because they begin browning at a lower temperature (honey contains fructose).

Hydrolysis

Hydrolysis is the chemical separation of a compound through the addition of water. For example, adding water to sucrose leaves glucose and fructose. The result of this hydrolysis is an invert sugar. An **invert sugar** is equal parts glucose and fructose (derived from water and sucrose). In a foam cake, the heating of eggs and sugar (prior to whipping) allows time for the conversion of sucrose (table sugar) to begin (with moisture from the fat—including egg yolks).

[NOTE: The inversion processes can involve the hydrolysis of sucrose with an acid and some heat (used in candy making).]

Foam

Foam is a mass of bubbles that is created in or on the surface by whipping or agitation. In foam cakes, the act of whipping egg whites causes a protein film that holds the foam. A child blowing bubbles with a wand dipped in a soapy solution creates a type of foam. All foams are a type of **colloidal dispersion** (a suspended substance) in which air is dispersed without dissolving. Not all ingredients foam. To foam, a liquid must have a low surface tension.

Surface tension is a property of a liquid that allows it to resist external forces. The surface of a liquid, where the liquid is in contact with gas, acts like a thin elastic sheet. (Remember the soap bubble? It's a pressurized bubble of air contained within a thin, elastic surface of liquid. This is surface tension.) Warm temperatures lower the surface tension of liquid eggs, making it easier for bubbles to form. Egg foams develop the volume and lightness of sponge, génoise, and chiffon cakes due to their ability to foam, and the innate surface tension of liquid eggs.

Denature

Natural proteins, at the molecular level, are shaped like coils or springs. When exposed to heat, salt, or acid, they **denature** ("de-nature," lose natural characteristics or break apart) and the coils unwind. Foams form when the protein in the eggs denatures. When proteins denature, they **coagulate** (bond together and form solid clumps). As a foam cake bakes, protein in the egg whites (ovalbumin) coagulates and gives the foam structure.

Denaturation

Denaturation is a chemical reaction from heat or acidity that breaks down a substance's molecular structure. With food, a protein's molecule loosens its hydrogen bonds that originally formed coils and springs, and then, it turns it into a long, shapeless chain. Denaturation occurs in egg whites due to the physical heat from whipping—which causes the proteins to unfold. Egg whites' **viscosity** (a measure of thickness, or resistance to flow), due to their large protein molecules, makes them easily denatured by whipping. In contrast, regular milk does not retain the foam that forms when it is whipped, because milk contains less protein and is less viscous. On the other hand, heavy whipping cream has the viscosity to stand up to whipping and retain its foam.

Egg Foam

Both egg yolks and whites can foam. Egg-white foam provides the most leavening and structure to a foam cake. A single egg white can expand six to eight times in volume when whipped. Older egg whites thin out over time and are easier to whip (An older egg white will whip to stiffer peaks than a fresh egg).

Salt

Adding salt to egg whites while whipping deflates the foam. It was a long held belief that salt "stabilized" rather than deflated the egg whites. [TIP: If salt is added to a foam cake batter, it should be added with the flour.]

pH Scale

When working with foods, **pH** is the level of acidity or alkalinity (a.k.a. basicity) of a given substance. The **pH scale** is a system of numbers used to measure the pH levels of a water-based liquid, with seven being neutral. The scale is a linear measure from 0 to 14. Neutral (neither acid nor alkaline) is a pH of 7 (water). Acid is a pH of less than 7 (lower numbers on the pH scale). Alkaline is a pH greater than 7 (high numbers on the pH scale). Alkaline substances release higher levels of hydrogen when mixed with water. Acids neutralize alkali and vice versa.

Egg pH

Fresh egg whites foam best at a pH of 4.6 to 4.8. In other words, fresh eggs are best for all foam cakes (versus bulk liquid, dried, or frozen egg whites). [NOTE: For more information about pH and pH scale, see the MYcaert lesson CA B3–9: pH in Cooking.]

Cream of Tartar pH

Cream of tartar (an acid) lowers the pH of egg whites. This is why cream of tartar is added to eggs for whipping in a foam cake or a meringue. Cream of tartar allows the egg whites to produce more foam and stabilizes the egg whites. White vinegar or lemon juice can be substituted for cream of tartar. These acids would also lower the pH of the egg whites. Cream of tartar also whitens the cake and provides a fine-grained texture.

The Maillard Reaction

The **Maillard reaction** is a chemical effect that occurs when proteins and sugars react and break down under heat. Amino acids and simple sugars rearrange into rings that reflect light and produce a browned appearance (and tantalizing aromas). It is a series of three complex reactions. These reactions occur between amino acids (proteins) and sugars (monosaccharide and some disaccharide sugars that can donate electrons to another chemical) being reduced at higher temperatures. The Maillard reaction (named for the scientist, Louis Camille Maillard) produces different aromas in bread than in standing rib roast or baked fish, because the amino acids and simple sugars differ in those foods. This process is responsible for the browning of a cake, as well as its toasted flavor. As the oven, grill, or pan temperatures increase, so does the Maillard reaction. [NOTE: The Food-Info.net website has for more information on complex reactions and Louis Maillard at http://www.food-info.net/uk/colour/maillard.htm.]

EXPLORING OUR WORLD...

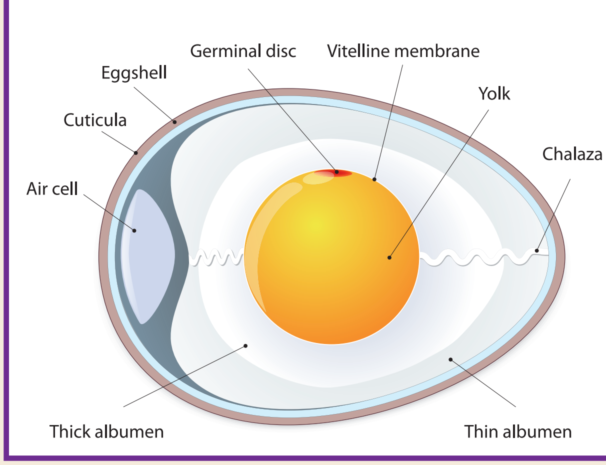
SCIENCE CONNECTION:
The Effects of an Acid on Protein

Experiment with egg whites to see the effects of an acid on an egg-white protein. Collect the following equipment and materials:

- 1 egg white, white vinegar, and water (room temperature)
- 2 clear glass custard cups or 100-milliliter beakers
- 2 small saucepans and a timing device.

Follow these procedures:

STEP 1. Pour about ½ an inch of vinegar into one custard cup (or 100 milliliter beaker). Pour about ½ an inch of room temperature water into the other.



This schematic shows the structure of a chicken egg.

STEP 2. Separate an egg. Do not allow any yolk in the egg white. Divide the egg white into 2 equal portions. If possible, do not use the chalazas (the cords that hold the yolk in place). Place one egg-white portion into the 2 glass custard cups (or 100-milliliter beakers).

STEP 3. Add ½ inch of tap water to both small saucepans. Place each container, with the egg white and liquid, into a separate saucepan of water.

STEP 4. Heat each pan at the same time, on the same size burner, and at the same temperature setting.

STEP 5. Using a timing device, observe the differences and record on the data table.

COMPARING EFFECTS OF WATER & VINEGAR ON EGG WHITE PROTEIN

Record your descriptions of the appearance of the egg white on the following timetable.

Time	Egg White in Water	Egg White in Vinegar
At 1 minute		
At 3 minutes		
At 5 minutes		

STEP 6. Summarize what you observed. How does this experiment apply to the preparation of foam cakes and other protein foods?

CO_2

Carbon dioxide (CO_2) is a colorless, odorless gas (except in high concentrations), and it is a natural by-product of cellular respiration. Baking soda, baking powder, and yeast are all leavening agents that produce CO_2. (Baking soda and baking powder are two common chemical leavening agents, while yeast is a living organism.) CO_2 is evident in the leavening of cakes and other baked goods.

Baking Soda

Baking soda ($NaHCO_3$), or sodium bicarbonate, is a chemical leavening agent that, when heated, produces and releases carbon dioxide using the formula $2NaHCO_3 \rightarrow CO_2 + Na_2CO_3 + H_2O$. (Sodium bicarbonate releases carbon dioxide, sodium carbonate, and water vapor.) In a recipe, Sodium bicarbonate needs paired with an acid. If baking soda is used in a recipe without an acid, it will produce a bitter taste and a yellowish color.

Baking soda is a single-action (reacts only once) chemical leavening agent that reacts when mixed with an acid, such as cream of tartar, buttermilk, molasses, sour cream, yogurt, lemon juice, vinegar, brown sugar, or cocoa. [TIP: When a foam cake that uses baking soda is baked, everything must be ready before the liquid is added to the leavening agent (the section on leavening components can be referred to).]

Baking Powder

Baking powder is a chemical leavening agent that contains baking soda, dry acids, and starch (as filler). It produces more carbon dioxide gas than baking soda. When heated, it produces carbon dioxide using the formula $NaHCO_3 + H^+$(from the acid) $\rightarrow Na^+ + H_2O + CO_2$. (Sodium, water, and CO_2 are all released.) Some cake recipes and formulas use both baking soda and baking powder.

Surface Area

In baking, the **surface area** is the part of a baked product that is directly exposed to the heat—the total uncovered exterior. The surface area of a foam cake determines its baking time. A larger pan has more surface area and, as a result, the cake will bake quicker. On the other hand, if a baker fills a smaller, deeper cake pan with the same volume of mix meant for the large pan, the batter will have a smaller surface area, take longer to bake, and, if left at same temperature, would have an undercooked center. As a general rule:

- Two 8 × 2 round pans bake for 30 to 40 minutes.
- One 8 × 8 × 2 square pan bakes for 25 to 30 minutes.
- Cupcakes, with a high ratio of surface area to volume, tend to dry out quickly in the oven. They bake for 14 to 19 minutes.

Batter Depth

Batter depth affects the baking time of all baked goods. As a general rule, Bundt® cakes have more depth than most cakes, and they bake for 40 to 45 minutes.

Oven Temperatures

Foam cake oven settings vary by type, pan, humidity, and altitude. [NOTE: More information is available on the Recipe.com website at http://www.recipetips.com/kitchen-tips/t--585/types-of-bakeware.asp.]

High Altitudes and Humidity

Baking in high altitudes (3,500 to 6,500 feet above sea level) requires an increase in oven temperature by 10°F to 20°F. Baking cakes on a rainy day may have the same effect as a high altitude. **Relative humidity (RH)** is a measure of the moisture in the air. It is the percentage of actual saturation compared to the density of vapor saturation. In other words, the higher the RH percent, the more moisture is available in the surrounding air. Both a high altitude and a high RH result in a lower barometric pressure. Rainy weather is caused by a low-pressure storm system. High elevations have dry, low-pressure air. This lower barometric pressure (thin air) tends to cause cakes to over rise, and then, to deflate. Recipes can be adjusted by decreasing the amount of leavening agent and sugar. Then, liquid and protein (milk, eggs, flour) are increased to strengthen the batter. To experiment with altitude and RH issues, students of baking should follow the directions below.

- Depending on elevation, decrease baking soda and baking powder by $^{1}/_{8}$ to $^{1}/_{4}$ teaspoon. (At 3,000 to 5,000 feet, decrease one teaspoon of soda to $^{7}/_{8}$ of a teaspoon. Above 5,000 feet, it would be $^{3}/_{4}$ of a teaspoon.)
- Increased evaporation also increases the concentration of sugar, which can weaken the structure, so decrease sugar by one to three tablespoons per cup.
- Increase oven temperature by 15°F to 25°F. Use the lower increase when baking delicate or chocolate cakes. Leavening and evaporation move more quickly at higher altitudes, so use a higher temperature. This will set the cake structure before it dries out.

FIGURE 6. On this gauge, notice the correlation between the barometric pressure numbers and the predicted weather.

- Decrease baking time by five to eight minutes per every 30 minutes (due to increase in oven temperature).
- Increase liquid by one to two tablespoons at 3,000 feet, and then increase by 1½ teaspoons for each additional 1,000 feet (keeps products from drying out).
- Increase protein in the batter (to trap gas) by adding two to three tablespoons of flour or by adding one egg white. [NOTE: Betty Crocker recommends adding a ¼ cup of all-purpose flour and increasing the water to 1½ cups (from 1¼ cups) in high altitudes. For more information about how rain affects baking, read Fred Decker's article, "Does Rain Affect Baking Cakes?," on eHow at http://www.ehow.com/info_12318209_rain-affect-baking-cakes.html.]
- RH should be monitored throughout the baking process: storage, proofing (breads), baking, and cooling.

Summary:

Baking is a science. Many scientific actions occur when making and baking foam cakes. Numerous physical changes and chemical reactions are necessary to prepare the perfect foam cake. The knowledge to bake a delicious foam cake is not a trick, or luck—it's science. Experiment until you get the artistic knack and the science skill to create the perfect foam cake.

Checking Your Knowledge:

1. Differentiate between a physical change and a chemical reaction.
2. Describe how foam is produced in foam cakes.
3. What makes the hydrolysis of sucrose so important to foam cakes?
4. Describe how coiled egg proteins react in acid? How do they react when heated?
5. How does cake flour effect gluten formation in foam cakes?

Expanding Your Knowledge:

Rain, humidity, and lower atmospheric pressure affect the results of baking and candy making. My grandmother never made peanut brittle on a humid or snowy day. She knew that the result was always too sticky. Find out more about how rain affects baking, including information on storing ingredients, reducing the amount of water in the recipe, adjusting baking time and/or temperature, and decorating cakes in humid weather. Begin your research by reading Fred Decker's article, "Does Rain Affect Baking Cakes," on the eHow website at http://www.ehow.com/info_12318209_rain-affect-baking-cakes.html.

Web Links:

The Amazing Multi-Tasking Egg

https://www.exploratorium.edu/cooking/icooks/article_5-03.html

Egg Foam in Baking

https://www.reluctantgourmet.com/the-egg-foam-method-in-baking/

How to Bake and Decorate in High Humidity

http://www.wedding-cakes-for-you.com/how-to-bake-and-decorate-in-high-humidity.html

The Science of Cake

https://www.theguardian.com/science/blog/2010/jun/09/science-cake-baking-andy-connelly

Troubleshooting Recipes

http://www.sugarduchess.com/2011/02/troubleshooting-recipes-for-baking-part-1/